Natural resources of the Indo-Gangetic Plains: a land-use planning perspective

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Current status of land/soil resources of the Indo-Gangetic Plains (IGP) is analysed to highlight the issues that need to be tackled in near future for sustained agricultural productivity. There are intra-regional variations in soil properties, cropping systems; status of land usage, groundwater utilization and irrigation development which vary across the sub-regions besides demographies. Framework for land use policy is suggested that includes acquisition of farm-level data, detailing capability of each unit to support a chosen land use, assess infrastructural support required to meet the projected challenges and finally develop skilled manpower to effectively monitor the dynamics of land use changes.

Keywords: Agricultural productivity, land use planning, natural resources, soil properties and soil management.

Introduction

INDIA is endowed with rich and diverse natural resources and climatic variations, which enable it to grow many plant species, commonly grown in the tropical, subtropical and temperate regions. In spite of the rich resource base, its burgeoning population makes it difficult to maintain a balance with food production. Self-sufficiency in food is a major challenge for the country. Natural resources are vital to agrarian livelihoods, and for this reason, sustainable use of available natural resources is critical for national food security. In India, natural resources are seen as vehicles of development, employment generation, poverty alleviation and diversified options for livelihood of millions of people. Since there are many competing end-uses of land resources in national economy, a multiple range of state and federal laws govern their use across the federal structure of the country. It is a common knowledge that the Indo-Gangetic Plains (IGP) produce about 50% of the total foodgrains to feed 40% of the population of the country[1]. Of the 610 administrative districts in India, 185 are located in the IGP. The IGP occupies a total area of approximately 52.01 m ha and represents eight agro-ecological regions (AER) and 14 agro-ecological sub-regions (AESRs). The area of the IGP is nearly 13% of the total geographical area of the country, and more than 280 million rural inhabitants reside in this area. The region includes states that compare to middle income countries and states that would rank amongst the poorest countries[2].

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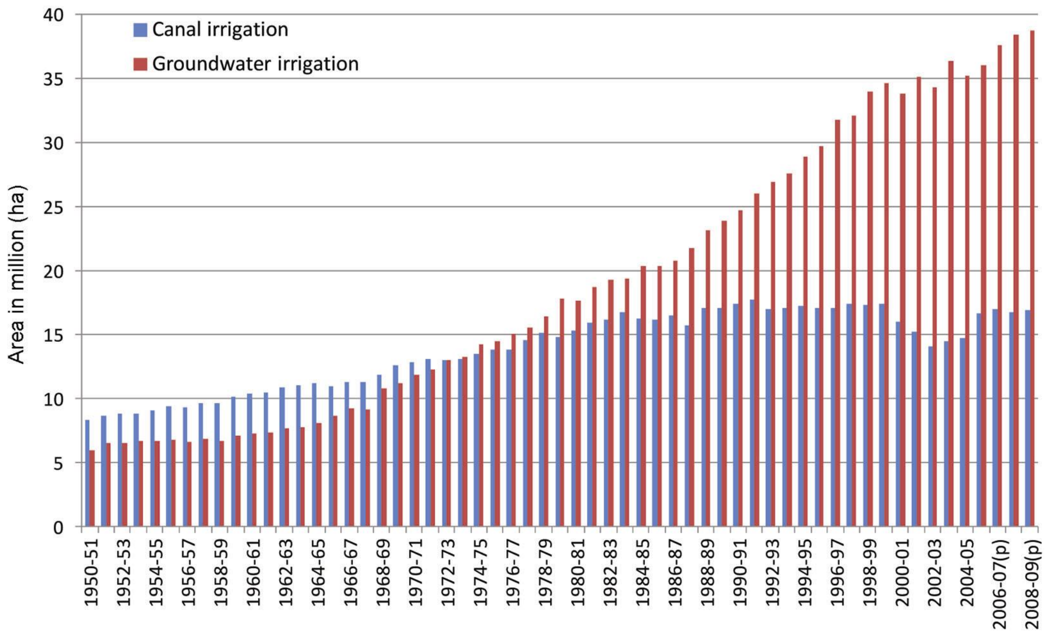

Figure 1. Area irrigated by canal and groundwater resources in India[14].

There is a perceptible degradation of natural resources in and outside the IGP[3–8]. According to the estimates by the National Bureau of Soil Survey and Land Use Planning, 22.84 m ha in the IGP is degraded[9]. Growing salinity hazard, lowering water table (overexploitation of groundwater) and decreased soil fertility are the major concerns. Of late, changes in physical properties like increased bulk density (BD) due to continuous use of farm machineries in rice–wheat cropping system has also been a major soil management concern[10]. Projected changes in biophysical environment as a direct consequence of climate change are expected to exacerbate the natural resource management (NRM) issues. Various reports suggest that the agricultural yields are now stagnating[11,12]. It is also evident that the ever-growing population of the country cannot be fed unless immediate steps are taken to manage the available natural resources in a sustainable manner.

The existing land use trend shows that other competing sectors like industry, habitation, infrastructure (roads, rails, etc.) are utilizing agricultural land. Acquisition of land for development projects has become a major conflicting issue between farmers and central/federal government(s). A report by the Regional Resource Institute and Society for Promotion of Wasteland Development suggests that 130 districts out of a total of 610 are facing land conflicts since 2011, over loss of 'common land' to various development projects[13].

Water is the most critical input in agriculture, especially in a monsoon-dependent country. The canal irrigated area in India has increased from 6 to 17 m ha since 1950 till 2009 (Figure 1)[14].

During the same period groundwater irrigation has gained 22 m ha. In 1950, only about 17 m ha area was irrigated using groundwater. In 2009, it has increased to 38 m ha. During 1950, canal irrigated area was about 8 m ha as against 6 m ha with groundwater. During the succeeding decades, the difference between these two sources kept decreasing and by 1972, they were contributing almost equally. From this point onwards, groundwater emerged as the dominant source of irrigation. The utilization of groundwater more than doubled by 1990 (23 m ha). The last two decades have seen almost 65% increase in the area irrigated by groundwater. The latest data (2011) indicate that in IGP, nearly 150 m ha area is irrigated by groundwater, as against 33 m ha by canal water. Thus IGP constitutes almost 80% of the groundwater irrigation in the country. It can be deduced that ground water management in IGP will play a major and critical role for sustainability of agricultural production in the country. According to Amarasinghe *et al.*[15], the entire IGP region (Figure 2) will have an abstraction ratio > 75. Their projections showed the groundwater abstraction ratio (the ratio between total groundwater withdrawals and the total utilizable groundwater resources) in Figure 2.

They argue that rice–wheat system in the western IGP may become hydrologically unsustainable. The ensuing text discusses the current status of land resources in the IGP, likely challenges in near and long-term future and strategies to overcome the challenges.

