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Review Article

Soil Health and Water Quality Issues for Sustainable Agricultural Production in the Eastern Region of India

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Background

The eastern region of India is situated between latitudes of 17° N and 29° N and longitudes of 80° E and 97° E. The region includes Assam, Bihar, Chhattisgarh, Jharkhand, Odisha, West Bengal and eastern part of Uttar Pradesh. Total geographical area of this region is 73.60 Mha, which is 22% of the total geographical area of the country. Out of the total geographical area of the eastern region, only about 45% (33.60 Mha) is the net cultivated area. The region is inhabited by about 34% of total population and contributes to the food grain production of 58 million tonnes (34.6% of the total production of the country). Food grain productivity in the region for year 2004-05 was the highest in West Bengal (2.5 t ha^{-1}) followed by eastern UP (2.1 t ha^{-1}), Bihar (1.5 t ha^{-1}), Assam (1.4 t ha^{-1}), Odisha (1.3 t ha^{-1}), Jharkhand (1.2 t ha^{-1}), and Chhattisgarh (1.0 t ha^{-1}). The cropping intensity in West Bengal, Odisha, eastern UP, Assam, Bihar, Jharkhand and Chhattisgarh is 177, 152, 151, 145, 142, 117 and 115% respectively (Table 1) with an average cropping intensity of 142%. The climate of the region is tropical, hot and sub-humid to humid with high rainfall. Annual rainfall in this region varies from 1091 to 2477 mm with an average of 1525 mm, which is sufficient and substantial for growing any crop. Bulk of the rain (about 80%) occurs during the monsoon season. The rainfall has erratic temporal and spatial distribution with considerable year-to-year variations. Even in years when the total rainfall is adequate, long dry spells and inadequate rainfall at the crucial stages of crop growth adversely contribute to instability of agricultural production. The plains of this region invariably suffer from the excess of stagnating water causing waterlogging and crop damage during monsoon. On the contrary, the undulating topography and sloping lands suffer from excessive runoff and nutrient losses. The coastal areas are vulnerable to seawater intrusion and cyclones.

The region is richly endowed with two basic natural resources *viz.* soil and water. Ultimate irrigation potential from major and medium irrigation projects in this region has been estimated at 19.66 Mha-m as against 58.48 Mha-m for the whole country. Historically, it was the most productive agricultural tract of the country and its agriculture maintained a lead over other regions. But presently agricultural development in this region is much below its potential. For improving and sustaining agricultural production in this region, it is necessary to analyze characteristics of the soil and water resources, and protect these two natural resources from degradation.

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Table 1. Natural resources endowment of different states of eastern region

States	Geographical area (´000 ha)	Net cultivated area (´000 ha)	Cropping intensity (%)	Food grain productivity (t ha^{-1})	Average annual rainfall (mm)	Net irrigated area (´000 ha)	Ground water resource (´000 ha m)	Ground water development (%)
Assam	7843	2751	145	1.40	2477	114	2471	9
Bihar	9359	5603	142	1.52	1204	4550	2699	46
Chhattisgarh	13780	5480	115	0.98	1430	1263	1607	6
Eastern UP	10402	6328	151	2.10	1091	4197	8112	47
Jharkhand	7970	1807	117	1.24	1277	258	653	33
Odisha	15571	6165	152	1.32	1451	2143	2099	23
West Bengal	8687	5427	177	2.50	1750	1911	2309	38
Eastern Region	73613	33563	142	1.58	1525	14436	19950	29

Source: Singh *et al.* (2009a)

Characteristics of Natural Resources in Eastern India

I. Soil Resources

Out of total eight different soil orders reported in India, six soil orders occur in the eastern region. Aridisol and Oxisol are not found in this region (Singh *et al.* 2009a). Area covered under six soil orders in different states of the eastern region is presented in Table 2. Eastern region is dominated by Inceptisol covering about 34 Mha. In general, 22-75% area in different states is under Inceptisol. Soils of the eastern UP, West Bengal and Odisha have more than 50% area under Inceptisol. Alfisols cover about 20 Mha area of the eastern region. About 10-50% areas in different states are under Alfisol. In Chhattisgarh state, 6.9 Mha (50%) area is under Alfisol. A considerable area (14.5 Mha) of this region comes under the soil order Entisol. More than 40% (3.76 Mha) area of Bihar is covered by Entisol. About 3 Mha area of the eastern region, largely in Chhattisgarh, is covered by Vertisol. Hilly areas of Chhattisgarh and eastern UP have 0.09 and 0.07 Mha, respectively under the soil order Mollisol. In Assam, 0.39 Mha area is covered by the soil order Ultisol.

