Pergamon

Wat. Sci. Tech. Vol. 39, No. 3, pp. 33–47, 1999.

Published by Elsevier Science Ltd
Printed in Great Britain.
0273–1223/99 $19·00 + 0·00

PII: S0273-1223(99)00030-X

DIFFUSE AGRICULTURAL WATER POLLUTION IN INDIA

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ABSTRACT

Concern over agricultural diffuse pollution sources in integrated water quality management has been growing recently. Such sources are likely to be even more critical in developing countries, including India, where agriculture and rural habitats are still dominant, unlike the G7 or other affluent industrialised nations. A number of special features of the Indian scene need to be considered. These include: (i) extremely varying rainfall and stream-flow patterns; (ii) still largely traditional agricultural practices with average application of fertilizers and pesticides and significant areas under dry farming or only marginal irrigation; (iii) a very large cattle population, with agriculture almost always linked with animal husbandry; (iv) a culture of living close to the river (if not in the river) with dominating instream uses of bathing, washing, cattle wading, waste disposal, etc. and large-scale floodplain farming; and (v) scant respect for rules, regulations and laws alongside an extremely weak law-enforcement machinery.

The paper shows that in the non-monsoon (non-flood) periods, which may account for all but 2 months of a year, agricultural diffuse pollution sources seem to have no impact on stream water quality. During these periods flows are low to minimal and pollution is dominated by the in-stream uses, sullage waters of rural communities and point discharges from urban/industrial sources, if any. Pollution due to agricultural return waters, either as wash-off or as seepage, appears to be rare during the 8-10 fair weather months. However, surface wash-off of pollutants from agricultural sources becomes the dominant factor during flood flows, and seepage/drainage from agricultural fields/soils continues to pollute streams for a month or two after the monsoons are over.

Application of chemical fertilizers and pesticides (or any other agricultural chemicals) in India is still low compared to developed countries, and while eutrophication due to high levels of washed-off nutrients is observed in rural ponds and other stagnant bodies of water receiving agricultural drainage, and excessive pesticide residuals are often reported for vegetables, fodder, milk, etc., monitoring of streams and rivers does not show any significant pollution due to nutrients or pesticides from agricultural diffuse pollution during fair weather months. High nitrate concentrations have been reported in groundwater and in many areas, such as Punjab and Haryana, these can often be linked directly to diffuse agricultural sources. The major problem of agricultural diffuse pollution appears to be the heavy silt loads, along with large quantities of dissolved salts, nutrients, organics and even heavy metals and bacterial contaminants washed off during floods. The silt tends to clog up the flow channel to further encourage seasonal floodplain agriculture. This results in a vicious circle, which degrades the channel, increases flood-damage and is undesirable from ecological and sustainability points of view. High concentrations of salts and nutrients encourage growth of weeds and macrophytes after the floods have passed. The presence of organics, heavy metals and bacterial contamination renders the streamwater unfit for in-stream use or abstraction.

With the introduction of intensive agriculture and adoption of modern farming techniques involving the application of much irrigation water and agricultural chemicals, the problems caused by diffuse agricultural pollution are bound to grow. Routine pollution control methods of discharge permits (or consent letters), EIAs or environmental audits, and normal enforcement measures by regulatory agencies are not likely to work for control of such pollution. Using the example of a small river in central India, Paisuni (Mandakini), the paper brings out the nature of the problems, and suggests a possible management approach. © 1999 IAWQ Published by Elsevier Science Ltd. All rights reserved

KEYWORDS

Agricultural diffuse pollution; India; water quality; pesticides; fertilizers.

INTRODUCTION, DEFINITION AND NATURE OF DIFFUSE AGRICULTURAL POLLUTION

Concentrated point pollution loads discharged into the environment are readily visible, easily monitored, cause significant impacts and can be abated by straightforward regulatory and technological measures. Effluents from urban centres and from major industries fall into this category. In contrast, pollution loads emanating from agriculture, animal husbandry, rural communities and even small-scale industrial units, generally have no defined or identifiable point of outfall and enter the environment in small quantities at a large number of points. The term "diffuse" essentially points to this feature of the discharge of such pollution loads which makes them somewhat difficult to notice, monitor or control. It was for this reason that, until a few years ago, the focus had been on regulating the point pollution loads from urban and industrial sources and the non-point or diffuse loads from agriculture, animal husbandry and rural sources were largely ignored in water quality management. Increasing use of chemical fertilizers, pesticides and other agricultural chemicals, and increasing quantities of nutrients and pesticides in agricultural runoff waters in recent years has caused the more developed western nations to become concerned about diffuse agricultural pollution.

The main water quality problems caused by diffuse agricultural pollution in developed countries are increases in concentrations of nitrates and pesticides, all of which are toxic. The other problems are increases in phosphates, total salts and sodium in water. Urban or industrial wastewaters rarely cause these problems and this helps to differentiate agricultural pollution.

Industries and urban communities use more-or-less constant quantities of water each day, and the effluents and pollutants discharged by them into the environment do not depend upon the climate or on streamflows and groundwater levels to any great extent. Thus their maximum impact occurs in periods when the dilution available is low, i.e. during low streamflow and groundwater table situations. In contrast, agricultural pollutants are generally washed away or leached to receiving waters by stormflows and seepage waters and thus their worst impact on water quality may be at the beginning of, during or just after major storm events. This characteristic applies equally to pollutants from animal husbandry and rural communities, and can help separate the contribution of point pollution sources from those of diffuse sources, even for organic (such as BOD), bacteriological (such as faecal coliforms) and other types of pollutants.