Current status of natural resources in IGP

Based on seven variables, viz. rainfall, drought, available water content of soil, area under degraded and waste lands, rainfed area, status of groundwater, and irrigation

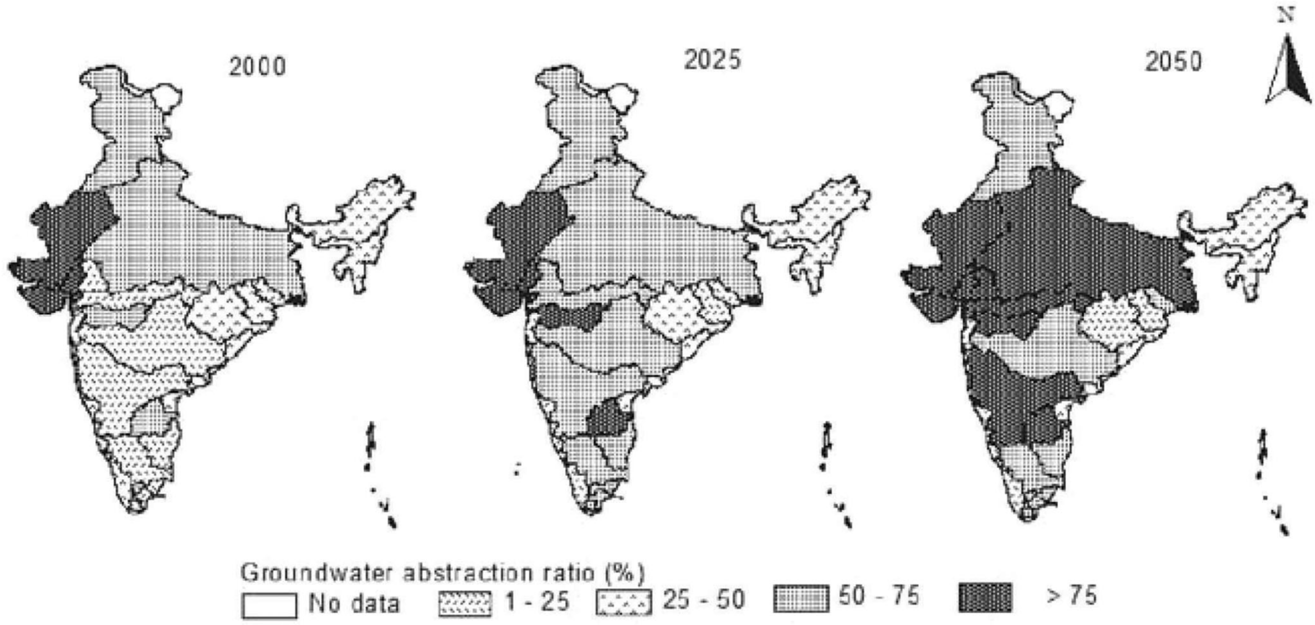

Figure 2. Groundwater abstraction ratio of Indian river basins[15] (groundwater abstraction ratio = total groundwater withdrawls/total utilizable groundwater resources).

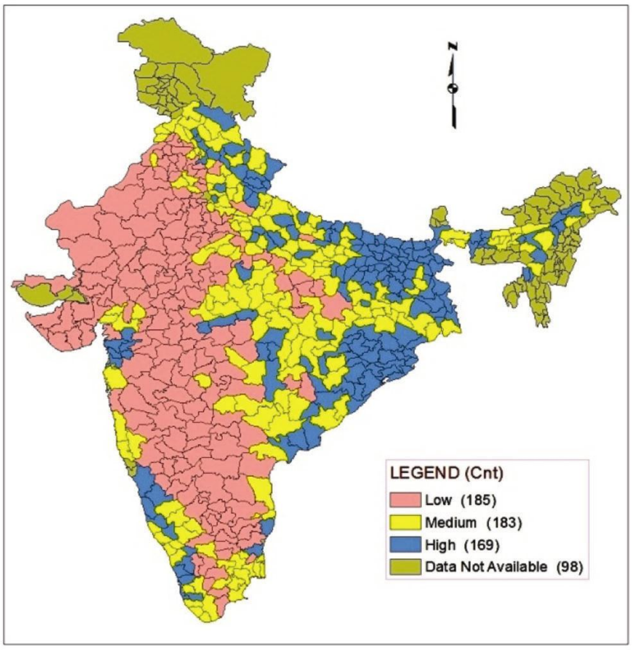

Figure 3. Natural resources Index of India[16] (Cnt-District, Count or number of districts).

intensity, the Central Research Institute for Dryland Agriculture (CRIDA) prepared a natural resources index (NRI) map of the country for the National Rainfed Area Authority (NRAA)[16] (Figure 3). The NRI accounts for two-thirds of the weight assigned; the rainfall and drought account for the major share of the NRI, as they decide the outcome of rainfed agriculture. The map shows that the eastern part of the country is resource-rich, middle part (split vertically) is medium-rich and the western part is relatively poor. Barring few pockets in Kerala, Karnataka, Goa and Gujarat, almost the entire progressive regions (western and South Indian states) have medium to poor NRI. Most of the impoverished districts/regions identified by different committees set up by the Government of India over the last 30 years, invariably include almost the entire middle and lower part of IGP, which also happens to be the high NRI area. It seems, therefore, that high NRI and poverty are mutually inclusive. Unabated population growth (in excess of 20% during the last decade), high population density (> 1000 persons/ km^2) and dependence on agriculture as the sole source of livelihood are amongst the major reasons for poverty in this region. Following Gupta and Yadav[17], the IGP can be divided in four distinct zones (Figure 4), viz. trans Indo-Gangetic Plains (TIGP), upper Indo-Gangetic Plains (UIGP), middle Indo-Gangetic Plains (MIGP) and lower Indo-Gangetic Plains (LIGP).