Physical properties of major soil sub-groups occurring in this region were determined by Singh and Kundu (2008a, 2008b, 2010) and Singh *et al.* (2009b, 2010). The soils are largely sandy loam to clay loam in texture which retain good amount of moisture. These soils exhibit medium to high available water capacity which helps in retaining

Table 2. Soils of the eastern region and their distribution

States	Soil orders											
	Entisols		Inceptisols		Alfisols		Vertisols		Mollisols		Ultisols	
	Area (Mha)	Percent	Area (Mha)	Percent	Area (Mha)	Percent	Area (Mha)	Percent	Area (Mha)	Percent	Area (Mha)	Percent
West Bengal	1.97	22.85	4.69	54.41	1.96	22.74	-	-	-			
Bihar	3.76	40.39	4.48	48.12	1.07	11.49	-	-	-			
Jharkhand	2.21	27.62	3.18	39.75	2.61	32.63	-	-	-			
Odisha	1.52	9.84	7.80	50.49	5.27	34.11	0.86	5.56	-	-		
Chhattisgarh	1.64	11.88	3.10	22.46	6.89	49.94	2.08	15.07	0.09	0.65	-	
Assam	1.81	30.42	2.96	49.75	0.79	13.27	-	-	-	-	0.39	6.56
Eastern UP	1.55	14.89	7.71	74.06	1.08	10.38	-	-	0.07	0.67	-	
Eastern Region	14.46	-	33.92	-	19.67	-	2.94	-	0.16	-	0.39	-

Source: Halder *et al.* (1992, 1996), Sarkar *et al*. (1998), Singh *et al.* (2003), Tamgadge *et al.* (1999)

Table 3. Water resources potential of major river basins of eastern India

Sl. No.	River basins	Catchment area (km^2)	Water resources potential (Mm^3)		Groundwater potential (Mm^3)
			Average	75% dependable	
1	Ganga-Brahmaputra-Meghna				
	(a) Ganga	>861452	525023	436312	171725
	(b) Brahmaputra	>194413	537240	491736	27857
	(c) Barak & other	>41723	48357	-	1795
2	Subarnarekha	29196	12368	9855	2185
3	Brahmani-Baitarani	51822	28477	20051	5879
4	Mahanadi	141589	66879	53786	21293

Source: Anonymous (1993)

moisture for post-monsoon crops. Saturated hydraulic conductivity of the soils is low indicating poor drainage conditions of the soils. Average erosion index of the soils indicates moderate erodibility. However, Entisols, Inceptisols, Vertisols and Mollisols have high to very high erosion index, indicating an urgent need for adoption of soil conservation measures.

II. Water Resources

a) Surface Water Resources

Total available surface water in different river basins of the country is 188 M ha-m per year. Water resource potential of the major river basins of eastern region is presented in Table 3. Three major river basins in the eastern region excluding Assam are Mahanadi, Brahmani-Baitarini and Subarnarekha. The annual surface water available in these three basins is 11.2 Mha-m and the total annual monsoon runoff is 11.7 Mha-m. Annual utilizable surface water in the three basins is estimated at 8.8 Mha-m. It has been observed that due to i) non-availability of suitable storage sites in hills and plains, and ii) extreme variability in precipitation, which disallows storage of flash and peak flows, all the stream flows can not be stored in the reservoirs. The live storage capacity under completed projects in the country is 20.65 Mha-m, out of which the share of eastern region is 2.92 Mha-m. The annual per capita water availability in Mahanadi, Brahmani-Baitarini and Subarnarekha basin is 2067, 2388 and 1982 m^3, respectively. Groundwater potential of Ganga, Brahmaputra, Barak and other basins has been estimated at 171725, 27857 and 1795 Mm^3, respectively. In Subarnarekha, Brahmani-Baitarini and Mahanadi basins, groundwater potential is estimated at 2185, 5879 and 21293 Mm^3, respectively.

