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Review Paper on “Irrigation Water Pollution and Its Minimization Measures”

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Abstract

Water is a scarce resource, thus, any reuse of water is desirable, as long as the costs associated with the reuse is less than the benefits of using it. The environmental and socioeconomic aspects of irrigation water pollution were becoming a serious problem worldwide. The quality of surface and groundwater in shallow open wells has deteriorated and the application of polluted groundwater for irrigation has resulted in increased salt content of soils. Outbreaks of waterborne diseases are also a growing concern. The economic value of changes in water quality is an important component of economic assessment of policies to reduce pollution from agricultural production. Farmers can take many steps to reduce loadings of agricultural pollutants to water resources. But improvements in water quality from farmer’s efforts to reduce pollutant loadings often take years to detect and document. Aquifers may take decades to show improvements in quality after management is improved. This has implications for the design of monitoring necessary to assess the effectiveness of water quality policies and programs. This study found that both structural and management practices are available for managing water and chemical inputs more efficiently or controlling runoff to minimize irrigation water pollutions. Those practices include efficient irrigation water management, integrated pest management, comprehensive nutrient management planning, animal waste management, conservation Agriculture and Industrial waste, sewage and storm water pretreatment.

Keywords: - Water, pollution, Irrigation

1. INTRODUCTION

With the growing competition for water and declining freshwater resources, the utilization of marginal quality water for agriculture has posed a new challenge for environmental management. In water scarce areas there are competing demands from different sectors for the limited available water resources. The ‘marginal quality water’ could potentially be used for other uses like irrigation. Hence, the reuse of wastewater for irrigation using domestic sewage or treated industrial effluents has been widely advocated by experts and is practiced in many parts, particularly in water scarce regions. Continuous application of polluted groundwater for irrigation can also increase the soil salinity or alkalinity problems in farmlands. However, safe utilization of wastewater for irrigation requires the use of proper treatment and several precautionary measures in place, as it may cause environmental and human health hazards. When treatment is not adequate, the application of domestic wastewater on land might cause various environmental problems like groundwater contamination (bacteriological and chemical), soil degradation, and contamination of crops grown on polluted water (Mukherjee and Nelliyat, 2007)

It is often difficult to determine the economic and environmental effects of water pollution because it is difficult to measure, and because the impacts of various pollutants on the environment are often unknown. It is also impossible to completely eliminate the potential for water pollution because chemicals are required in the root zones and on the foliage of plants. However, the potential for water pollution can be minimized. Leaching and water pollution can be minimized by proper irrigation system design and management, because a well-designed and well-managed irrigation system can properly apply only the required amounts of water and chemicals. Chemigation irrigation systems which are designed for chemical applications by injection with the irrigation water, have great potential for reducing water pollution from irrigated lands. Chemigation systems can reduce water pollution by allowing prescription chemical applications to be made. If chemicals are applied frequently and only in amounts required by the irrigated crop, excessive amounts will never be present or subject to leaching losses (Zazueta and Haman, 2014). There are enormous causes for irrigation water pollution. Thus, it is essential to assess the extent of irrigation water pollution to set the alternative mitigation measures for boosting maximum yield of field crops. Therefore, this study was initiated with the objective to assess the irrigation water pollution and its minimization measures.

2. Materials and Methods

For the fulfillment of this paper, different sources such as journals, proceedings, thesis works, annual reports, fact sheets and publications regarding to irrigation water pollution and its minimization measures have been reviewed. The definition, classification, previous research results, risks and minimization solutions of irrigation water pollution have been properly documented. In addition, indicators, causes, status, demographic and socio-economic aspects of irrigation water pollution and mitigation measures were rationally assessed and presented.

3. Definition, Classification and indicators of Irrigation Water Pollution

Water pollution is the pollution of bodies of water, such as lakes, rivers, the oceans, as well as groundwater. It occurs when pollutants reach these bodies of water, without treatment. Waste from homes, factories and other buildings get into the water bodies (USDA, 2013).

3.1. Classification of irrigation water pollution

Based on its source water pollution is categorized as point source or nonpoint source pollution.

3.1.1. Point source pollution

It is an observable, specific, and confined discharge of pollutants into a surface or underground water body. Examples include surface water discharges from feedlots, food processing plants, and agrichemical processing plants, and groundwater contamination from chemical spills (Zazueta and Haman, 2014).