In developing countries, such as India, urbanisation and industrialisation are not as far advanced as in developed nations, and most of the population still live in traditional rural communities and practice agriculture and animal husbandry for their livelihood. Sewer systems or point outfalls are rare, only small amounts of sullage waters flow through surface drains, except during rainy periods when most of the accumulated pollutants are flushed to receiving waters. Thus the problem of diffuse pollution, including diffuse agricultural pollution, is of greater importance and concern for any integrated water quality management programme in a developing country such as India. This paper presents the Indian scenario and the Indian experience in this respect in a limited, but representative, manner. It should be kept in mind that India is a vast and diverse country and no description can fit all the situations.

THE INDIAN SCENARIO

It is well known that: (i) India is a densely populated country; (ii) very large fractions of this population live in rural communities; (iii) very large parts of the total land area are under agriculture; and (iv) the cattle populations are very large. This can also be seen in the data provided in Table 1 for (a) Godavari, one of the major rivers of India and (b) Paisuni, a small tributary of the Ganges system. In both river basins about 50% of the total land area is under cultivation on an overall basis, though it may vary from 40% to 70% in individual parts of the basin. Another 5-15% is cultivatable fallow and grazing land which is fast being converted to farmland. Forests account for 20-25% of the total land, though the fraction may vary from as little as 5% to as much as 50% in smaller basins/sub-basins. Habitation and urban uses consume 3-6% of the total land, and the balance of 5-10% may be wasteland considered unfit for any use. Human populations in the basins/sub-basins included in Table 1 vary from around 60 persons/km^2 in the Paisuni basin to between 150 and 200 persons/km^2 in various parts of the Godavari basin, and of these 70-80% are rural. In the case of the Madhya Pradesh part of the Godavari basin, almost 95% of the over 10 million population is all rural. Cattle populations range from 60 to 200 heads per km^2.

Table 1. Land use, population and cattle in the Godavari and Paisuni river basins

Basin/ sub-basin	*Land under different uses (km²)*					*Total land area (km²)*	*Population in millions*		*Cattle population in millions*
	Forest	*Waste land*	*Habitation*	*Fallow land*	*Cultivated land*		*Total*	*Rural*	
Godavari basin:									
Madhya Pradesh	36,583	297	1,446	4,269	20,255	63,850	10.712	10.208	4.170
Maharashtra	29,858	1,930	4,356	21,599	99,913	157,656	25.056	18.024	34.569
Andhra Pradesh	21,064	7,738	4,582	12,608	27,209	73,201	14.376	12.205	4.108
Total basin	**87,505**	**9,965**	**10,384**	**38,476**	**147,377**	**294,707**	**50.144**	**40.437**	**42.847**
Paisuni basin:									
Madhya Pradesh	178	37	14	21	144	394	0.027	0.019	0.033
Uttar	346	122	73	109	912	1562	0.092	0.068	0.094
Total basin	**524**	**159**	**87**	**130**	**1056**	**1956**	**0.119**	**0.087**	**0.127**

Seasonal variation in rainfall and streamflow. Rainfall in India occurs due to the "Monsoon" phenomenon and is highly seasonal. The rainy season over most of India comprises barely 8-10 weeks during the June-September period, though it may be somewhat longer in the north-eastern hill states and along the western coast. Also in the south-eastern parts there is a second bout of cyclonic rainfall during October-December. Over the bulk of the country October to May is essentially a dry period with no more than 5-10% of the annual rain falling in this period. Table 2 gives the monthly rainfall distribution for a few typical stations in the Godavari basin. As a result of the highly seasonal rainfall, streamflows and groundwater tables also show great seasonal fluctuations from very low in the summer months of April-May to very high in rainy season periods. Table 3 shows typical seasonal variations in streamflows.

Table 2. Typical rainfall distributions in the Godavari and Paisuni river basins

State	*Station*	*Monthly average rainfall (mm)*												*Annual*
		Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*rainfall (mm)*
Godavari basin:														
Maharashtra	Nasik	-	-	-	-	-	86	186	82	113	57	-	-	524
	Nanded	9	29	10	-	-	28	209	92	69	60	-	-	506
	Bhandara	20	92	-	-	-	535	375	330	137	137	2	40	1583
Andhra Pradesh	Adilabad	20	-	5	4	25	129	182	213	183	183	-	5	809
	Mdak	6	3	13	15	23	159	205	235	177	177	25	28	961
	Khammam	8	3	5	12	29	138	259	236	160	160	32	3	1005
Paisuni basin:														
Madhya Pradesh	Chitrakoot	18	10	9	10	14	91	317	281	146	146	16	6	942
Uttar Pradesh	Rajapur	18	3	10	16	13	125	326	347	190	190	9	10	1109

Table 3. Typical seasonal fluctuations in stream flows

Basin and gauging station	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
	Monthly mean rates of flow (m^3/sec)											
Godavari basin:												
Cheria	1.0	0.5	0.5	0.3	0.2	10.7	113.6	349.9	120.2	46.2	5.8	2.3
Mancherial	41	41	29	20	9	50	203	1453	1450	796	95	48
Koida	371	312	284	176	156	924	4.945	3.221	6.920	3.592	809	478
Rajahmundry	406	307	280	214	216	816	4.958	4.570	7.568	3.558	675	431
Paisuni basin:												
Ramghat	2.1	2.0	2.0	1.8	1.4	36.4	838	796	427	12.5	3.6	2.4

Irrigation practice and extent of irrigation. While Punjab, Haryana and western districts of Uttar Pradesh have now attained high intensities of irrigation with 60-80% of the sown areas receiving irrigation, and parts of other basins also reach similar figures, in most parts of the country significant areas of land are still under dry farming. Table 4 shows the intensity of irrigation in some basins/sub-basins and also the fractions irrigated by surface waters and by groundwater. With relatively low intensities of irrigation and greater dependence on groundwater, the problems of agricultural runoff waters and of agricultural pollution of waterbodies are bound to be limited and local, except during and immediately after rain when both surface washoff and leaching of accumulated pollutants are going to take place.