b) Ground Water Resources

The region also has a large groundwater potential. Total utilizable groundwater resource for irrigation is estimated at 19.5 Mha-m year^{-1}. However, average utilization of this resource is only 29%. It varies from 6% in Chhattisgarh and 9% in Assam to 46% in Bihar and 47% in eastern UP. Thus, there is ample scope for further exploitation of groundwater resource. However, utmost caution is needed in coastal belts to avoid seawater intrusion. In several areas endowed with thick but relatively less pervious clay layer at the land surface (*e.g.* Midnapore district of West Bengal), over-exploitation of groundwater has caused substantial fall in water table. The actual ground water exploitation level is less than 20% in 25 districts of Odisha, 6 districts in Bihar, all the districts of Chhattisgarh and Assam, 6 districts of West Bengal and 12 districts of Jharkhand. Under-exploitation of groundwater and rising water table in the canal commands has reduced the underground space for water storage. Consequently, there is reduction in groundwater recharge. The reduced amount of natural recharge adds to the runoff excess, thereby aggravating floods and flood-related damages.

Irrigation Status

Net irrigated area in eastern India is 14.89 Mha, out of which 4.2 Mha is in eastern UP, 2.51 Mha in Bihar, 2.69 Mha in Odisha, 3.91 Mha in West Bengal, 1.26 Mha in Chhattisgarh, 0.20 Mha in Jharkhand and 0.17 Mha in Assam. As most of the cultivated area in eastern region does not have provision for assured irrigation, even a short spell of drought adversely affects the stability of agricultural production, thereby resulting in low productivity. This has led to agricultural development much below its potential, limited employment in agricultural sector, and a large proportion of the population below poverty line with high incidences of malnutrition. On an average, 60% of the created irrigation potential is utilized for irrigation. In Assam and Jharkhand, utilizable irrigation potential is below 50% level.

Ultimate irrigation potential from major and medium irrigation projects in eastern region has been estimated at 19.66 Mha-m as against 58.48 Mha-m for the whole country. Major irrigation projects of the plain region on Sharda, Gandak, Kosi, Sone and Mahanadi rivers are barrage systems and therefore suffer from the problems of untimely supply of water due to fluctuating flow at the source. Several medium irrigation projects of these plains are pump (lift), canal systems. In eastern region, an ultimate minor irrigation potential of 33.07 Mha has been assessed as compared to 81.48 Mha for the whole country. Thus, the eastern region possesses total irrigation potential of 53 Mha, which constitutes about 38% of the country's total potential of 140 Mha. The region has an extensive network of rivers, *nallas* and lakes from which water could be lifted for irrigation by installing appropriate water lifting systems.

III. Climate Resources

The climate of the region is tropical, hot and humid to sub-humid with high rainfall. The average annual rainfall in this region varies from 1091 to 2477 mm with a regional average of 1526 mm, which is sufficient and substantial for growing any crop. Assam gets mean annual rainfall of 2477 mm, which is the highest in the region, followed by West Bengal (1750 mm), Odisha (1451 mm), Chhattisgarh (1430 mm), Jharkhand (1277 mm), Bihar (1204 mm), and eastern UP (1091 mm). Bulk of the rain (about 80%) occurs during the monsoon season. It has erratic temporal and spatial distribution with high year-to-year variation. High intensity and heavy rains cause frequent floods in the eastern region, especially in plains, and coastal deltaic areas. The coastal areas are also vulnerable to seawater intrusion and cyclones.

Average annual potential evapotranspiration of eastern region varies between 1742 and 1986 mm with an average value of 1750 mm, which is higher than the country's average (1755 mm). Maximum and minimum potential evapotranspiration values are observed in Odisha and Assam, respectively. In all the states of eastern region, average potential evapotranspiration exceeds average annual rainfall, except in Assam.

Soil and Water Related Constraints

I. Soil related constraints

Soil Degradation

Extent of degraded areas in eastern region under various categories is reported in Table 4. Chhattisgarh and Assam states show severe soil degradation problems in 53.7 and 76.8% of the total land area, respectively. Loss of top-soil is a common result of degradation in all the states of eastern region. Waterlogging and flooding are the other major concerns. Singh *et al.* (2003) and Singh and Kundu (2009) dealt on various prospects of managing the salt affected soils of the eastern region.

