South Asia Environmental Capacity Building: Agriculture and Water Pollution

December 2020

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Module 1: Land soil water continuum

1.1 Understanding the concept of land

According to FAO (1981), land comprises the physical environment, including climate, relief, soils, hydrology and vegetation, to the extent that these influence potential for land use. The past and present activities of human activities can also be included in the definition of land, for example these can be land reclaimed from the sea, vegetation clearance, and also adverse results, e.g. soil salinization. Purely economic and social characteristics, however, are not included in the concept of land as these form part of the economic and social context (**Figure 1**).

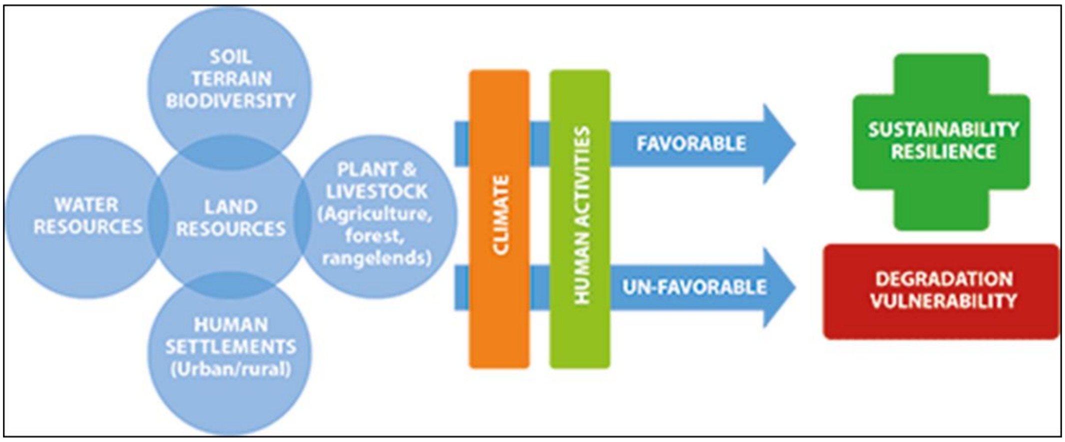

Figure 1 Concept of land resources(Source: CLIMATE-SMART AGRICULTURE Sourcebook, Module B.7 Sustainable Soil/Land Management for Climate-Smart Agriculture, FAO)

A land mapping unit is a mapped area of land with specified characteristics. Land mapping units are defined and mapped by natural resource surveys, e.g. soil survey, forest inventory. Their degree of homogeneity or of internal variation varies with the scale and intensity of the study. In some cases, a single land mapping unit may include two or more distinct types of land, with different suitability, e.g. a river flood plain, mapped as a single unit but known to contain both well-drained alluvial areas and swampy depressions.

Land is thus a wider concept than soil or terrain. Variation in soils, or soils and landforms, is often the main cause of differences between land mapping units within a local area: it is for this reason that soil surveys are sometimes the main basis for definition of land mapping units. However, the fitness of soils for land use cannot be assessed in isolation from other aspects of the environment, and hence it is land which is employed as the basis for suitability evaluation.

1.2 Eco sensitive zones

1.2.1 What are Eco-Sensitive Zones (ESZs)?

Eco-Sensitive Zones or Ecologically Fragile Areas (**Figure 2**, **Figure 3**, **Figure 4**) are areas within 10 kms around Protected Areas, National Parks and Wildlife Sanctuaries (Drishtiias, 2018). These are spread across coastal areas, western ghats, eastern ghats, Himalayan region and north east parts of India. ESZs are notified by the Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India under Environment Protection Act 1986.

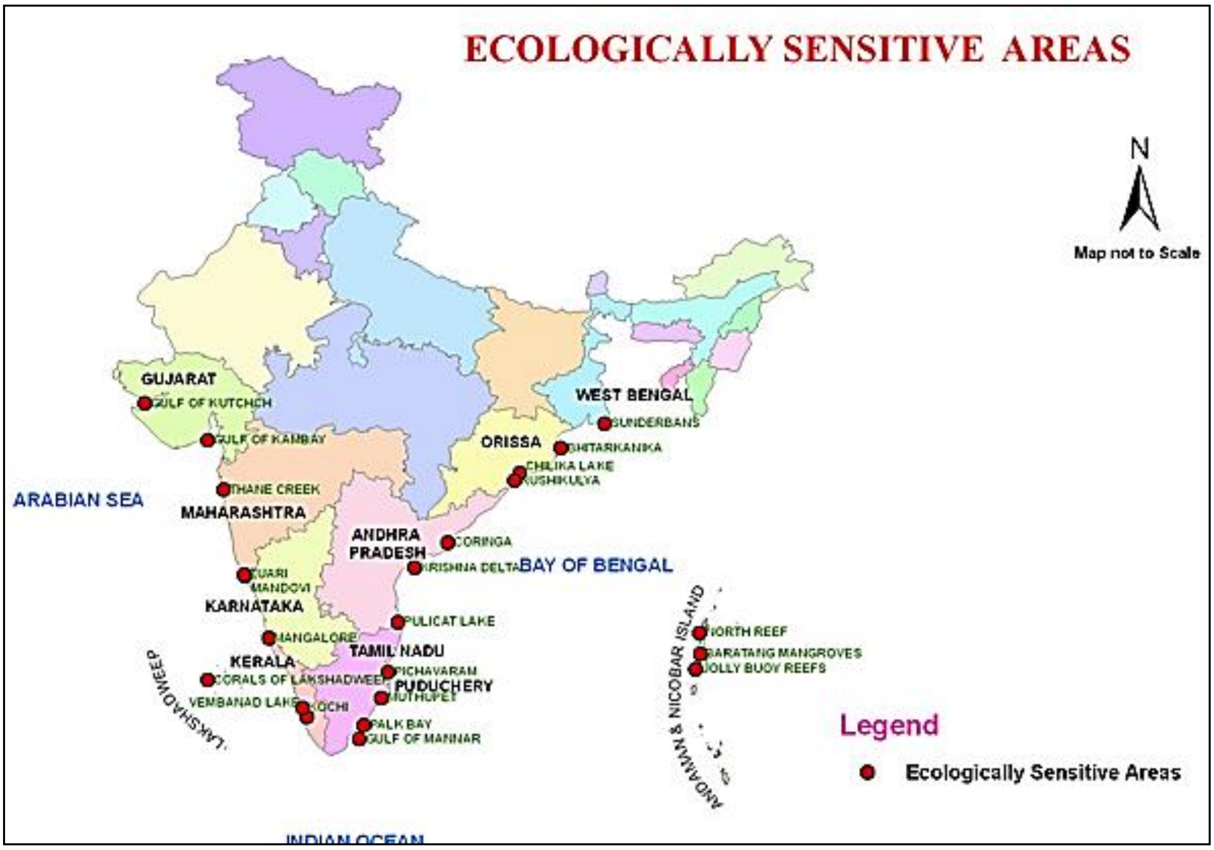

Figure 2 Coastal eco-sensitive areas in India (Source: Institute for Ocean Management, Anna University Chennai)