The UIGP and MIGP are relatively large in areal extent. In this article, TIGP and West Indo-Gangetic Plains (WIGP) are used interchangeably. Similarly, MIGP and LIGP regions are collectively referred to as eastern IGP (EIGP). Appraisal of Figures 3 and 4 indicates that the IGP is well endowed with natural resources compared to Peninsular and western India. Though high rainfall (it has greater weight in NRI) implies higher NRI, the districts like Vaishali, Katihar, Araria in EIGP often get inundated by flood waters during monsoon, wiping away the standing *kharif* crops and households, including livestock, thus leaving the helpless. Gupta and Yadav[17] have observed that agricultural productivity, high rainfall and poverty seem to be in parallel in districts located between 78.83 and 86.13N long. Many of these districts have large tracts of chaur (waterlogged soils), tal (active flood plains) and diara (lamp-shaped depressions/shifting river course) lands which get flooded during monsoon and fields get vacated very late for wheat crop during winter season. Besides, in districts like Bankura, Purulia and West Midnapur in West Bengal, groundwater largely remains unutilized. The change in groundwater regulations in many districts and its effective utilization in parts of West Bengal recently, resulted in a jump in crop yields[18]. Reports suggest that greater natural endowments without purposeful management could also lead to poverty. While this may not be a new observation, it must be noted that natural resources in this part of India are also under stress. For instance, 109 districts in IGP experience the problem of salinity (Figure 5). Mandal and Sharma[19] estimated 3.09 m ha area in IGP represents salt-affected soils. Groundwater surveys have shown that about 41–84% of the well water in different states of IGP is brackish (Figure 6). Based on criteria suggested by Central Soil Salinity Research Institute (CSSRI), Karnal[20] groundwater with higher residual sodium carbonate (RSC) covers about 25% of the total area of Punjab[21] and occurs in parts of Amritsar (KharaMajha), Bhatinda (Mansa and Phul), Ferozepur (Zira and Dharamkot), Moga (Bagha Purana, Nihalsighwala), Ropar (Kharar), Sangrur (Malerkotla and Sangrur) and southern Ludhiana. In Haryana, this poor quality irrigation water is used in the districts of Jind (Rajaund, Narwana), Karnal (Nilokheri, Nissang), Kaithal (Gulha Cheeka, Pundari, Dand, Kaithal), Panipat (Assandh), Bhiwani, Mahendergarh

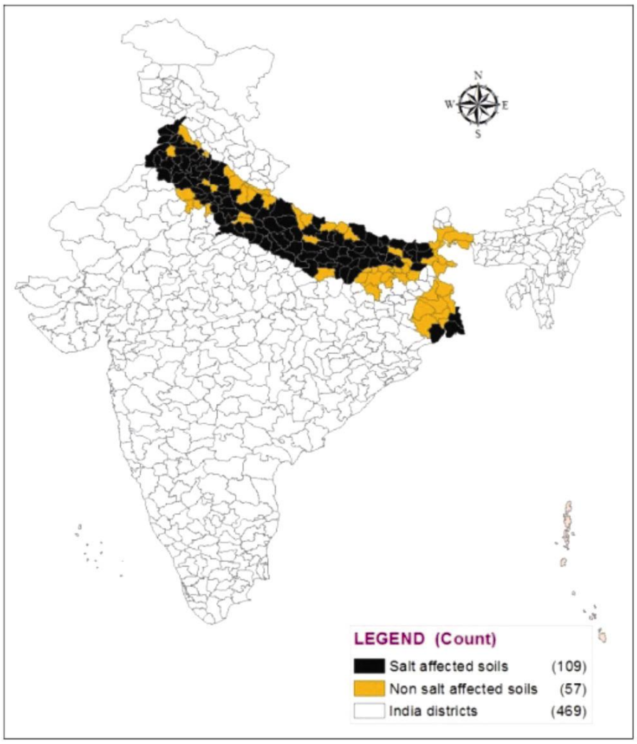

Figure 5. Spatial distribution of salt-affected soils in IGP[19] (values in parentheses show the number of districts).

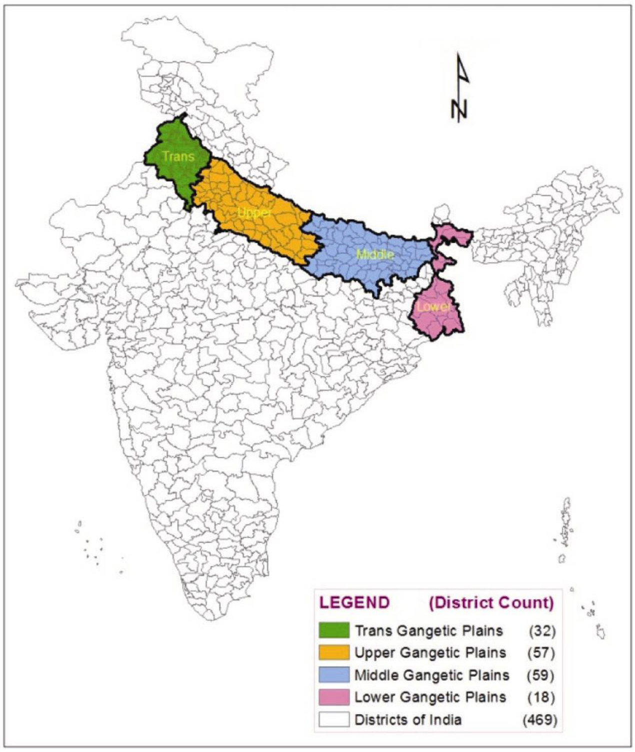

Figure 4. Four distinct zones in the Indo-Gangetic Plains[17].

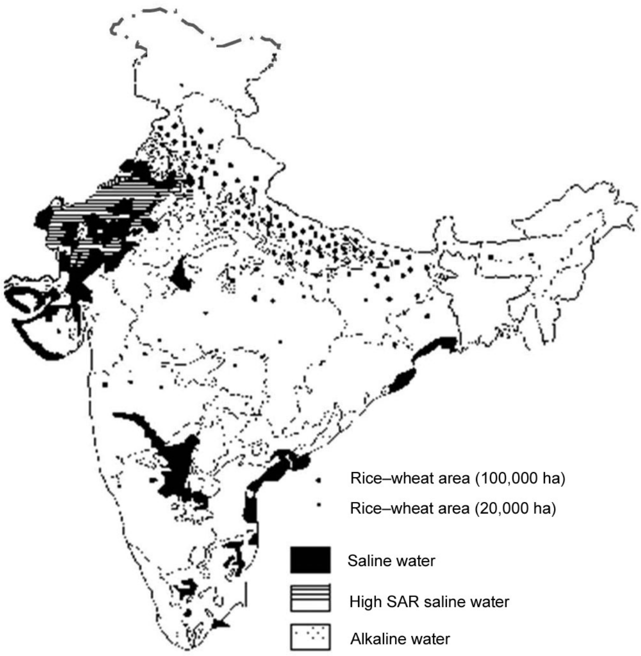

Figure 6. Schematic map showing distribution of groundwater quality for irrigation in India[22] (SAR, Sodium absorption ratio).

(Narnaul, Dadri, Pataudi), Gurgaon (Bawal), Fridabad (Ballabargh and Sohna) and Sirsa, covering almost 21% of the total area of the state. Alkali waters are also common in Agra, Mathura, Aligarh, Mainpuri, Etah, Unnao, Fatehpur, Ballia and several other districts of Uttar Pradesh and to the east of the Aravalli range in Rajasthan, including parts of Jaipur, Kota, Udaipur, Tonk, Nagaur, Sikar and Jhunjhunu districts. Associated with salinity, the groundwaters in some pockets may contain toxic levels of boron, fluoride, nitrate, selenium and silica[21,22]. This is a major soil management problem which requires attention.

