South Asia Environmental Capacity Building: Agriculture and Water Pollution

Handout

Agriculture-based Water Pollution

November 2020

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1.1 Current Scenario of Indian Agriculture

As per the 2019 annual report by the Ministry of Agriculture & Farmers Welfare (2018), agriculture plays an important role in India's economy by providing employment for about 54.6% of its total workforce in agricultural and allied sectors. Agriculture sector accounts for 17.1% of nation's Gross Value Added (GVA) for the year 2017-18 (at current prices). The report further states that as per the Land Use Statistics 2014-15, the total geographical area of the country is 328.7 million hectares, of which 140.1 million hectares is the reported net sown area and 198.4 million hectares is the gross cropped area with a cropping intensity of 142%. The net sown area works out to be 43% of the total geographical area, while the net irrigated area is 68.4 million hectares.

1.1.1 Cropping Seasons, Crops and Water Footprint

The major crops include rice, wheat, cereals, pulses, oil seeds, sugarcane, cotton, jute and so on. There are two main cropping seasons, namely ***kharif*** (April–September) and ***rabi*** (October–March). The major *kharif* crops include rice, sorghum, pearl millet, maize, cotton, sugar cane, soybean and groundnut, and the *rabi* crops are wheat, barley, gram, linseed, rapeseed and mustard. With its good range of climates and soils, India has a good potential for growing a wide range of horticultural crops such as fruits, vegetables, potato, tropical tuber crops, mushrooms, ornamental crops, medicinal and aromatic crops, spices and plantation crops. Foodgrain (cereals and pulses) crops dominate the cropping pattern and account for about 60 percent of total gross cropped area (FAO, 2005).

Water footprint of a product (alternatively known as "virtual water content") expressed in water volume per unit of product (usually m^3/ton) is the sum of the water footprints of the process steps taken to produce the product.

Blue water footprint: Volume of surface and groundwater consumed as a result of the production of a crop.

Green water footprint: Volume of rain water consumed.

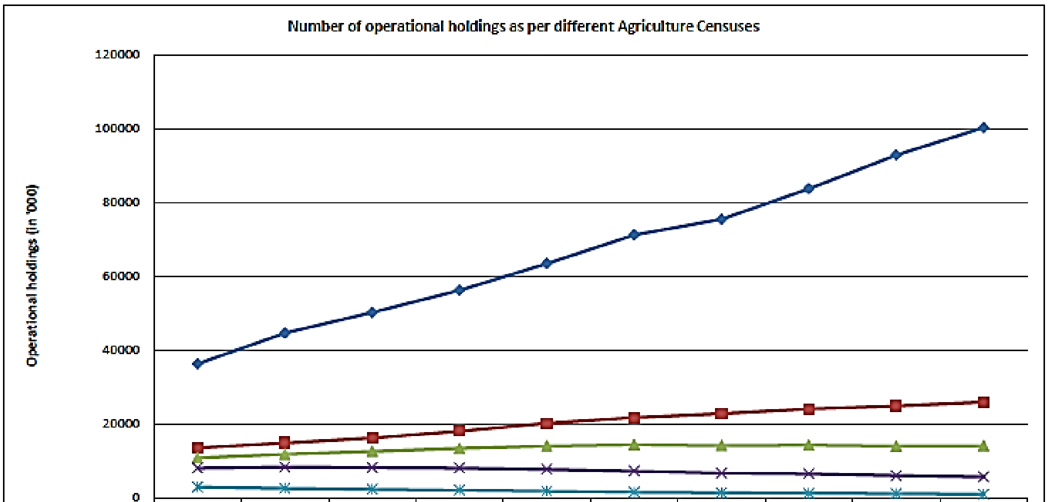
Grey water footprint: Volume of freshwater that is required to assimilate the load of pollutants based on existing ambient water quality standards (Mekonnen & Hoekstra, 2011)

1.1.2 Trend of Farm Landholdings in India

Due to fragmentation of landholdings, large and medium holdings become small and marginal holdings in India thereby bringing challenges in mechanisation to the farmers. **Table 1** shows the types of landholdings while **Figure 1** depicts the trend of landholdings in India. FAO (2005) reports that India suffers from varying degrees of land degradation and soil fertility depletion are a cause of concern for Indian agriculture.

Table 1 Size classes and Size groups of Agricultural land holdings in India (Source: Agriculture Census of India 2015-16, Ministry of Agriculture & Farmers Welfare, 2019)

S. No.	Group	S. No.	Classes (in ha.)
I	Marginal	1	Below 0.5 ha.
		2	0.5 < 1.0 ha.
II	Small	3	1.0 < 2.0 ha.
III	Semi-medium	4	2.0 < 3.0 ha.
		5	3.0 < 4.0 ha.
IV	Medium	6	4.0 < 5.0 ha.
		7	5.0 < 7.5 ha.
		8	7.5 < 10.0 ha.
V	Large	9	10.0 < 20.0 ha.
		10	and above.



	1970-71	1976-77	1980-81	1985-86	1990-91	1995-96	2000-01	2005-06	2010-11	2015-16
Marginal	36200	44523	50122	56147	63389	71179	75408	83694	92826	100251
Small	13432	14728	16072	17922	20092	21643	22695	23930	24779	25809
Semi-Medium	10681	11666	12455	13252	13923	14261	14021	14127	13896	13993
Medium	7932	8212	8068	7916	7580	7092	6577	6375	5875	5561
Large	2766	2440	2166	1918	1654	1404	1230	1096	973	838

Figure 1 Trend of landholding types in India (Source: Agriculture Census of India 2015-16, Ministry of Agriculture & Farmers Welfare, 2019)

There exists a gap of about 10 million tonnes of nutrients (NPK) between the removal of nutrients by crops and their addition through fertilizers. The use of plant nutrients per hectare is relatively low and imbalanced, and this is one of the major reasons for low crop yields in India. FAO (2020) is implementing a Global Environment Facility-funded Green-Ag Project to catalyse a transformative change in India's agriculture sector. The aim is to support national and global environmental benefits and conserve critical biodiversity and forest landscapes. The project aims to harmonize priorities and investments between India's agriculture and environment sectors to achieve national and global environmental benefits without compromising India's development objectives. It is being implemented in partnership with the Ministry of Agriculture and Farmers' Welfare and the State Governments of Madhya Pradesh, Mizoram, Odisha, Rajasthan and Uttarakhand.

1.2 Types of Agriculture and Water Demand

There are various ways of classifying agriculture; however, focus will be more on water and chemicals consumption by each type of agriculture. Any agricultural practice should aim at sustainability through the various interlinking factors as shown in Figure xx.

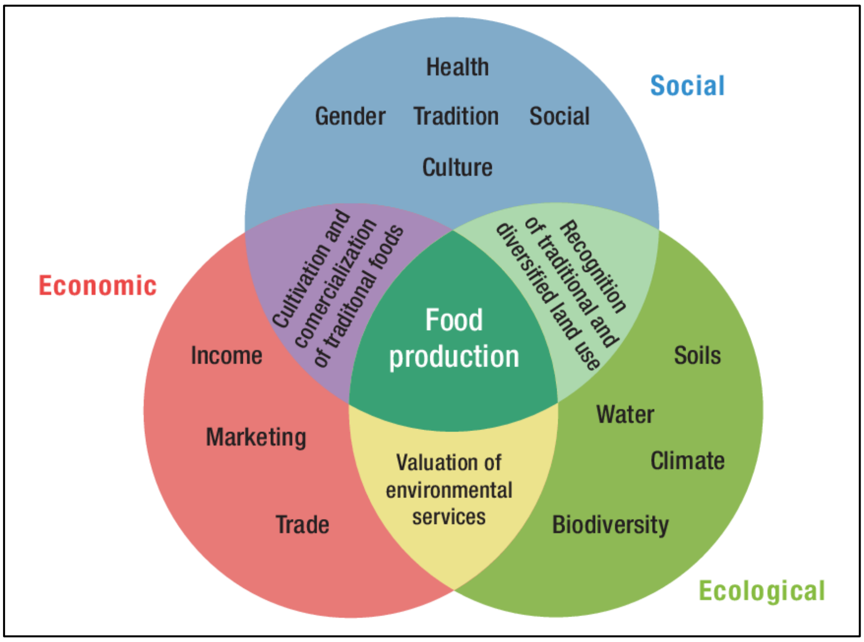


Figure 2 interrelationships between basic components of sustainability within the context of agriculture (Source: FAO, Liniger et al., 2011)

1.2.1 Based on scale of production

1.2.1.1 Subsistence farming

This widely used farming system can be seen throughout India. The farmer and / or his family grow their own grain or sell it at the local market. Majority of farmers in the country practice subsistence farming. It is characterized by small and scattered land holdings and use of primitive tools.

- Less fertilizers, mostly organic
- Limited land availability and irrigation

1.2.1.2 Commercial agriculture

The goal of commercial agriculture is high yield, so that produce can be exported to other countries or areas for profit. Wheat, cotton, sugarcane, and maize are some of the commercial crops and are grown in provinces including Gujarat, Punjab, Haryana and Maharashtra. Commercial farming is about growing crops and / or raising animals for consumption, food, or export, especially for profitable purposes.

- Extensive use of fertilizers and pesticides (mostly)
- May or may not be irrigated

1.2.2 Based on irrigation availability

i. Rainfed/Dry land farming

Both rainfed and dryland farming come under non-irrigated agriculture. Rainfed farming is practised in humid regions while dryland farming in semi-arid and arid regions. It includes an effective system of soil and crop management through various traditional agricultural practices.

- No irrigation systems
- Usage of fertilizers may usually be limited to ensure that weeds do not consume soil moisture needed by the cultivated plants.

ii. Irrigated agriculture

Here, irrigation facilities are made available for extensive cropping throughout the year. The various types of irrigated agriculture include flooding, sprinkler, drip etc. In general, intensive fertilizer application is seen in irrigated areas. However, based on the various methods, the irrigation efficiency and yield productivity also vary as shown in **Figure 3, Table 2** and **Table 3**.

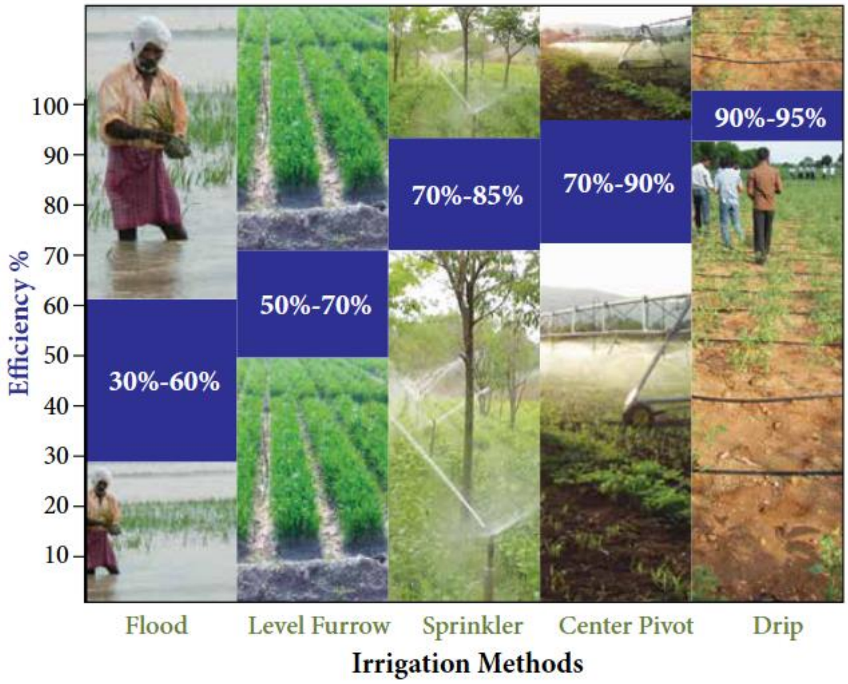


Figure 3 On-farm irrigation efficiency of different irrigation methods (Source: MANAGE, 2016)

Table 2 Response of different crops to sprinkler irrigation (Source: MANAGE, 2016)

Crop	Water saving (%)	Yield increase (%)	Crop	Water saving (%)	Yield increase (%)
Bajra	56	19	Gram	69	57
Barley	56	16	Groundnut	20	40
Bhendi	28	23	Jowar	55	34
Cabbage	40	3	Lucerne	16	27
Cauliflower	35	12	Maize	41	36
Chillies	33	24	Onion	33	23
Cotton	36	50	Potato	46	4
Cowpea	19	3	Sunflower	33	20
Fenugreek	29	25	Wheat	35	24
Garlic	28	6			

Table 3 Response of different crops to dripr irrigation (Source: MANAGE, 2016)

Crop	Water saving (%)	Yield increase (%)	Crop	Water saving (%)	Yield increase (%)
Mango	34.8	80	Pomegranate	45	98
Banana	45	52	Tomato	39	50
Grapevine	48	23	Watermelon	36	88

Lady's finger	40	16	Sugarcane	49.3	133.3
Brinjal	53	14	Cotton	46.6	88
Chillies	62	44	Onion	46.1	53.8
Papaya	68	75	Potato	54.1	79.5

1.2.3 Selective Modern techniques

There are multiple modern techniques in agriculture aimed at improved yields from limited land and water. The well-known methods include vertical farming, soil less cultivation (Aeroponics, Aquaponics, Hydroponics etc.), and precision farming and so on. **Table 4** shows selective modern techniques applicable for land-based and indoor farming methods that aim at optimal resource allocation including water and chemicals.