Table 4. Typical irrigation intensities in India

Basin/Sub-basin	*Irrigated area (% sown area)*	*Fraction irrigated by: surface sources (%)*	*groundwater sources (%)*
Ganga basin:			
Harvana	63.6	32.4	67.6
Uttar Pradesh	47.8	35.2	64.8
Bihar	40.2	25.6	74.4
West Bengal	38.8	65.1	34.9
Raiasthan	28.1	14.8	85.2
Madhya Pradesh	10.1	39.4	60.6
Himachal Pradesh	16.2	36.8	63.2
Entire Ganga basin	**35.8**	**34.3**	**65.7**
Godavari basin:			
Madhya Pradesh	8.3	36.8	63.2
Maharashtra	13.7	49.9	50.1
Andhra Pradesh	45.4	33.6	66.4
Entire Godavari basin	21.2	41.4	58.6
Paisuni basin:	28.6	43.4	56.6

Application of chemical fertilisers. This is again at a relatively low level in India as shown in Table 5. The maximum usage of chemical fertilisers is in Punjab where 162, 58 and 31 kg respectively of chemical N, P and K were applied per ha of sown area during 1987-88. The figures now would be close to 200, 75 and 50 kg respectively for N, P and K per ha of sown area per year. However the rates of application are much lower in other parts of India, and even the next highest, in Haryana, may be only half as large. Low rates of application of chemical fertilisers will greatly reduce, if not remove, the chance of significant amounts of leaching into receiving waters.

Table 5. Typical rates of agricultural chemicals used in India

Basin/part of basin in state	*Annual average fertilizer use (kg/ha of sown area)*			*Annual average pesticide use (kg/km² of sown area)*		
	N	*P*	*K*	*Organo-chlorine*	*Organo-phosphorus*	*Others*
Ganga basin:						
Harvana	91	17	9	38	24	33
Uttar Pradesh	63	12	6	68	19	27
Bihar	35	8	4	34	13	46
West Bengal	52	11	12	122	67	163
Raiasthan	24	5	1	106	28	89
Madhya Pradesh	21	4	10	59	4	18
Himachal Pradesh	38	14	19	46	34	126
Entire Ganga basin	46	12	7	62	26	87
Godavari basin:						
Madhya Pradesh	13.5	7.4	1.4	112	1	20
Maharashtra	20	9.3	4.8	110	11	13
Andhra Pradesh	87	51	7.4	166	40	36
Entire Godavari basin	31.5	13.	4.8	115	15	17
Mandakini basin	22	3	4	48	19	24
Punjab	162	58	31	102	88	13

The situation in regard to application of pesticides is also similar. While some crops like cotton, sugarcane, pulses, lentils, fruit and vegetables are now routinely sprayed with pesticides, the average rates of application are still extremely low as shown in the righthand part of Table 5. Organochlorine pesticides still account for almost half the total use of pesticides. However the use of new crop-specific and pest-specific complex chemicals is also growing fast.

Indian culture is perhaps unique for the importance given to water. All religious and social ceremonies involve some worshipping of water and offering water to various deities. Most festivals involve a holy dip in a river, tank or other body of water. Water sources, whether rivers, tanks or wells, are places of social congregation. Most domestic washing is done close to the water source, rather than in homes as in the west. Bathing in rivers was particularly encouraged by making it a religious ritual. The largest and most important religious congregations/fairs of Hindus all take place on the banks of streams/rivers and involve mass bathing. It may not be easy to comprehend that over half a million people took a bath in a 5 km stretch of the Ganga at Allahabad on 23rd January 1997, the full-moon day of the Hindu month "Paush". On Kumbh-days, it may be 8-10 times larger. While the Ganga, Godavari, Narmada, Yamuna and Kshipra may be considered particularly holy, it would be a really rare and dirty stream on which there is no spot for mass bathing on special days of the year. With so much bathing, washing and other activities in streams, a lot of diffuse pollution occurs due to these activities. An extreme example of living on the river is the house-boats on the River Jhelum at Srinagar in Kashmir. The extent of pollution caused by mass bathing is clear from the examples given in Table 6. The bulk of such pollution is organic (BOD/COD) and bacteriological (coliform MPN). Due to such inputs almost continuously all along the banks, BOD/COD and coliform counts in Indian rivers/streams tend to remain high even when there are no point outfalls entering them. While the pollution loads from such on-stream activities cannot be treated as concentrated point outfalls, they would also not fully fit the definition of "diffuse" pollution. In any case they are not diffuse agricultural pollution.

To the above-mentioned on-stream activities may be added cattle wading, particularly by water buffaloes, which are the milch-cattle of choice in India, and floodplain agriculture, particularly vegetables. Such activities add heavy loads of suspended matter, silt, nutrients, organics and even bacteria, and also destabilise the banks and the bed.

Table 6. Stream water quality criteria in India (as laid down by the Central Pollution Control Board)

Designated best use	*Class of water*		*Criteria*
Drinking water source without conventional treatment but after disinfection	A	(i)	Total coliform MPN <50/100 ml
		(ii)	pH between 6.5 and 8.5
		(iii)	DO above 6 mg/l
		(iv)	$BOD_{5,20^{\circ}}$ below 2 mg/l
Outdoor bathing (organised)	B	(i)	Total coliforms MPN<500/100 ml
		(ii)	pH between 6.5 and 8.5
		(iii)	DO above 5 mg/l
		(iv)	$BOD_{5,20^{\circ}}$ below 3 mg/l
Drinking water ource after conventional treatment and disinfection	C	(i)	Total coliform MPN< 5000/100 ml
		(ii)	pH between 6 and 9
		(iii)	DO above 4 mg/l
		(iv)	$BOD_{5,20^{\circ}}$ below 3 mg/l
Propagation of wildlife and fisheries	D	(i)	pH between 6.5 and 8.5
		(ii)	DO 4 mg/l or more
		(iii)	Free ammonia-N 1.2 mg/l or less
Irrigation, industrial, cooling, controlled waste discharges	E	(i)	pH between 6.0 and 8.5
		(ii)	EC below 2250 micro mhos/cm
		(iii)	Sodium absorption ratio below 26
		(iv)	Boron below 2 mg/l

In summation it can be said that when examining diffuse agricultural pollution in India one should devote special and adequate attention to the local situation regarding: (i) intensity of agriculture and irrigation; (ii) agricultural practices, particularly the use of fertilisers and pesticides; (iii) animal husbandry; (iv) on-stream activities like mass bathing, washing, cattle wading and floodplain agriculture; and (v) most important of all, the extreme seasonal variations in rainfall and stream flows.