In case of areas with are considered to be sensitive corridors, connectivity and ecologically important patches, crucial for landscape linkage, even area beyond the 10 km width can also be included in the eco-sensitive zone.

The basic aim in setting up Eco-Sensitive Zones is to minimize the negative impacts of certain activities by creating a “shock absorber” for the fragile ecosystem encompassing the protected areas like National Parks and Wildlife Sanctuaries. It acts as a transition zone for areas which has less protection to areas which has high protection. The activities in ESZs are in regulatory in nature rather than prohibitive in nature as described by the National Board for Wildlife (MoEFCC, 2007). India’s forest cover as in 2011 is shown in **Figure 5**.

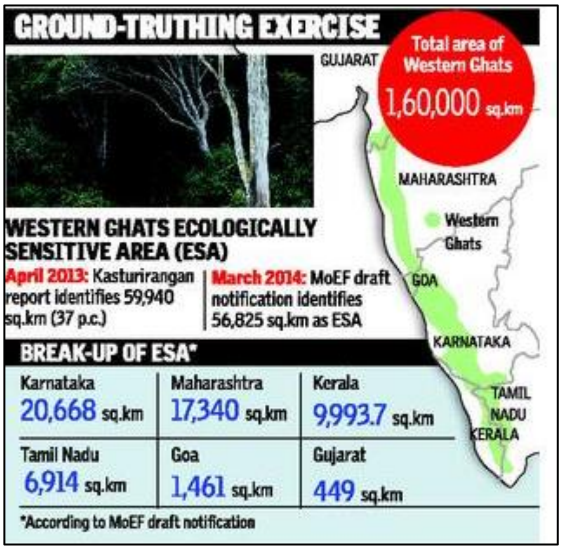

Figure 3 Western Ghats and ESA by each state (Source: The Hindu, 7 Aug 2014)