Soil Acidity

Soil acidity is an important constraint responsible for low productivity in the eastern region. Data on the extent and degree of soil acidity in different states are presented in Table 5. In eastern region, 27.44, 10.47 and 0.17 Mha areas are classified under slightly, moderately and strongly acidic soils. Strongly acidic soils occur

Table 4. Percentage of areas under various soil degradation problems in eastern states

States	Water erosion		Physical deterioration		Chemical deterioration (Salinization)	Land affected by more than one problem				Total degraded land (%)
	Wt	Wd	Water logging	Flooding		(Cs+Pw)	(Cs+Pf)	(Et+Pf)	Wt+Cn, Pf, Pw, Cn	
West Bengal	19.7	-	6.9	1.1	-	1.9	1.3	-	-	30.9
Bihar and Jharkhand	23.3	-	11.5	-	1.3	-	-	-	-	36.1
Odisha	34.4	-	4.4	-	0.5	-	-	-	-	39.3
Chhattisgarh	50.2	-	0.5	0.4	-	-	-	-	2.6	53.7
Assam	17.7	-	2.5	10.5	-	-	-	-	45.9	76.8
Eastern UP	27.8	2.3	2.5	5.5	4.5	-	-	-	9.5	52.1

Source: Haldar *et al.* (1992, 1996), Sarkar *et al.* (1998), Singh *et al.* (2003), Tamgadge *et al.* (1999)

Cs= Chemical deterioration (salinization), Wt= Loss of top soil, Pw= Physical deterioration (waterlogging), Wd= Terrain deformation, Pf= Physical deterioration (flooding), Et= Wind erosion

in Chhattisgarh and Assam states only. More than 50% of the total area of eastern region is affected by the problem of soil acidity.

Fertilizer Consumption Status

Fertilizer consumption in this region is the lowest in the country. The consumption in the states of West Bengal, Bihar, Eastern UP, Jharkhand, Odisha, Chhattisgarh and Assam is 122.4, 130.68, 100.7, 68.2, 41.4, 46.5 and 46.6 kg NPK ha^{-1}, respectively. In four out of seven states, average fertilizer consumption is less than the national average of 90 kg NPK ha^{-1}. Primary cause for low fertilizer consumption in eastern states is waterlogging by surface flooding during *kharif* season and *rabi fallow* due to non-availability of irrigation water. Studies have clearly indicated that while fertilizer use in *kharif* rice has been negligible, farmers often use more than recommended doses of fertilizers in irrigated rice during *rabi* season (Table 6).

Heavy metal pollution of soils

The state of Odisha has large deposits of ores and minerals of heavy metals Fe, Mn, Cr, Pb and Ni (Table 7). The soils around the mining areas contain 100-300 ppm Fe, 60-100 ppm Mn, 60-75 ppm Cu, 30-100 ppm Cr, 50-150 ppm Ni, 10-20 ppm Pb and 200-250 ppm Zn.

Combustion of coal through thermal plants adds large amounts of pollutant elements to the soil and water. The thermal plant at Talcher daily burns 9000 T of coal from which 3600 T of fly ash is produced. This fly ash contains total 424 ppm Fe, 34 ppm Zn, 39 ppm Cu, 241 ppm Mn, 33 ppm Pb, 13 ppm Cr and 4.5 ppm Cd. Thus total fly ash deposits daily 1526 kg Fe, 122.9 kg Zn, 140 kg Cu, 867 g Mn, 119 kg Pb, 47 kg Cr and 16 kg Cd (Sahu 2003). About 15% of these heavy metals from the ash pond seep into the flow of Nandira river to pollute its water. Use of fly ash @ 5 to10 t/ha to improve physical conditions of light-textured soils thus causes heavy metal pollution of the soils.

