IMPACTS OF AGRICULTURE ON WATER QUALITY

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INTRODUCTION

In many arid, developing countries, water has become .-an important constraint to further socio-economic development. As population continues to increase, availability and reliable control of more and more water of appropriate quality is becoming necessary to increase agricultural production., hydropower generation and industrial activities as well as to provide for higher domestic needs. Two or-more decades ago, levels of population were significantly lower in all developing countries than they are at present, and for the most part water available for various human activities was generally considered to be reasonably adequate. When water demands exceeded supply, new sources of water were available which could be developed economically, efficiently and technologically comparatively easily. Furthermore, the environmental consciousness of the world as a whole was significantly lower than what it is today. Accordingly, with a reasonably adequate quantity of sources of clean water available, water quality was not a major consideration. The main emphasis was primarily to ensure that an adequate quantity of water was available for various human uses. To the extent water quality was considered within the context of water resources planning, the primary interest was on sediments.

Several events happened simultaneously during the past two decades which have radically altered this cosy situation. First, both the human and animal populations have increased significantly which resulted in corrresponding increases in demands of water. Second, with advances in knowledge and technology, numerous new types of industrial products and agricultural chemicals are being produced. During the production, transportation, and use of these products, infinite variety of wastes are being generated, some of which eventually found their way to surface water and groundwater sources. Third, it was gradually realized that the environmental impacts of some of these new products were highly adverse in terms of human and animal health. Rachel Carson's memorable book ***Silent Spring*** [1] graphically brought to the attention of people the long-term highly detrimental environmental impacts of toxic agricultural chemicals like DDT or DDE. The impact of mercury pollution in the Minimata Bay in Japan, and the consequent human sufferings due to the so-called Minimata disease, further highlighted the importance of the proper management of water quality. Fourth, many of the major rivers flowing past urban and industrial centers rapidly became open sewers, whose water could no longer sustain valuable commercial fish or be used for human consumption without expensive treatment. This not only reduced an important source of water available but also contributed to a significant aesthetic loss. Finally, increasing knowledge base of the long-term impacts of hazardous wastes, a very significant part of which is dispersed through the medium of water, on the human health and the environment, very firmly put water quality management in the national and international agenda in the seventies.

Several events ... have radically altered this cosy situation

While water quality is affected by all human activities, the main emphasis of this paper is on water quality implications of agricultural activities.

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It should be noted that just as agricultural activities have numerous impacts on water quality, similarly water quality considerations have important implications for agricultural activities. Generally speaking, the major impacts of agricultural activities on water quality are the following:

i) alterations in sediment load due to changes in land use practices;
ii) changes in salinity due to agricultural activities;
iii) water quality deterioration due to anthropogenic chemicals like nitrates and pesticides;
iv) possible eutrophication of water bodies due to leaching of fertilizers; and
vi) water quality degradation of water due to agro-processing industries.

The individual impacts of the above mentioned factors vary from place to place depending on a variety of factors, which could change from time to time due to many issues, including management activities.

If quality of water is to be considered for agricultural uses, the following four important factors need to be considered:

i) salinity of water being used for irrigation;
ii) presence of certain chemicals or trace elements which could affect yields, or make some crops unsuitable for human or animal consumption;
iii) levels of concentration of sodium (high) or calcium (low) which could reduce the rate of infiltration of irrigation water; and
iv) extent of bacterial and viral contamination of water, especially where wastewater is used for irrigation.

The main focus of the present paper however, is on the impacts of agricultural activities on water quality management.

LAND USE AND SEDIMENT CONSIDERATIONS

Existing land use patterns change due to the introduction of irrigated agriculture. As a general rule, cropping intensities increase, cropping patterns are changed, and fallow periods are reduced or even eliminated. These changes could directly affect the rate of soil erosion as well as the runoff regime from such areas. Much of the soil eroded often contributes to higher sediment loads in watercourses, which could contribute to increasing sediment load in irrigation water downstream and higher than expected reservoir sedimentation, with concomitant economic losses.