Table 4 Modern farming techniques in the context of water usage

	Land-based farming techniques	Indoor farming techniques
Feature	• Spread over large area • Prone to pest attack • Lower productivity • More chemical application • Soil as the growing media • Less crop per drop	• Space requirement is limited • Resistant to pest attack • Higher productivity • Less chemical application • Mostly soil less cultivation • Vertical farming • More crop per drop
Example	• Precision farming • Green house farming	• Aeroponics • Aquaponics • Hydroponics

1.3 Selective Traditional Practices in India

Traditional agricultural practices have been an integral part of food production in India since ages. These practices have the potential to mitigate the adverse effects of climate change with spatial and sequential diversity. Traditional agriculture has adaptive and mitigation ability towards these anthropogenic threats that can provide sustainable production and environmental safety. It is a dynamic tool for the conservation of natural resources such as water and argo-ecosystem from landscape to family farms. The traditional farming system is based on the ecological principle and the interaction between human environment and existing natural resources. Traditional agriculture includes a set of practices which are collectively called traditional agriculture practices (TAPs). TAPs are conservative and localized in the indigenous community. These practices are adaptive to the local environment and based on indigenous local knowledge (ILK) which grants it more pliability where other practices may fail. TAPs can be defined as a set of knowledge– practice–trust nexus which has developed by its adaptive nature and passes on to the next generation through a cultural transmission that explains the relationship between living beings with their environment (Watson, 2019).

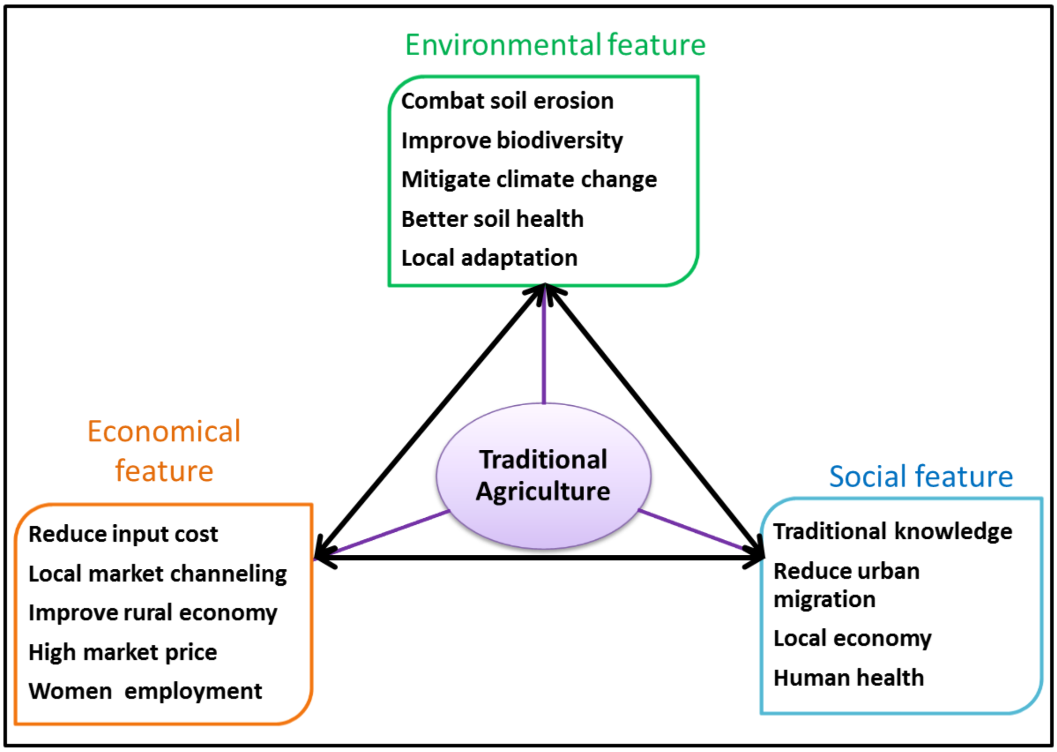


Figure 4 Sustainability potential of traditional agriculture (Source: Patel et al., 2020)

Table 5 Different traditional agricultural practices performed in India (Source: Patel et al., 2020)

Traditional agricultural practices	Characteristic features	Performing community	State
Forest gardening	Selection of superior species which can be incorporated in home gardens	Mostly in humid regions of India	Almost entire India
Rice fish culture	Humid regions and coastal belts of India	Throughout India	Arunachal Pradesh, AP, Assam, Punjab, Kerala, Tamil Nadu, UP, West Bengal
Aqua forestry	Cultivating fish and prawn in saline water while growing coconut and other trees on the bunds of ponds	Most of the coastal Population	Coastal areas of Andhra Pradesh

Traditional agricultural practices	**Characteristic features**	**Performing community**	**State**
Terraces or bund Cultivation	It is a slope and valley type cultivation which useful for improving crop production and retaining moisture for soil conservation	Khasis, Jaintias and Garos	Meghalaya
Badi cropping System	It is similar to home gardening practice which is mainly used by tribal for the maintenance of soil fertility	*Baiga* tribes	Madhya Pradesh
Live bunding/ vegetative bunding	Bushes of *subabul, shevri* and grasses like *vetiveria* are planted between the bunds of field across the slope for soil conservation against the water erosion	Most of the local farmers	Uttar Pradesh
Livestock panning and fallowing	Farmer used panning of cow, sheep, goat and fallowing the field at the end of winter to improve fertility of the field for the next crop	Aheer and Gadaria	Madhya Pradesh and Uttar Pradesh
Utera cropping System	Under rain fed agro-ecosystem, the next crop is planted before harvesting to utilize the soil moisture of the previous crop	*Baiga* tribes	Madhya Pradesh
Alder-based farming system in Jhum cultivation	Alder (Alnus nepalansis) is cultivated in jhum cultivation, a legume tree that fixes atmospheric nitrogen for nutrients and leaf litter to retain the soil moisture	Indigenous tribes, *Angami,* Chakhesang, Chang, Yimchunger and Konyak	Nagaland
Farming below the sea level	In this process, a series of buds has been created to regulate the flooding and salinity in agriculture by the use of biobuds such as coconut tree, banana waste, bamboo, coir and clay	*Kuttanad* Farmer of costal Area	Kerala
Kaipad (rice–fish farming)	Rice cultivation is performed from April to October and prawn/fish farming from November to April	Farmers of coastal area	Kerala
Pannendu Pantalu	It is known as 12-crop system, in which millets, pulses, oil crop and various vegetables are grown on the	Most of the farmers	Andhra Pradesh

Traditional agricultural practices	Characteristic features	Performing community	State
	single piece of land		
Homesteads (Kyaroo)	A number of tree species is growing for fuel, fodder and timber along with livestock, poultry and fish to satisfying the basic need of the farmer	Most of the farmers	Himachal Pradesh and Jammu and Kashmir
Zabo System	*Zabo* means impounding of water, mostly practised by the *Chakhesang* tribe of Nagaland up to 100% slope, which is a combination of forest, agriculture, animal husbandry and pisciculture	Chakhesang tribe	Nagaland
Sanda practice (double transplanting)	It is an excellent practice for water management in rainfed condition in which rice nursery is transplanted two times in a cropping season	Local farmers	Uttar Pradesh

1.4 Green revolution and its implications on water resources

In the 1960s, green revolution started in through high-yielding varieties of rice and wheat to increase food production in order to alleviate hunger and poverty. Post-Green Revolution, the production of wheat and rice almost doubled due to initiatives of the government; however, the production of other food crops such as indigenous rice varieties and millets declined. This led to the loss of distinct indigenous crops from cultivation and also caused extinction.

To increase yield, agrochemical-based pest and weed control was used in abundance. This impacted the environment as well as human health. Increase in the area under irrigation led to rise in salinity of the land. Although high yielding varieties made India food secure, they also led to significant genetic erosion. By the 1970s, the new seeds, which were responsive to controlled irrigation and petrochemical fertilisers and pesticides, had replaced the traditional farming practices of millions of farmers. This method of farming used high amount of water, extracting water from the aquifers where irrigation water did not reach.

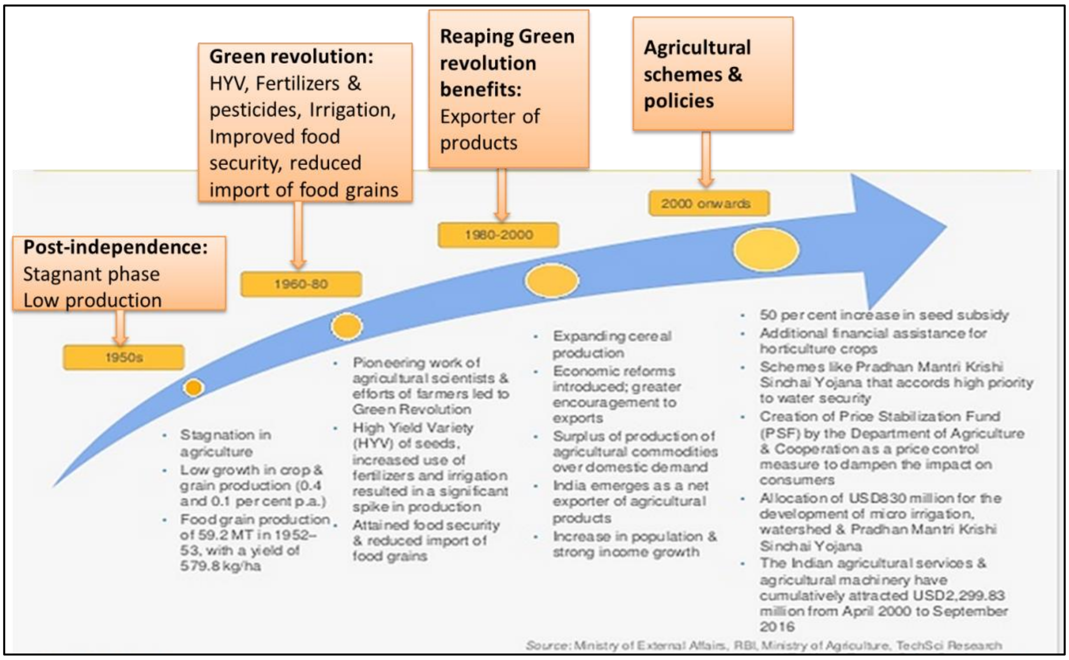


Figure 5 Evolution of agriculture in India

1.4.1 Impacts on the ecology

The major ecological and societal impacts of the Green Revolution can be summarized as follows: loss of landraces that were indigenous to our country, the loss of soil nutrients making it unproductive. Excessive use of pesticides and fertilizers (**Figure 6**) increases the presence of its residues in foods and environment. The farmers shift to unsustainable practices to obtain more yields leading to the following consequences:

- Reduced indigenous landraces in our country
- Reduced soil nutrients → unproductive agricultural lands
- Traces of pesticides in food chain
- Soil & water degradation due to unsustainable practices to obtain more yield