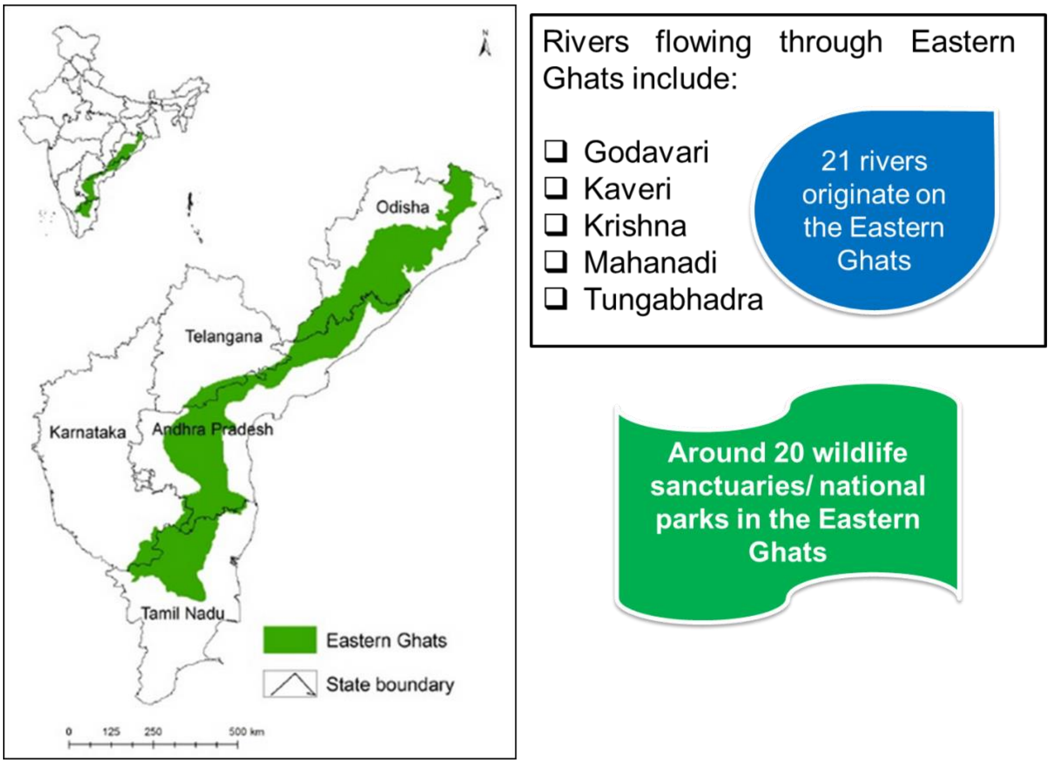

Figure 4 Eastern Ghats are ecologically sensitive areas

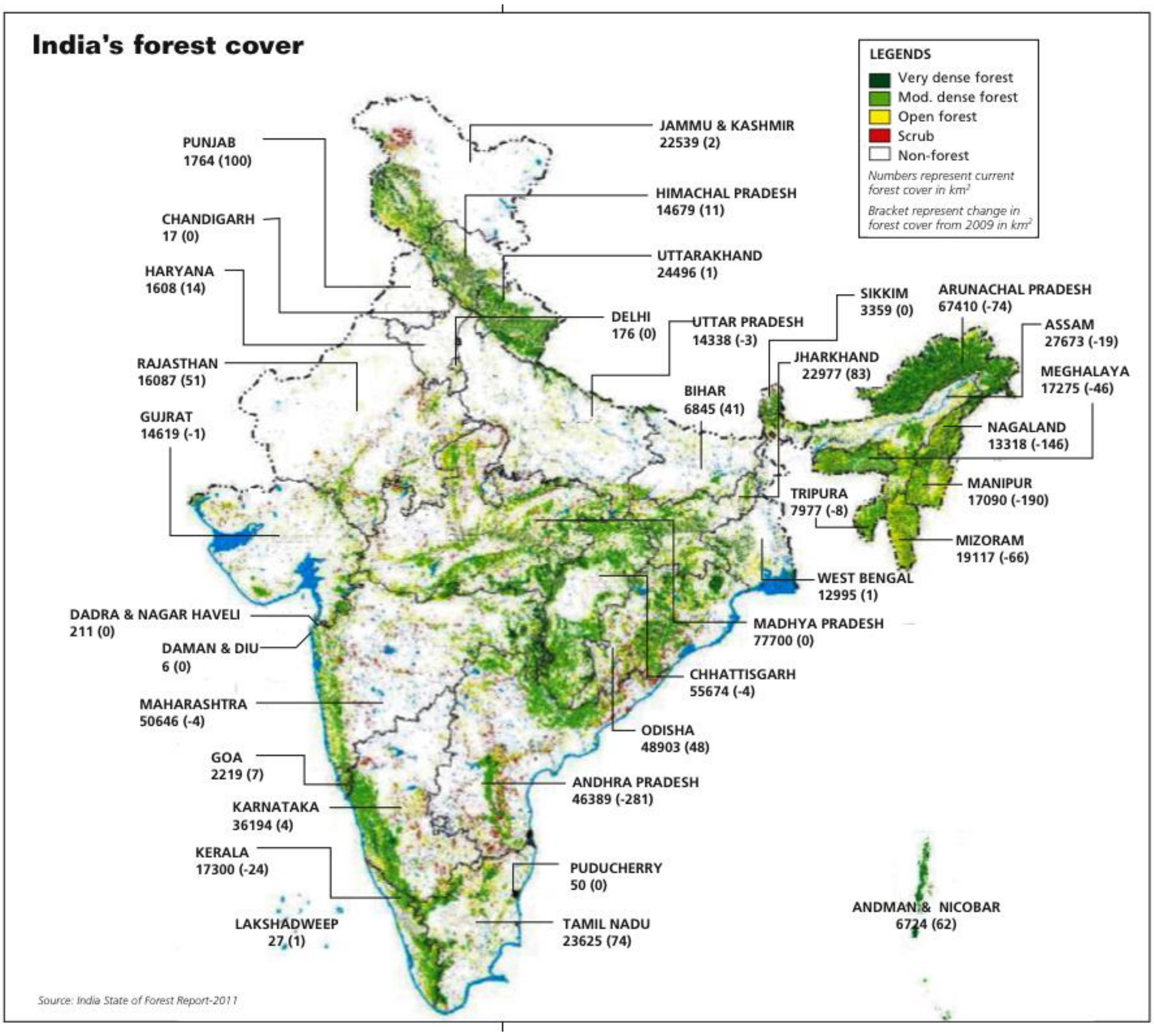

Figure 5 India's forest cover as in 2011 (Source: India State of Forest Report-2011)

1.2.2 Extent of Eco-Sensitive Zones

(Source: MoEFCC, 2007)

The zones around many protected areas has already seen a lot of development in close vicinity to their borders while some protected areas already lies in urban developed areas for example Sanjay Ghandi National Park in Maharashtra and Guindy National Park in Tamil Nadu are located in urban areas. Therefore determining the extent of the ESZs around Protected areas will have to be kept flexible and case specific. The width of the ESZs and the type of regulations will be area specific and will differ from one protected area to another (**Figure 6**). In general the width of an ESZ is kept up to 10 Km from a protected area as provided by the Wildlife Protection Strategy 2002.

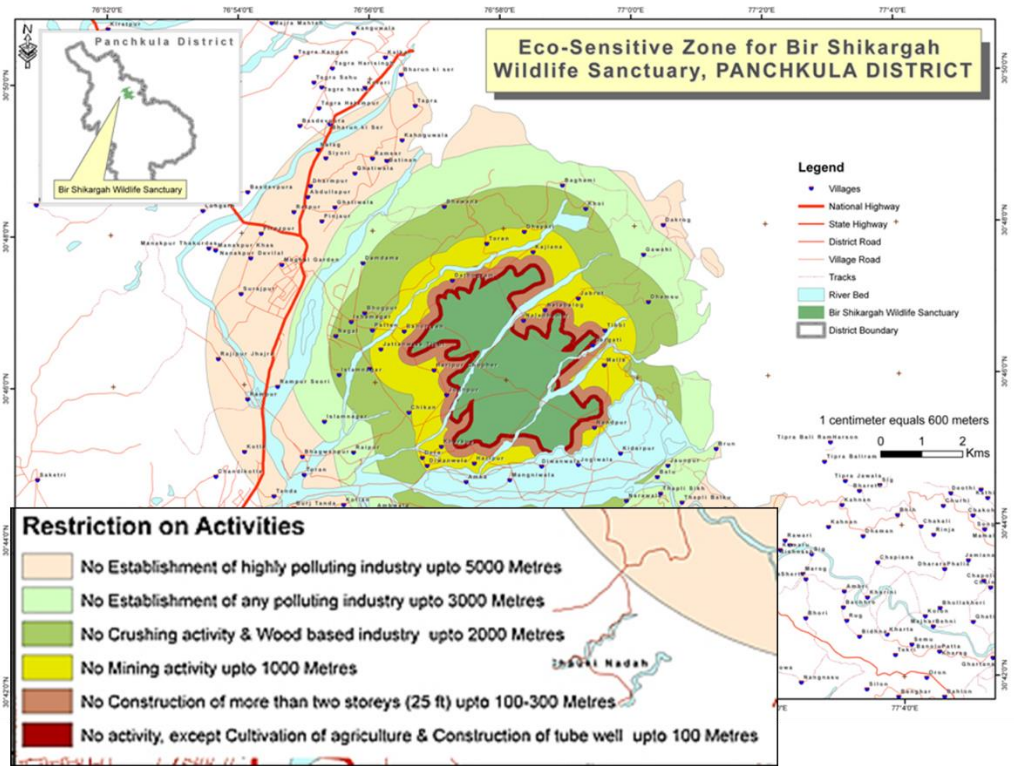

Figure 6 Eco-sensitive zone for Bir Shikargah Wildlife Sanctuary, Panchkula District, Haryana (Source: http://haryanaforest.gov.in/en-us/Wild-Life/Protected-Area)