3.1.2. Nonpoint source pollution (NPS)

It is defined as diffuse discharges of pollutants throughout the natural environment. It occurs over extensive areas. As water from rainfall, snowmelt, irrigation, or human activities moves over and through the ground it can pick up and carry away natural and synthetic pollutants, eventually depositing them into lakes, rivers, wetlands, coastal waters, and underground sources of water. Other types of land use activities such as road construction, mine drainage, rainwater runoff from city streets (that is not collected in storm drains), from agriculture and from many rural villages, produce water pollution that does not come from any specific pipe or channel but instead tends to be dispersed across the landscape. Therefore it cannot be easily measured because of the 'diffuse' nature of this type of pollution, which is collectively called 'non-point source' (NPS) pollution. Agricultural storm water discharges and return flows from irrigated agriculture are included as nonpoint sources even though they may have a single point of discharge. Other examples of nonpoint source pollution are sediment loading in streams, phosphorus pollution of lakes from seepage of lakeshore septic tanks, and nitrate pollution of groundwater from feedlots or from fertilizer applications to fields (FAO, 2013).

3.2. Indicators used to monitor Irrigation water quality

A comprehensive and practical guide to field sampling and data analysis for water quality monitoring is that of Bartram and Balance (1996) which is still relevant today. Analytical methods for analysis of pollution in water and sediments can be found in a variety of manuals including those from APHA-AWWA-WEF (2006) (FAO, 2013). Design of field sampling and quality control including correct preservation of samples collected in the field are essential elements of a successful water quality monitoring program. indicators for the regular monitoring of surface water are: water temperature; pH; dissolved oxygen; permanganate index; COD; BOD5; NH3-N; TP; TN; Cu; Zn; Fluoride; selenium; arsenic; Hg; Cd; Cr; Pb; Cyanide; volatile phenol; petroleum; ionic surface active agent; sulfide; paracolon). Supplementary measurements used for drinking water include nitrate, sulfate, chloride, Fe and Mn (FAO, 2013).

4. Sources/Categories of Irrigation water pollution

4.1. Nutrients

The leaching of nutrients from watersheds into streams, lakes, and groundwater is a natural part of nutrient cycling. When growers manipulate the soil-water-plant system to increase agricultural production, they can change the natural balance of nutrient cycling. Nutrient sources associated with agricultural production practices include fertilizers, biodegradation of crop residues, agricultural and municipal wastes applied to land, and waste generated directly by animals. Nutrients from these sources become pollutants when they are transported off site into nearby streams and lakes or when they percolate in excessive amounts to groundwater (Bianchi and Harter, 2012).

4.2. Trace elements and heavy metals

Unlike nutrients and salts, trace elements typically do not originate from agricultural chemical applications. Rather, irrigation mobilizes naturally present trace elements. Trace elements are found at very low concentrations in all waters. Many trace elements are at a low concentration essential for human, animal, and plant health. At higher concentrations, however, they may becomess toxic to organisms. Trace elements of concern to irrigated agriculture include selenium, molybdenum, arsenic, vanadium, and boron (Bianchi and Harter, 2012). High concentration of heavy metals in drinking water has been responsible for a variety of chronic diseases, such as chronic anemia, liver cirrhosis, renal failure and a variety of cancers (Duan *et al*., 2011; Al-Bahry *et al*., 2014).

4.3. Pesticides

Pesticides (insecticides, miticides, herbicides, fungicides, and nematicides) that move from their site of application into surface or groundwater can affect the post application usefulness of water through their potential to impact organisms other than their primary targets. The presence and bio-availability of pesticides in soil can adversely impact human and animal health, beneficial plants and soil organisms, and aquatic vegetation and animals (USDA, 2013).

4.4. Salinity

Irrigation water naturally contains a certain amount of dissolved minerals (salts). The amount of salt in the water depends on its source. Groundwater leaching through alluvial sediments derived from marine sedimentary rocks. Irrigation waters pumped from such aquifers have much higher salt content. When irrigation water, regardless of its salt content, is applied to crops, the salts accumulate in the soil while the applied irrigation water is consumed by plants or lost to evaporation. To maintain the productivity of irrigated lands, accumulated salts must be leached below the root zone (Zazueta and Haman, 2014).

4.5. Sediment

Sediment deposition occurs when the amount of sediment (solid material that has been transported from its site of origin by air, water, or gravity) exceeds the carrying capacity of the force that is moving it. Farmlands generally become a nonpoint source of pollution when farm operations remove a substantial amount of the vegetative cover, exposing the soil surface to the erosive action of water and wind. Eroded soil subsequently becomes sediment, creating the potential for water degradation (BRC, 2015).