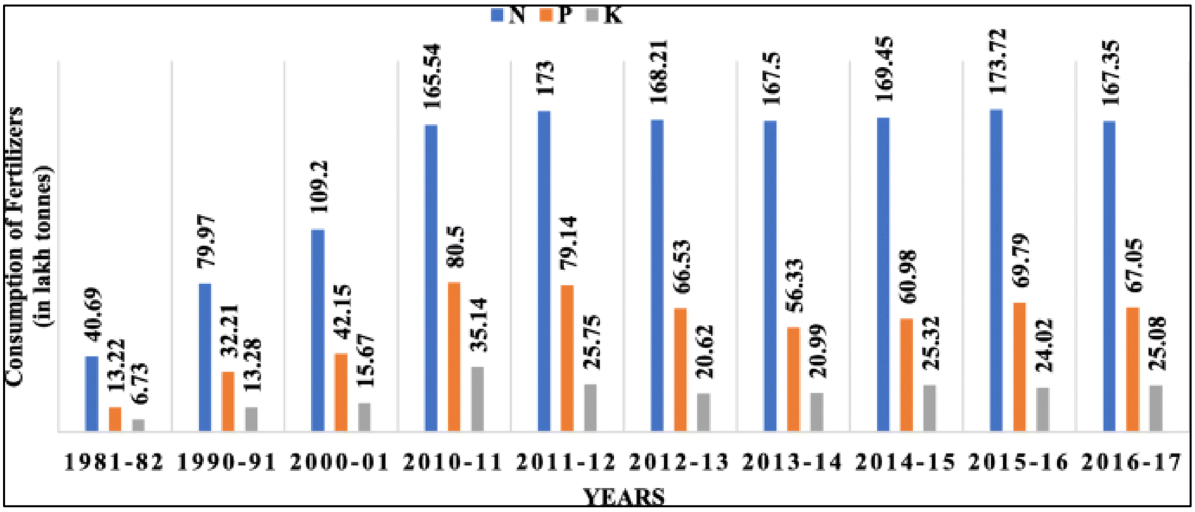


Figure 6 Consumption of fertilizers (N- Nitrogen, P- Phosphorous, and K- Potassium) post-Green Revolution period (Source: Eliazer Nelson et al., 2019)

1.4.2 Impact on the society

The increased financial risk due to lower productivity in the recent decades has led to higher rates of suicide among farmers as they are unable to withstand the increasing expenses for farming and debts small farmers sell their lands to large commercial farmers, and unable to withstand the food inflation and economic crisis the farmers left farming resorting to other occupation (Nelson et al., 2019). The specific points are as follows:

- Expenditure of farm inputs due to degraded land and water
- Farmer's income and land sale for commercial activities
- Health risk from polluted food chain
- Rapid urban migration due to income loss and suicides among farmers

1.4.3 Impact on the water resources

Both quantity as well as quality of water resources in the country has come to be seriously impacted as a result of Green Revolution. The cultivation of HYVs across the country has multiplied the irrigation demand as a result of which as much as 80% of India's water resources stand diverted for irrigation. The canal irrigation networks developed and strengthened to support Green Revolution take the lion's share from rivers and other surface water bodies, leading to drying up and disappearance of these sources. Further, failure or absence of canal irrigation has led to large-scale dependence on groundwater instead. Today more than 50% of the irrigated area depends on groundwater and in several districts it is more than 80%. According to Central Groundwater Board (CGWB), about 92% of the country's ground water draft is used for irrigation. This has led to a situation where over 28% of the groundwater assessment units in the country have groundwater use substantially greater than the rate of recharge which is causing scarcity of water for drinking and other essential needs in the affected areas. Further, depleting water tables increase concentration of natural contaminants like arsenic and fluoride in the groundwater. In addition, intensive use of chemical fertilizers, pesticides and herbicides also degrade water quality.

Extensive use of chemicals on land leached the earth, polluting the aquifers. Pesticides, chemical fertilisers, dried aquifers were reasons for the outbreak of several diseases. Punjab and Haryana soon became the cancer capitals of the country (Eliazer Nelson et al., 2019). The specific points can be summarised as:

- Eutrophication of ponds/lakes/rivers etc.
- Groundwater contamination from nitrates and other chemicals
- Increased dependence on groundwater: 50-80% in irrigated areas
- Reduced ground water recharge and overdraft ➔ rapidly declining ground water table

2 Agriculture Water Pollution

Agricultural pollution is the pollution emitted into the environment as a product from the growth and development of livestock, food crops, animal feed, and biofuel crops (Lindwall, 2019). Agriculture, which accounts for 70 percent of the world's water supply, plays a major role in water pollution. The farms release large amounts of agrochemicals, organic matter, drug residues, sediments and salts into the body of water. "In many high-income countries and in many emerging economies, agricultural pollution has surpassed environmental and industrial pollution as a major factor in the decline of inland water quality," said Eduardo Mansur, Director of FAO's Land and Water Division. He further added "Accepting that we have a problem is the first step to finding solutions."

Nitrate from agriculture is now the most common chemical contamination in groundwater and rivers. Eutrophication caused by nutrient accumulation in lakes and coastal waters has an impact on a wide variety of fish species and the plant eco system which we are yet to discover completely. In addition to the data gaps, 415 coastal areas have been identified as being vulnerable due to food related insecurity. Agriculture is a source of air pollution too. Livestock account for about 40 percent of global emissions in air, 16 percent by mineral fertilizers and 18 percent by crop residues (Lindwall 2019).

2.1 Fertilizers and Pesticides for improved yields

Fertilizers and pesticides are intensively used for boosting crop production. Among all the fertilizers, urea is the mostly commonly used fertilizer followed by MP, DAP/TSP and also organic fertilizer though used infrequently (Chakrabarty 2014). Among the pesticides used Furadan and Diazinon are the most common. Farmers usually do not apply the correct amounts of fertilizer and this needs more standardization depending on the crop sown and the agro-ecological zones (Chakrabarty 2014). Most of the farmers and agrochemical dealers are not aware about the impact of fertilizer and pesticide on crop production and environment in the long term. Fertilizer is considered one of the main inputs for increasing crop yields. To understand the role of fertilizer for increasing production the Nobel prize-winning wheat scientist Dr Norman E Borlaug's dialogue is cited "If the high yielding wheat and rice varieties were the catalyst that ignited the Green Revolution, then chemical fertilizer was the fuel that poured its forward thrust"(Shah, 2008). The use of pesticides, including insecticides, fungicides, herbicides, rodenticides, to protect crops from pests, allowed to significantly reduce the losses and to improve the yield of crops such as corn, maize, vegetables, potatoes, cotton, as well as to protect cattle from diseases and ticks and to protect humans from malaria vectors (FP Carvalho 2006). Using modern varieties of fertilizers and pesticides result in the increase of agricultural production. However, there have been concerns of environmental problems resulting from inorganic soil management practices (AT Ayoub 1999). Fertilizers burn, delay emergence of foliage, injure plant tissues and sometimes result in death of plants. Sometimes chlorosis may result, which is an indication of high soil pH due to accumulation of inorganic nutrients.

Figure 7 Drainage of fertilizers (Image Source: Google)

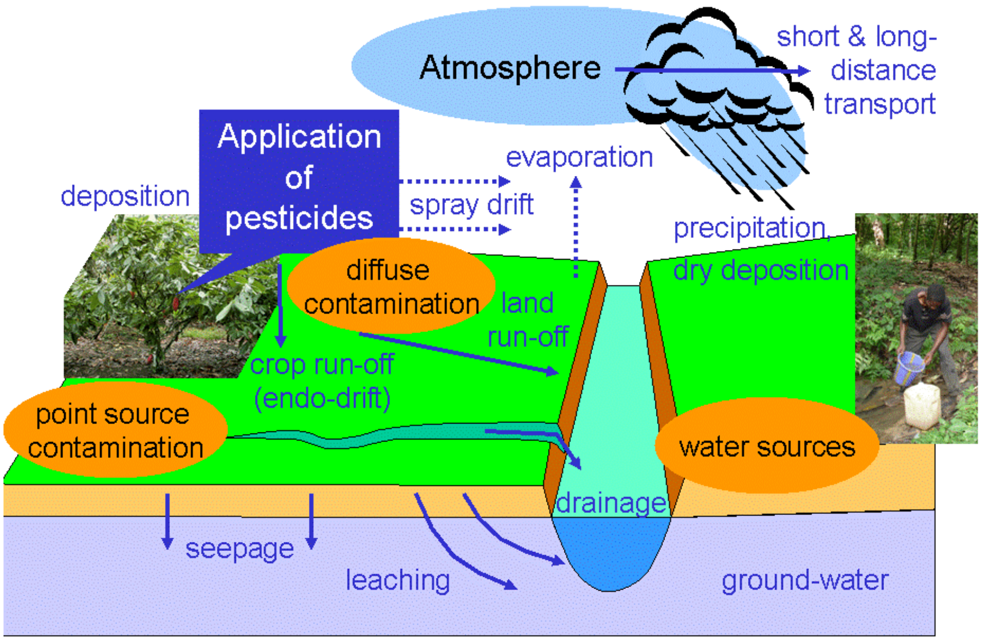


Figure 8 Pesticides pathways (Image source: Google)

(Zhong WH 2007) reported an increase in soil microbial biomass with fertilizer application; however, their results did not emphasise the ratio of beneficial to non-beneficial organisms. On the other hand, it showed that the use of chemical fertilizers resulted in accumulation of carcinogenic nitrosamines in soil environments, which consequently reduced the occurrence of beneficial microorganisms (Chakrabarty 2014). Alternative methods of soil fertility management are being developed to minimize problems associated with inorganic fertilizer usage. Therefore, it is important to study the inter-relationships between the crop and other soil factors that contribute to the productivity of a system. These include interactions between cropping systems and the microbial communities that facilitate or enhance nutrient uptake in soils. The mycorrhizal community is an important microbial component of the ecosystem (MC 2008) described mycorrhizae as symbiotic associations between fungi and roots of plants to form a single functional organ that is principally responsible for nutrient transfer. Beneficial associations with arbuscular mycorrhizal fungi (AMF) have been reported in many crops (Smith SE 1997).

2.1.1 Problem of nitrates in Groundwater

Nitrogen is essential for all living things as it is a component of protein and occurs in nature. Nitrogen exists in the environment in many forms and changes forms as it moves through the nitrogen cycle. However, excessive concentrations of nitrate-nitrogen or nitrite-nitrogen in drinking water can be hazardous to health, especially for infants and pregnant women. (AT 1999)

Nitrogen is the nutrient applied in the largest quantities for lawn and garden care and crop production. In addition to fertilizer, nitrogen occurs naturally in the soil in organic forms from decaying plant and animal residues. In the soil, bacteria convert various forms of nitrogen to nitrate, a nitrogen/oxygen ion (NO_3-). This is desirable as most of the nitrogen used by plants is absorbed in the nitrate form. However, nitrate is highly leachable and readily moves with water through the soil profile. If there is excessive rainfall or over-irrigation, nitrate will be leached below the plant's root zone and may eventually reach groundwater.

Natural **nitrate** levels in **groundwater** are generally very low (typically less than 10 mg/L NO_3), but **nitrate** concentrations grow due to human activities, such as agriculture, industry, domestic effluents and emissions from combustion engines. Nitrate-nitrogen (NO_3-N) in groundwater may result from point sources such as sewage disposal systems and livestock facilities also, while non-point sources include fertilized cropland, parks, golf courses, lawns, gardens.

Nitrate has become one of the most common groundwater contaminants in rural and urban areas. It must be regulated in drinking water primarily because excess levels can cause methemoglobinemia, or "blue baby" disease. Sodium nitrate may damage blood vessels, making arteries more likely to harden and narrow, leading to heart diseases.

2.1.2 Removal of nitrates

Nitrates can be removed from water by reverse osmosis, distillation, or through ion exchange resin. Nitrates are difficult contaminants to eliminate from water. Several methods have been proven to remove nitrates, (Dahab 1991).

2.2 Sources of water and associated pollution

British poet W. H. Auden once noted, "Thousands have lived without love, not one without water." (Prothero 2011) However, while we all know that water is important for health, we waste it anyway. About 80 percent of the world's wastewater - mostly untreated – returns to nature, polluting rivers, lakes, and the sea. This widespread water pollution threatens the health of the environment. Unsafe water kills more people every year than war and all other forms of violence combined.