1.2.3 Activities Allowed in ESZs

Some of the activities allowed in ESZs are given below (MoEFCC, 2007)-

a) *Prohibited activities*: In the Eco-Sensitive zones, activities like industries which causes pollution, Commercial mining, saw mills, establishment of major hydroelectric projects (HEP), commercial use of wood, discharge of effluents or any solid waste or production of hazardous substances are all prohibited.

b) *Regulated activities*: : In the Eco-Sensitive zones, activities like felling of trees, establishment of hotels and resorts, commercial use of natural water, erection of electrical cables, drastic change of agriculture system, e.g. adoption of heavy technology, pesticides etc., widening of roads.

c) *Permitted activities*: : In the Eco-Sensitive zones, activities like ongoing agricultural or horticultural practices, rainwater harvesting, organic farming, use of renewable energy sources, adoption of green technology for all activities are permitted.

1.2.4 Significance of ESZs

a) To minimize the impact of urbanization and other developmental activities, the areas adjacent to protected areas have been declared as Eco-Sensitive Zones.

b) The purpose of declaring eco-sensitive zones around protected areas is for creating some kind of a 'Shock Absorber' for the protected area. (MoEFCC, 2017)

c) They also act as a transition zone from areas of high protection to areas involving lesser protection.

d) ESZs help in in-situ conservation, which deals with conservation of an endangered species in its natural habitat, for example the conservation of the One-horned Rhino of Kaziranga National Park, Assam.

e) Eco-Sensitive Zones minimize forest depletion and man-animal conflict. The protected areas are based on the core and buffer model of management, through which local area communities are also protected and benefitted.

1.2.5 Challenges and Threats to Eco-Sensitive Zones

a) Developmental activities

Activities such as construction of dams, roads, urban and rural infrastructures in the ESZ, create interference, negatively impact upon the environment and imbalance the ecological system. For example, construction of road would lead to cutting down of trees which would further impact upon, soil erosion thereby destroy the habitats of the species preserved under the ESZ.

b) Governance and new laws

Failing to recognize the rights of forest communities and curbing poaching of animal, legislations like Environmental Protection Act 1986, and Wildlife Protection Act 1972, undermine the ESZs in favour of developmental activities. For example - the new draft notification for reducing the ESZs of Bannerghatta National Park.

c) Tourism

As the pressure of tourism is rising, the government is developing new sites and gateways to the ESZ. To cater to the increasing demand for eco-tourism, land around parks and sanctuaries is being cleared through deforestation, displacement of local people etc. The tourists leave behind garbage such as plastic bags and bottles etc. which lead to environmental degradation.

d) Introduction of exotic species

Exotic species like Eucalyptus and Acacia auricularis etc. and their plantations create a competing demand on naturally occurring forests.

e) Climate change

Biodiversity and climate change are interconnected, for example, the rise in global temperature has generated land, water and ecological stress on the ESZs.

For example, forest fires or the Assam floods which badly affected the Kaziranga National Park and its wildlife.

f) Local communities

Slash and burn techniques used in agriculture, pressure of increasing population and the rising demand for firewood and forest produce, etc. exerts pressure on the protected areas.

1.3 Interaction of vegetation, soil and water

Source: Zeng, Zeng, Shen, Dickingson, & Zeng, 2005 - Vegetation-soil-water interaction within a dynamical ecosystem model of grassland in semiarid areas.

Land ecosystems are primarily determined by climatic conditions (sunlight, temperature, precipitation, CO_2 concentration, etc.) and soil properties (soil type, nutrient distribution). On the other hand, vegetation interacts with the environment (soil and surrounding atmosphere) through the exchange of energy, momentum and materials such as water vapour and various gases, and thus influences climatic variables such as temperature and precipitation. The study of these mutual interactions is an important issue for both regional and global climate changes.

According to Wang, Chu, Liu, Cheng, & Whittecar (2017), vegetation, soil and water interactions are key to the earth's natural systems. These interactions affect and can be affected by the activities of humans and climate change. If proper land management practices are not followed, it can result in land and soil degradation which in turn will result in altering the hydrological processes in that area. This may lead to consequences like severe flooding, drought, soil erosion through wind and water, which can in turn lead to further vegetation loss. These interactions will become more important and interwoven with the changing climate due to human activities. Our understanding is very limited, with few algorithms and parameterization schemes that can be used to account for these dynamic interactions. Existing hydrologic models (e.g., Soil and Water Assessment Tool or SWAT) and land–atmosphere models (e.g., Community Land Model or CLM) do not represent such important dynamic interactions well.

Patterns of biosphere–geosphere interaction (**Figure 7**) usually vary gradually within a homogeneous distributed ecosystem, but can undergo dramatic change over regions where multiple ecosystems (e.g. desert, grassland and forest) coexist.