Sediment affects water quality physically, chemically, and biologically. Water-borne sediment is a ***physical pollutant*** when the sediment causes physical damage to the environment or poses a risk to biota or to human health. Damage caused by sediment is expensive both economically and environmentally in terms of prevention and restoration of degraded natural resources, damage to infrastructure and costs of water filtration. Sediment is also a ***chemical pollutant*** because many types of chemicals are carried on the surfaces of sediment particles. Particles of clay and silt effectively adsorb (sequester) nutrients, heavy metals and persistent organic pollutants (POPs) including many (but not all) pesticides and herbicides, from the water column. Contaminated sediments affect small organisms such as worms, crustaceans, and insect larvae that inhabit the bottom of a water body in what is known as the ***benthic environment***. Some kinds of toxic sediments kill benthic organisms, reducing the food available to larger animals such as fish. Benthic organisms consume some of the carbon contained in some contaminants in the sediment as a food source, which results in ***bioaccumulation*** of toxins. When larger animals feed on these contaminated organisms, the toxins are taken into their bodies, moving up the food chain in increasing concentrations in a process known as ***biomagnifications*** (FAO, 2013).

4.6. Pathogens

Pathogens are microorganisms and parasites that can cause illness in humans and in animals. A small subset of all pathogens, the *zoonotic pathogens,* are shed in the feces of livestock and many wildlife species and can infect other animals as well as humans. The potential for pollution of surface waters increases when flows resulting from irrigation or rainfall come from land that has received untreated human or animal waste or when irrigation water contains animal manure. The occurrence of pathogens in groundwater depends on manure application rates, the amount of rainfall and irrigation, the efficiency and uniformity of irrigation, the depth of groundwater, and the type of soil and aquifer (Zazueta and Haman, 2014).

4.7. Temperature

Thermal pollution of surface waters has three basic sources that relate to farmlands which include:-

- ✓ Development and subsequent cultural operations in irrigated agriculture can result in the loss of streamside vegetation that shades streams and helps to maintain the cool water temperatures required by many cold water fishes, especially trout, salmon, and steelhead.
- ✓ Drainage of irrigation water that has warmed while crossing a farm field can raise the temperature of a cold water stream.
- ✓ Stream water diversions for irrigation and wetland management can lower overall stream flows (Bianchi and Harter, 2002).

4.8. Mercury

It is a naturally occurring element found in cinnabar deposits and areas of geothermal activity. Anthropogenic sources of mercury in wastewater can come from the residential, commercial, or industrial sectors. The methylation of mercury poses a significant environmental threat. Mercury has been used historically in fungicide formulations and can still be found in many commercial products. Mercury is present in a variety of consumer and commercial products including dental amalgam, batteries, compact fluorescent lights, jewelry, skin creams, paint, thermometers, switches, etc. While many of these products have a low probability of reaching the sanitary sewer system in large quantities, their removal from the environment is beneficial (CWS, 2015).

4.9. Cultivation

Agriculture disrupts all freshwater systems hugely from their pristine states. It would be convenient if the component activities of agriculture could be simply and quantitatively related to their impacts on freshwater systems (Moss, 2008). Cultivation practices are major contributors to water quality degradation. The nature of the impact depends on the climate and on local relief (flat, hilly or mountainous land). Generally, cultivation has two main types of impacts – one on surface water, and the second on groundwater quality. For surface water, two types of impacts are of most concern – the first is loss of topsoil as a result of erosion, then deposition in water courses and lakes; the second is runoff of nutrients (N and P) from excessive use of fertilizer. A lesser problem is pesticide runoff when these are applied incorrectly or when rain washes off the applied pesticide. Another more local water quality problem occurs when farmers desalinize irrigated fields by applying large amounts of water (FAO, 2013).

4.10. Water pollution in large-scale irrigation schemes

Large-scale irrigation impacts on surface and groundwater quality. Subsequent evaporation from shallow water tables results in the accumulation of salts in the soil surface layers. There is widespread pollution of groundwater from nutrients, pesticides and salts. Irrigated rice production has led to excessive sodium and other salt build up and higher pH in the ground waters. The development of large irrigation projects has been an important factor in increasing food security, but it has water quality problems caused by salt and fertilizer runoff as well as other pollutants such as pesticides. These have exposed aquatic ecosystems and human health to serious risks and have presented a major challenge requiring urgent attention (FAO, 2013).