Water pollution occurs when hazardous substances usually chemicals and microorganisms - pollute a stream, river, lake, sea, aquifer, and other watercourse, lowering the water level and making it dangerous to humans or the environment (Anju 2010), water is at risk of pollution like never before. Water is known as the "solvent universal," water dissolves more solids than any other liquid in the world. Toxic substances from farms, cities, and factories will be easily dissolved and mixed with them, creating water pollution.

2.2.1 Categories of water pollution

a) Surface water pollution

Surface water pollution includes pollution of rivers, lakes, and oceans. Since rivers flow at the lowest elevation in watersheds, most water channels and drains in the watershed flow to the rivers naturally. Thus, agriculture runoff flows as return flow to rivers and treated wastewater also flows to the rivers. The rivers have self-cleansing properties like oxygen and plants in the riverine eco system which keep the rivers healthy. However, when the pollution load increases, the river's ability to keep itself clean is crossed and the river's dissolved oxygen starts falling. The first signs of distress in rivers is the fall in fish species. Lakes are comparatively closed eco system, freshwater flows at much lower velocity. Once contaminated water starts entering the lake, very common in peri urban and newly urbanised areas, where lakes have lost their importance as source of fresh water, contamination is largely unnoticed till the level of pollution becomes quite high. A subset of surface water pollution is marine pollution.

b) Marine pollution

One common path of entry by contaminants to the sea are rivers. An example is directly discharging sewage and industrial waste into the ocean. Pollution such as this occurs particularly in developing nations. Large vortexes in the oceans trap floating plastic debris. Plastic debris can absorb toxic chemicals from ocean pollution, potentially poisoning any creature that eats it. Many of these long-lasting pieces end up in the stomachs of marine birds and animals. This results in obstruction of digestive pathways, which leads to reduced appetite or even starvation (Zaikab 2011). There are a variety of secondary effects stemming not from the original pollutant, but a derivative condition. An example is silt-bearing surface runoff, which can inhibit the penetration of sunlight through the water column, hampering photosynthesis in aquatic plants.

c) Groundwater pollution

Analysis of groundwater contamination may focus on soil characteristics and site geology, hydrogeology, hydrology, and the nature of the contaminants. Causes of groundwater pollution include:

- Naturally-occurring (geogenic),
- On-site sanitation systems,
- Sewage,
- Fertilizers and pesticide,
- Commercial and industrial leaks,
- Hydraulic fracturing,
- Landfill leachate (United States Geological Survey 1998)

2.2.2 Sources of pollution

Point sources: Point source water pollution refers to contaminants that enter a waterway from a single, identifiable source, such as a pipe or ditch. Examples of sources in this category include discharges from a sewage treatment plant, a factory, or a city storm drain.

Non-point sources: Nonpoint source pollution refers to diffuse contamination that does not originate from a single discrete source. This type of pollution is often the cumulative effect of small amounts of contaminants gathered from a large area. A common example is the leaching out of nitrogen compounds from fertilized agricultural lands, (Moss 2008). Nutrient runoff in storm water from "sheet flow" over an agricultural field or a forest are also cited as examples of non-point source pollution (Zhang, 2005). The non-point and point sources of pollution in water are shown in **Figure 9**.

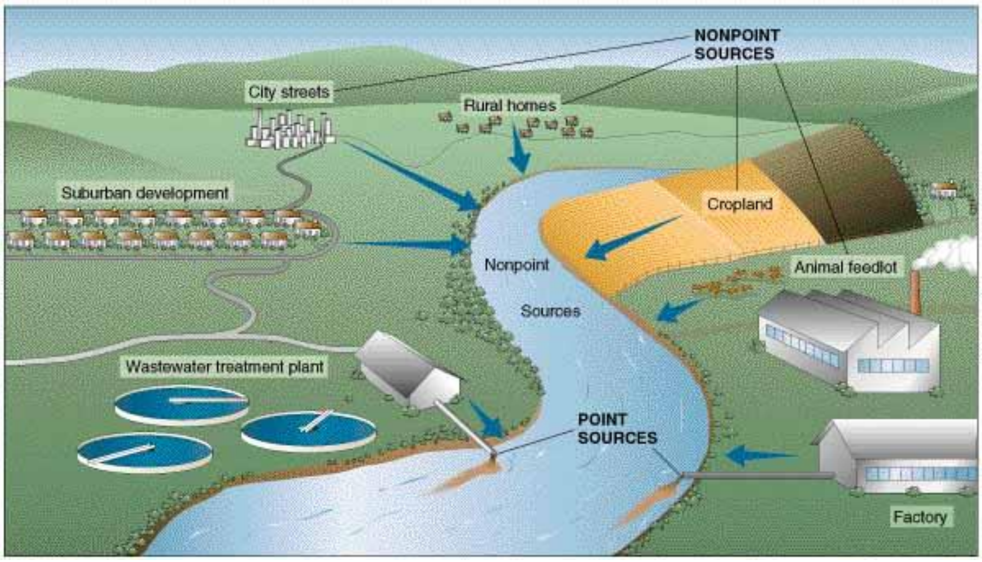


Figure 9 point and non-point source of pollution, Source: Blendspace

2.2.3 Types of Contaminants

Five main types of water pollutants: (WHO, 2017)

1. Microbial

Pathogens can be viruses, protozoa or viruses. For example, germs are found in water. However, when they begin to increase above safe levels, water pollution occurs. Other examples of waterborne pathogens are Salmonella, Giardia lamlia, Norovirus, Cryptosporidium parvum, and E. coli. High levels of germs can result from on-site sanitation systems or poorly managed sanitation, older cities with aging infrastructure may have sewage systems which need repairs, which can lead to sewage overload. Pathogen release can also be caused by animal dysfunction. The presence of E.coli bacteria often indicates that water is contaminated with human or animal waste.

2. Organic Material

Substances include petroleum products, insecticides and herbicides, detergents, disinfecting germs, and prescription drugs. One of the most common toxic chemicals is methyl tert-butyl ether (MTBE), MTBE was previously used as a gas cleaner. Although it is now a banned chemical, it will take years before it can be completely removed from contaminated water systems. Water contaminated with chemicals can cause leukaemia, lymphoma and tumours, thyroid glands, and kidneys.

3. Inorganic Material

Inorganic substances include substances such as ammonia, chemical waste, fertilizers, and heavy metals. Heavy metals such as arsenic, mercury, copper, chromium, zinc and barium - although harmless in very small amounts, act as a pollutant when kept in the water. This could be due to seepage from garbage dumps, or accidental industrial spills. Amongst inorganic pollutants nitrate pollution is most common. Addition of nitrogen as fertilizer is amongst the many other additions of nitrogen to the natural cycle which has caused alterations, different crops need different levels of nutrients which are often not followed, one uniform level of fertilizers is often administered. After the plant uptake of nitrogen, the balance remains in soil which leaches to groundwater because of nitrification, may then be found in lakes and rivers. Applied annually, most of the nutrients are absorbed by the crop, but when applied in excess, they can be lost to the environment through volatilization into the air, leaching into ground water, direct emission from soil to air, and runoff into surface water. This type of water pollution, can happen at various altitudes during the river course from the foothills to the delta region, However, if the contamination begins at the foothills itself then the river progressively becomes more and more contaminated giving rise to serious health concerns.

4. Macroscopic contaminants

Macroscopic contaminants are large objects, visible on waterways or on water bodies. Garbage, which is disposed into the water course, or reaches the river course from urban storm water drains. This has led to the construction of a "huge Pacific waste dump," in the ocean now the size of France. Other types of unsightly dirt include small pieces of plastic, pieces of wood, and metal. Although it may seem easy enough to manage, time is of the essence. These major pollutants must be removed to avoid disturbing the marine environment and pollution from the chemical degradation of these substances.

5. Thermal

Hot water pollution is the rise or fall of water temperature caused by human influence. The most common cause of hot water pollution is the use of water as coolant by energy plants and industrial producers. It can also be caused by the discharge of very cold water from the bottom of the ponds into the warm rivers. High water temperatures reduce oxygen levels, can kill fish and alter food composition, and reduce biodiversity. Urban flow can also increase the temperature of the surface water.

2.3 Rainfed vs Irrigated Agriculture

Table 6 Rainfed vs Irrigated Agriculture in India

Type of agriculture	**Rainfed**	**Irrigated**
	Rainfed agriculture is a type of farming that relies on rainfall for water. It provides much of the food consumed by poor communities in developing countries.	Supply water by means of canals, pipes, sprinklers, ditches, or streams.
Region	Spread over districts in most states of India	The plains of North India are mostly canal irrigated. Other parts are coastal lowlands and some parts of Peninsular India. The states are: Andhra Pradesh, Assam, Haryana, Jammu & Kashmir, West Bengal, Punjab Rajasthan, Bihar, Karnataka, Tamil Nadu and Uttar Pradesh.
Main crops	permanent crops (such as rubber, tea, and coffee) and annual crops (such as wheat, maize, and rice)	Paddy, Wheat, Sugarcane, Maize, Cotton, Vegetables, Potato and oilseeds
Disadvantages	Rainfed agriculture constitutes 80% of global agriculture, and plays a critical role in achieving global food security. However, the growing world population, water scarcity, and climate change threaten rainfed farming through increased vulnerability to droughts and other extreme weather events.	Stream water diversions for irrigation and wetland management can lower overall stream flows.
Pollution	waterlogging at places contributes to salinity, sodicity. Waterlogging threaten large areas of the world's most productive land and pollute groundwater Soil erosion in downstream, causes sedimentation The run-off from the first rainfall event of the season contains fertilizers and pesticides	Pesticides retention, Nutrient leaching, Accumulation of trace elements, Increase in soil salinity

2.4 Peri-urban vs Rural agriculture

Table 7 Peri-urban vs Riral Agriculture in India

Type of agriculture	Peri-urban Agriculture	Rural Agriculture
	Peri-urban agriculture is generally defined as agriculture undertaken in places on the fringes of urban areas. The people in these areas may or may not be completely dependent on agriculture as their primary source of income	Agriculture in rural areas is the primary occupation
Region	On periphery of urban city, large mega urban regions	Many districts across states in India still retain their complete rural character
Disadvantages	Peri-urban agriculture face challenges of polluted water from cities. The irrigation canal waters are diverted to meet urban water demand Air and dust from cities are affecting crop production	No fixed income and poverty in drought Lack of electricity and equipment Primarily depend on rain for agricultural production Subsistence farming
Pollution	Waterlogging causes malaria and dengue. Manure may contain chemicals and heavy metals unsuitable for use can be hazardous for nearby communities Air pollution enters the crop cycle, impacts crop quality The extent of groundwater pollution in this region is such that instead of calcium bicarbonate, sodium chloride and potassium sulphate may be found more commonly. Presence of nitrates in groundwater is also a clear indication of pollution due to sewage and excessive use of fertilizers	can include pollution by degradation of soil, water, and air or by organic contaminants. Soil erosion and sedimentation. Tillage can damage soil.

3 Agriculture Water Quality Management

Water being the major resource input in agriculture (other than soil itself), the quality of water has profound influence on the crop yield. Further, water being a versatile solvent has tendency to pick salts in contact and hence can be a major source of pollution if not managed properly by agriculturists. Quality of water and soil is influenced by each other. Growing scarcity of water and rising pollution has brought the attention towards management of water quality in agriculture which includes water quality testing, water source protection, irrigation water management, salt management, table water management, drainage management and disposal, and monitoring and evaluation system (FAO, 2011).

3.1 Irrigation water quality

Among water quality parameters, salinity and presence of sodium (if present in excess called Sodicity) are of primary concern since these are common and when in excess have negative consequence on agriculture yield. Thus, irrigation water quality are determined by physio-chemical parameters: Salinity hazard which include total soluble salt content, Sodium hazard which is relative proportion of sodium to calcium and magnesium ions, pH indicates acidic or basic character, alkalinity from carbonate and bicarbonate concentration and some other specific ions including chloride, sulphate, boron, and nitrate (Tak 2012). However, another potential irrigation water quality parameter that may affect its suitability for agriculture, especially low height edible vegetables, is microbial pathogens. **Tables 8-11** explain irrigation water quality requirements, impact of these parameters and quality gradation of irrigation water.