WATER QUALITY AND STREAM FLOWS

Water quality is a complex concept depending on the intended beneficial uses, and also on the perceptions of the local community or extent of permissible or acceptable risks. The Central Pollution Control Board (CPCB) of India has classified streams and laid down ranges of acceptable values of various parameters as given in Table 6. The situation currently prevailing, and the likely role of diffuse pollution in it, is discussed in the following sections, classifying the water quality parameters into: (a) organic pollution indicators; (b) bacteriological pollution indicators; (c) suspended matter indicators; (d) common-ion or salinity indicators; (e) heavy metals and toxic pollutant indicators; and (f) nutrient indicators.

Indicators of organic pollution. Traditionally organic pollution of water bodies and the self-purification of such pollution through microbes has been the aspect of water quality management which is paid the maximum attention, the basic objective being to maintain the waters in an aerobic state fit enough for freshwater fish like salmon and trout to survive. Thus dissolved oxygen (DO) is considered to be the single most critical indicator of the "health" of a stream. In addition to point loads of organic pollutants, diffuse sources like rural communities, animal husbandry, in-stream uses, and to some extent even agricultural residues, also contribute to organic pollution of water bodies. Such diffuse organic pollutants enter the river all along its length and their loads increase substantially during the rainy season, particularly at the beginning when a lot of pollutants accumulated over land are washed off into the river. It is due to diffuse pollution that even lengths of streams with no point outfalls still fail the CPCB specified criteria in respect of BOD, particularly during the rainy season. While no detailed studies have been carried out to quantify the diffuse pollution loads, or to assess the contribution of specific sources of diffuse pollution, it can be appreciated that rural communities, animal husbandry and on-stream uses will contribute much larger shares than agricultural residues. Also two points need to be very clearly noted: (i) DO levels do not appear to become critical even in streams that continually have a BOD much larger than specified; probably anaerobic stabilisation of organic matter on the stream bed, after it is rapidly biocoagulated, and the significant generation of oxygen by photosynthetic activity, are the reasons for it and (ii) BOD or even DO levels do not appear to have the same significance in the Indian ethos as indicators of water quality, and the prescribed criteria need to be renewed and revised. Some typical data in respect of DO and BOD are given in Table 7.

Table 7. Organic, bacteriological and suspended matter pollution in some Indian rivers

River	*Location*	*Range of observed values*			
		DO [mg/l]	*$BOD_{5\text{-}20^\circ}$ [mg/l]*	*Coliform [MNP/100ml]*	*Turbidities]NTU]*
Brahmani	Rourkela D/S	6-10	4-40	10^5-10^8	21-420
	Talcher U/S	9-11	2.8-4.2	10^3-10^7	6-175
Cauveri	Karnataka exit	7-8	1-2	10^4-10^9	8-31
	Pitchavaram	2-8	3-24	10^6-10^{10}	1-10
Chambal	Nagda	4.5-16	2-5	10^4-10^6	5-410
	Kota	3.4-7.1	0.4-4.4	10^3-10^5	3-355
	Etawah	7.4-14.4	1.0-3.0	10^3-10^5	
Ganga	Narora	7.5-8.6	1-3	10^5-10^7	3-50
	Bithoor	508-9.7	2-3	10^9-10^{14}	7-210
	Allahabad	5.2-8.1	6-14	10^5-10^9	9-470
	Patna	5.6-7.8	1-3	$10^4 10^8$	18-1700
	Calcutta	5.2-8.6	2-6	10^5-10^9	150-500
Krishna	Kolhapur	5.5-7.7	3-8	10^3-10^6	2-28
	Vijayawada	5.8-8.2	2-3	10^4-10^7	5-30
Mahi	Sevalia	7-9	0.5-5	10^3-10^7	8-65
	Vasad	7-10	1.0-7	10^3-10^7	6-82
Narmada	Garudeshwar	6-9	5-10	10^3-10^7	12-415
	Bharuch	5-10	1-7	10^3-10^6	5-1500
Sabarmati	Dharoi	6-9	2-8	10^4-10^4	5-350
	Ahmedabad	0-3	40-70	10^5-10^9	360-1200
Tapi	Kathore	7-10	2-8	10^3-10^6	8-1145
Yamuna	Delhi U/S	6.5-10.1	3-5	10^4-10^6	6-180
	Mathura U/S	6.9-12.3	3-16	10^6-10^{10}	185-800
	Agra U/S	6.3-15.8	3-10	10^6-10^{10}	90-850
	Etawah	6.5-9.2	4-6	10^5-10^8	8-780

Indicators of bacteriological pollution. Being connected with safety of water from the health point of view, these are probably the most critical to a community. Diffuse inputs of bacterial loads from rural communities, cattle bathing and other in-stream activities, and even agricultural sources, are obviously the cause of the coliform count remaining so high in more or less all streams in India. Although people are unconcerned, this is only because they are not aware of the hazard, and faecal coliforms should be treated as the most critical indicator of stream quality in India since large numbers of people bathe in, and use, untreated stream water. This situation will not change as rivers are such an important component of Indian culture. Some typical data for coliform MPN are given in Table 7.