Table1. Categories of major water pollutants

Pollutant category	**Definitions/Examples**
Dioxins	Highly toxic, carcinogenic, petroleum-derived chemicals that are persistent in the environment and may be found in fish tissue, water column, or sediments.
Metals	Substances identified only as 'metals'; also, selenium, lead, copper, arsenic, manganese, others (Note: may, in some cases, include mercury).
Mercury	A toxic metal with neurological and developmental impacts on wildlife and humans; found in fish tissue, water column, or sediments. In agriculture, mercury can be associated with mercury-treated seed.
Nutrients	Primarily nitrogen and phosphorus; in excess amounts, these nutrients over-stimulate the growth of weeds and algae and can lead to serious algae blooms and oxygen depletion in rivers and lakes that can cause fish-kills. Agricultural use of fertilizer is a major source of nutrients in rivers, lakes and reservoirs.
Organic enrichment/ oxygen depletion	Low levels of dissolved oxygen; high levels of COD or biochemical oxygen demanding substances (e.g. organic materials such as plant matter, food processing waste, sewage) that use up dissolved oxygen in water when they degrade. Runoff from fields contributes to the buildup of organic matter in rivers, lakes and reservoirs.
Pathogens	Bacteria and pathogen indicators *E.coli*, total coliforms, faecal coliforms, *Enterococci*; used as indicators of possible contamination by sewage, livestock runoff and septic tanks.
Polychlorinated biphenyls (PCBs)	A toxic mixture of chlorinated chemicals that are no longer used in the US but some are still used in China; these are persistent in the environment; used in industry and electrical equipment; primarily found in fish tissue or sediments.
Pesticides	Substances identified as 'pesticides'; also, chlordane, atrazine, carbofuran, and others; many older pesticides such as DDT are banned in China, but are used illegally and are persistent in the environment.
Sediment	Excess sediments, siltation; affects aquatic life by altering and suffocating habitat and clogging fish gills. Agriculture is a major cause of sediment runoff into rivers, lakes and reservoirs.
Toxic organics	Chemicals identified only as 'toxic organics'; also, priority2 organic compounds, non-priority2 organic compounds, polycyclic aromatic hydrocarbons (PAH), and others; often persistent in the environment.
Salts	High salt concentrations prevent the uptake of water by plants. The plant symptoms are similar in appearance to those of drought. Agricultural drainage has higher salt concentration than irrigation water and increases salinity in water bodies.

1 Adapted from US-EPA, 2009; FAO, 2013

2 The United States classifies organic compounds as 'priority' (most polluting) and 'non-priority' (less polluting or for which there are inadequate data).

5. Causes for Irrigation Water pollution

There are different causes for irrigation water pollution that have been explained by authors, but the major causes include:-

5.1. Consequences of Improper Irrigation System Design

Poor irrigation system design can result in the construction of irrigation systems that cannot provide the necessary soil-water-nutrient environment for optimum crop growth. This will result in reduced yields, reduced quality, or higher costs per unit of production when compared to well-designed irrigation systems. The improper design of irrigation systems can have several consequences and can be classified as those affecting public health, waste of natural resources, water pollution, operator safety, and economic factors, including cost of irrigation, economic return from irrigation, and irrigation system life expectancy. Excess applications of water and the resulting leaching of chemicals can result in the pollution of surface or groundwater supplies. When fertilizers and chemicals are applied through irrigation systems, failure to properly design, install, and manage backflow prevention equipment can result in the backflow of nutrients and chemicals and pollution of water supplies (Zazueta and Haman, 2014).

5.2. Livestock feeding and grazing operations

By confining animals in small areas or lots, farmers and ranchers can efficiently feed and maintain livestock. But these confined areas become major sources of animal waste. An estimated 238,000 working farms and ranches in the United States are considered animal feeding operations, generating about 500 million tons of manure each year. Runoff from poorly managed facilities can carry pathogens such as bacteria and viruses, nutrients, and oxygen-demanding organics and solids that contaminate shell-fishing areas and cause other water quality problems. Ground water can also be contaminated by waste seepage (USEPA, 2005).

5.3. Industry and Sewage wastewater

According to the fourth World Water Development Report presently only 20% of globally produced wastewater receives proper treatment (UNESCO, 2012; UN, 2015). Wastewater contains a number of pollutants and contaminants, including: plant nutrients (nitrogen, phosphorus, and potassium), pathogenic microorganisms (viruses, bacteria, protozoa and helminths), heavy metals (e.g. cadmium, chromium, copper, mercury, nickel, lead and zinc), organic pollutants (e.g. polychlorinated biphenyls, poly-aromatic hydrocarbons, pesticides, and biodegradable organics (BOD, COD)) and micro-pollutants (e.g. medicines, cosmetics and cleaning agents). All of these can cause health and environmental problems and can have economic/financial impacts (e.g. increased treatment costs to make water usable for certain purposes) when improperly or untreated wastewater is released into the irrigation water system (UN, 2015).

6. Minimization strategies for Irrigation water pollution

There are both structural and management practices available for managing water and chemical inputs more efficiently and controlling runoff to minimize irrigation water pollutions. Those practices include efficient irrigation water management, integrated pest management, comprehensive nutrient management planning, animal waste management, conservation Agriculture and Industrial waste & sewage pretreatments.