> **Existing land use patterns change due to the introduction of irrigated agriculture**

A major problem facing many developing countries is clearing of forests to increase the availability of agricultural land to provide food for a continually increasing population. If vegetative covers change over an area, the rates of soil losses change as well. Similarly, livestock grazing affects soil loss from pastures. Overgrazing, which is quite common in many areas of developing countries, significantly increases the rates of soil erosion by reducing grass cover as well as contributing to top soil deterioration by compaction and loosening of soil particles by animal activities. Results of studies of soil loss from Deochanda India, at different levels of soil loss, are shown in Table 1 [2].

Table 1. Soil loss from pastures at different grazing levels, Deochanda, India [2].

Pasture Conditions	Runoff %	Soil Loss (t/ha)
Natural pasture (no grazing)	11	0.4
Proper grazing	19	0.79
Overgrazing	27	2.37

While erosion of soil from land and its transportation by water and subsequent deposition elsewhere is a normal process which occurs naturally without any human activities, agricultural practices-especially improper ones - significantly accelerate this process. Even though it is often not possible to quantify reliably and to differentiate between naturally occurring erosion and soil loss due to human interventions for major rivers in developing countries, Table 2 shows the sediment yields of some selected rivers. It indicates the magnitude of surface runoff per unit area, sediment yields in tons per km², and sediment concentration in ppm. It also shows that the sediment concentrations vary from a high of 40,500 ppm for Haihe in China to a low of 34 ppm for the Zaire River.

Table 2. Sediment yields of selected rivers (adopted from [3,4]).

RIVER	COUNTRY	CATCHMENT AREA ($10^6 km^2$)	RUNOFF (cm)	SEDIMENT (t/km^2)	YIELD (ppm)
Haihe	China	0.05	4	1,620	40,500
Huanghe	China	0.077	6	1,403	22,041
Chiang Jiang	China	1.94	46	246	531
Mekong	Viet Nam	0.79	59	203	340
Ganges/Brahmaputra	Bangladesh	1.48	66	1,128	1,720
Indus	Pakistan	0.97	25	454	1,849
Tigris/Euphrates	Iraq	1.05	4	50	1,152
Amur	USSR	1.85	18	28	160
Niger	Nigeria	1.21	16	33	208
Nile'	Egypt	2.96	1	38	3,700
Zaire	Zaire	3.82	33	11	34
Mississippi	USA	3.27	18	107	602
Amazon	Brazil	6.15	102	146	143
Orinco Venezuela	0.99	111	212	191	

*Before Aswan High Dam

The sediments carried by a river deposit upstream of a dam, a process which continually reduces its reservoir capacity. For example, the construction of the Hoover Dam reduced the sediment discharge of the Colorado River at Yuma, Arizona, where it enters Mexico from 135 million tons to only 0.1 million tons per year. Similarly, the River Nile used to carry 100- 150 million tons of suspended matter annually at Aswan before the construction of the High Aswan Dam. Nearly all of this sediment load is now deposited in the High Dam Lake or in the river before the Dam as shown in Fig. 1. Increased agricultural activities which occur due to the construction of water control projects could accelerate the various soil erosion processes, which in turn could intensify the rates of sedimentation of reservoirs. This could lead to shorter than planned lives of reservoirs, which could render the schemes uneconomic. Table 3 shows the extent of sedimentation in various reservoirs in a major developing country like China in terms of percentage losses of storage capacities, and the periods over which sedimentation occurred.

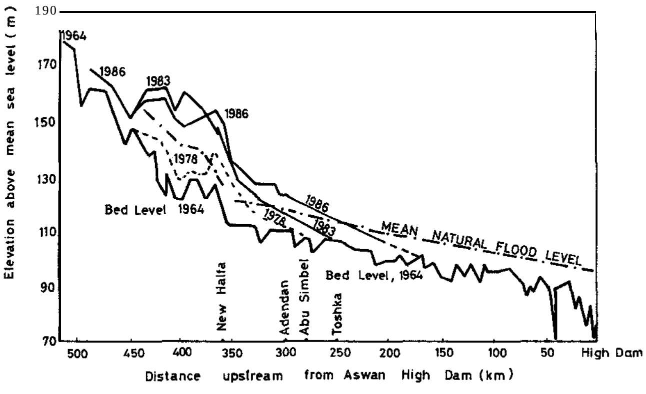

Figure 1. Bed levels in the River Nile upstream from the Aswan High Dam.