Soil resources of IGP

The descriptive statistics of available soil data on IGP is given in Tables 1–4. The data pertain to 59 soil profiles (~ 450 layers) spread over the region. Mean sand content in the soils of TIGP is 46%. The mean depth of soil exceeds 150 cm and the dominant texture is sandy loam (112 layers), loam (80 layers), clay loam (42 layers) and silt loam (42 layers) according to USDA classification. The exchangeable sodium percentage (ESP) ranges from 0.4 to 83. Estimates by Mandal and Sharma[19] showed that the extent of saline–sodic soils in IGP is 2.05 m ha. Uttar Pradesh contributes 1.76 m ha, while Punjab and Haryana share almost equal area (0.14 m ha)[19]. In 112 samples ESP is greater than 15, which implies that almost 25% of the soil samples have excess ESP and hence the soils are salt-affected (sodic and saline sodic). Also, 50% crop yield reduction occurs when ESP is more than 40 (ref. 23).

In the UIGP sandy loam soils (30% of the layers in 163 profiles) are dominant, which is followed by loam (164 layers) and clay loam (116 layers). The UIGP soils do not differ much from the TIGP soils in terms of depth, but mean sodium adsorption ratio (SAR) value of around 30 indicates that the entire region is highly salt-affected and soil management is critical to enhance and sustain high agricultural productivity.

The distribution of salt-affected soils of the IGP[19] is shown in Figure 7. Only 52 districts of the region mostly located in EIGP are not affected by sodicity or salinity. Evidence shows that conjunctive use of surface water (SW) and groundwater (GW) in some parts of WIGP has

Table 1. Descriptive statistics of few properties of TIGP soils*

	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	OC (%)	BD ($Mg\ m^{-3}$)	FC (%)	PWP (%)	ESP	SAR	sHC (mm/day)
Mean	153.44	46.70	32.50	20.80	0.28	1.57	20.62	9.20	22.91	2.41	4.85
SEM	3.28	1.20	0.81	0.64	0.05	0.03	1.23	0.76	1.42	0.58	0.12
SD	25.21	23.79	16.13	12.74	1.03	0.31	9.37	5.77	22.93	3.50	2.36
Variance	635.49	565.91	260.17	162.42	1.06	0.10	87.83	33.25	525.59	12.28	5.56
Coefficient of variance	0.16	0.51	0.50	0.61	3.63	0.20	0.45	0.63	1.00	1.46	0.49
Minimum	111.00	3.70	0.80	1.00	0.03	1.36	3.50	0.05	0.40	0.17	0.07
Maximum	300.0	98.00	71.80	71.10	20.00	1.99	36.50	21.50	83.00	20.21	12.38
Sum	9,053.00	18,445.70	12,839.10	82,15.60	110.47	134.63	1,195.90	533.83	5,979.08	89.06	1,885.28

*Source: Ray *et al.*[47] (on the basis of 59 soil profile data).
OC, Organic carbon; BD, Bulk density; FC, Field capacity; PWP, Permanent wilting point; ESP, Exchangeable sodium percentage; SAR, Sodium absorption ratio; sHC, Saturated hydraulic conductivity.

Table 2. Descriptive statistics of few properties of UIGP soils*

	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	OC (%)	BD ($Mg\ m^{-3}$)	FC (%)	PWP (%)	ESP	SAR	sHC (mm/day)
Mean	155.6	51.73	28.77	19.53	0.27	1.51	18.59	7.69	19.52	29.95	5.85
SEM	1.27	0.75	0.49	0.37	0.02	0.02	1.20	0.92	1.17	13.92	0.09
SD	16.18	23.84	15.43	11.77	0.75	0.28	5.22	4.03	24.51	82.34	2.06
Variance	261.89	568.22	238.21	138.58	0.57	0.08	27.29	16.24	600.50	6780.17	4.23
Coefficient of variance	0.10	0.46	0.54	0.60	2.79	0.18	0.28	0.52	1.26	2.75	0.35
Minimum	32.00	2.60	0.80	0.10	0.02	1.28	8.04	2.09	0.20	0.21	0.02
Maximum	192.0	98.75	75.30	96.00	16.00	1.92	24.10	15.20	233.00	364.90	30.25
Sum	25,366.0	51,883.26	28,859.75	19,590.75	261.22	289.17	353.27	146.12	8,511.39	1,048.18	3,031.67

*Source: Ray *et al.*[47] (on the basis of 163 soil profile data).
OC, Organic carbon; BD, Bulk density; FC, Field capacity; PWP, Permanent wilting point; ESP, Exchangeable sodium percentage; SAR, Sodium absorption ratio; sHC, Saturated hydraulic conductivity.

Table 3. Descriptive statistics of few properties of MIGP soils*

	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	OC (%)	BD (Mg m^{-3})	FC (%)	PWP (%)	ESP	SAR	sHC (mm/day)
Mean	150.75	31.05	41.46	27.93	0.26	1.44	24.85	10.24	21.29	1.66	5.18
SEM	1.78	1.05	0.76	0.56	0.01	0.01	0.92	1.07	1.91	0.32	0.08
SD	18.80	25.86	18.54	13.82	0.17	0.12	3.04	3.54	21.97	1.18	1.75
Variance	353.38	668.92	343.57	190.95	0.03	0.01	9.25	12.50	482.58	1.40	3.05
Coefficient of variance	0.12	0.83	0.45	0.49	0.66	0.08	0.12	0.35	1.03	0.71	0.34
Minimum	95.00	0.11	0.60	2.00	0.04	1.19	19.30	4.70	1.30	0.27	0.21
Maximum	185.0	96.20	81.80	67.60	1.14	1.70	29.20	15.90	97.00	4.80	8.81
Sum	16,884.00	18,848.72	24,920.30	16,811.40	151.21	136.36	273.30	112.60	2,810.23	23.22	2,724.60

*Source: Ray *et al.*[47] (on the basis of 112 soil profile data).
OC, Organic carbon; BD, Bulk density; FC, Field capacity; PWP, Permanent wilting point; ESP, Exchangeable sodium percentage; SAR, Sodium absorption ratio; sHC, Saturated hydraulic conductivity.