Surface soil samples collected from 18 villages situated within 2 to 15 km of the chromite

Table 5. Extent and degree of soil acidity in different states of eastern India (Mha)

States	Strongly acid (pH<4.5)	Moderately acidic (pH 4.5 - 5.5)	Slightly acidic (pH 5.5 - 6.5)	Total
West Bengal	-	0.56	4.20	4.76
Bihar	-	0.04	2.32	2.36
Odisha	-	0.26	8.41	8.67
Chhattisgarh	0.15	6.30	4.39	10.84
Assam	0.02	2.31	2.33	4.66
Eastern U.P.	-	-	0.02	0.02
Jharkhand	-	1.00	5.77	6.77
Eastern India	0.17	10.47	27.44	38.08
Total India	6.19	24.81	58.94	89.94

Source: Sharma and Sarkar (2005)

Table 6. Fertilizer consumption in different states of eastern India (Mha)

States	Fertilizer consumption in *kharif* + *rabi* (kg ha^{-1})			
	N	P_2O_5	K_2O	Total
West Bengal	63.8	33.4	25.2	122.4
Bihar	110.3	12.5	7.7	130.6
Jharkhand	40.7	24.9	2.5	68.2
Odisha	26.7	8.5	6.3	41.4
Chhattisgarh	30.7	11.9	3.9	46.5
Assam	22.2	12.7	11.7	46.6
Eastern U.P	78.2	18.6	3.9	100.7
Eastern India	53.2	17.5	8.8	79.5
All India	59.2	22.1	8.5	89.8

Source: Fertiliser Statistics (2003-2004), Fertilizer Association of India, New Delhi

Table 7. Heavy metal deposits in Odisha

Ores/minerals	Suspected pollutant elements	Total deposits (million tonnes)	Share of country (%)
Iron	Fe, Mn, Al	3567	27.1
Manganese	Mn	50	28.4
Chromium	Cr, Ni, Cd	183	98.4
Lead	Pb	9	1.8
Nickel	Ni	270	91.8
Coal	Zn, Fe, Cu, Cr, Ni, Pb, Co, U, Th	47889	28.6

Source: Directorate of Mines, Odisha

mines at Sukinda of Jajpur district in Odisha were found contaminated with Cr^{6+}. All the soils were moderately acidic and they contained on an average 0.404 ppm Cr^{6+}. Considering 0.05 ppm of Cr^{6+} toxic to plants and animals, 143 out of total 167 soil samples analysed were polluted. Villages lying within 3 km radius from the mines have soils polluted with Cr^{6+} (Sahu and Nayak 2002).

Medium and lowlands adjacent to the lateritic uplands as well as the lands close to the Fe-ore mining areas in Odisha suffer from Fe toxicity. About 30,000 ha of Fe-toxic lands have been identified in Odisha (Sahu 2003). These soils contain >300 ppm of DTPA extractable Fe. Rice grown in such lands suffer from Fe-toxicity with symptoms of bronze coloration of leaves, stunted growth, shy tillering, emergence of defective panicles & chaffy spikelets. Affected rice plants contain more than 300 ppm Fe. Grain yield of 17 rice genotypes varied from 4.0 to 5.5 t/ha in normal soil and 1.3 to 3.3 t/ha in Fe-toxic soils of Odisha.

The large scale mining and allied activities going on in the Jharkhand region has caused severe damage to the land resources of the area. Vast areas of rich forests and agricultural land belonging to the indigenous people have been laid waste because of haphazard mining. Eliminating of existing vegetation and alteration of soil profile due to open cast mining operations, including shifting of overburden and reject dumps, have caused severe soil erosion and silting of adjoining courses and degraded the productive capacity of the lands in the area. Excessive underground mining, especially of coal, is causing subsidence of land in many areas as a result of which such lands have been rendered unsafe for habitation, agriculture and grazing. The Jharkhand government has granted 524 leases for mining various major minerals 206 of which have been granted for coal alone. In addition, 2,717 leases covering an area of 8,426 ha have been granted for extracting minor minerals in the state. Mining ruins the land, water, forests and air. The loss or pollution of natural resources degrades the quality of human life in these areas. Increasingly, mineral-based production units like coal-fired power plants, steel plants and cement factories are located near the mines. A cluster of thermal power stations are planned near the major rivers of Jharkhand.

A precise estimate of the amount of agricultural land lost to mining is not readily available. Every mining enterprise, however, means the conversion of land to such purposes as roads, railways and ropeways for mineral transport, townships for housing miners and manager, infrastructure for administrative purposes, land for stockyard and preliminary processing operations. In effect, the total land affected by mining is many times larger than the simple lease area. Several strategies for the management of over burden and mine spoils have been suggested by Sikka *et al.* (2009).