Indicators of suspended matter. Suspended solids in a water body are visible to the eye and make the water look dirty and possibly coloured. Besides measuring the suspended solids (SS), the turbidity is also an indicator of suspended matter in water. Colour is primarily due to colloidal matter but may also be due to suspended or dissolved matter. Some typical data for the turbidities in different reaches are given in Table 7. The points to be noted are: (i) diffuse agricultural pollution is an important contributor to suspended matter, particularly in rainy seasons; (ii) in the Indian perception, soil or algal suspended matter are not considered dirty or undesirable; (iii) black or coloured suspended matter from industrial and urban pollution is easily recognised and detested by all.

Common ions and salinity indicators. Once added to water, they are not easily removed and hence keep building up as one proceeds down a river. The data in Table 8 indicate that salts or salinity do not build up in Indian rivers during the fair weather periods, and high concentrations during fair weather are essentially the impact of point industrial urban loads, such as at Nagda. It appears that salts are primarily contributed by diffuse loads and are largely flushed out only during the rainy months as shown by the significant salt concentrations during the rainy months in Table 11. It may be stated that while diffuse pollution loads from agricultural and other activities are significant, and are washed off to the seas during flood flows, they do not appear to pose any problems.

Table 8. Concentration of common ions in some Indian rivers

River	*Location*	*Cl^-* (mg/l)	*HCO_3^-* (mg/l)	*NO_3^-* (mg/l)	*SO_4^{2-}* (mg/l)	*Na^+* (mg/l)	*Ca^{2+}* (mg/l)	*Mg^{2+}* (mg/l)	*TDS* (mg/l)
Ganga	Bithoor	12	172	0.6	18	28	43	21	350
Chambal	Nagda	150	205	0.1	164	71	124	60	800
	Kota	21	100	0.8	11	12	26	11	200
	Etawah	30	185	1.8	26	17	38	18	330
Yamuna	Delhi U/S	15	160	2.1	27	8	28	12	300
	Mathura U/S	115	220	4.1	54	53	41	19	550
	Agra U/S	134	210	4.1	54	53	41	19	550
	Etawah	137	200	2.8	49	52	43	19	550
Godavari	Rajamundry	14	160	0.9	9	26	19	6	300
Krishna	Kolhapur	105	140	8	97	33	46	52	550
	Vijayawada	45	158	13	34	57	34	20	400
Cauveri	Karnataka exit	41	140	0.4	18	30	22	26	300
	Pitchavaram	102	21	0.3	46	61	27	13	450
Brahmani	Rourkela D/S	25	58	5.6	39	13	60	20	250
	Talcher U/S	17	54	2.5	6	6	36	9	160
Sabarmati	Dharoi	45	130	0.4	16	60	30	16	300
	Ahmedabad	300	460	0.8	120	270	50	32	1400
Mahi	Sevalia	25	130	5	8	25	2q	15	250
	Vasad	40	190	7	8	40	30	22	300
Narmada	Garudeshwar	20-40	90-160	4	30	38	40	20	250
Tapi	Kathore	37	190	5	11	23	35	25	300
Mandakani	Anusya	12	175	0.5	5	35	50	31	300-350
	Ram Ghat	16	175	0.8	11	40	42	33	30-350
	Karvi	18	150	0.8	14	50	39	30	275-325
	Rajapur	27	150	0.7	16	60	25	23	250-300

Heavy metals and toxic pollutants. There is very little data on the content of heavy metals, pesticides or other toxic chemicals in Indian streams. Even when significant amounts of heavy metals, pesticides or other toxic chemicals enter a stream from industrial/urban sources (such as large amounts of heavy metals, DDT and other toxicants being discharged by industries into Najafgarh Drain in Delhi and thence reaching the River Yamuna), these are bio-flocculated and carried to the bottom to accumulate and be flushed out with the next floods. Bio-assimilation and even bio-magnification would be likely hazards, but most Indians are not fish-eaters, and Minimata or Itai-Itai or such diseases caused through eating contaminated fish are unheard of in India. With relatively low amounts of pesticides applied, and the virtual absence of runoff waters during fair weather, heavy metal, pesticide, or other toxic pollution from diffuse agricultural pollution does not appear to be of likely concern in India at this time.

Nutrients. The presence of large amounts of nutrients, essentially N, P and K, in water bodies results in blooms of algae and other aquatic flora which are not only non-aesthetic, but under conditions of decay, may turn the water body anaerobic or excrete toxic chemicals, making the water unsafe for use. Under aerobic conditions prevalent in water bodies, nitrogen compounds are oxidised to nitrites and nitrates. With more and more nitrogenous fertilisers being applied to crops, nitrates, which are injurious to human health are becoming a major concern. The internationally accepted limit for nitrates in drinking waters has been sequentially reduced from 60 mg/l to currently stand at 45 mg/l, although the European Economic Community has set 25 mg/l as the guide level with 50 mg/l as the mandatory limit. There are no clear limits set for TKN, phosphates and potassium, but 10 mg/l of each would be considered tolerable, as these may result in algal blooms but no toxicity (except when TKN is in the form of free ammonia, which is highly toxic to fish). As seen from Table 9, the situation with regard to nutrient concentrations in Indian streams and rivers is that they are at sufficiently low levels at present not to cause any concern. The only exception is the River Krishna, where nitrates are very high at all three stations. While no detailed study has been carried out on the Krishna, the source of the high nitrates is likely to be the diffuse nitrogenous pollution from sugarcane fields and other crops, the rocky terrain providing little scope for percolation or retention in soils, unlike in the northern plains.