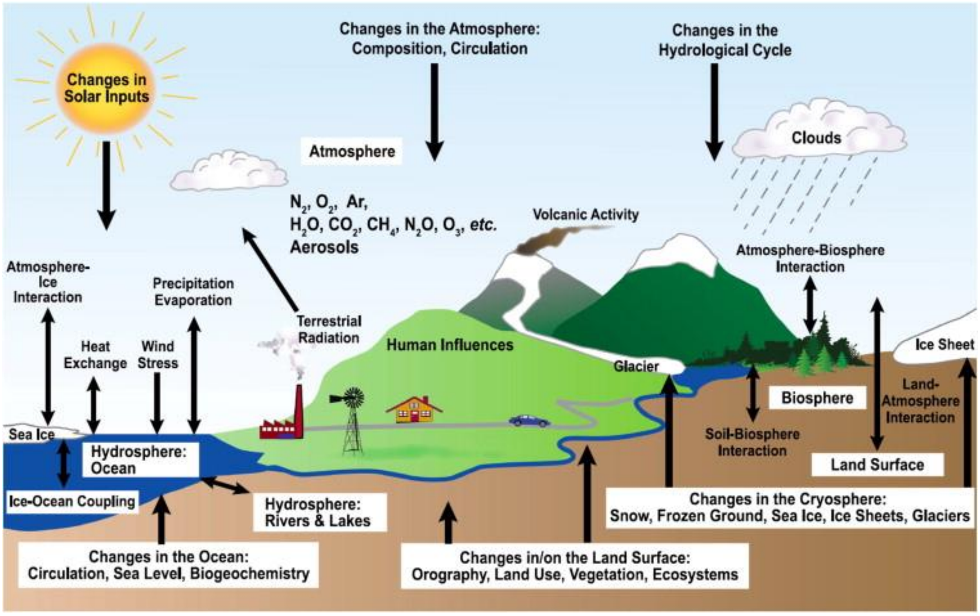

Figure 7 soil moisture–climate interactions (Source: Seneviratne et al., 2010)

The triggering of the transition between different ecosystems as well as the features of the corresponding biosphere–geosphere interactions have been studied at various spatial and temporal scales(Wang et al., 2017). For example, analytically tractable simple models use the concept of equilibrium to represent a stable ecosystem, and show that the transition between different equilibrium states can occur with changing climatic conditions such as carbon cycle, temperature and precipitation. Conceptual and intermediate-level models have demonstrated grassland–desert transitions in the Sahel/Sahara region and a possible forest–savanna transition over Amazonia. Dynamical global vegetation models (DGVM) also predicted the collapse of the Amazon forest in response to changing climate driven by an assumed doubling of CO_2 concentration in the next 50 years. These models demonstrated that under certain conditions, subtle variations of climate could be strongly amplified by atmosphere–vegetation feedback and trigger an abrupt switch of ecosystem from one state to another(Wang et al., 2017).

1.4 Changing land use since industrial revolution

As per the Industrial Revolution and Land Transformation by Grigg (1987), Agriculture must provide food supplies if population growth is to be sustained; conversely population growth requires changes in the way agriculture is carried on, prompting the expansion of the area under cultivation and the more intensive use of land already in cultivation. Both cause land transformation.

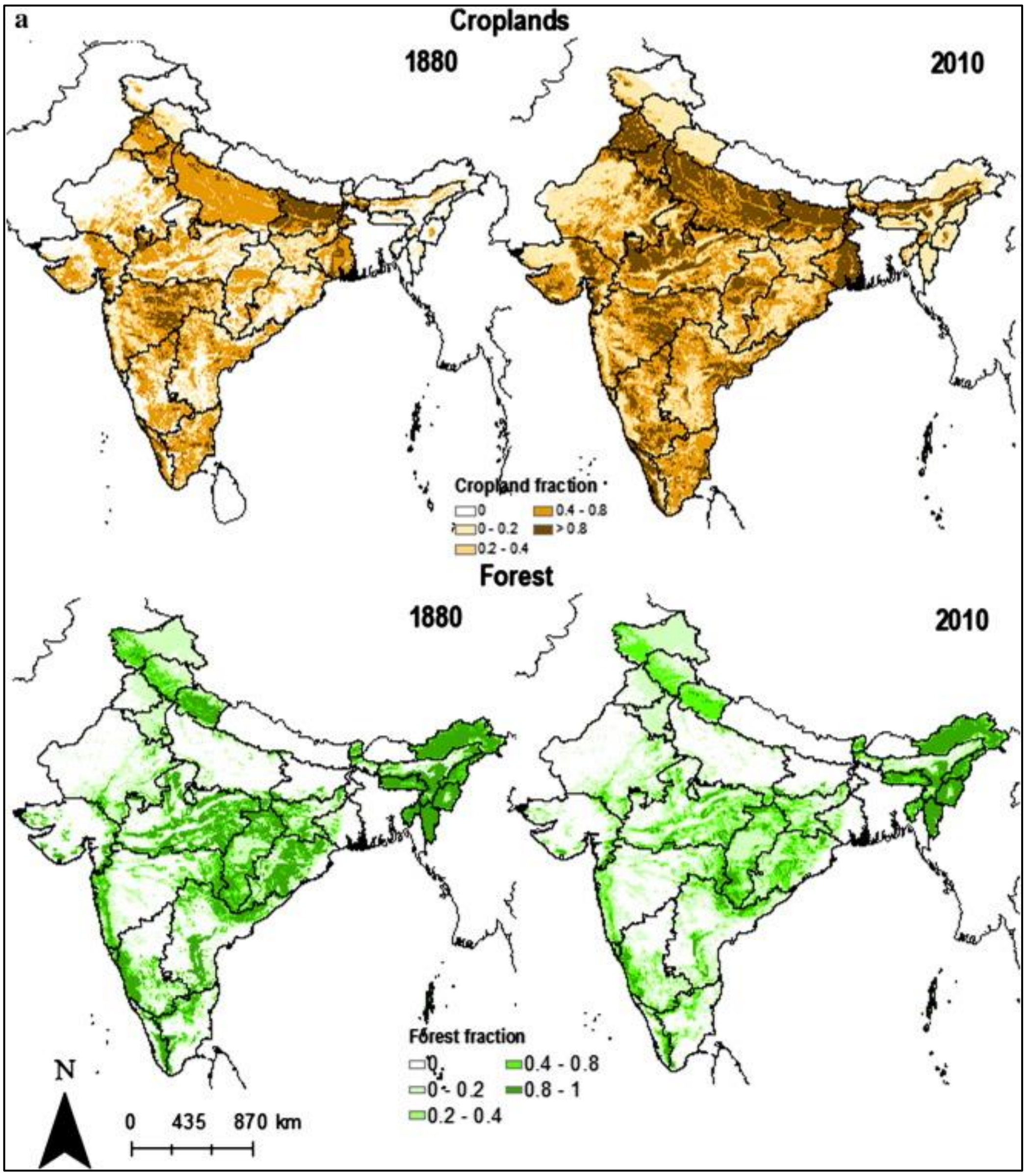

Figure 8 Land use change in India (Source: Tian et al., 2014)

The major pattern of land cover change over the last three centuries has been deforestation and agricultural expansion (**Figure 9**). However, changes in land use practices such as agricultural land management, fire suppression, and urbanization have also been significant drivers of global change.