Impact of fallow-rice cropping system on soil health and groundwater quality

Most of the agricultural farms in the eastern region practice fallow-rice cropping system. The fields remain fallow through the dry season due to inadequate water availability, when 30 to 90 kg nitrate N per ha is formed and accumulated in the soil profiles. Kundu *et al.* (2004) studied influence of three different field management practices of dry season on nitrate buildup in 25 soil profiles in Khurda district of Odisha. Dry-season nitrate N buildup in 0-60 cm soil profile ranged from 52.5 to 86.0 kg/ha (mean 66.8 kg/ha) for ploughed clean, 35.2 to 57.0 kg/ha (mean 46.3 kg/ha) for non-ploughed weedy, and 20.0 to 41.4 kg/ha (mean 30.4 kg/ha) for horsegram grown fields. When these fields are flooded and puddled for planting *kharif* rice, nitrate gets lost from the soil profiles through denitrification and leaching. Such loss of nitrate every year from agricultural farms not only depletes N fertility of soils but also contributes to the pollution of ground water (Table 8). Drought-tolerant, short-duration legumes grown during dry season can assimilate part of the nitrate N accumulated in the soil profile and conserve it against undesirable losses (Kundu *et al.* 2002).

II. Water related constraints

A substantial portion of the eastern region comprises of hills and valleys. The intense rains during monsoon season generate rapid overland flows on the unprotected hills resulting into sheet, rill and gully erosion. Deforestation and shifting cultivation in the region further accelerate the problems. Water-related constraints are different for different geographical entities. From water management point of view, the eastern region may be categorized into three distinct geographical

Table 8. Effect of dry-season field management on N loss from soil profiles* under rice-based cropping system. Khurda district, Odisha. 2003

Dry-season management of field	NO_3 N accumulated in 0-60 cm soil profile through dry season (kg N/ha)	NO_3 N remaining in 0-60 cm soil profile after field preparation for planting *kharif* rice (kg N/ha)	N loss from the soil profile (kg N/ha)
Ploughed, clean	66.8	14.5	52.3
Non-ploughed, weedy	46.3	12.1	34.2
Horse gram grown	30.4	9.7	20.7

Source: Kundu *et al.* (2002, 2004, 2006). * Data represent means of 25 soil profiles.

entities: (i) Plains of eastern UP, Bihar, West Bengal and Assam; (ii) Hilly tracts of Vindhyas in eastern UP, Kamoor hills of Bihar, Bihar plateau region spread over Bihar, West Bengal and Odisha and Chhattisgarh region; and (iii) Coastal plains of West Bengal and Odisha.

Groundwater quality problems and affected districts in different states of eastern region are presented in Table 9. Groundwater quality is not a problem in eastern UP and Jharkhand states. However, excess concentration of iron is observed in 4, 5, 3 and 11 districts in West Bengal, Odisha, Chhattisgarh and Bihar, respectively. Iron problem is also witnessed along the northern bank of Brahmaputra in Assam. Salinity problem is witnessed in coastal areas of Odisha and West Bengal; Durg, Dantewada and Raipur districts of Chhattisgarh; and Begusarai district of Bihar. Arsenic contamination beyond critical level is reported from Malda, south 24-Parganas, Nadia, Hooghly, Murshidabad, Bardhaman and Howrah districts of West Bengal; Rajnandgaon district of Chhattisgarh; and Bhojpur and Patna districts of Bihar. Problem of excess concentration of fluoride in groundwater is reported from Birbhum district of West Bengal; Bolangir district of Odisha; and Giridih, Jammui and Dhanbad districts of Jharkhand. Adverse effects of different contaminants are visible not only on the crops grown in the region but also on the health of human beings and animals.

Kundu and Singh (2004, 2006), Kundu *et al.* (2005, 2009a, 2009b) and Panda *et al.* (2009) determined quality of groundwater in inland as well as coastal blocks of Odisha and assessed their suitability for use in irrigation. Analyses of ground water quality in Assam (Sarkar *et al.* 2006) showed that high iron content is a problem for its large scale use for irrigation. Occurrence of iron toxicity and high-iron induced P and K deficiency in lowland rice limit crop productivity in irrigated areas. Iron precipitated from ground water used for irrigation often clog soil pores and impede drainage and aeration capacity of the soils, especially heavy-textured soils. To overcome the problem of iron toxicity, following soil and water management practices are suggested: (i) aeration of paddy soil with weeder, (ii) storage and aeration of ground water in a tank for precipitating iron before its use for irrigation, (iii) use of modest dose of lime (Sikka *et al.* 2009).