Salinity the most important water quality parameter is measured in terms of electrical conductivity (EC). Salinity causes the salts accumulate in the root zone to such an extent that the crop is no longer able to extract sufficient water from the salty soil solution. On the other hand, reduction in water infiltration can occur when irrigation water contains **high sodium** relative to the calcium and magnesium contents. (Arshad 2017). This condition is termed “sodicity,” and results from excessive accumulation of sodium in soil. The most common measure to assess sodicity in water and soil is called the Sodium Adsorption Ratio (SAR). The SAR defines sodicity in terms of the relative concentration of sodium (Na) compared to the sum of calcium (Ca) and magnesium (Mg) ions in a sample. The SAR is used to estimate the sodicity hazard of the water, where:

$$SAR = \frac{Na}{\sqrt{(\frac{Ca+Mg}{2})}}$$ *(all concentrations are in milli equivalents per litre (meq/L)*

SAR is a measure of the tendency of the irrigation water to cause the replacement of calcium (Ca) ions attached to the soil clay minerals with sodium ions (Na). The Residual sodium carbonate (RSC) is the measure of the excess of carbonates and bicarbonates over magnesium (Mg) and calcium (Ca). With high RSC (>1.25) there is a tendency for Ca and Mg to precipitate in the soil, thus increasing the proportion of Na and increasing the SAR of the soil solution. Irrigation water with an **abnormal pH levels** range may cause a nutritional imbalance or may contain a toxic ion. Lime is commonly applied to the soil to correct a low pH and sulphur or other acid material may be used to correct a high pH. **Chloride** is a common ion in most of the irrigation waters. Although chloride is essential to plants in very low amounts however, it can cause toxicity to sensitive crops at high concentrations. It is usually first evidenced as marginal leaf burn and interveinal chlorosis. **Boron**, is an essential element for plant growth however, if present in amounts appreciably greater than needed, it becomes toxic. Boron toxicity symptoms normally show first on older leaves as a yellowing, spotting, or drying of leaf tissue at the tips and edges. Drying and chlorosis often progress towards the centre between the veins (interveinal) as more and more boron accumulates with time. On trees, such as almonds and other tree crops a gum or exudate on limbs or trunk is often noticeable as a symbol. While the sulphate ion is a major contributor to salinity. Excessive **nitrogen** quantities when present or applied, causes crops to get disturbed because of over-stimulation of growth and result in delayed maturity or poor-quality yields.

Table 8 Recommended limits for constituents in reclaimed water for irrigation (Rowe and Abdel-Magid, 1995)

Constituent	Long-term use (mg/L)	Short-term use (mg/L)	Remarks
Aluminum (Al)	5.0	20	Can cause non productivity in acid soils, but soils at pH 5.5 to 8.0 will precipitate the ion and eliminate toxicity.
Arsenic (As)	0.10	2.0	Toxicity to plants varies widely, ranging from 12 mg/L for Sudan grass to less than 0.05 mg/L for rice.
Beryllium (Be)	0.10	0.5	Toxicity to plants varies widely, ranging from 5 mg/L for kale to 0.5 mg/L for bush beans.
Boron (B)	0.75	2.0	Essential to plant growth, with optimum yields for many obtained at a few-tenths mg/L in nutrient solutions. Toxic to many sensitive plants (e.g., citrus) at 1 mg/L. Most grasses relatively tolerant at 2.0 to 10 mg/L.
Cadmium (Cd)	0.01	0.05	Toxic to beans, beets, and turnips at concentrations as low as 0.1 mg/L in nutrient

			solution. Conservative limits recommended.
Chromium (Cr)	0.1	1.0	Not generally recognized as essential growth element. Conservative limits recommended due to lack of knowledge on toxicity to plants
Cobalt (Co)	0.05	5.0	Toxic to tomato plants at 0.1 mg/L in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
Copper (Cu)	0.2	5.0	Toxic to a number of plants at 0.1 to 1.0 mg/L in nutrient solution.
Fluoride (F –)	1.0	15.0	Inactivated by neutral and alkaline soils.
Iron (Fe)	5.0	20.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of essential phosphorus and molybdenum
Lead (Pb)	5.0	10.0	Can inhibit plant cell growth at very high concentrations.
Lithium (Li)	2.5	2.5	Tolerated by most crops at up to 5 mg/L; mobile in soil. Toxic to citrus at low doses recommended limit is 0.075 mg/L
Manganese (Mg)	0.2	10.0	Toxic to a number of crops at few-tenths to a few mg/L in acid soils.
Molybdenum (Mo)	0.01	0.05	Nontoxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high levels of available molybdenum.
Nickel (Ni)	0.2	2.0	Toxic to a number of plants at 0.5 to 1.0 mg/L; reduced toxicity at neutral or alkaline pH
Selenium (Se)	0.02	0.02	Toxic to plants at low concentrations and to livestock if forage is grown in soils with low levels of added selenium
Vanadium (V)	0.1	1.0	Toxic to many plants at relatively low concentrations.
Zinc (Zn)	2.0	10.0	Toxic to many plants at widely varying concentrations; reduced toxicity at increased pH (6 or above) and in fine-textured or organic soils.

Table 9 Classification of salt-affected soils based on analysis of saturation extracts. (James et al., 1982)

Criteria	Normal	Saline	Sodic	Saline-Sodic
EC^{e} (mmhos/cm)	<4	>4	<4	>4
SAR	<13	<13	>13	>13

Table 10 Soil salinity tolerance levels for different crops. (Ayers and Westcot, 1976)

Crop	Yield potential, ECe				Maximum ECe
	100%	90%	75%	50%	
Field crops					
Barleya	8.0	10.0	13.0	18.0	28
Bean (field)	1.0	1.5	2.3	3.6	7
Broad bean	1.6	2.6	4.2	6.8	12
Corn	1.7	2.5	3.8	5.9	10
Cotton	7.7	9.6	13.0	17.0	27
Cowpea	1.3	2.0	3.1	4.9	9
Flax	1.7	2.5	3.8	5.9	10
Groundnut	3.2	3.5	4.1	4.9	7
Rice (paddy)	3.0	3.8	5.1	7.2	12
Safflower	5.3	6.2	7.6	9.9	15
Sesbania	2.3	3.7	5.9	9.4	17
Sorghum	4.0	5.1	7.2	11.0	18
Soybean	5.0	5.5	6.2	7.5	10
Sugar beet	7.0	8.7	11.0	15.0	24
Wheata	6.0	7.4	9.5	13.0	20
Vegetable crops					
Bean	1.0	1.5	2.3	3.6	7
Beetb	4.0	5.1	6.8	9.6	15
Broccoli	2.8	3.9	5.5	8.2	14
Cabbage	1.8	2.8	4.4	7.0	12
Cantaloupe	2.2	3.6	5.7	9.1	16
Carrot	1.0	1.7	2.8	4.6	8
Cucumber	2.5	3.3	4.4	6.3	10
Lettuce	1.3	2.1	3.2	5.2	9
Onion	1.2	1.8	2.8	4.3	8
Pepper	1.5	2.2	3.3	5.1	9
Potato	1.7	2.5	3.8	5.9	10
Radish	1.2	2.0	3.1	5.0	9
Spinach	2.0	3.3	5.3	8.6	15
Sweet corn	1.7	2.5	3.8	5.9	10
Sweet potato	1.5	2.4	3.8	6.0	11
Tomato	2.5	3.5	5.0	7.6	13
Forage crops					
Alfalfa	2.0	3.4	5.4	8.8	16
Barley haya	6.0	7.4	9.5	13.0	20
Bermudagrass	6.9	8.5	10.8	14.7	23
Clover, Berseem	1.5	3.2	5.9	10.3	19
Corn (forage)	1.8	3.2	5.2	8.6	16
Harding grass	4.6	5.9	7.9	11.1	18
Orchard grass	1.5	3.1	5.5	9.6	18
Perennial rye	5.6	6.9	8.9	12.2	19
Sudan grass	2.8	5.1	8.6	14.4	26
Tall fescue	3.9	5.8	8.61	3.3	23

Tall wheat grass	7.5	9.9	13.3	19.4	32
Trefoil, big	2.3	2.8	3.6	4.9	8
Trefoil, small	5.0	6.0	7.5	10.0	15
Wheat grass	7.5	9.0	11.0	15.0	22

[1]Based on the electrical conductivity of the saturated extract taken from a root zone soil sample (ECe) measured in mmhos/cm.

[a]During germination and seedling stage ECe should not exceed 4 to 5 mmhos/cm except for certain semi-dwarf varieties.

[b]During germination ECe should not exceed 3 mmhos/cm.

Table 11 Limits of boron in irrigation water. (Adapted from Rowe and Abdel-Magid, 1995)

A. Permissible Limits (Boron in parts per million)			
Class of water	**Crop group**		
	Sensitive	**Semitolerant**	**Tolerant**
Excellent	<0.33	<0.67	<1.00
Good	0.33 to 0.67	0.67 to 1.33	1.00 to 2.00
Permissible	0.67 to 1.00	1.33 to 2.00	2.00 to 3.00
Doubtful	1.00 to 1.25	2.00 to 2.50	3.00 to 3.75
Unsuitable	>1.25	>2.5	>3.75

B. Crop groups of boron tolerance (in each plant group, the first names are considered as being more tolerant; the last names, more sensitive).		
Sensitive (1.0 mg/L of Boron)	**Semitolerant (2.0 mg/L of Boron)**	**Tolerant (4.0 mg/L of Boron)**
Pecan	Sunflower (native)	Athel (Tamarix aphylla)
Walnut (Black, Persian, or English)	Potato	Asparagus
Jerusalem artichoke	Cotton (Acala and Pima)	Palm (Phoenix canariensis)
Navy bean	Tomato	Date palm (P. dactylifera)
American elm	Sweetpea	Sugar beet
Plum	Radish	Mangel
Pear	Field Pea	Garden beet
Apple	Ragged Robin rose	Alfalfa
Grape (Sultania and Malaga)	Olive	Gladiolus

Kadota fig	Barley	Broad bean
Persimmon	Wheat	Onion
Cherry	Corn	Turnip
Peach	Milo	Cabbage
Apricot	Oat	Lettuce
Thornless blackberry	Zinnia	Carrot
Orange	Pumpkin	
Avocado	Bell Pepper	
Grapefruit	Sweet Potato	
Lemon	Lime Bean	
(0.3 mg/L of Boron)	(1.0 mg/L of Boron)	(2.0 mg/L of Boron)

3.2 Salinity management

Saline soils are those which have an electrical conductivity of the saturation soil extract of more than 4 ds/m at 25°C (Richards 1954). Soil salinity control relates to controlling the problem of soil salinity and reclaiming salinized agricultural land (Brinkman, 1980). Drainage is the primary method of controlling soil salinity. The system should permit a small fraction of the irrigation water (about 10 to 20 percent, the drainage or leaching fraction) to be drained and discharged out of the irrigation project (J.W. van Hoorn and J.G. van Alphen (2006).

Drainage is the primary method of controlling soil salinity. The drainage system designed to evacuate salty water also lowers the water table. To reduce the cost of the system, the lowering must be reduced to a minimum. Gypsum ($CaSO_4.2H_2O$) is the most common Ca-containing element to control salinity. It is low-cost, abundant, and non-toxic, and can be added to either irrigation water or soil. Other than gypsum many other amendments can also be introduce to reduce soil salinity (**Table 12**).

Table 12 Various amendments for reclaiming sodic soil and amount equivalent to gypsum (Fipps, 2003)

Amendment	Physical description	Amount equivalent 100% gypsum
Gypsum*	White mineral	1.0
Sulphur†	Yellow element	0.2

Sulfuric acid*	Corrosive liquid	0.6
Lime sulphur*	Yellow-brown solution	0.8
Calcium carbonate†	White mineral	0.6
Calcium chloride*	White salt	0.9
Ferrous sulphate*	Blue-green salt	1.6
Pyrite†	Yellow-black mineral	0.5
Ferric sulphate*	Yellow-brown salt	0.6
Aluminium sulphate*	Corrosive granules	1.3

*Suitable for use as a water or soil amendment.
†Suitable only for soil application.