6.1. Capturing and Recycling Irrigation Runoff as a Pollution Prevention Measure

Capture and recycle technology began as a strategy to conserve water and to reduce water and energy costs. A recycling system may also control storm water. The cost of implementing a system depends on various factors such as the volume of runoff to be captured and topographic features that determine the number of retention basins needed to capture runoff. Basically, a capture and recycle system has a network of channels and ditches that capture runoff irrigation water from the nursery beds, and divert it to basins that retain the water. The water can then be pumped from these retention basins back onto production areas or to a storage basin (Wilson and Broembsen, 2006).

Another benefit from recycling is a modest decrease in fertilizer costs due to the recycling of nutrients in the irrigation water. Also, with a capture and recycle system, there is more management flexibility in the use of different forms of fertilizers, in scheduling fertilizer applications, and in using certain pesticides in mitigating pest outbreaks. High levels of Phytophthora could warrant disinfection of recycled water from fast turnover retention basins or sumps. Water can also be filtered before reuse to remove most pathogens. Retention of captured runoff in basins reduces pathogens levels due to natural processes such as settling out and biological and physical degradation (Wilson and Broembsen, 2006).

6.2. Conservation agriculture

Conservation agriculture uses a variety of techniques to reduce soil erosion during all stages of ploughing, planting, harvesting and fallowing. It combines minimum or no-till-systems with measures to optimize the protective cover of living vegetation (including cover crops), mulch and resulting litter layer, as well as crop diversification to make better use of the soil profile for moisture and nutrients through alternating species. It is characterized by three linked principles, namely:

(i) Minimum mechanical soil disturbance,
(ii) Permanent organic soil cover, and
(iii) Diversification of crop species grown in sequences and/or associations.

Conservation tillage is the minimum (or zero) use of hand or mechanical tillage practices for preparing the land and planting, leaving at least 30 percent residue cover on the ground. Crop residues provide a more effective protective cover over the soil and are more readily broken down into litter and incorporated as soil organic matter by soil organisms.

6.3. Using Compost to reduce water pollution

Organic wastes, such as manure, waste water treatment solids, or even grass clippings, are a major source of nonpoint source pollution. The process of composting takes these raw materials and stabilizes them under controlled conditions. Stabilizing the material takes the nutrients, such as nitrogen, and ties them up in the compost's organic matter. The nutrients are slowly released over time, increasing the opportunity for up-take by plants and reducing downstream water pollution problems...1 For that reason composting is recognized as a Best Management Practice by the EPA's Non Point Source Program (USEPA, 2003; USCC, 2008) compared to raw manure, not only is composted manure itself less polluting, but as a manufactured product it can be transported further from the place of generation (USCC, 2008).

Using compost has several positive benefits. It improves the water dynamics of soil, including water infiltration, percolation, and water-holding capacity. This can reduce irrigation needs, and associated leaching potential. For example, a study in the pollution-prone sandy soils of Florida showed that annual applications of ¾-1" of compost per acre would result in increased soil moisture and reduced water seepage below the root zone, "thus reducing the potential for nitrogen and atrazine (an herbicide) to leach into groundwater" (Savabi, 2005; USCC, 2008).