Table 3. Sediment yields of selected reservoirs in China.

RESERVOIR	RIVER	CATCHMENT AREA (km*)	STORAGE (10^6m^3)	SEDIMENTATION		
				10^6m^3	Years	% of storage
Sanmenxia	Huanghe	688,421	9,700	3,391	7.5	35
Qingtongxia	Huanghe	285,000	627	527	5	84
Yanguoxia	Huanghe	182,800	220	150	4	68
Liujiaxia	Huanghe	172,000	5,720	522	8	11
Danjiangkou	Hanshui	95,217	16,000	625	15	4
Guanting	Yongdinghe	47,600	2,210	553	24	24
Hongshan	Laohe	24,486	2,560	440	15	17
Gangnan	Hutuohe	15,900	1,558	185	17	12
Xiiqiao	Hongliuhe	1,327	200	156	14	71

SALINITY DUE TO AGRICULTURAL ACTIVITIES

Since water used for irrigation contains a mixture of naturally occurring salts, they are added to the soil with each irrigation application. Much of the irrigated water applied is accounted for by the evapotranspiration demands of crops, and most of the salt contained in irrigation water is lift behind. With each additional application of irrigation, more and more salt is introduced to the soil. If salt is allowed to accumulate in the root zone, after a certain level, crop yields start to decline. It is thus essential to apply sufficient water periodically which will percolate through the root zone and carry with it some of the accumulated salt.

If the soil used for agricultural production is saline, salt concentrations of drainage water increases as well. This means some precautions may have to be taken for reuse of drainage water or its external disposal, especially when it may be to discharged to a river or lake, either directly or indirectly. This is because the higher salinity of drainage water could increase the salt content of receiving water, which could in some cases restrict its potential use downstream.

For an arid country like Egypt, it is estimated that because of irrigation in Upper Egypt, nearly 2.3 billion m^3 of drainage water is returned to the Nile annually, either directly or indirectly. This means that total soluble salt concentration of the Nile is higher in Lower Egypt (250 ppm) as compared to Upper Egypt (180-200 ppm) [5]. Fortunately, because of the high dilution effect of the Nile, this increase in salt concentration is not significant in terms of any type of possible water use.

However, if the salinity of drainage water itself in Egypt is considered, it is, of course, much higher than the river water. The salt concentrations vary from location to location, depending on soil type, texture, irrigation practices, cropping patterns and other special factors like sea water intrusion. Even at each individual location, salinity of drainage water varies every month, with the highest observed values in January and February when the irrigation system is closed for annual maintenance, and during June to August when crop-water requirements reach peak values due to maximum evapotranspiration losses. The average salinity of drainage water in Middle Delta for 1986 is shown in Fig. 2.