A specific research study on *Effect of Intensive Application of Fertilizers on Ground Water Quality in Agricultural Fields* carried out by the Ground Waters Wing of the Public Works Department of Tamilnadu concludes that application of chemical fertilizers to agricultural crops does raise the concentration of N, P and K in groundwaters of the area, particularly during periods immediately after the application. However: (i) the rise is not large in magnitude, nor appears to be proportional to the rate of application; and (ii) the concentrations get reduced to normal levels within a few weeks of application. The study revealed that over 85% of the applied nitrogen and over 95% of the applied P and K is retained in soils and no more than 5% of any of the N, P or K was washed off or leached away in water. Also, none of the N, P, or K were observed to accumulate in soils on a long-term basis at even the highest dosages applied in the study.

Another research study by Dr S. K. Lunkad, Professor of Geology, Kurukshetra University, Haryana, compiles data on the relative consumption of nitrogenous fertilizers and the nitrate levels in groundwaters in various states of India as given in Table 10. Obviously, it can be said that: (i) nitrate levels are at levels much higher than those considered acceptable or safe for human consumption in many areas of India, particularly in the states of Haryana, Punjab, Gujarat, Maharashtra, Karnataka and some areas of Tamilnadu; (ii) rates of application of nitrogenous fertilisers have an obvious impact on the average nitrate concentrations in the groundwaters in the state, and to a lesser extent on the maximum observed concentrations in the state; and (iii) the peninsular regions of Maharashtra, Tamilnadu, Karnataka, Madhya Pradesh, etc., show a much larger presence of nitrates in groundwaters than would be indicated by application of nitrogenous fertilisers in these states. The last observation could be either due to nitrate-bearing rocks being present in the igneous Deccan Trap rocks or the low nitrate retaining capacity of the soils of these areas.

Overall role of diffuse agricultural pollution. Since diffuse pollution loads are brought to streams through wash-off and seepage, it would be desirable to examine seasonal fluctuations in water quality of streams as given in Table 11. At most of the stations the concentrations of TDS and BOD are higher during the high-flow months of June to October, indicating significant contributions from diffuse sources. The exceptions are Nagda D/S on the Chambal, the River Khan at Indore, the River Kshipra at Ujjain and the River Kharoon at Raipur, in all of which contributions from urban/industrial sources are large enough to produce higher concentrations during the low-flow periods of January-May.

Agricultural sources form part of, but do not dominate, the contribution from diffuse pollution in the case of organics (BOD) and bacteriological pollutants (coliforms), both of which appear to be heavy in all streams in India. These pollutants are primarily contributed by rural communities, animal husbandry and on-stream activities.

Table 9. Nutrient concentrations in some Indian rivers

River	*Location*	*Mean observed concentrations (mg/l)*		
		NO_2-NO_3 nitrogen	*Total Kjeldahl N*	*Phosphorus*
Ganga	Narora	0.40	6.80	NA
	Bithoor	0.70	13.75	NA
	Varanasi	1.22	4.60	NA
	Calcutta	0.16	0.65	NA
Chambal	Nagda	0.10	0.30	NA
	Kota	0.90	0.74	NA
	Etawah	1.90	1.60	NA
Yamuna	Delhi U/S	2.10	NA	NA
	Mathura U/S	4.20	NA	NA
	Agra U/S	4.30	NA	NA
	Etawah	2.90	NA	NA
Godavari	Rajamundry	1.00	NA	0.50
Cauveri	Karnataka exit	0.40	0.60	ND
	Pitchavaram	0.40	0.75	ND
Brahmani	Rourkela D/S	5.80	ND	ND
	Talcher U/S	2.70	ND	ND
Sabarmati	Dharoi	0.15	0.85	ND
	Ahmedabad	0.30	7.00	ND
Mahi	Sevalia	1.40	0.40	ND
	Vasad	1.60	0.40	ND
Narmada	Garudeshwar	1.00	0.50	ND
Tapi	Kathore	1.50	0.50	ND
Paisuni	Anusya	0.10	0.30	0.10
	Ram Ghat	0.20	1.20	0.15
	Karvi	0.20	1.00	0.15
	Rajapur	0.20	0.80	0.13
Krishna	Kolhapur	8.40	1.70	NA
	Rajapur	17.70	2.60	NA
	Vijayawada	23.00	1.50	NA

Concentrations of nutrients and pesticides in stream waters are too low to be of concern. Diffuse pollution from agricultural sources is bound to be the most dominant contributor to these, if present. However it is not possible to draw any conclusions from the current data about the extent of such pollution. The situation regarding nitrates in groundwater has already become very critical, particularly in Haryana, Punjab and the peninsular south, essentially related to diffuse agricultural pollution.

Currently the largest impact of diffuse agricultural pollution in India appears to be on TDS concentrations and on silt loads, both of which increase very significantly. Silt loads also contain significant amounts of organics, nutrients, heavy metals, pesticides and even bacteria, but at present it is difficult to separate the contribution of agricultural sources from those of other diffuse sources.

CASE STUDIES

Case Study of the Godavari River Basin

The Godavari is one of the major rivers of India, originating from the Western Ghats near Nasik and flowing into the Bay of Bengal near Rajahmundry, draining an area of 312,812 km^2. The average annual yield of the river is 118,000 MCM. The peak flow at the outfall can be as high as 50,000 m^3/sec for short periods.

Although there are a few large towns, e.g. Nasik, Ahmadanagar, Aurangabad, Nagpur, Balharpur, Visakhapatnam and Rajahmundry, the basin is essentially rural dominated. Data on the population, land-use, etc., have already been given in Tables 1-5.