Table 4. Descriptive statistics of few properties of LIGP soils*

	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	OC (%)	BD (Mg m^{-3})	FC (%)	PWP (%)	ESP	SAR	sHC (mm/day)
Mean	133.9	29.31	39.71	31.07	0.47	1.57	26.03	17.05	32.65	0.46	5.12
SEM	2.78	1.02	0.73	0.65	0.04	0.02	1.37	1.10	6.37	0.02	0.07
SD	30.37	25.02	17.89	15.98	0.89	0.17	8.43	6.79	31.83	0.07	1.59
Variance	922.29	625.94	319.88	255.21	0.78	0.03	71.11	46.04	1013.38	0.00	2.53
Coefficient of variance	0.23	0.85	0.45	0.51	1.88	0.11	0.32	0.40	0.98	0.14	0.31
Minimum	29.00	0.20	1.00	1.00	0.05	1.30	8.40	6.00	1.00	0.37	0.25
Maximum	186.0	99.80	84.40	81.70	10.18	2.00	39.50	32.50	97.00	0.55	8.77
Sum	15,934.0	17,675.10	23,904.90	18,705.10	274.32	109.74	989.00	647.80	816.20	3.68	2,784.81

*Source: Ray *et al.*[47] (on the basis of 59 soil profile data).
OC, Organic carbon; BD, Bulk density; FC, Field capacity; PWP, Permanent wilting point; ESP, Exchangeable sodium percentage; SAR, Sodium absorption ratio; sHC, Saturated hydraulic conductivity.

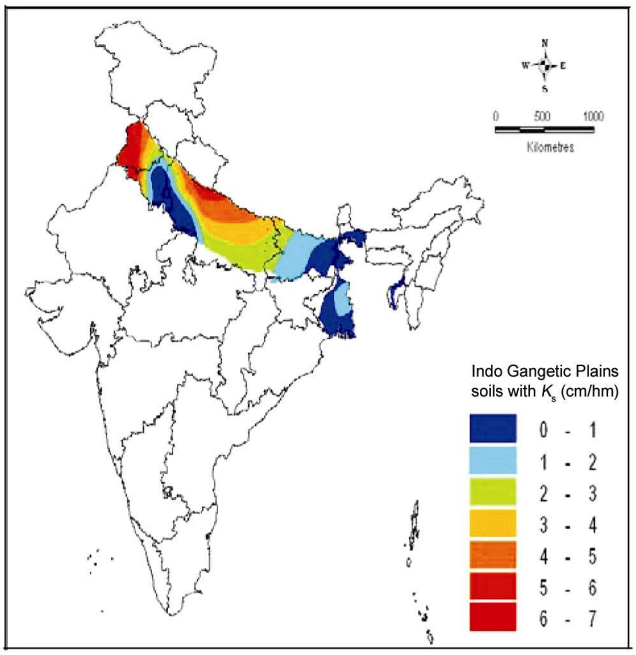

Figure 7. Generalized saturated hydraulic conductivity (K_s) map of IGP[48].

prevented waterlogging and salinity build-up[24]. The CSSRI, Karnal has tested different conjunctive use modes for utilizing multi-quality waters.

In the middle region (MIGP; Table 3), the dominant texture changes to silt loam (128 layers of 112 profiles). Relatively high clay content (27.93%) is reflected in the silty clay loam texture (113 layers), clay loam (65 layers) and clay texture (61 layers). The mean SAR value is much lower (~ 2), but high ESP (21.3) remains a concern, demanding necessary steps for preventive soil management. In many situations, measures such as simple leaching can salvage such saline-sodic soils. Clay content of little over 31% combined with 40% silt and 30% sand, makes the LIGP soils well drained. The saturated hydraulic conductivity (sHC) data do not show significant difference in the mean sHC of this region in comparison to other regions. However, the range (0.25–8.77 mm/day) is the narrowest of all, with minimum sHC value of 0.25 mm/day being the highest amongst minima. Such sHC values indicate poor drainage of soils. The available water content (AWC) is lowest of all the IGP soils. Due to high sodium on soil exchange, retention of water at permanent wilting point (PWP) is high, resulting in low AWC. As reported by Hudson[25], higher organic matter (OM) content increases the volume of water held at field capacity at a much greater rate (average slope = 3.6) than that held at the permanent wilting point (average slope = 0.72). As a result, highly significant positive correlations were found between OM content and AWC for sand ($r^2 = 0.79$), silt loam ($r^2 = 0.58$) and silty clay loam ($r^2 = 0.7$) texture groups. In all texture groups, as OM content increased from 0.5% to 3%, AWC of the soil also increased many fold.

It is notable that mean BD of TIGP and UIGP soils is higher than the MIGP and LIGP soils. Excessive tillage and wet tillage (puddling), use of rotavators and freewheeling of tractors and harvesters (combined) in IGP has, in general, resulted in gradual compaction of soils, leading to a reduction in long-term soil productivity, especially under rice–wheat cropping system[26]. There is an increasing acceptance that excessive tillage and puddling are causing compaction in soils where rice–wheat cropping system is continuously practised[27,28]. Singh *et al.*[26] have reported increased bulk density in Punjab soils accompanied by the formation of hard pan at 15–22.5 cm depth due to migration of silt and clay from the upper layers to this layer, which results in consolidation.

They also observed decrease in saturated hydraulic conductivity. After initial increase from 0.77 mm/h in the 0–7.5 cm zone to 4.32 mm/h in the next zone (7.5–15 cm), it declined to 1.77 and 1.06 mm/h in the 15–22.5 and 22.5–30 cm soil zones respectively. Soil submergence and repeated puddling in rice generally degrades soil structure[28]. Singh *et al.*[26] have shown that growing maize after rice arrested increase in BD in the subsurface. Therefore, alternative options such as rice–legume and rice–maize may be explored. Recent studies have shown that the rice–wheat system can be profitably replaced with maize–wheat–mungbean system[29]. The data showed that BD in the IGP ranges from 1.2 to 2.0 Mg m^{-3}. Many reports suggest that reduced soil porosity because of higher BD reduces available water capacity. Pandey *et al.*[28] reported higher BD and sHC in soil (0–15 cm depth) in puddled rice in comparison with unpuddled rice field. Three years of continuous rice–wheat cropping sequence showed that in puddled soils, bulk density was greater than in unpuddled soils. Tang *et al.*[30] have reported that bulk density of no tillage plots after rice was better suited for wheat growth. Results of many field studies conducted in India also confirm that the gains in wheat productivity are quite significant, if the fields are not puddled during the preceding rice season[17]. The capillary porosity was 4.1–5.5% more in no tillage plots compared to conventional tillage plot. Thus soil tillage has a key influence on soil physical environment. Changes in BD can alter mechanical impedance to growing roots. Crop water availability decreases due to increased mechanical resistance, which may limit root growth. Research findings thus indicate that apart from change in cropping sequence, permanent raised beds could be advantageous in the IGP, especially in the rice–wheat system, for enhancing productivity and sustainability.