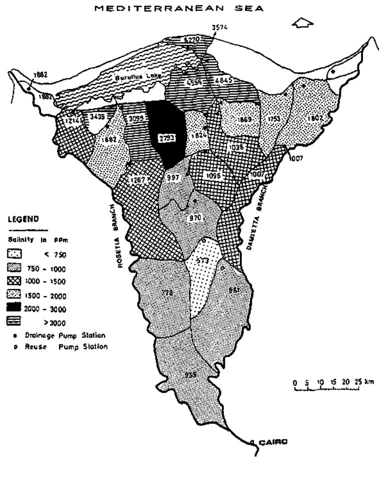

Figure 2. Average salinity of drainage water in the Middle Delta, 1986

In the area of water quality monitoring from agricultural activities, salinity is now the most commonly observed parameter in all parts of the world for many reasons. First, the relation between increase in salinity and decrease in agricultural yield is direct and very noticeable to farmers and other agricultural professionals. Second, agricultural chemicals, generally speaking, may affect water and associated environmental quality, but they do not affect yields, which have a direct impact on farm incomes. In fact, in nearly all developing countries, further increase in the levels of use of chemicals like fertilizers from the present modest application rates is most likely to increase yields, even though they could deteriorate water quality. Increase in farm incomes affect farmers directly and immediately whereas environmental problems are of more general societal concern and mostly take some time to develop. In addition, such environmental problems may affect other members of the society more than farmers. Third, impacts of salinity on the environment have been known for a long time-at least over a century-in contrast to concern with potential adverse environmental impacts of agricultural chemicals which is comparatively of recent origin. Fourth, salinity measurements can be carried out with simple equipment and by people with limited training. In contrast, measurements of pesticide residues require sophisticated and expensive equipment and well-trained personnel. For these reasons, in terms of agricultural water quality management, salinity has received the maximum attention so far.

the relation between increase in salinity and decrease in agricultural yield is direct

PESTICIDES AND NITRATE CONTAMINATION

While impacts of agricultural activities on water quality in terms of sediments and salinity have been important considerations for many decades, concern with pesticides and nitrate contamination has been of comparatively recent origin. With the advent of the Green Revolution, use of fertilizers and pesticides per unit area has increased significantly. Even then the extent of water quality deterioration due to increasing use of agricultural chemicals was considered to be minor, and its potential overall impact was underestimated. It would be correct to say that up until about the mid-seventies, overall concern with fertilizer and pesticide pollution of surface and groundwater was very limited even in developed countries.

its potential overall impact was underestimated

During the past decade, contamination of water by pesticides and nitrates has become an important cause for concern primarily in Europe and North America, especially for groundwater. This is because substantial amount of groundwater is currently used for domestic purposes. For example, groundwater accounts for 99 % of total Cairo figures available in Egypt. Consumption is 73 % in the Federal Republic of Germany, 70% in The Netherlands and 30% in Great Britain. In Cairo, nearly 40 million m^3 of groundwater is used every day, and in Upper Egypt, groundwater accounts for 30-50 % of the domestic water consumption. In the United States, groundwater is the primary source of domestic water supply for over 90% of the rural population and for about 50 % of the total population. Some 40 million people in the U.S. obtain water for domestic use from small wells. This means that they are not covered by the Federal Safe Drinking Water Act which requires testing and treatment of water. it is thus essential that groundwater be protected from various pollutants which affect its quality. This is especially important when groundwater is used as the primary source of water for human consumption, since quality of drinking water used has major health implications.

Increasingly contamination of groundwater by agricultural chemicals is being observed in areas that are intensively farmed, irrespective of whether they are irrigated or non-irrigated. In addition to routine use of agricultural chemicals, i.e. non-point sources, a comprehensive analysis should include point sources like manufacturing sites, transport/transfer facilities, commercial storage, mixing, formulating, rinsing and disposal sites as well as major spill sites. On the basis of existing information, it can be said that 39 pesticide compounds have been detected in 34 states in the U.S.A. or Canadian provinces [6,7]. If, however, other chlorinated hydrocarbon compounds and mutabilities are included, the situation becomes much worse: over 70 compounds in 31 states or provinces [8].

Based on available information, it is difficult to get a clear overall picture of pesticide contamination of groundwater even in North America or Europe: the situation is worse in the developing world, because of several reasons. First, monitoring of pesticides in groundwater is of comparatively recent origin. Studies carried out so far are so varied in design that overall generalization is difficult. Second, numerous pesticides have been used in the past and no determined attempt has been made to look for them all in water bodies because of technical and economic constraints. The monitoring and detection processes have mostly focused on chemicals that are toxic and mobile, often under directives of regularly agencies like the U.S. Environmental Protection Agency (EPA). Third, measurements of concentrations of pesticides in water, which are mostly extremely low and measured in terms of only µg per liter, are difficult and require special equipment, techniques and procedures for sampling and analysis. Nearly all developing countries currently do not have the expensive equipment necessary as well as the sophisticated expertise required to initiate a country-wide monitoring program. Fourth, even in countries where pesticide concentrations in water are being monitored, attention is mostly focused on the presence of parent compounds. Very few studies are currently available which also monitor the presence of metabolites. This is important since even if parent compounds may not leach into the groundwater, metabolites may do so. Fifth, the level of use of pesticides in developing countries is significantly less than in developed countries, but pesticide use in many developing countries have been increasing steadily in the recent past. It is logical to assume that with higher pesticide use rates in such countries, more and more chemicals will leach to the groundwater.