Water pollution by hexavalent chromium in Odisha: Water samples collected from various sources of 16 villages situated within 2 to 15 km distance from the chromite mines of Sukinda of Jajpur district in Odisha were analyzed for chromium pollution. Data in Table 10 show that most of the surface water samples were contaminated with Cr^{6+} while ground water samples were less polluted due to low mobility of Cr^{6+} in soil profile (Sahu and Nayak 2002).

Impact of mining activities on water quality in Jharkhand: Mining wastes pollute streams and rivers. Ore fines and toxic substances carried by rain water into nearby water courses, alters their chemistry and often makes the water unfit for human use. By locating mineral treatment facilities near the mines, water pollution problems get worse. These units use enormous quantities

Table 9. Groundwater quality problems and affected districts in different states of eastern region

Contaminants	Affected states and districts (in part)
	West Bengal
Salinity (EC > 3000 µS/cm at 25 ° C)	Howrah, Midnapore, South 24 Parganas,
Fluoride (>1.5 mg/l)	Bankura, Bardhaman, Birbhum, Dakhindinajpur, Malda, Nadia, Purulia, Uttardinajpur
Chloride (> 1000 mg/l)	South 24 Parganas, Howrah
Iron (>1.0 mg/l)	Bankura, Bardhaman, Birbhum, Dakhindinajpur, E. Midnapur, Howrah, Hugli, Jalpaiguri, Kolkatta, Murshidabad, N-24praganna, Nadia, S-24pragannas, Uttardinajpur, West Midnapur
Nitrate (>45 mg/l)	Bankura, Bardhaman
Arsenic (>0.05 mg/l)	Bardhaman, Hooghly, Howrah, Malda, Murshidabad, Nadia, North 24 Praganas, South 24 Pragannas
	Odisha
Salinity (EC > 3000 µS/cm at 25 ° C)	Cuttack, Balasore, Puri
Iron (> 1.0 mg/l)	Balasore, Bargarh, Bhadrak, Cuttack, Deogarh, J.Singhpur, Jajpur, Jharsuguda, Kalahandi, Kandmahal, Keonjhar, Khurda, Koraput, Mayurbhanj, Nayagarh, Puri, Rayagada, Sambalpur, Sundergarh, Suvarnapur
Fluoride (> 1.5 mg/l)	Bolangir, Angul, Balasore, Bargarh, Bhadrak, Boudh, Cuttack, Deogarh, Dhenkanal, Jajpur, Keonjhar, Suvarnapur
Nitrate (> 45 mg/l)	Angul, Balasore, Bargarh, Bhadrak, Bolangir, Boudh, Cuttack, Deogarh, Dhenkanal, Gajapati, Ganjam, J.Singhpur, Jajpur, Jharsuguda, Kalahandi, Kendrapara, Keonjhar, Khurda, Koraput, Malkangiri, Mayurbhanj, Nawapada, Nayagarh, Phulbani, Puri, Sambalpur, Sundergarh, Suvarnapur
	Jharkhand
Fluoride (>1.5 mg/l)	Bokaro, Giridih, Godda, Gumla, Palamu, Ranchi
Iron (>1.0 mg/l)	Chatra, Deoghar, East Singhbhum, Giridih, Ranchi, West Singhbhum
Nitrate (>45 mg/l)	Chatra, Garhwa, Godda, Gumla, Lohardega, Pakur, Palamu, Paschimi Singhbhum, Purbi Singhbhum, Ranchi, Sahibganj
	Chhattisgarh
Nitrate (>45 mg/l)	Bastar, Bilaspur, Dantewada, Dhamtari, Jashpur, Kanker, Kawardha, Korba, Mahasamund, Raigarh, Raipur, Rajnandgaon
Iron (>1.0 mg/l)	Bastar, Dantewada, Kanker, Koriya,
Fluoride (>1.5 mg/l)	Bastar, Bilaspur, Dantewada, Janjgir-Champa, Jashpur, Kanker, Korba, Koriya, Mahasamund, Raipur, Rajnandgaon, Surguja
Arsenic (>0.05 mg/l)	Rajnandgaon
	Bihar
Fluoride (>1.5 mg/l)	Aurangabad, Banka, Buxar, Bhabua(Kaimur), Jamui, Munger, Nawada, Rohtas, Supaul
Iron (>1.0 mg/l)	Aurangabad, Begusarai, Bhojpur, Buxar, Bhabua(Kaimur), East Champaran, Gopalganj, Katihar, Khagaria, Kishanganj, Lakhiserai, Madhepura, Muzafferpur, Nawada, Rohtas, Saharsa, Samastipur, Siwan, Supaul, West Champaran
Nitrate (>45 mg/l)	Aurangabad, Banka, Bhagalpur, Bhojpur, Bhabua, Patna, Rohtas, Saran, Siwan
Arsenic (>0.05 mg/l)	Begusarai, Bhagalpur, Bhojpur, Buxar, Darbhanga, Katihar, Khagaria, Kishanganj, Lakhiserai,Munger, Patna, Purnea, Samastipur, Saran, Vaishali