Formation of $CaCO_3$ begins in subsurface horizons due to various pedo-chemical processes[12,31]. This causes high subsoil sodicity, which impedes drainage as evidenced by decreased sHC. In the TIGP region, 16 surface layers had higher surface sHC compared to the subsurface layers (Tables 1–4). In UIGP also similar trend was observed. In most of the sandy loam soils, decreased sHC in subsurface layers can be due to compaction, higher ESP and low organic carbon (OC). Various studies[26–28] have shown that subsurface compaction can cause detrimental effects, especially in the rice–wheat system. Limiting subsurface compaction is thus a major challenge in IGP. A generalized sHC map (Figure 7) shows variations in accordance with the textural composition. Despite lower sHC, the LIGP region is relatively free of salt-affected soils. The LIGP is a traditional rice-growing area, whereas TIGP, UIGP and to some extent MIGP are non-traditional rice areas. It is interesting to note that salinity has developed fast in non-traditional rice areas, where extensive irrigation was introduced simultaneously during the green revolution. Drainage in most of TIGP is difficult because of the saucer-shaped topography; lack of surface and subsurface drainage system has contributed to salinity build-up, thus rendering the water brackish. Groundwater in about 65% of the Bhakra command area occupying most of TIGP, is of poor quality.

Soil management

Over a period of time, more nutrients have been removed than added through fertilizers, and farmers had to apply more fertilizers to maintain the yield level. Also, micronutrient deficiencies started appearing in IGP with the adoption and spread of intensive agriculture[32]. Among other factors, zinc deficiency has become most widespread in the entire IGP region[33]. It is a fact that intensive cultivation of Indian soils without sufficient inputs of OM has led to a general decline in soil OC[32–34].

However, the application of nitrogen, phosphorus and potassium (NPK) plus farm yard manure (FYM) showed more productivity than that in (NPK) alone; and NPK plus FYM emerged as a cost-effective technology for Indian farmers[35]. The IGP soils predominantly have 2 : 1 layer silicates that ensure good substrate quality; and this shows their high potential for C sequestration under appropriate cropping and management[36,37]. It is thus envisaged that the present soil organic carbon (SOC) stock can be further increased by the use of recommended improved seeds, NPK fertilizers, micronutrients, FYM and the inclusion of legumes in cereal–cereal cropping systems. Surface mulching and reduced tillage options such as conservation agriculture can also bring similar results effecting increase in SOC stock.

Laser levelling and land preparation

Integrating laser levelling with other best management practices has been shown to increase productivity of rice–wheat systems by 7–19% and reduce water consumption for irrigation by 12–30% in on-station and farmer-participatory trials in India, increasing net returns by US$ 113–300/ha per year[38]. This has been reflected in a rapid increase in the number of laser units employed in the northwest Indian IGP between 2001 and 2008, from zero to 925 and in the laser-levelled area from zero to 0.2 m ha (ref. 38, 39). In future, levelling operations could be expected to accelerate and add to productivity.

Per capita cultivated land availability and land use planning

Land availability in India has been declining with increasing population. Currently, (2011) it is 0.26 ha/person. Per capita land availability is usually assessed from the data on total geographical area (TGA) of the unit and human population living in that unit. However, these numbers could be misleading. For instance, in sparsely populated arid regions, per capita land availability may be higher but soil degradation and lack of soil moisture forces the farmers to till only limited land parcel. Per capita cultivated land availability is a better indicator, as the land under active cultivation is considered to arrive at this number.

At present, cultivated area of the country is almost 58% the total geographical area, a very high proportion by any standard. Of the remaining area, 22% is classified as forest for use, leaving thereby only 20% for all other land uses, including residential, industrial, infrastructure, public utility and others. In IGP, it becomes worse as almost every possible parcel of land is already under cultivation. The forest cover on an average does not exceed 6% of the TGA (Table 5). Future projections suggest that India will have more than 700 million urban persons by 2040s. Demand for land in agriculture and non-agricultural sectors, including establishment of industries, recreation, housing, roads, parks and railway lines is putting immense pressure on scarce land resources. The problem becomes more severe in a market-driven, unplanned diversification, as well as urbanization that leads to non-sustainable development. Demand-driven or market-driven land use changes can severely impact natural resources of the country, which may not be conspicuous immediately, but cause long-term damage. Hence, land use planning becomes imperative. The Government of India has released in September 2013, the first draft of the National Land Use Policy. It emphasizes on identification of land utilization zones and land use management areas. To achieve this, land resource inventory needs to be developed. Such an exercise is likely to consume both resources and time, but greatly facilitates decision makers to decide upon the future strategies for sustainable agriculture in IGP.

Agro-climatic characteristics largely determine the land use patterns. It is in this context that collection of farm-level data in IGP assumes importance for its continued contribution to the agricultural production in the country. The situation demands to: (i) acquire farm-level data detailing capability of each unit to support a chosen land use; (ii) project cereal, oilseed and other food demands of the country in 2050 assuming improved lifestyles, (iii) project best and worst climate change scenarios and simulate land capabilities to withstand these changes; (iv) assess infrastructural support required to meet the projected challenges and finally (v) develop skilled manpower to effectively monitor the dynamics of land use changes and effectively formulate plans for effective solutions.

The next four decades are likely to see major changes in our land use/landscape. Many competing land uses such as agriculture, residential requirements, recreation, mining, biodiversity support, forest protection, water provisioning, urban planning, carbon sequestration and others will be in conflict with each other. The continued changes will have to be managed in an economically and environmentally sustainable manner. We need to conceive simulation tools to take considered decisions. The priority has to be creation of a database, especially for IGP and constructing different land use scenarios for assessing the implications of land use assumptions for the country/state or at village-level planning. Thus the existing soil information database, needs to be strengthened further with the help of latest technology. Satellite data acquisition and its integration with the existing data could be a way forward.

Land use policy

The current land use is often dictated by economic fluctuations in food prices worldwide. Farmers also decide on crops based on their perception of crop prices and family requirements. The country needs to plan economic implications of such reactive crop choices. Quantification of land use decisions on national economy must be understood and various scenarios be simulated to take steps for better policy decisions.