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On the basis of the above five reasons, it can be confidently predicted that the list of pesticides and their metabolites in groundwater will continue to increase in the future. Furthermore, it is highly likely that pesticide contamination of groundwater will be observed in increasingly more and more geographical areas in the future.

There are many factors which affect the leaching of pesticides to water bodies. Among the main factors are properties of individual pesticides, soil characteristics, hydrogeological conditions, climatic factors and cropping patterns which dictate type, rate and timing of application of pesticides. Because of so many variables, it is not possible to make generalized comments on the extent of pesticide leachings to water bodies as well as their concentration levels.

At our present state of knowledge not enough is known on the impacts of pesticides on human and animal health. This is because the extent and level of toxicological research on all of the currently approved list of pesticides is grossly inadequate. Furthermore, very limited information is available on synergistic effects of different combinations of pesticides. There are also methodological problems in terms of extrapolating from high doses of consumption, skin contact or inhalation of volatile chemicals over short time periods to long periods of low levels of sustained use and exposure. Additional uncertainties are contributed by the complexities inherent in translating health impacts from animal studies in laboratories to human beings in the real world. To all these uncertainties must be added the overall problems associated with analysis and perception of risks, which have important social, economic, institutional, political, and emotional implications.

Because of the lack of a long period of reliable data on potential health impacts of different pesticides, their toxicological evaluation and setting of permissible standards for water used for domestic purposes are difficult tasks under the best of circumstances. In a directive issued in 1980, the Council of the European Committees (EEC) established a maximum admissible concentration of 0.1 µmg/ liter of any single pesticide in drinking water, and of 0.5 µg/liter as the maximum permissible limit for possible combination of all pesticides and related chemicals. In 1984, these standards were incorporated in Dutch legislation. West Germany, followed suit in 1986, but the implementation of the standards was postponed till 1989 in order that analytical procedures could be developed to measure reliable pesticide concentrations below the limit value of 0.1 µg per liter. In many EEC countries, however, there is considerable opposition to establishing these standards established mainly because these were based on detection limits of chemical analysis and not on toxicological considerations. The overriding philosophy behind the establishment of these limits was that no pesticide residues should be present in domestic water, and not on knowledge available in terms of impacts on human health.

There are further differences between the member nations of EEC. For example, the Netherlands has blacklisted 31 different pesticides whose use is not allowed in groundwater protection areas. However, a similar black list prepared by West Germany in 1985 contains some 70 pesticides. Interestingly, when these two black lists were prepared, very few of the listed pesticides were subjected to field trials or to monitoring [9].

The World Health Organization [10,11] and the U.S. EPA have used a different approach to the limits of pesticide residues in drinking water. The method used by WHO and EPA is to establish an acceptable daily intake (ADI) of pesticide residues in all food and drinks. The ADI is determined by long term toxicological studies in terms of no-observed-effect level. It is then multiplied by a safety factor, e.g. 0.01. A part of this ADI is then earmarked for domestic water. In the WHO (1987) guidelines, 10% of ADI was reserved for herbicides and 1% for bio-accumulating pesticides like chlorinated hydrocarbons. Viewed in this fashion, WHO guidelines values are significantly higher than the 0.1 µg per liter EEC directive. WHO recommended guidelines for some selected pesticides in drinking water are shown in Table 4.