Contaminants	Affected states and districts (in part)
	Assam
Fluoride (>1.5 mg/l)	Goalpapra, Kamrup, Karbi Anglong, Nagaon,
Iron (>1.0 mg/l)	Cachar, Darrang, Dhemaji, Dhubri, Goalpapra, Golaghat, Hailakandi, Jorhat, Kamrup, Karbi Anglong, Karimganj, Kokrajhar, Lakhimpur, Morigaon, Nagaon, Nalbari, Sibsagar, Sonitpur
Arsenic (>0.05 mg/l)	Dhemaji

Source: Central Ground Water Authority (2010)

Table 10. Hexavalent chromium content of water samples studied in villages around chromite mines of Jajpur district, Odisha

Water source	No. of samples analyzed	No. of samples containing >0.05 ppm Cr^{6+}	% of Cr^{6+} contaminated samples
Mines drain	3	3	100
Rivulet	5	5	100
Floodwater in paddy fields	5	3	60.0
Pond	7	4	57.1
Open well	9	2	22.2
Tube well	16	1	6.25

Source: Sahu and Nayak (2002)

of water for washing the ores. The untreated effluents, slimes or tailings are often released into neighbouring streams or lakes. In many cases, the latter are the sources of water supply to the population.

The large scale mining operations going on in the region have adversely affected groundwater table in many areas with the result that yield of water from the wells of adjoining villages has drastically reduced. Further, effluents discharged from mine sites have seriously polluted the streams and under groundwater of the area. Acid mine drainage, liquid effluents from coal handling plants, colliery workshops and mine sites and suspended solids from coal washeries have caused serious water pollution in the region, adversely affecting fish and aquatic life.

Damodar and Subernrekha river valleys are the cradle of industrialization in Chhotanagpur plateau region. Damodar is the most polluted amongst Indian rivers and ironically almost all polluting industries are government owned. About 130 million litres of industrial effluents and 65 million litre of untreated domestic water finds way to Damodar drainage system every day. A study of the area showed that one coal washery alone was discharging about 45 tonnes of fine coal into the Damodar every day and there are as many as eleven coal washeries in the region with an installed capacity of 20.52 million tonnes annually.

Today the picture of Damodar or Damuda, considered a sacred river by the local tribals, is quite like a sewage canal shrunken and filled with filth and rubbish, emanating obnoxious odors. Other major rivers of the region are also seriously polluted. The Karo river in the West Singhbhum is polluted with red oxide from the iron ore mines of Noamundi, Gua and Chiria. The Subernrekha shows a different type of pollution which is even more hazardous in nature. Metallic and dissolved toxic wastes from TISCO, Jamshedpur and HCL Ghatsila and radioactive wastes from the uranium mill and tailings ponds of the uranium corporation of India limited at Jaduguda flow into Subernrekha and its tributaries.

The release of different toxic metals like As, Hg, Cr, Ni, etc. from the coals and mine spoil heaps in Damodar and its tributaries have caused severe damage to water quality. Continuous dewatering by underground mines also affects water resources. These mines annually pump out millions of litres to drain mine galleries and release it into nearby water courses. This has caused flooding, silting, water logging and pollution in the mining areas of Jharkhand. They have also reduced the surrounding water table, and also reduced the available groundwater.

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