3.3 Agriculture- based water pollution

Human settlements, industries and agriculture are the major sources of water pollution. Agriculture, which accounts for 70 percent of water abstractions worldwide, plays a major role in water pollution. Farms discharge large quantities of agrochemicals, organic matter, drug residues, sediments and saline drainage into water bodies (UNEP, 2016). Nitrate from agriculture is the most common chemical contaminant in the world's groundwater aquifers (WWAP, 2013). Apart from irrigation the livestock sector is growing and intensifying faster than crop production in almost all countries. The associated waste, including manure, has serious implications for water quality (Neil Palmer, 2009). Major agricultural contributors to water pollution (and the main targets for water-pollution control) are nutrients, pesticides, salts, sediments, organic carbon, pathogens, metals and drug residues. Water pollution from nutrients occurs when fertilizers are applied at a greater rate than they are fixed by soil particles or exported from the soil profile. Excess nitrogen and phosphates can leach into groundwater or move via surface runoff into waterways. Phosphate is not as soluble as nitrate and ammonia and tends to get adsorbed onto soil particles and enter water bodies thorough soil erosion (J. Mateo-Sagasta 2017). Acute pesticide poisoning causes significant human morbidity and mortality worldwide – especially in developing countries, where farmers often use highly hazardous pesticide formulations. Highly saline water alter the geochemical cycles of major elements – such as carbon, iron, nitrogen, phosphorus, silicon and sulphur (Herbert et al., 2015) – with overall impacts on ecosystems. improper tillage and soil management in agriculture are increasing erosion and sediment runoff into rivers, lakes and reservoirs and particles of clay and silt in sediment can adsorb many types of chemicals on their surfaces, including nutrients, heavy metals and persistent organic pollutants. Sediments, therefore, is a key means by which such pollutants are transported to water bodies.

Table 13 Pollutants from Agriculture run-off (FAO 2017)

Pollutant category	Indicators/examples
Nutrients	Primarily nitrogen and phosphorus present in chemical and organic fertilizers as well as animal excreta and normally found in water as nitrate, ammonia or phosphate
Pesticides	Herbicides, insecticides, fungicides and bactericides, including organophosphates, carbamates, pyrethroids, organochlorine pesticides and others (many, such as DDT, are banned in most countries but are still being used illegally and persistently)
Salts	Ions of sodium, chloride, potassium, magnesium, sulphate, calcium and bicarbonate. Measured in water, either directly as total dissolved solids or indirectly as electric conductivity
Sediment	Measured in water as total suspended solids or nephelometric turbidity units – especially from pond drainage during harvesting
Organic matter	Chemical or biochemical oxygen-demanding substances (e.g. organic materials such as plant matter and livestock excreta), which use up dissolved oxygen in water when they degrade
Pathogens	Bacteria and pathogen indicators. E.g. Escherichia coli, total coliforms, faecal coliforms and enterococci
Metals	E.g. selenium, lead, copper, mercury, arsenic and manganese

3.4 Strategies for agriculture-based water pollution

The right policies and incentives can encourage farmers towards more sustainable approach. A combination of approaches is needed including regulations, economic incentives and information. The strategies can be on-farm or off- farm. On farm practices include management measures for reducing the risk of water pollution due to organic and inorganic fertilizers and pesticides include limiting and optimizing the type, amount and timing of applications to crops. Off-farm practice means to avoid or limit the export of pollutants. riparian buffer strips or constructed wetlands, can cost-effectively reduce loads entering surface water bodies. Integrated nutrient management (INM) and Integrated pest management (IPM) are two main strategies for agriculture-based water pollution.

3.4.1 Integrated nutrient management

Refers to the maintenance of soil fertility and of plant nutrient supply at an optimum level for sustaining the desired productivity through optimization of the benefits from all possible sources of organic, inorganic and biological components in an integrated manner (Lemunyon 2006). Providing the nutrients needed for crop production involves focusing on 4Rs: the right amount, the right source, the right placement and the right time. Paying attention to these factors will provide adequate nutrition for crop production while reducing the risk of nutrient losses in the environment. **4R includes** the **right fertilizer** source applied at the **right rate**, the **right time**, and the **right place** for a crop producing sustainable economic, social, and environmental outcomes. The 4Rs are all interdependent and interconnected (Davis 2007). **Figure 10** explains the INM.

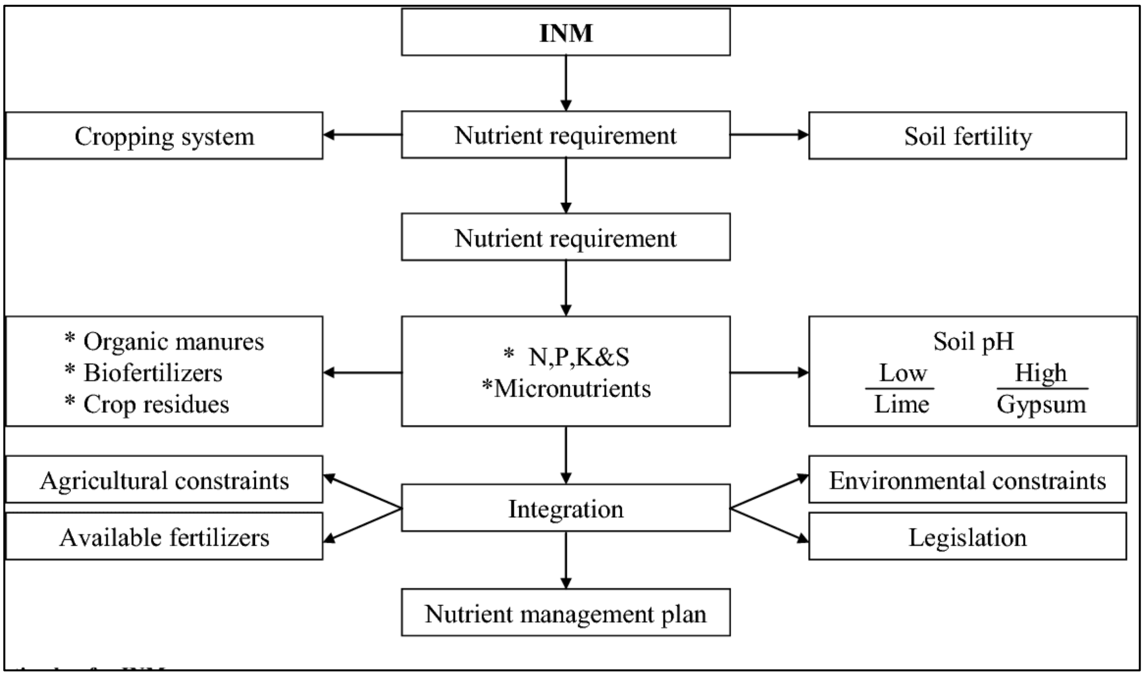


Figure 10 Components of INM, (A. Srivastava, 2009)

3.4.2 Integrated Pest Management

Integrated Pest Management or IPM (Figure xx), as it is commonly known, is a system of managing pests which is designed to be sustainable. IPM involves using the best combination of cultural, biological and chemical measures for particular circumstances, including plant biotechnology as appropriate. (Flint 2012).

This provides the most cost effective, environmentally sound and socially acceptable method of managing diseases, insects, weeds and other pests in agriculture. The IPM process starts with monitoring, which includes inspection and identification, followed by the establishment of economic losses levels. Integrated pest management employs a variety of actions including cultural controls such as physical barriers, biological controls such as adding and conserving natural predators and enemies of the pest, and finally chemical controls or pesticides. Reliance on knowledge, experience, observation and integration of multiple techniques makes IPM appropriate for organic farming (excluding synthetic pesticides). (A. K. Singh 2017).

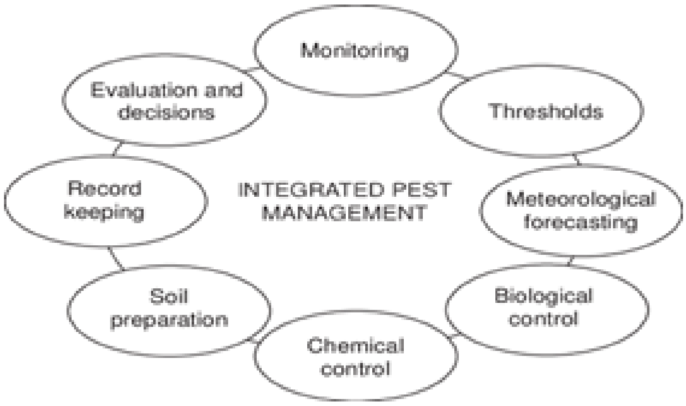


Figure 11 Components of IPM, Source: Singh, 2017

IPM emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms.

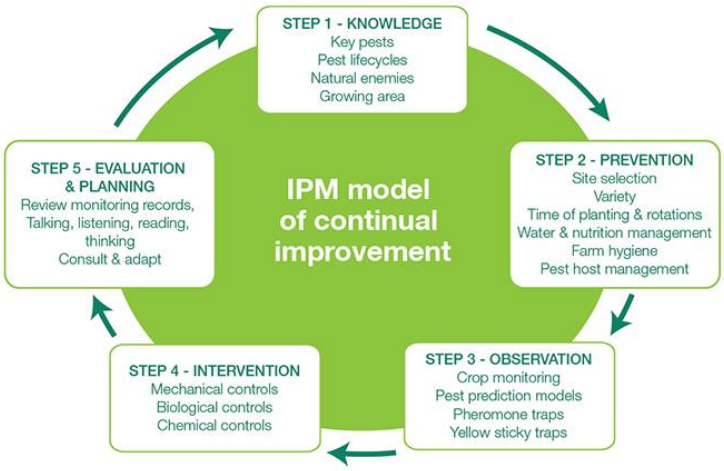


Figure 12 IPM model, Source: GRDC, 2010

4 Relevant Policies and Success Stories in Sustainable Agriculture

Water pollution from agriculture is complex and multidimensional, and managing it effectively is a herculean task. The efforts need to focus on the key drivers of agricultural expansion and intensification, such as unsustainable dietary shifts. They also need to limit the export of pollutants from farms, protect water bodies from agricultural pollution loads and help restore affected water ecosystems. Influencing both farm- and landscape-scale practices may require regulation, the use of economic instruments, education and awareness-raising, cooperative agreements, and research and innovation. Recent analyses suggest that a combination of approaches (regulations, economic, incentives and information) works better than regulations alone (OECD, 2012; OECD, 2017). [1]

4.1 Select Policies linked to Agriculture in India and Water Quality

Table 14 List of selective policies in India linked to Agriculture and Water quality

S. No	Name of the Policy	Reference to Agriculture/Irrigation Water	Reference to Agriculture Water Pollution
	National Water Policy 2012[2]	• **ADAPTATION TO CLIMATE CHANGE** • 4.3 The adaptation strategies could also include better demand management, particularly, through adoption of compatible agricultural strategies and cropping patterns and improved water application methods, such as land levelling and/or drip / sprinkler irrigation as they enhance the water use efficiency, as also, the capability for dealing with increased variability because of climate change. • **DEMAND MANAGEMENT AND WATER USE EFFICIENCY** • 6.5 Water saving in irrigation use is of paramount importance. Methods like aligning cropping pattern with natural resource endowments, micro irrigation (drip, sprinkler, etc.), automated irrigation operation, evaporation-transpiration reduction, etc., should be encouraged and	Addresses Water quantity, water use efficiency but there is no reference to agriculture water quality.

[1] http://www.fao.org/3/a-i7754e.pdf

[2] Source: http://jalshakti-dowr.gov.in/sites/default/files/NWP2012Eng6495132651_1.pdf

		incentivized. • 6.7 There should be concurrent mechanism involving users for monitoring if the water use pattern is causing problems like unacceptable depletion or building up of ground waters, salinity, alkalinity or similar quality problems, etc., with a view to planning appropriate interventions.	
2.	National Agriculture Policy 2000[3]	• Raising the Productivity of Inputs • Raising Value-Added per Hectare • Protecting the Interest of Poor Farmers • Modernizing Agricultural Sector • Checking Environmental Degradation • Agricultural Research and Training • Removing Bureaucratic Obstacles	The policy has reference to environmental degradation but does not include agriculture water pollution.

3	National Water Mission	**Goal 4: Improving Water Use Efficiency by 20%**
		• 4.6 - Promotion of water efficient techniques and technologies
		  • Promotion of micro irrigation techniques such as sprinkler and drip irrigation.
		  • Expand "Farmers' Participatory Action Research Programme".
		(Agency: Ministry of Environment, Forest & Climate Change and State Governments)
		• Strategy 4.12 : Incentivize use of efficient irrigation practices and fully utilize the created facilities
		(Agency: Ministry of Jal Shakti, Department of Drinking Water and Sanitation)
			The focus of national water mission, one of the missions under national action plan for climate change is on water use efficiency in agriculture without any emphasis on the pollution being caused by agriculture.