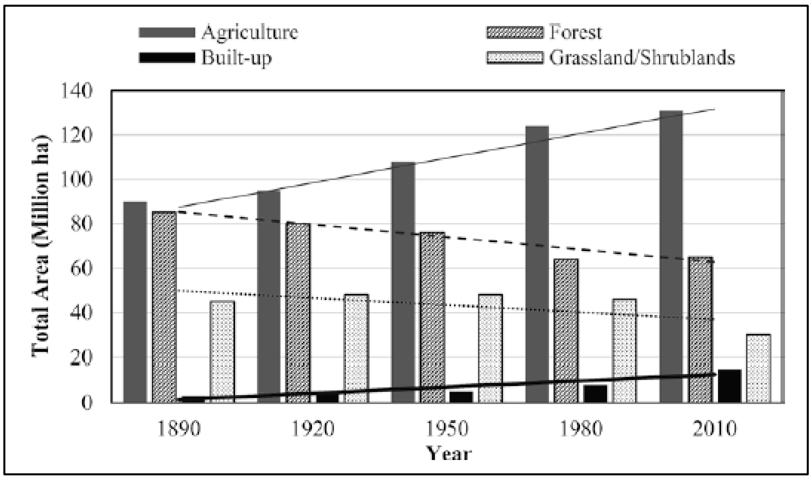

Figure 9 LULC changes in India between 1880-2010 (Source: Tian et al., 2014)

Module 2 Pathways of contamination

Water on earth is not available as pure H_2O, it being a versatile solvent has dissolved salts and gases. When the dissolve substances in water exceed the acceptable level for intended use then it is called contamination and the substance is called pollutant. For instance, much of daily basic requirements of iron and fluoride is met from water we drink, since they are generally present in water. However, excess of these beyond certain concentration makes the same essential elements as pollutants of water. Broadly, water quality is discussed in three contexts:

i. Water quality for consumption: Water for intended use such as public water supplies, agriculture, and industrial.
ii. Pollution point of view: Water after consumption discharges as wastewater
iii. Ambient water quality: Water in ambient conditions as rivers, lakes, groundwater and ocean

2.1 Point and non-point sources of pollution

2.1.1 Point sources

Point source water pollution refers to contaminants that enter in a waterway from a single, identifiable source, such as a pipe or ditch (Moss, 2008). The United States Environmental Protection Agency (US EPA) defines point source pollution as any pollution that enters the environment from an easily identified and confined area.

Examples of point sources include:

- Discharge from wastewater treatment plants;
- Industrial waste from industry;
- Mixed sewage runoff;
- Urban wastewater drains

2.1.2 Non-point sources

These are contamination that doesn't originate from a single source instead it is the cumulative effect of all small amounts of contaminants in an area (Moss, 2008).

Examples of non-polluting sources include the following:

- Residues from construction, forestry and agricultural fields;
- Bacteria and microorganisms from leaching from septic systems and animal waste;
- Chemicals (from manure and farm waste) and pesticides from agricultural areas, golf courses, stadiums and residential grounds;
- Oil, grease, antifreeze, and metals that's are washed off in roads, parking lots, and sidewalks;
- Toxic chemicals with improper disposal;
- Garbage dumped on roads, sidewalks and beaches, or directly in the water by people.

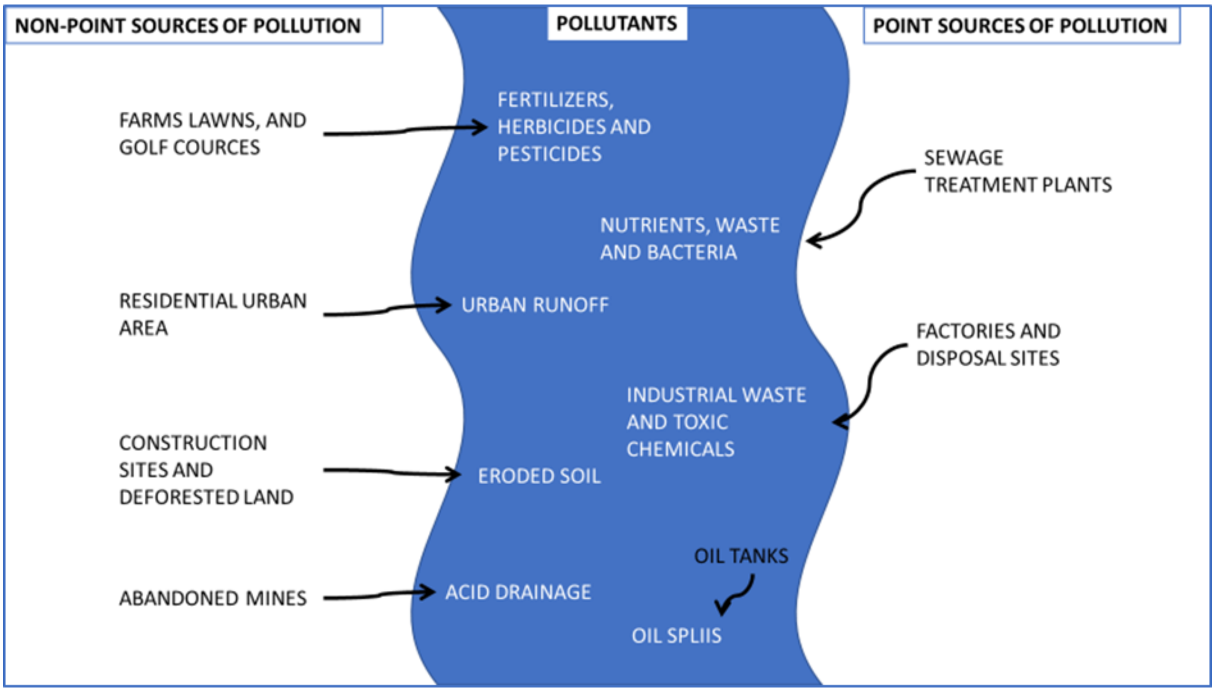

Figure 10 Sources of Water Pollution (Adapted from Yousuf & Singh, 2019)