From land use planning perspective for livelihood, four categories of use can be defined, namely agriculture, forestry, fisheries and livestock. Based on the status of available natural resources, suggestive priorities are depicted in Table 6. Due modifications with reference to the development/management unit (e.g. watershed, village,

Table 5. Demographic characteristics and natural resources utilization in IGP

	TIGP				UIGP				MIGP				EIGP			
	Minimum	Maximum	Average	Sum	Minimum	Maximum	Average	Sum	Minimum	Maximum	Average	Sum	Minimum	Maximum	Average	Sum
TGA (km^2)	114	5,874	2,600	83,196	898	7,680	3,148	179,428	572	5,228	2,746	162,013	1,467	9,960	4,705	84,682
Population	558,890	3,487,882	1,286,614	41,171,638	896,129	16,753,235	2,806,853	159,990,597	634,927	5,959,798	2,815,759	166,129,800	1,670,931	10,082,852	5,006,151	90,110,719
Population density (person/km^2)	302.81	9251.63	780.14		354.15	11,289.24	1,020.55		144.57	2,409.81	1,075.26		522.56	6,358.77	1,323.62	
Rural population	29,004	1,643,882	822,968	26,334,991	369,861	3,944,454	1,805,391	102,907,307	526,132	4,683,820	2,476,382	146,106,511	1,123,859	6,065,179	3,399,241	61,186,341
Rural population (%)	2.75	87.37	66.12		2.5	96.55	71.24		56.52	96.54	88.67		19.05	91.64	74.39	
Urban population	125,505	2,062,681	463,645	14,836,647	38,449	16,333,916	1,001,461	57,083,290	28,095	2,510,093	339,378	20,023,289	163,699	7,551,347	1,606,910	28,924,378
Urban population (%)	12.63	97.25	33.88		3.45	97.5	28.76		3.46	43.48	11.33		8.36	80.95	25.61	
Decadal growth (%)	4.58	32.02	13.88		8.73	73.93	22.3		14.16	32.59	23.21		9.49	30.44	15.77	
Literacy (%)	60.43	86.43	73.21		43.61	86.34	69.66		49.13	77.05	65.5		47.89	80.16	65.86	
Net sown (ha)	24,000	475,000	201,000	6,432,000	93,000	486,000	209,930	11,966,000	17,000	338,000	164,746	9,720,000	86,000	642,000	299,111	5,384,000
Net sown area (%)	18.93	134.68	70.74		24.77	103.56	63.88		11.85	81.52	60.53		38.25	156.81	60.8	
Cropping intensity (%)	153	199	158		113	199	148		105	181	143		123	260	180	
Agricultural productivity (Rs/ha)	30,652	69,196	46,173	1,477,541	22,391	81,855	41,109	2,343,220	16,776	62,954	30,179	1,780,571	24,416	114,815	70,222	1,263,990
Fertilizer consumption (NPK) kg/ha	98	501	279	8,928	105	637	237	13,488	13	516	160	9,440	18	749	214	3854
Rainfall (mm)	173	1,486	587	18,781	409	1,256	770		956	1,817	941		1,314	3,454	1923	
Net irrigated area (%)	8.77	100	82.69		42	100	82.66		2.45	99	64.54		12.14	96	54.82	
Ground water development (%)	70	265	153.34		49	232	87.56		23	80	51.39		4	87	35.17	
Forest area (ha)	100	68,300	8,006	256,200	1,400	132,000	15,302	872,200	100	178,200	20,490	1,208,900	1,500	259,500	68,178	1,227,200
Forest area (%)	0.08	31.55	3.48		0.51	26.19	4.33		0.09	47.75	6.85		0.68	72.69	11.87	
Cow density	12.01	45.34	23.77		9.65	76.89	35.93		29.27	141.28	76.8		60.85	229.7	144.95	
Buffalo density	52.64	155.04	90.31		32.53	310.1	101.44		9.83	118.61	59.18		0.11	57.36	6.21	
Milk production index	0.51	0.82	0.63		0.31	1	0.72		0.64	0.93	0.77		0.68	0.9	0.79	

Table 6. Current utilization status of natural resources and qualitative potential for the future development in IGP

	WIGP		UIGP		MIGP		EIGP	
Land use	Current utilization	Potential for improvement	Current utilization	Potential for improvement	Current utilization	Potential for improvement	Current utilization	Potential for improvement
Agriculture	High	Low	Medium	Medium	Low	High	Low	High
Forestry	Low	High	Low	High	Low	High	Low	High
Fisheries	Low	Low	Low	Medium	Low	High	Medium	High
Livestock	High	Low	Medium	Medium	Low	High	Low	High

district, etc.), of these priorities could be integrated into a development plan.

In WIGP, potential for improving agriculture is low, because of the already achieved levels and constraints imposed by sodicity and salinity. Research findings suggest that poplar could be economically more rewarding than the rice–wheat system in Punjab and Haryana and many farmers have benefitted from adoption of agroforestry[40,41]. Similar findings are reported from western Uttar Pradesh[42]. Thus forestry can be promoted as an important land use. Sodicity and salinity problems are afflicting UIGP as well; hence, the level of existing medium productivity is expected to improve moderately. Due to similar reasons, fishery as a source of livelihood is not expected to thrive in WIGP. This category of land use has been integrated to the farming system in parts of MIGP and all EIGP. However, the realized yields are low and a large potential remains untapped. The entire IGP can be termed as 'devoid' of forest, because of its notable absence. Though agro-forestry has been adopted in parts of Punjab and Haryana, the successful model has not been replicated, despite high potential in the entire IGP. Livestock has flourished in WIGP primarily because it was a livestock-based economy prior to the green revolution. Intensive agriculture developed with a synergistic relationship due to many reasons, including proximity to the market, better infrastructure, demand–supply gap and impoverished groups. The farmers in EIGP have shown ingenuity of multiple uses of water by integrating fisheries/duckery and/or poultry with agriculture. However, as discussed earlier, forestry or dairy component is absent. Further the systems need to be evolved through policy support, physical infrastructure and technical support. The potential for promoting and enhancing productivity of four main land uses in MIGP and EIGP is relatively less utilized. While the gap between the potential and realized agricultural yields in MIGP and EIGP has been well documented, it is notable that the highest agricultural productivity in India has been recorded in Murshidabad district (EIGP). The district is, however, listed as one of the most disadvantaged by the Planning Commission of India (on the basis of prevalence of poverty indicated population of oppressed castes/tribes (listed in the schedule by the Government), agricultural productivity per worker and agricultural wage rate). Therefore, it is essential that options beyond the listed four land uses are also given consideration. The population dependant on agriculture needs to be engaged in non-agricultural activities such as industry. Research findings, on the other hand, suggest that fertile lands in Uttar Pradesh (by extension EIGP) should not be readily permitted to be converted into non-agricultural usage. Industrial or other uses in MIGP and EIGP have to be encouraged on less productive lands. Fragmentation of land is a major constraint in MIGP and EIGP. Hence, Land Ceiling Act must be reviewed to allow migration within the categories below middle level for viable agriculture. Marginal and small farmers in these regions can be encouraged to grow vegetables for absorbing them in employment generation. Utilization of another natural resource – water remains poor as indicated by the poor water use efficiency (40–60%) observed across all major and medium irrigation projects[43].