Table 10. Fertilizer usage and groundwater nitrate levels (1990-92 data)

State	*Average nitrogenus fertilizer application kg-N/ha/year*	*Nitrate concentrations in groundwater*	
		Maximum reported (%)	*Average of all observations (mg/l)*
Punjab	162.33	567	55.1
Haryana	91.06	1800	99.5
Uttar Pradesh	52.56	634	22.6
West Bengal	43.00	480	14.2
Tamilnadu	30.70	1030	26.0
Bihar	23.60	350	21.0
Gujarat	22.16	410	49.6
Karnataka	20.43	200	46.8
Andhra Pradesh	14.60	208	13.2
Maharashtra	10.59	(385)	45.7
Orissa	8.53	(849)	14.8
Madhya Pradesh	8.40	473	30.2
Himmachal Pradesh	4.20	177	8.6
Jammu & Kashmir	1.40	275	7.9
North Eastern States	0.92	45	6.6

Source: Dr S. K. Lunkad's paper in SANKALP, Special Publication ES-Z, June 1993, pp 1-13.

The Central Pollution Control Board in its publication ADSORBS/28/1993-94, entitled ***Basin Sub-basin Inventory of Water Pollution - Godavari Basin***, attempts to assess the wastewaters and pollution loads generated from different activities in each district within the basin. While the assessments are based on a number of unvalidated assumptions and cannot be termed reliable estimates, they give a relative idea (see Table 12). Agricultural runoff waters are estimated to be no more than 10% of the total wastewater, but the total diffuse wastewater (also including sullage from rural communities) accounts for 35% of total wastewater generated in Maharashtra, 65% in Andhra Pradesh (AP), as much as 84% in Madhya Pradesh (MP) and 55% in the total basin, the balances of 62%, 35%, 16% and 45% being the contribution of point loads to total wastewater inflows for Maharashtra, AP, MP and the total basin respectively. In terms of BOD loads generated, CPCB estimates diffuse sources to generate about 90%, 67%, 52% and 66% of the total BOD loads generated, for MP, AP, Maharashtra and the total basin respectively. While CPCB does not separate the contribution from agricultural sources these do not seem to have even been included in the diffuse loads, since the BOD contribution of washed out residues may be not inconsiderable.

Table 13 presents water quality parameters in the Godavari and its tributaries. There are no significant water quality problems anywhere, except probably in some small streams locally where point outfalls of urban/industrial wastes join, such as at Nagpur, Nasik, Aurangabad, Sirpur, Balharpur, etc. The main pollution parameters of concern would be coliforms and turbidity both of which would be primarily caused by diffuse pollution as shown by their almost identical concentration throughout the basin.

There is only one pocket in the basin that has critical groundwater problems, and this is around the major industrial port of Vishkhapatnam. Concentrations in this area of pollutants, in which diffuse pollution could have had a role if it was not definitely known that all these pollutants have essentially emanated from industrial sources, rise to levels given in Table 14.

Table 11. Seasonal fluctuation in water quality of some Indian rivers

River	*Station*	*Mean monthly values over the years 1984-88*																							
		Total Dissolved Solids (TDS)												*5 Days - 20° BOD (mg/l)*											
		J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*
Chambal	**Nagda U/S**	364	387	435	490	524	643	840	410	410	390	387	374	1.1	1.9	1.6	2	2.1	1.7	1.4	1.3	1.5	1.4	1.3	1.3
	Nagda D/S	4265	4191	5466	5275	5555	3518	3085	1836	1537	3768	3861	4042	84	93	102	103	105	60	45	22	26	77	81	90
Narmada	**Mandla**	175	185	163	165	168	255	353	313	220	177	155	163	1.6	1.6	1.7	1.7	2.1	2.2	2.6	2.3	1.4	1.6	2	1.8
	Hoshangabad	196	212	205	208	189	210	352	378	270	255	221	184	3	3.9	3.8	3.1	3.3	3.5	3.6	4.3	3.3	2.7	2.5	2.7
	Mandaleshwar	271	232	226	255	270	353	389	312	432	331	300	282	1.3	1	1.4	1.6	1.8	2.5	2.4	2	2.4	1.4	1.3	1.6
Khan	**Indore D/S**	706	704	695	679	596	626	601	707	622	621	731	723	9	12	13	14	13	9	11	12	9	8	9	11
Kshipra	**Ujjain D/S**	360	408	415	396	410	381	412	373	535	389	373	405	4	4	4.2	3.9	3.8	4	4.2	5	3.4	4	4.2	3.9
Kharoon	**Raipur**	270	277	268	316	300	263	298	280	271	262	257	249	5.5	5.3	3.9	3.7	3.8	3.4	4.3	4.1	3.8	4	3.8	3.8
Kalisot	**Mandi deep**	121	145	109	97	147	122	233	242	282	222	205	98	3.4	4.2	2.6	2.6	4.4	3.8	3.1	4.3	3	3.5	2.8	3.3
Tapti	**Nepa Nagar**	304	315	250	354	263	509	399	450	380	378	336	297	1.3	1.9	2.1	2.9	3	1.9	2.6	2.3	2.5	1.9	1.6	1.5
	Burhanpur	400	325	355	429	358	486	469	507	338	368	314	349	1.5	1	1.3	2.3	2.1	1.6	2.2	1.3	1.6	2	1.8	1.5
Wainganga	**Seoni**	233	213	217	225	275	283	290	325	440	260	195	180	1.7	1.4	1.5	1.9	2.1	1.8	3.4	2	1.7	1.7	1.6	1.9

Source: Madhya Pradushan Niwaran Mandal - Natural Water Monitoring Reports

Table 12. CPCB assessment of pollution loads in Godavari basin

Type of pollution load	*Madhya Pradesh*	*Maharashtra*	*Andhra Pradesh*	*Total basin*
Wastewaters generated				
Agricultural diffuse	49.64	132.63	40.92	223.19
Rural and other diffuse	396.49	310.05	303.24	1009.78
Industrial/urban	73.35	743.64	181.54	998.53
Total, MCM/year	**519.48**	**1186.32**	**525.70**	**2231.50**
Organic (BOD) load generated kg/day				
Diffuse agricultural load				
Rural and other diffuse	406.678	344.802	311.532	1063.012
Industrial/urban	48.468	316.263	140.245	504.976
Total kg/day	**455.146**	**661.065**	**451.777**	**1567.988**