2.2 Water quality standards for consumption

A. Public water supplies

Table 1 Water quality parameter (Source: IS 10,500:1991)

S.No	Parameter	Unit	Acceptable concentration	Remarks
1	pH	pH	6.5 - 8.5	Low pH - corrosion, metallic taste High pH – bitter/soda taste, deposits. Affects mucous membrane; bitter taste; corrosion; affects aquatic life
2	Total Dissolved	mg/l	2000	Hardness, scaly deposits, sediment, cloudy coloured water, staining, salty or bitter taste,

	Solids (TDS)			corrosion of pipes and fittings. Undesirable taste; gastro intestinal irritations; corrosion or incrustation
3	Hardness	mg/L $CaCO_3$.	600	Dissolved calcium and magnesium from soil and aquifer minerals containing limestone or dolomite. Poor lathering with soap; deterioration of the quality of clothes; scale forming; skin irritation; boiled meat and food become poor in quality
4	Alkalinity	mg/L $CaCO_3$.	600	Low Alkalinity (i.e. high acidity) causes deterioration of plumbing and increases the chance for many heavy metals in water are present in pipes, solder or plumbing fixtures. Boiled rice turns yellowish
5	Calcium	mg/l	200	Poor lathering and deterioration of the quality of clothes; incrustation in pipes; scale formation
6	Iron, Fe	mg/l	1	Brackish colour, rusty sediment, bitter or metallic taste, brown-green stains, iron bacteria, discoloured beverages
7	Manganese, Mn	mg/l	0.3	
8	Chloride	mg/l	1000	Taste affected; corrosive
9	Fluoride	mg/l	1.5	Dental and skeletal fluorosis; non-skeletal
10	Pesticide	ml	0.001	Affects central nervous system

B. Water quality for irrigation use

Table 2 Water quality for irrigation (Source: IS 10,500:1991)

S.no	Parameter	Unit	Acceptable concentration		Consequences
			Long-term use (mg/L)	Short-term use (mg/L)	
1	Aluminum (Al)	mg/L	5	20	Can cause non productivity in acid soils, but soils at pH 5.5 to 8.0 will precipitate the ion and eliminate toxicity.
2	Arsenic (As)	mg/L	0.1	2	Toxicity to plants varies widely, ranging from 12 mg/L for Sudan grass to less than 0.05 mg/L for rice.
3	Beryllium (Be)	mg/L	0.1	0.5	Toxicity to plants varies widely, ranging from 5 mg/L for kale to 0.5 mg/L for bush beans.
4	Boron (B)	mg/L	0.75	2	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.
5	Cadmium (Cd)	mg/L	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.
6	Chromium (Cr)	mg/L	0.1	1	Not generally recognized as essential growth element. Conservative limits recommended due to lack of knowledge on toxicity to plants
7	Cobalt (Co)	mg/L	0.05	5	Toxic to tomato plants at 0.1 mg/L in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
8	Copper (Cu)	mg/L	0.2	5	Toxic to a number of plants at 0.1 to 1.0 mg/L in nutrient solution.
9	Fluoride (F –)	mg/L	1	15	Inactivated by neutral and alkaline soils.
10	Iron (Fe)	mg/L	5	20	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of essential phosphorus and molybdenum
11	Lead (Pb)	mg/L	5	10	Can inhibit plant cell growth at very high concentrations.
12	Lithium (Li)	mg/L	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
13	Manganese (Mg)	mg/L	0.2	10	Toxic to a number of crops at few-tenths to a few mg/L in acid soils.
14	Molybdenum (Mo)	mg/L	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.
15	Nickel (Ni)	mg/L	0.2	2	Toxic to a number of plants at 0.5 to 1.0 mg/L; reduced toxicity at neutral or alkaline pH
16	Selenium (Se)	mg/L	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
17	Vanadium (V)	mg/L	0.1	1	Toxic to many plants at relatively low concentrations.
18	Zinc (Zn)	mg/L	2	10	Toxic to many plants at widely varying concentrations; reduced toxicity at increased pH (6 or above) and in fine-textured or organic soils.

C. Water quality requirement for thermal power plants

Table 3 Water quality discharge standards for thermal plants, source: IS 10,500:1991

S.No	Parameter	Unit	Acceptable concentration			
			Inlet pont	Water discharged to the stream	water reused for cooked vegetable	water reused for field crops
1	pH at 25°C	---	9.8 (0.42)	06-Sep	06-Sep	06-Sep
2	Conductivity at 25°C	S/cm	750 (42)	*	*	*
4	TH	mg/l as CaCO3	260	*	*	*
5	T.ALK	mg/l as CaCO3	40	*	*	*
6	Turbidity	NTU	0.7 (0.04)	**	*	*
7	PO4	mg/l	2 (0.01)	15	10	*
8	NH3	mg/l	1 (0.04)	*	*	*
9	SiO2	mg/l	18	*	*	*
10	TDS	mg/l	470 (33)	1500	1500	1500
11	Cl-	mg/l	50	350	400	400
12	R-CL2	mg/l		*	*	*
13	T-Fe	mg/l	0.6 (0.04)	5	5	5
14	NH4	mg/l	20	*	*	*

2.3 Wastewater quality parameters

Wastewater quality parameters and the standards for discharge in various recipient environments are given in **Table 4.**

Table 4 Wastewater quality parameters and discharge standards by CPCB

S.No.	Parameter	Unit	Standard limit for disposal into			Remarks
			Surface water	Land	Sewers	
1	pH	--	5.5 to 9.0	5.5 to 9.0	5.5 to 9.0	If the pH of water is too high or too low, it can lead to death of organism. pH can also affect the solubility and toxicity of chemicals and heavy metals in the water