Table 4. WHO recommended guideline limits for pesticides in drinking water (note both Bentazone and Metolachlor are blacklisted by the Dutch)

Pesticide	WHO Guideline (µg/1)
Atrazine	2
Bentazone	25
2,4-D	100
Lindane	3
MCPA	0.5
Methoxychlor	30
Metolachlor	
Pendimethalin	17
Pyridate	60
Simazine	17
Trifluralin	170

In contrast to pesticides where many different types of chemicals are involved, the main concern with fertilizers in terms of water quality management is undoubtedly nitrates. Also, nitrates have been studied more intensively than pesticides [12]. This however, does not mean that fertilizers do not contain other contaminants. For example, phosphate fertilizers contain varying concentrations of zinc, manganese, boron or molybdenum, all of which are considered to be important plant nutrients, as well as potential water quality contaminants like arsenic, cadmium, chromium, copper, nickel, lead, selenium and vanadium. Similarly, many trace elements are present in pesticides as well. However, well-documented cases of serious water quality contamination by trace elements from fertilizers and pesticides are very limited. To the extent water contamination takes place, it could be due to anionic trace elements (primarily oxyanions). Generally cationic trace elements like heavy metals do not accumulate in water bodies. In terms of agricultural activities, the most serious trace metal contamination is in the soil due to continued application of sewage sludges and/or treated wastewater [13].

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In recent years nitrate contamination of water has become a serious problem in parts of Europe and North America. The concern primarily stems from the fact that the presence of nitrates at higher levels than the maximum limit of 45 mg per liter in drinking water could cause methemoglobinemia in babies below the age of 6 months. There is also increasing concern that nitrates could be reduced to nitrate in the alimentary canals of humans, and then react with amines to form nitrosamines, which are carcinogens. This could contribute to the development of gastric cancer. There are, however, some dissenting views on this issue.

The sources of nitrate contamination of water are many. These could come from leaching from geological formations, precipitation, human and animal wastes, cultivation practices-essentially fallowing, and the use of fertilizers. Naturally, the total quantities of nitrates added to the water bodies from the different sources is location specific. For example, current estimates indicate that precipitation contributes to annual addition of 8-20 kg of N per ha, with many studies reporting 10-14 kg per ha range. Similarly, it was estimated that 15 Mt of N are annually disposed of in the United States in wastes, 40% of which are from animals, 30 % from crop residues and 20-25 % from municipal wastes [14]. Even the main reasons for the high nitrate concentrations of groundwater vary from location to location in USA: high fertilizer application in the potato-growing areas of north-east Maine, intensive animal wastes from dairy production in south-east Pennsylvania and northern Maryland and poultry operations in Delaware and parts of North Carolina, and high density of septic tanks and fertilizer use in Long Island.

The main concern however, has been from leaching of nitrates from the use of fertilizers applied to increase agricultural yields. There are several important factors which could affect nitrate leaching. Some of these factors are site specific like climate (amount and distribution of precipitation, temperature, and evapotranspiration) and soil (texture, slope, and nitrogen content). Other factors like crops (cropping patterns and intensity and water and nitrogen uptake), application of irrigation water (amount and timing) and fertilizers (type, amount and application time).

On the basis of field investigations carried out, less than half of the N input into the soil is removed by crops. This means in a country like the United States, where rates of fertilizer application are high, some 100 kg per ha or more of fertilizer is either retained in the soil or leached out contributing to environmental pollution. Studies carried out in the eastern Corn Belt of the U.S.A., which has extensive tile drainage, indicated that nitrate concentration of drainage water increased as fertilizer application rates increased. In the north central U.S., a number of studies carried out show annual losses of 20-100 kg NO, N per ha were common. The drainage water is discharged to surface water and thus, it could contribute to water pollution.

nitrate concentration of drainage water increased as fertilizer application rates increased

The potential of nitrate contamination of water bodies is high, especially as 9-12 Mt of fertilizer N input to soils has been recorded in the U.S.A. in recent years. Power [15] made an annual N input analysis for the US agriculture as shown in Table 5. This analysis indicates that a total of 21.1 Mt of N was returned to the soil annually, but crops removed only about 11.9 Mt. Thus, 9.2 Mt was either left in the soil or leached out.