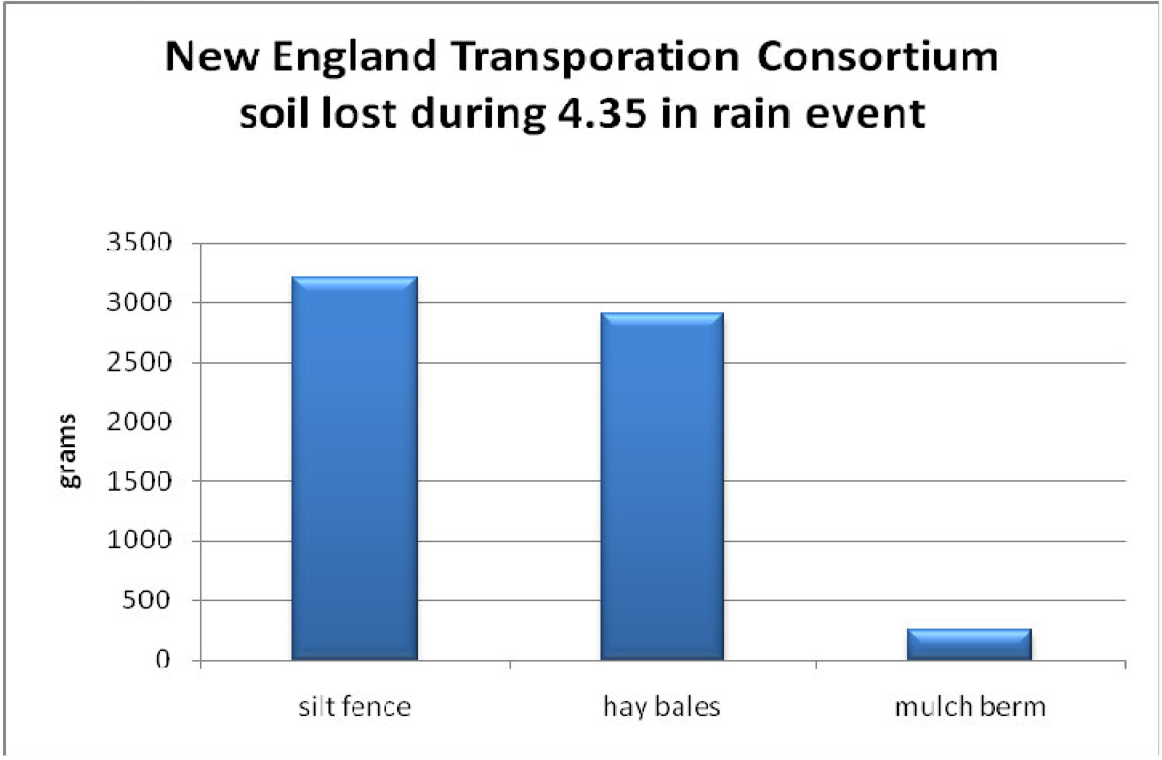


Figure1. Sediment removal comparison (Source: Dumars et al, 2000; USCC, 2008)

Since it is not always feasible to prevent erosion during construction, compost can be effectively used to filter storm water leaving a construction site. Typically construction sites use silt fence or hay bales to provide sediment control around the perimeter of the site. Using composted mulch, either in freestanding filter berms or contained in long tubes called "filter socks", has proved to be much more effective. While the typical practices act as temporary storm water detention devices, counting on gravity to settle out solids, the compost-based practices work both as a detention and a filter, removing suspended solids, settleable solids, along with soluble pollutants such as petroleum hydrocarbons and nutrients (Faucette, 2006).

6.4. Comprehensive nutrient management

Improved soil, water and fertilizer management practices are needed to improve the production and environmental performance of irrigated agriculture (Siyal *et al.,* 2012). Sustainable agricultural production incorporates the idea that natural resources should be used to generate increased output and incomes without depleting the natural resource base. In this context, integrated nutrient management (INM) maintains soils as storehouses of plant nutrients that are essential for vegetative growth. INM's goal is to integrate the use of all natural and man-made sources of plant nutrients, so that crop productivity increases in an efficient and environmentally benign manner, without sacrificing soil productivity of future generations. INM relies on a number of factors, including appropriate nutrient application and conservation and the transfer of knowledge about INM practices to farmers and researchers (Fairhurst. 2012).

6.5. Integrated Pest Management (IPM)

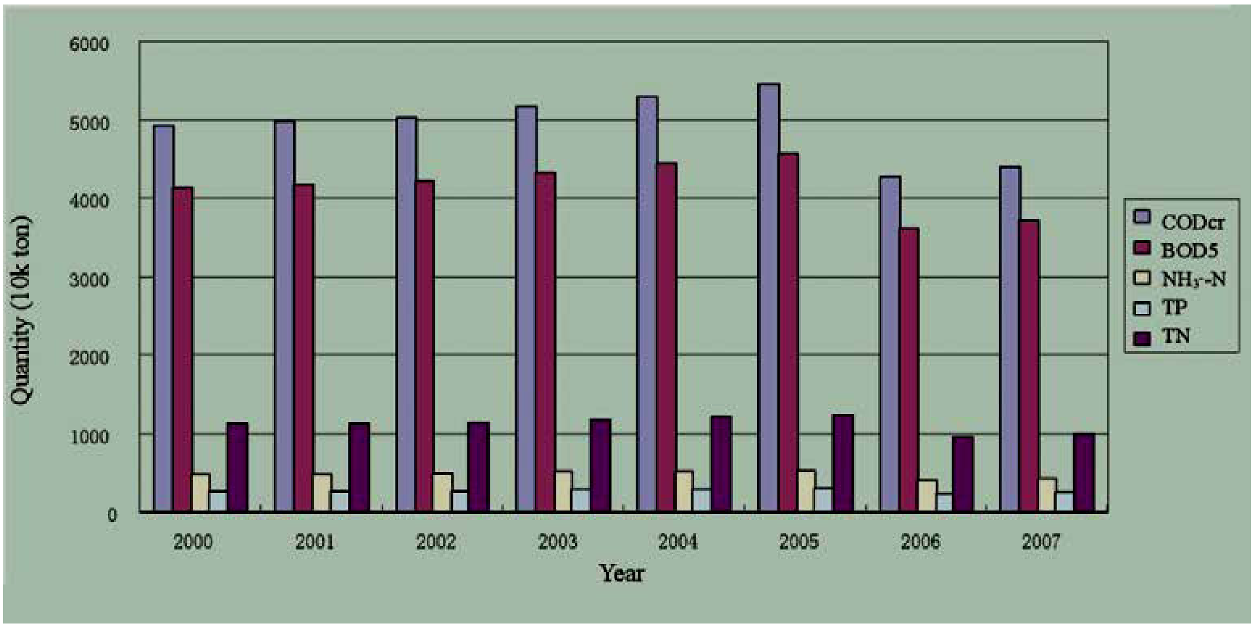
The term 'pesticide' includes all chemicals of all types used to kill or control pests. In agriculture, this includes herbicides (weeds), insecticides (insects), fungicides (fungi), nematocides (nematodes) and rodenticides (vertebrate poisons). IPM is a pest control strategy that uses a variety of complementary strategies that together, reduce pests, costs and the use of chemical pesticides. Farmers practicing IPM follow four steps (USEPA, 2010; FAO, 2013):