Table 13. Stream water quality in Godavari basin

Stream and location	*Coliform (MPN/100 ml)*		*Turbidity (NTU)*		*Ec (µmho/om)*		*DO (mg/l)*		*BOD (mg/l)*		*TKN (mg/l)*		*$N\text{-}NO_3$ (mg/l)*		*Sodium absorption ratio*	
	W	*S*	*W*	*S*	*W*	*S*	*W*	*S*	*W*	*S*	*W*	*S*	*W*	*S*	*W*	*S*
R. Godavari																
Nasik	1000	1800	2	3	15	22	6.4	7.8	4.0	3.7	0.8	0.5	0.2	0.1	3	1
Aurangabad	1000	1800	2	1	69	103	7	5.6	3.9	4.8	0.8	0.7	0.3	0.1	6	10
Nanded	18800	1800	2	2	54	50	6.3	7.4	5.5	4.2	1.0	0.5	0.6	0.1	6	15
Mancherial	240	260	15	20	653	560	5.6	5.4	2.4	2.4	3.6	2.9	0.1	0.2	9	10
Bhadiachlam	280	220	15	15	415	425	7.3	5.7	1.4	1.4	2.2	2.0	0.1	0.1	4	8
Rajahmundry	1600	1600	30	30	290	330	8.6	4.7	1.5	1.4	0.8	0.5	0.1	0.2	4	4
R.Mnjira																
At AP Border	1800	1800	5	13	55	86	6.2	6.8	5.6	3.5	1.0	1.1	0.2	0.3	14	6
R. Peddavagu																
After confluence of Sirpur Mills effl.	1600	1600	58	45	483	665	4.8	3.7	5.6	6.8	0.6	0.4	0.5	0.2	12	9
R. Wainganga																
At Balaghat	800	920	4	6	ND	ND	7.1	6.7	2.1	1.4	1.1	0.7	0.2	0.1	4	2

W - Winter, S - Summer

Table 14. Pollutant concentrations in Vishkhapatnam

Pollutant	Peak level observed	Highest annual average
TDS (mg/l)	1348	1110
Sodium (mg/l)	384	264
Potassium (mg/l)	146	62
Phosphates (mg/l)	4.4	2.7
Nitrates (mg/l)	58	51
Lindane (mg/l)	128	101

Case Study of Paisuni (Mandakini) Basin

Mandakini is a small river, about 70 km long, draining 1956.3 km^2 of MP and UP states to join the River Yamuna and is thus a subtributary of the Ganga basin. There are no industries nor any major town in the basin and the population is only 199,000. About 54% of the land is under cultivation, 27% under forests and the remaining 19% wasteland, fallow or under habitational use. The only pollution occurring would be diffuse pollution, from agricultural sources, rural communities and from mass river bathing as the river is considered holy.

Mr G.K. Kannan carried out an intensive study on the ecology of the Rier Paisuni (Mandakini) and has presented his findings in his Ph.D. thesis. As analysed by him, although there are no problems in respect of common water quality parameters like pH, DO, EC, TDS, common ions, nutrients, organics or toxic compounds, severe environmental problems are observed in terms of soil erosion, bank erosion, river-bed aggradation, growth of macrophytes, disturbance in population of phytoplankton and increase in coliform counts. The obvious cause is the increasing diffuse pollution from agricultural, rural and mass bathing activities. Bed-aggradation and growth of macrophytes are fast destroying the aesthetic and tourist/pilgrimage values of the river. Coliforms make the river unsafe for bathers.

Kannan suggested urgent measures in the catchment, and particularly the floodplain, to manage agricultural and other activities in order to protect the river. He proposed that this should be done involving the local elders and religious heads (to whom the river environment should be of great value) and obtaining people's cooperation, without seeking recourse to regulatory or other type of government intervention. This is because of the extremely unsuccessful, and even counter-productive, results of pollution control by a highly corrupt and inefficient government machinery.

INFERENCES REGARDING DIFFUSE AGRICULTURAL POLLUTION IN INDIA

From the data presented and discussions above, the following inferences can be drawn:

(i) Problems of high nitrates, other nutrients, or pesticides in stream waters, caused by diffuse agricultural pollution have not been observed, probably due to low levels of application of such chemicals. However, groundwater nitrate levels are already showing the impact of diffuse agricultural contributions and the levels in several states are far beyond acceptable limits.

(ii) Higher TDS and often even BOD during high-flow monsoon months, as compared to low-flow fair weather periods, clearly show the magnitude of diffuse agricultural pollution in most stream reaches.

(iii) The BOD continuously remaining high even when there are no point inflows, the DO values, and also high coliform counts in all reaches show diffuse sources of these to be significant almost everywhere. However these sources would be rural communities, animal husbandry and in-stream activities and not agricultural sources.

(iv) Soil erosion, growth of macrophytes and ecological disturbances appear to be the most critical impacts of diffuse agricultural pollution currently.

INDIAN EXPERIENCE AND RECOMMENDATIONS

There is absolutely no experience of controlling diffuse agricultural pollution in India so far. Even the experience of legal and regulatory control of industrial and urban sources of pollution is not very successful due to lack of resources, inefficiency and large-scale corruption. Control over diffuse pollution is not possible without the active and sincere cooperation of the people. In India, cooperation is not possible in anything in which the government or the law are involved. Breaking the law and disobeying or by-passing government is routine. Thus it would be best to campaign for abatement and control of diffuse pollution by appealing to the good sense, awareness and religious feelings of people, so important in our culture. The most critical parameters would be silt load (or TSS), TDS and coliforms, and the control measures would be afforestation, limiting abstraction of water, appropriate management of agriculture, and general sanitation measures near rivers.