Table 5. Annual N input-output for US agriculture, 1977

N input-output	Mt
output	
harvested crops	7.6
crops residues	4.3
Total	11.9
Input	
fertilizer	9.5
symbiotically-fixed N	7.2
crop residues	3.0
manure-organic wastes	1.4
Total	21.1

Uncontaminated groundwater generally contains less than 3 mg N per liter, and if this level is exceeded, human activity can be suspected, unless there are other possible explanations. Also, it has been observed that nitrate concentrations decrease with groundwater depths and they are also highest at the top of the water table and decrease with depth. This means that older irrigated areas, which generally have shallow water tables (less than 30m), nitrate contamination is often prevalent due to leaching through the vadose zone.

In most European countries, the maximum permissible nitrate concentration in drinking water is 50 mg per liter. This level is fixed on the basis of hygienic and toxicological factors. In both Europe and the U.S.A., nitrate concentrationof groundwater in many areas has increased steadily over the past three decades, though the causes, rates, of increases and their current levels vary from area to area. The present levels exceed the acceptable limits in many areas to the extent that in a state like Nebraska along, babies in 38 towns must be given bottled water due to high levels of nitrate concentrations in domestic water supply.

Use of excessive N fertilization not only increases nitrate concentration of groundwater but also could adversely affect the quantity and quality of crops produced. This means that farmers have to bear higher costs for fertilizers used as well as loss of revenue due to poorer quality and quantity of products. Results of a demonstration project of over 16,000 ha of primarily irrigated corn in Nebraska indicate that yields can be maintained by reducing averag fertilizer N application rate by up to one third from 262 to 174 kg/ha. Unquestionably the solution of the twin problems of using optimal N fertilizer application to increase crop yields and protection of water quality lies in adopting better management practices.

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WATER QUALITY IMPACTS OF AGRO-PROCESSING INDUSTRY

In terms of water quality of the agro-processing industry, it is difficult to make generalized statements since the extent and magnitudes of these impacts will depend primarily on types of industry and wastewater treatment processes used. A major factor which could contribute to water quality deterioration from all types of agro-industry is the potential discharge of effluents with high BOD content. For example, average BOD loading of wastewater from distilleries is often in the range of 40,000 to 50,000 mg/1. Thus, unless appropriate care is taken to ensure that wastewater is properly treated, the potential for surface water and groundwater contamination could be significant. While permissible limits of BOD discharge from industrial affluents could vary from country to country (e.g. 6mg / 1 in Egypt but 30 mg/1 in India), the fact remains the BOD levels of effluents from agro-processing industry are invariably high, requiring proper waste-treatment. Discharge of effluents containing high BOD levels will reduce the dissolved oxygen (DO) concentrations of water bodies. DO concentration is an important factor that dictates aquatic life in rivers. Thus, at DO levels of 5 ppm or above, all types of fish can survive. As DO levels start to decline, more desirable types of fish start to come under stress, and if levels decline further and/or low levels of DO remain levels candecline to zero. This contributes to the anaerobic conditions when fish life completely disappears in that stretch of river. This is now not an uncommon condition in many parts of the world, where BOD levels are too high for sustaining a diversified aquatic life.

CONCLUDING REMARKS

Impacts of agricultural activities on water quality are many. The magnitudes of these impacts can be reduced only by better management practices, which invariably include some efficient method of source control for the potential pollutants, e.g. better land use practices to ensure less generation of sediments, and more efficient use of fertilizers and insecticides which will minimize water contamination, and higher levels of treatment of wastewater from agro-processing industry. It is assumed that treatment processes can remove chemicals like pesticides and fertilizers, at least for water for domestic consumption, in reality they seldom do. While technologically speaking, granular activated carbon filtration can remove synthetic organic compounds like pesticides, studies in Canada and the United States indicate that water treatment systems used have generally been ineffective to remove all such contaminants. Also, source control is a more economic solution than allowing water quality contamination and then using treatment processes to purify that water.

More work is necessary to develop and implement agricultural management practices for better water quality control. For example, while nitrate contamination of water can never be eliminated from agricultural activities, it can be significantly reduced by carefully controlling the timing and amount of nitrogen fertilizer used, by developing more effective slow-release fertilizers and by practicing more efficient irrigation methods. These types of preventive actions would not only reduce water quality contamination but also would prove to be highly economical by reducing the total cost of both chemicals applied and treatment processes necessary.

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