Land use planning may also have to address carbon sequestration in the near future. Singh *et al.*[36] have estimated that about 69% carbon in the IGP soils is confined to the upper 40 cm soil layer, where C stock ranges from 8.5 to 15.2 t C ha^{-1}. Their estimates indicate that agricultural soils of IGP may contain 12.4–22.6 t ha^{-1} of organic C in the top 1 m soil depth. Since agricultural soils contain significantly lower C content than the soils of natural forest ecosystem in the same climate zone, management practices such as residue placement and reduced/or no tillage are required to enhance C sequestration. A mix of agroforestry with crop fields may be an ideal option to enhance C sequestration in soils. Bhattacharyya *et al.*[44] and Ghosh *et al.*[45] have suggested inclusion of pulses in the rice-based cropping system, and organic nutrient management practices have significant impact on maintaining SOC in soils of IGP.

AESR-based planning for rice and wheat in IGP

Using our soil database (sHC values) and length of growing period estimation, AESRs of IGP were modified from the existing 17 to a total 29 units[46]. These modifications were accomplished using tools in GIS platform, climate data and expert opinion. Using district-level rice yield data, rice-growing areas in the IGP were divided into four

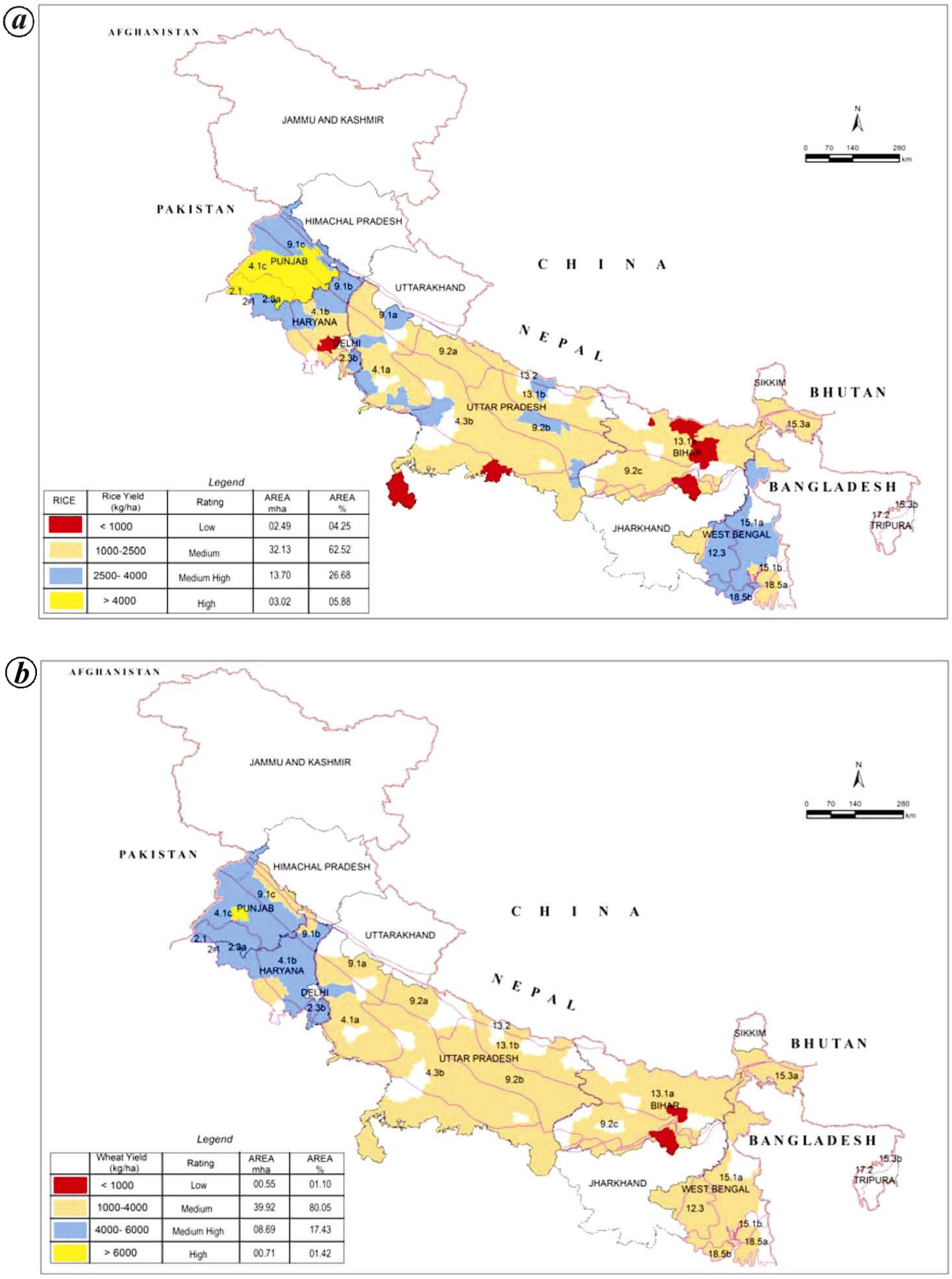

Figure 8. ***a***, AESR-based planning for rice in IGP[46]. ***b***, AESR-based planning for wheat in IGP[46].

regions such as low, medium, medium high and high representing areas with rice yield of < 1000, 1000–2500, 2500–4000 and > 4000 kg ha^{-1} respectively (Figure 8 *a*). These assessments show that nearly 33% area produces medium high to high category yields, while medium level yield is observed in 63% of the total rice-growing areas[44,46]. Such information can be used for intensification and prioritizing areas for higher agricultural productivity. In a similar exercise, wheat-growing areas of IGP were divided into four regions (Figure 8 *b*) such as low, medium, medium high and high representing areas with wheat yield of < 1000, 1000–2500, 2500–4000 and > 4000 kg ha^{-1} respectively. More than 64% of the total wheat-producing area belongs to medium high to high range of wheat yield, implying the potential that could be achieved[44,46]. With economic growth, the consumers in India have been found to shift their budgetary allocation form cereal-based food towards high-value commodities like fruits and vegetables, milk, fish, meat and meat products[47]. To keep pace with these changes, diversification from rice–wheat in the IGP could lead to higher income with lesser use of water resources. However, we need to asses the impact of such diversification based on which a structured plan could be prepared at local and/or regional level.

Conclusion

Analysis of land resources of the IGP region highlighted different issues that need to be tackled in near future for sustaining agricultural productivity. Soil management to overcome subsurface compaction, change in cropping system, management of salt-affected soils and land use planning strategies for efficient utilization of available resources are suggested. Framework for future policies and institutional changes/modifications are also recommended. In WIGP and UIGP, forestry as a land use has high potential and research suggests that rice–wheat can be replaced with agroforestry. In MIGP and EIGP, review of the Land Ceilings Act is suggested for allowing migration within the categories below middle level for viable agriculture. Marginal and small farmers in these regions need to be encouraged to take up vegetable cropping. We also argue for better utilization of water resources in regions where it is low and engaging at least some part of the population in the non-agriculture/industrial sector.

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