4.	Central Pollution Control Board[4] [5]	• Home Standards Water Quality Standards • Water Quality Standards • Industry Specific Standards Effluent/Emission General Standards	The reference is to the quality of water being supplied for irrigation rather than

[3] http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=TAD/CA(2018)4/FINAL&docLanguage=En

[4] https://cpcb.nic.in/wqstandards/

[5] http://cpcbenvis.nic.in/water_pollution_main.html#

			agriculture being a source of pollution.
5.	Pradhan Mantri Krishi Sinchayee Yojna[6]	• **Accelerated Irrigation Benefit Program:** It involves loan assistance to states to help them complete the incomplete major/ medium-sized irrigation projects that were at an advanced completion of the stage, thus accelerating the execution of the irrigation projects. • **PMKSY (Har Khet ko Pani):** This refers to increase the cultivable land area under assured irrigation, and also increase the physical access of water on the farm. • **PMKSY (More Crop Per Drop):** The focus here is improving water use efficiency in an organized and focused manner. • **PMKSY (Watershed Development):** This program focuses on prudent utilization of water and land resources, through various mediums such as prevention of soil erosion, increasing crop productivity, harvesting rainwater, etc.	The focus is no availability of water for irrigation and productivity in terms of more crop per drop of water used.
6.	Micro Irrigation Schemes	Through the micro-irrigation subsidy proposition that falls under the Per Drop More Crop element of PMKSY, both state and the central government, on an average, contribute to 55% and 45% of the total finances incurred in setting up irrigation systems for small and marginal farmers and for other farmers respectively. Nevertheless, state-specific variations exist.	The adoption of micro-irrigation may help in reducing agriculture water pollution.
7.	National Mission for Sustainable Agriculture [7]	Promoting sustainable agriculture through a series of adaptation measures focusing on ten key dimensions. • Improved crop seed • Livestock and fish cultures • Water Use Efficiency • Pest Management • Improved Farm Practices • Nutrient Management • Agricultural insurance • Credit support • Markets • Access to Information • Livelihood diversification	Few dimensions like pest management, nutrient management, improved agriculture practices may be useful if implemented correctly.

[6] https://pmksy.gov.in/

[7] https://nmsa.dac.gov.in/

4.2 Statistics on schemes

Table 15 Expenditure on major schemes under the Department of Agriculture, Cooperation and Farmers Welfare (in Rs crore) [8]

Major schemes	AE 2016-17	BE 2017-18	RE 2017-18	% change of RE 2017-18 over BE 2017-18	BE 2018-19	% change of BE 2018-19 over RE 2017-18
Interest Subsidy for Short Term Credit to Farmers	13,397	15,000	14,750	-1.7%	15,000	1.7%
Pradhan Mantri Fasal Bima Yojana	11,052	9,000	10,698	18.9%	13,000	21.5%
Pradhan Mantri Krishi Sinchai Yojana (Per Drop More Crop)	1,991	3,400	3,000	-11.8%	4,000	33.3%
Rashtriya Krishi Vikas Yojna	3,892	4,750	3,050	-35.8%	3,600	18.0%
National Mission on Horticulture	1,493	2,320	2,190	-5.6%	2,536	15.8%
National Food Security Mission	1,286	1,720	1,400	-18.6%	1,691	20.8%
Sub-Mission on Agriculture Mechanisation	367	550	777	41.2%	1,165	50.0%

Note: AE: Actual expenditure; RE: Revised estimate; BE: Budgeted estimate.

Sources: Union Budget 2018-19; PRS.

Table 16 Allocation to major heads of expenditure under the Department of Agriculture, Cooperation and Farmers' Welfare in 2020-21 (Rs crore) [9]

Schemes	2018-19 Actuals	2019-20 Budgeted	2019-20 Revised	% change in RE of 2019-20 over BE of 2019-20	2020-21 Budgeted	% change in BE of 2020-21 over RE of 2019-20
PM-KISAN	1,241	75,000	54,370	-27.5%	75,000	37.9%
Interest subsidy for short-term credit to farmers	11,496	18,000	17,863	-0.8%	21,175	18.5%
Pradhan Mantri Fasal Bima Yojana	11,937	14,000	13,641	-2.6%	15,695	15.1%
Pradhan Mantri Krishi Sinchai Yojana (Per Drop More Crop)	2,918	3,500	2,032	-41.9%	4,000	96.8%
Market intervention scheme and price support	1,400	3,000	2,010	-33.0%	2,000	-0.5%

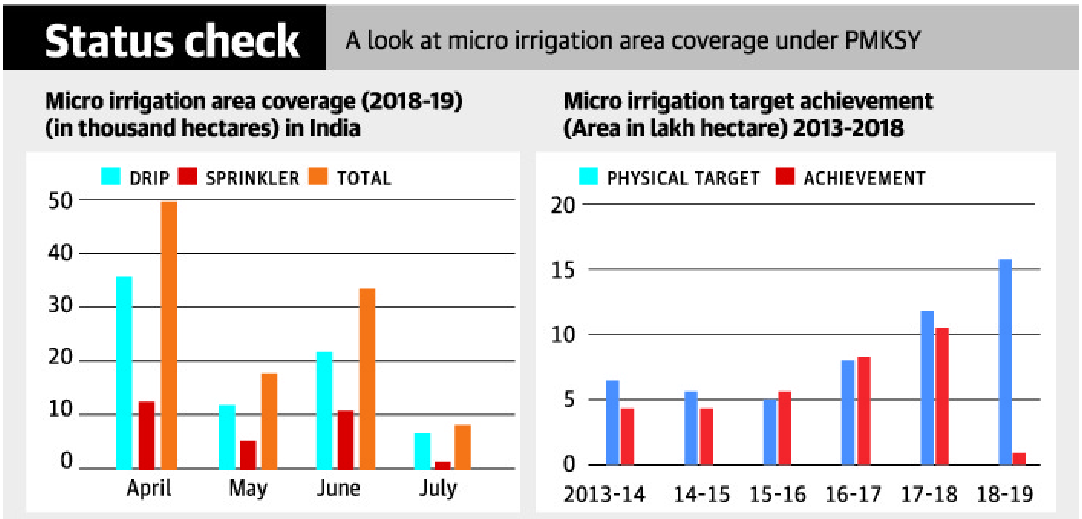
[8] https://www.prsindia.org/parliamenttrack/budgets/demand-grants-2018-19-analysis-agriculture-and-farmers%E2%80%99-welfare

[9] https://www.prsindia.org/parliamenttrack/budgets/demand-grants-2020-21-analysis-agriculture-and-farmers%E2%80%99-welfare

scheme (MIS-PSS)*						
PM-AASHA	4,721	1,500	321	-78.6%	500	55.8%
Pradhan Mantri Kisan Man Dhan Yojana	-	900	200	-77.8%	220	10.0%
Green Revolution	11,758	12,561	9,965	-20.7%	13,320	33.7%
Rashtriya Krishi Vikas Yojna	3,370	3,745	2,760	-26.3%	3,700	34.1%
National Mission on Horticulture	1,997	2,225	1,584	-28.8%	2,300	45.2%
National Food Security Mission	1,606	2,000	1,777	-11.2%	2,100	18.2%
Department	**46,076**	**1,30,485**	**1,01,904**	**-21.9%**	**1,34,400**	**31.9%**

*for procurement of pulses and oilseeds. Sources: Demand no. 1, Expenditure Budget, Union Budget 2020-21; PRS.

- ❖ Progress on Watershed development projects and Pradhan Mantri Krishi Sinchai Yojana (PMKSY) - (Source: Ministry of Agriculture and Farmers Welfare)



Source: PMKSY, Ministry of Agriculture and Farmers'Welfare

Figure 13 Progress on Watershed development projects and Pradhan Mantri Krishi Sinchai Yojana

- ❖ Crop Insurance

Table 17 Public funding of crop insurance (Source: PMFBY)

Year	Farmers' premium (Rs crore)	Expenditure by central and state governments (Rs crore)			Share of public funding in total expenses
		Premium contribution	Claims support	Total	
2013-'14	2,460	2,283	3,352	5,635	70%
2014-'15	2,707	2,241	2,733	4,974	65%
2015-'16	3,257	2,194	14,589	16,783	84%
2016-'17	4,209	17,982	0	17,982	81%
2017-'18	4,291	20,760	0	20,760	83%

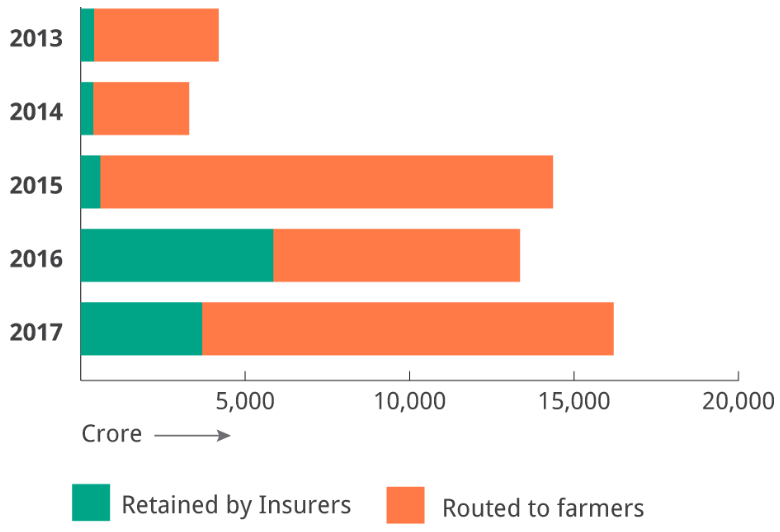


Figure 14 Portion of government expenditure on kharif crop retained by insurers (Source: PMFBY)

The government pays 80%-85% of the premiums to make crop insurance affordable for farmers. This indicates that PMFBY primarily runs on public funds. The quantum of public expenditure is huge, more than Rs 47,000 crore in 2017-18 and 2018-19 during which only 25%-30% of the crop area was covered. According to the Economic Survey of India 2018, less than 5% of agricultural households had insured their crops. The study focussed on wheat and paddy--two of the most popular crops (Economic Survey of 2018) [10] The reasons that farmers cited for low insurance were: [11]

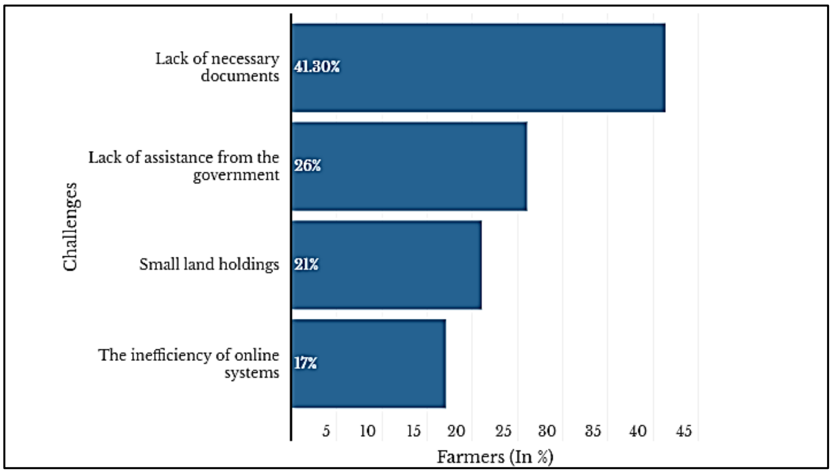


Figure 15 Challenges in availing crop insurance

[10] https://scroll.in/article/910611/heres-how-modis-crop-insurance-scheme-profits-private-insurers-far-more-than-it-does-farmers
[11] http://www.basixindia.com/index.php?option=com_content&task=view&id=228&Itemid=231

4.3 Success stories of sustainable agriculture and challenges

The inspiring stories and successful farming practices compiled by the government of India can be accessed by clicking the link:

https://www.manage.gov.in/publications/Success%20Stories%20-%20Farmers%20.pdf

4.4 Recommendations on policies for sustainable agriculture

Some of the recommendations as discussed in the OECD report on Review of agriculture policy in India are stated below. For the complete report, please refer to http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=TAD/CA(2018)4/FINAL&docLanguage=En

4.4.1 Scaling back of Fertiliser subsidies

- Put an end to the system whereby the subsidy rate varies with international prices by setting a fixed, nominal subsidy rate and gradually phase out over a period to be decided and communicated in advance.
- Devote the savings generated to educating farmers in efficient and sustainable use of fertilisers and other chemical inputs, to accelerate development of the soil card system and to research and development efforts to promote responsible and sustainable fertiliser use adapted to specific conditions and crops.
- Broaden the pilot programme to replace fertiliser subsidies with a direct benefit transfer (DBT) allowing farmers to make their own decisions about the best use of the available funds, and continue to adjust the scheme in light of experience in implementation.