1. **Set action thresholds:** Before taking any pest control action, IPM first sets an action threshold, a point at which pest populations or environmental conditions indicate that pest control action must be taken. Sighting a single pest does not mean control is needed. The level at which pests will become an economic threat is critical to guide future pest control decisions.
2. **Monitor and identify pests:** Not all insects, weeds or other living organisms require control. Many organisms are innocuous, some even beneficial. IPM programmes work to monitor and accurately identify pests, so appropriate decisions can be made for their control in conjunction with action thresholds. This monitoring and identification ensures that pesticides will be used only when they are needed and that only the right pesticide will be used.
3. **Prevention:** The first step in an IPM programme is to take preventative measures such as rotating between different crops, selecting pest-resistant varieties and planting pest-free rootstock. These control methods can be effective and cost efficient and present little to no risk to people or the environment.
4. **Control:** Once monitoring, identification, and action thresholds indicate that pest control is required, and preventive methods are no longer effective or available, IPM programmes evaluate the proper control method both for effectiveness and risk. Effective, less risky pest controls are chosen first, including highly targeted chemicals, such as pheromones to disrupt pest mating, or mechanical control, such as trapping or weeding. If further monitoring, identification, and action thresholds indicate that less risky controls are not working, then additional pest control methods would be employed, such as targeted spraying of pesticides. Broadcast spraying of non-specific pesticides is a last resort.

6.6. Animal waste management

The problem of water quality in the livestock industry is from solid and liquid waste (manure). Liquid manure is urine, or any manure to which water is added in the collection, storage or treatment processes. The main pollutants in animal waste are chemical oxygen demand (COD), biological oxygen demand (BOD), ammonia nitrogen (NH_3-N), total phosphorus (TP), total nitrogen (TN) and metals. Animal wastes often contain growth hormones and antibiotics. The storage, processing, handling and spreading of manure play an important role both in reducing water pollution and increasing economic benefits to farmers, especially as manure adds organic fertilizer and carbon to the soil and promotes good soil texture. Excessive use of manure leads to a situation where the soil and crops cannot fully adsorb the nutritive components in manure and leads to surface and groundwater pollution. Therefore, the amount of manure used must be part of a comprehensive fertilizer management plan (FAO, 2013).

Figure2. Total pollution loads released to the environment from pigs, cattle and poultry, from 2000 to 2007.



Source: China Animal Husbandry Yearbook, 2008; FAO, 2013

6.7. Industrial waste and sewage pretreatment program

In addition to wastewater from residential and commercial sources, wastewater treatment facilities also receive wastewater from industrial users. The solid waste treatment and resource recovery technologies that can be applied include aerobic composting, sanitary landfill and incineration (FAO, 2013).

Aerobic composting – is a microbiological process in which organic domestic waste is biodegraded into an organic soil conditioner and fertilizer. The process uses specific conditions of temperature, humidity, carbon and nitrogen ratio and ventilation, together with the application of bacteria, fungi, actinomycete (bacteria) and/or other microorganisms that are widely distributed in nature, to biodegrade organic domestic waste into stable humus (used as fertilizer). The compost product is dark brown and smells of soil; it is an excellent soil conditioner for the soil reaction.

Sanitary landfill – is the burial of domestic waste. This requires specific conditions to prevent the penetration of rainwater, and the bottom of the landfill is sealed to prevent percolation of liquids from the waste into the groundwater and to prevent contamination of nearby water wells. In modern systems methane gas emissions from the landfill are captured and used as fuel.

Incineration – is widely used internationally to burn waste in high-temperature ovens. This method can be effective if carried out properly; if not it can produce a variety of toxic gases and by-products during the combustion process.

6.8. Integrated drainage and wetland management

This system combines irrigation, drainage and wetland. The irrigated area is higher than the pond; field drainage is through pipes or ditches to the wetland where nitrogen and phosphorus are biodegraded by wetland plants. Water from the wetland can be reused in the field, or discharged to nearby watercourses. Compared with conventional irrigation and drainage, research shows that total nitrogen TN, $NH4^+$ -N and NO_3—N concentrations at the outlet of the wetland were lowered by 17 percent, 14 percent and 51 percent respectively compared with the field drainage water (Peng *et al.*, 2009; FAO, 2013).

6.9. Regulatory framework to control irrigation water pollution

Water pollution in agriculture is recognized worldwide. However, unlike point sources, the experience worldwide is that non-point source (NPS) pollution is difficult to regulate effectively because of its inherently diffuse nature. The European Union Water Framework Directive (WFD) was adopted in 2000 (European Council, 2000; FAO, 2013) as a means of protecting inland surface waters (rivers and lakes), transitional waters (estuaries), coastal waters and groundwater. The WFD uses the integrated water resource management (IWRM) approach in which the river basin is the management unit for water. The directive requires Member States to create management plans for each river basin on a six-year cycle. Point and Non-point source pollution are to be managed using an integrated approach (FAO, 2013).

Many countries in sub-Saharan African have national policies, strategies (e.g., National Environment Action Plans) and legislation that stipulate the need for appropriate environmental planning and management. These policies usually apply to both public- and private-sector investment in irrigation (McCartney *et al.,* 2007).

6.10. Storm-water Treatment

It is the removal of pollutants from storm-water prior to releasing the storm-water to the public storm-water system. Source control is the practice of preventing contact between storm-water and potential sources of pollutants. By providing soil- or landscaped-based permanent storm-water treatment, development projects can protect water quality and reduce maintenance frequency of the treatment facilities. Most soil-based treatment systems are bio-retention areas and bio-swales, a swale lined with grass or other vegetation. Other systems include but are not limited to paver systems, vertical pipes/boxes or dry well boxes with a mixture of soil, sand, and rock, and other systems as new methodologies are developed (ACPWA, 2016).

7. SUMMARY AND CONCLUSIONS

Agricultural production releases residuals that may degrade the quality of the water resources and impose costs on water users. The extent and magnitude of this degradation is difficult to assess because of its non-point nature. Worldwide water quality assessments strongly suggest that agriculture is the single largest leading source of water quality problems. Disturbing the soil through tillage and cultivation then leaving it without vegetative cover may increase the rate of soil erosion. Dislocated soil particles can be carried in runoff water and eventually reach surface water resources, including streams, rivers, lakes, reservoirs, and wetlands. Runoff transports pollutants over the soil surface by rainwater, melting snow, or irrigation water. The leading causes of impairments in rivers are siltation and nutrients. For lakes and estuaries nutrients are the leading pollutants.

When irrigation water is applied to the cropland, a portion of it runs off the field into drainage ditches and flows back to a receiving body of water or percolate to the ground. These irrigation return flows may carry dissolved salts, as well as nutrients and pesticides, into surface or groundwater. Residues of chemical fertilizers and pesticides may wash off the field into streams or leach through the soil into ground water. The increased concentrations of naturally occurring toxic minerals can harm aquatic wildlife, human beings, domestic & wild animals and degrade the soils fertility. Another problem becoming common to estuaries and coastal water is harmful algal blooms. Blooms of both microscopic and macroscopic marine algae can produce: toxic effects on aquatic organisms like fish, nuisance conditions from odors and discoloration of waters, or severe oxygen depletion of bottom water habitats. Livestock operations also produce large amounts of waste, which if not properly disposed, can threaten human health as well as contribute to excess nutrient toxicity problems in streams, rivers, lakes, and estuaries.

When pollutants degrade water quality, they impose costs on water users. These costs may be in the form of degraded ecosystems that people wish to remain healthy, reduced recreational opportunities, reduced commercial fishing catches, increased water treatment costs, threats to human and animal health, and damage to reservoirs and water conveyance systems. Therefore, efficient irrigation water management, integrated drainage and wetland management, integrated pest management, comprehensive nutrient management planning, animal waste management, conservation Agriculture and Industrial waste, sewage and storm water pretreatment should be employed as a long term solution.

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