4.4.2 Smart crop-energy- water management

- Generalise the introduction of restrictions on hours during which free electricity for pumping water is provided, particularly in areas where withdrawals are already in excess of recharge capacity.
- Improve the reliability of electricity supply to ensure that electricity is delivered during the allotted periods, and to separate the feeders for irrigation water supply.
- Launch a massive campaign of awareness raising and education among farmers to alert them to the risks associated with a “business as usual” scenario. In the longer term, more

careful use of water while preserving the current production structure and practices will not be sufficient.

- Electricity pricing will also need to be reviewed to correct the perverse incentive currently created by the power subsidies.
- Accelerate research in crop varieties (and breeds of livestock) needing less water, more drought resistant and adapted to the climatic and agrological conditions in the areas under stress.
- Enlist all concerned actors, public and private, upstream, and downstream in developing collective-action groundwater and watershed management schemes encompassing infrastructure development, new technologies and new institutions.
- Put in place overall water management schemes that cap agriculture water use according to available water resource, and, where appropriate,4 invest in efficient irrigation technologies such as drip irrigation and precision agriculture, including in rain-fed areas where water is plentiful and irrigation, to date, little used.
- In areas facing the most important water risks, consider stronger measures such as limiting extraction or introducing water charges which reflect the opportunity cost of the resource before investments in water use efficiency.

4.4.3 Prioritising and reinforcing research and development

Research efforts in India, was at about 0.4% of agricultural GDP during 2012-14 and remains relatively low compared to Brazil (1.8%) and high-income countries (at around 3.0%), although it was close to China (0.6%). The government, cognisant of the importance of research for the future of the sector, has committed to increasing the agriculture research budget.

4.4.4 Strengthening extension services and education

The extension service is widely credited as having been a key factor in the spread of the green revolution in India, but public commitment to the system and its effectiveness have been erratic over the intervening period. Public funding was increased strongly in recent years and extension intensity, as measured by spending as a percentage of agricultural GDP, rose quite sharply from 0.14% at the beginning of the century to 0.18% during 2011-13. If the living standards of India's large smallholder population are to be improved, extension services will need to go beyond the traditional areas of technology transfer to encompass business skills, facilitate the diversification needed to overcome resource scarcities and provide farmers with the skills to operate in and deliver the products demanded by the development of agro-food value chains.

4.4.5 Harnessing the potential of the digital economy

Modern technologies such as ICT have enormous potential to overcome deficiencies in personnel and infrastructure for the delivery of new knowledge and skills to farmers. Investment in the infrastructure is needed for a well-functioning digital economy both for agricultural and for rural development. More specifically, the full potential of ICT, big data, and precision agriculture will need to be harnessed to the task of generating sustainable productivity growth, including resolving the water crisis, agriculture water pollution and coping with climate change.

Glossary

Advection: a method of nutrient transport through water flows.

Aerobic: characterized by the presence of oxygen; pertains to organisms (such as some bacteria) that require oxygen to maintain life processes (such as composting or biological treatment processes). Carbon dioxide is a product of aerobic processes.

Agribusiness: Agriculture operated by business and involving all activities in the business of agricultural production.

Agriculture: The occupation of farming animals, plants and fungi needed for human life.

Allelopathy: the suppression of growth of one species of plant or microorganism by another due to the release of toxic substances by the organism.

alluvial deposits: materials such as clay, silt, sand, gravel, and mud that have been eroded, transported, and deposited by running water: alluvion; alluvium.

an approximately horizontal layer of soil differing from adjacent layers in physical, chemical, or biological properties such as color, structure, texture, consistence, kinds and numbers of organisms present, or degree of acidity or alkalinity.

Anaerobic : characterized by the absence of oxygen; pertains to organisms (such as some bacteria) that do not require oxygen to maintain life processes (such as digestion of sewage sludge or manure and decomposition).

Biofuel: Fuel that is made from the energy source of living things or the waste that they produce. e.g. vegetable oil, algae and sugar cane.

Conventional farming: A method of farming practiced by industrial farmers which requires external high energy inputs in order to achieve high yields. Conventional farming often involves the use of fertilizers, pesticides and machinery.

Developing country: A lowly-industrialised country usually with a poor performing economy that is usually primarily based on agriculture. The average income for an individual is often less than $2 a day.

Ecological: Practices that care for and/or work in harmony with the environment.

Erosion (soil): The weathering of the earth, often by wind, water or farming practices which often results in the loss of topsoil.

Erosion: the loosening, transportation, and wearing away of the land surface by running water, wind, ice, or other geological agents; the single most important process of soil degradation resulting in loss of soil productivity and increased water pollution from sediment and agricultural chemicals.

Eutrophication: the process by which a body of water becomes rich in nutrients, characterized by high concentrations of phosphorus (P) and nitrogen (N), frequently shallow depths, and seasonal oxygen deficiency in the deeper areas; occurs naturally and by human activity, usually in the form of industrial or municipal wastewater or agricultural runoff. Eutrophication causes algal blooms, fish kills, and other water quality problems.

Evapotranspiration: the loss of pure water from the soil as a result of both soil surface evaporation (the process by which liquid is changed to a vapor or gas) and plant transpiration (the photosynthetic and physiological process by which plants release water vapor into the air).

Extreme weather: Severe weather events that are unusual or unseasonal.

Factory farming: A method of intensive farming where animals are raised in confinement, often indoors, in order to maximize their growth rate for maximum profit. Also known as industrial animal farming.

Farmer's market: A place where consumers can buy produce direct from farmers.

Fertility (soil): the quality of a soil that enables it to provide nutrients in adequate amounts and proper balance for plant growth when other growth factors such as light, moisture, and temperature are favorable. Two main methods for ensuring fertility are biological nutrient cycling and the addition of chemical fertilizers.

Food security: A situation where the continual supply of food to feed a population is stable.

Food shortage: The lack of sufficient food to meet demand.

Food sovereignty: The right of people to control and define their own food systems and policies, without influence from corporations and governments.

GMO: Genetically Modified Organism. An organism whose DNA has been genetically engineered for select characteristics deemed favorable.

greenhouse effect: warming of the earth's surface partly caused by concentration of gases such as water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), and chlorofluorocarbons (CFCs) in the earth's atmosphere. The concentration of gases acts as a cover—absorbing longer, infrared waves and trapping heat in the atmosphere. Soil management can have a significant impact on greenhouse gas concentrations inasmuch as soils can be sources or sinks of greenhouse gases.

gully erosion: severe erosion of the soil by running water that creates deep channels: gully; gullies.

Independent farmer: A farmer who owns and operates their farm with minimal influence from organizations.

organic carbon: the total amount of carbon held in the organic matter in the soil; chemical compounds based on carbon chains or rings that also contain hydrogen with or without oxygen, nitrogen, or other elements. Cultivation causes marked reductions in total organic carbon content in the soil; but it can be replaced by crop residues, manures, or other sources of organic matter added to soils.

Organic: A certification given to produce grown without the use of synthetic fertilizers or chemicals, are not GMO and in the case of meat - the animals are not given antibiotics or growth hormones.

Pasture-raised: To raise animals outside in their natural environment (but with access to shelter) where they are able to forage and behave according to their natural instincts.

Ph: a measurement scale indicating acidity and alkalinity in which values less than 7 are acidic, the value of 7 is neutral, and values from 7 to 14 are basic (alkaline). pH of a soil environment affects productivity by influencing solutbilities of heavy metals and minerals, mobilities of anionic trace elements, and activities of microorganisms.

Photolysis: chemical decomposition or dissociation by the action of radiant energy (i.e., light); a method of chemical degradation of

rill erosion: erosion of soil by running water carving out visible channels that are small enough to be filled in by tillage.

Runoff: rainfall excess that is not absorbed by the soil.

Salinity: the concentration of dissolved salt in water traditionally referring to major anions and cations (Na, Ca, Mg, K, Cl, SO_4, HCO_3, CO_3, NO_3) found in irrigation water, but now also including toxic trace elements. Salinity in soils has deleterious effects on physical soil condition and is frequently accompanied by waterlogging, which results in poor aeration of the root zone. Salinity reduces crop yields, affects germination, seedling and vegetative growth, and has adverse effects on water quality. Salinity is measured using electroconductivity (µS/cm) or total dissolved solids (mg/L).

Salinization: the process by which salts accumulate in soil. Chemical weathering of minerals in soils and rocks—dissolution, hydrolysis, carbonation, acidification, and oxidation-reduction—is the primary cause of dissolved mineral load (salinity). Secondary causes of salinity include evaporation, release and dissolution of fossil salts, atmospheric deposition, seawater intrusion, human-induced irrigation, and salt seeps.

sheet erosion: erosion of the soil by running water that removes soil in thin uniform sheets.

Sodicity: of, relating to, or containing sodium (Na). Soils are classified as sodic when Na is the prevalent cation in saline soils. Sodic soils may limit plant growth by having toxic concentrations of exchangeable Na that keep soil dispersed and maintain poor soil structure.

soil horizon

Solum: the upper horizons of the soil profile in which the natural processes of soil formation take place; true soil. The solum is where most plant roots grow.

Abbreviations

As-Arsenic

BCM-Billion Cubic Meter

BIS-Bureau of Indian Standard

BOD-Biological Oxygen Demand

Ca-Calcium

CA-Catchment Area

CaCO3-Calcium Carbonate

CAD-Command Area Development

CAT-Catchment Area Treatment

CBIP-Central Board of Irrigation & Power

CCA-Culturable Command Area

cc-Cement Concrete

Cd-Cadmium

CD-Cross Drainage

Cfm-Cubic feet metre

CGWB-Central Ground Water Board

Cl-Chloride

cm-Centimetre

Co-Cobalt

COD -hemical Oxygen Demand

Cr-Chromium

CSMRS-Central Soil and Material Research Station

Cu-Copper

CWC-Central Water Commission

d/s-Downstream

DO-Dissolved Oxygen

ER- Effective rainfall

IMD-Indian Meteorological Department

IMO-Irrigation Management Organisation

IRR-Internal Rate of Return

km/hr.-Kilometre per hour

K-Potassium

Mg/l-Milligram per litre

Mg-Magnesium

NA-Not Applicable

Na-Sodium

NH-National Highway

NO3-Nitrate

NOF-Non Overflow

R-Irrigation requirement

SO2-Sulphur dioxide

SO4-Sulphate

SOI-Survey of India

SOR-Schedule of Rates

WBM-Water Bound Macadam

WKMC-Western Kosi Main Canal

WR- Water requirement

WRD-Water Resources Department

WR-Water Resources

Zn-Zinc

Agricultural organisations based in India

Agricultural Promotion and Investment Corporation of Odisha Limited

All India Kisan Sabha

All India Kisan Sangharsh Coordination Committee

All India United Kisan Sabha

Bharatiya Kisan Sangh

Bharatiya Kisan Union

Central Institute of Agricultural Engineering, Bhopal

Central Sheep and Wool Research Institute

Coconut Development Board

Coffee Board of India

Commission for Agricultural Costs and Prices

Cotton Corporation of India

Deccan Development Society

Haryana Seeds Development Corporation

Kerala Farmers Federation

Koyambedu Wholesale Market ComplexM

Manas Rural Development InstituteN

National Bank for Agriculture and Rural Development

National Commission on Agriculture

National Commission on Farmers

National Dairy Development Board

National Egg Coordination Committee

National Horticulture Mission

National Institute of Agricultural Extension Management

Navdanya

North Eastern Tea AssociationS

Sheep Research Center (Mannavanur)

Swabhimani Shetkari SaghtanaT

Tamil Nadu State Agricultural Marketing Board

Uzhavar Santhai

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