2	Temperature	^oC	Shall not exceed 5^oCabove the receiving water temperature.	--	--	influence on water chemistry
3	Oil and grease, max	mg / l	10	10	20	It causes ecology damages for aquatic organisms and form a layer on water surface that decreases dissolved oxygen.
4	Total residual chlorine	mg / l	1			increases a person's risk for chlorine exposure
5	Ammonicalnitrogen (as N)50	mg / l			50	When present in water at high enough levels, it is difficult for aquatic organisms to sufficiently excrete the toxicant, leading to toxic build-up in internal tissues and blood, and potentially death
6	Total nitrogen (as N)	mg / l	100			Excess nitrogen can cause overstimulation of growth of aquatic plants and algae.
8	Biochemicaloxygen demand (3 days at 27oC),	mg / l	20	100	250	high BOD may indicate faecal contamination or increases in particulate and dissolved organic carbon from non-human and animal sources that can restrict water use and development, necessitate expensive treatment and impair ecosystem health
9	Chemical oxygendemand	mg / l	250			COD indicates presence of all forms of organic matter, both biodegradable and nonbiodegradable and hence the degree of pollution in waters
10	Aresnic (As)	mg / l	0.2	0.2	0.2	Health impact of excess arcenic include Gastrointestinal, skin, and nerve damage, cancer
11	Mercury (As H)	mg / l	0.01		0.01	mercury readily crosses biological membranes and can accumulate to

						harmful concentrations in the exposed organism and become increasingly concentrated up the food chain
12	Lead (as Pb)	mg / l	0.01		0.01	Acute effects of lead are inattention, hallucinations; delusions, poor memory, and irritability are symptoms of acute intoxication.
13	Cadmium (as Cd)	mg / l	0.02		0.01	Health impact of cadmium include Gastrointestinal, kidney and lung damage
14	Total chromium(as Cr)	mg / l	2		2	bound to floating particles in water and create health problems
15	Copper (as Cu)	mg / l	3		3	Increase of total body level of copper cause genetic disorders
16	Zinc (as Zn	mg / l	5		15	zinc can lead to stomach cramps, nausea and vomiting.
17	Fluoride (as F)	mg / l	2		15	Acute high-level exposure to fluoride causes immediate effects of abdominal pain
18	Manganese (as Mn)	mg / l	2	2	2	Cause problems with memory, attention, and motor skills
19	Iron (as Fe)	mg / l	3	3	3	It can clog pipes and screens, and can leave brownish stains on laundry, reddish-brown particles on fixtures, and can cause an unpleasant taste
20	Nitrate Nitrogen	mg / l	10			it oxidizes the iron in the haemoglobin of the red blood cells to form methaemoglobin

2.4 Ambient water quality standards

The Central Pollution Control Board (CPCB) of India has identified water quality requirements in terms of a few chemical characteristics, known as primary water quality criteria. Further, Bureau of Indian Standards has also recommended water quality parameters for different uses in the Standard IS 2296:1992.

Table 5 Water Quality Standards in India for different use (Source IS 2296:19920)

Characteristics	Designated best use				
	A (Drinking Water Source without conventional treatment but after disinfection)	**B (Outdoor bathing (Organised))**	**C (Drinking water source after conventional treatment and disinfection)**	**D (Propagation of Wild life and Fisheries)**	**E (Irrigation, Industrial Cooling, Controlled Waste disposal)**
Dissolved Oxygen (DO)mg/l, min	6	5	4	4	-
Biochemical Oxygen demand (BOD)mg/l, max	2	3	3	-	-
Total coliform organisms MPN/100ml, max	50	500	5,000	-	-
pH value	6.5-8.5	6.5-8.5	6.0-9.0	6.5-8.5	6.0-8.5
Colour, Hazen units, max.	10	300	300	-	-
Odour	Un-objectionable			-	-
Taste	Tasteless	-	-	-	-
Total dissolved solids, mg/l, max.	500	-	1,500	-	2,100
Total hardness (as $CaCO_3$), mg/l, max.	200	-	-	-	-
Calcium hardness (as $CaCO_3$), mg/l, max.	200	-	-	-	-
Magnesium hardness (as $CaCO_3$), mg/l, max.	200	-	-	-	-
Copper (as Cu), mg/l, max.	1.5	-	1.5	-	-
Iron (as Fe), mg/l, max.	0.3	-	0.5	-	-
Manganese (as Mn), mg/l, max.	0.5	-	-	-	-
Chloride's (as Cu), mg/l, max.	250	-	600	-	600
Sulphates (as SO_4), mg/l, max.	400	-	400	-	1,000
Nitrates (as NO_3), mg/l, max.	20	-	50	-	-
Fluorides (as F), mg/l, max.	1.5	1.5	1.5	-	-
Phenolic compounds (as C_2H_5OH), mg/l, max.	0.002	0.005	0.005	-	-
Mercury (as Hg), mg/l, max.	0.001	-	-	-	-
Cadmium (as Cd), mg/l, max.	0.01	-	0.01	-	-

Selenium (as Se), mg/l, max.	0.01	-	0.05	-	-
Arsenic (as As), mg/l, max.	0.05	0.2	0.2	-	-
Cyanide (as Pb), mg/l, max.	0.05	0.05	0.05	-	-
Lead (as Pb), mg/l, max.	0.1	-	0.1	-	-
Zinc (as Zn), mg/l, max.	15	-	15	-	-
Chromium (as Cr^{6+}), mg/l, max.	0.05	-	0.05	-	-
Anionic detergents (as MBAS), mg/l, max.	0.2	1	1	-	-
Barium (as Ba), mg/l, max.	1	-	-	-	-
Free Ammonia (as N), mg/l, max	-	-	-	1.2	-
Electrical conductivity, micro mhos/cm, max	-	-	-	-	2,250
Sodium absorption ratio, max	-	-	-	-	26
Boron, mg/l, max	-	-	-	-	2

2.5 Soil moisture and soil type

According to NASA's Earth Science Office, soil moisture is the water that is held in the spaces between soil particles. Surface soil moisture is the water that is in the upper 10 cm of soil, whereas root zone soil moisture is the water that is available to plants, which is generally considered to be in the upper 200 cm of soil. Soil moisture is the water stored in the soil and is affected by precipitation, temperature, soil characteristics, and more. These same factors help determine the type of biome present, and the suitability of land for growing crops. The health of our crops relies upon an adequate supply of moisture and soil nutrients, among other things. As moisture availability declines, the normal function and growth of plants are disrupted, and crop yields are reduced. And, as our climate changes, moisture availability is becoming more variable.

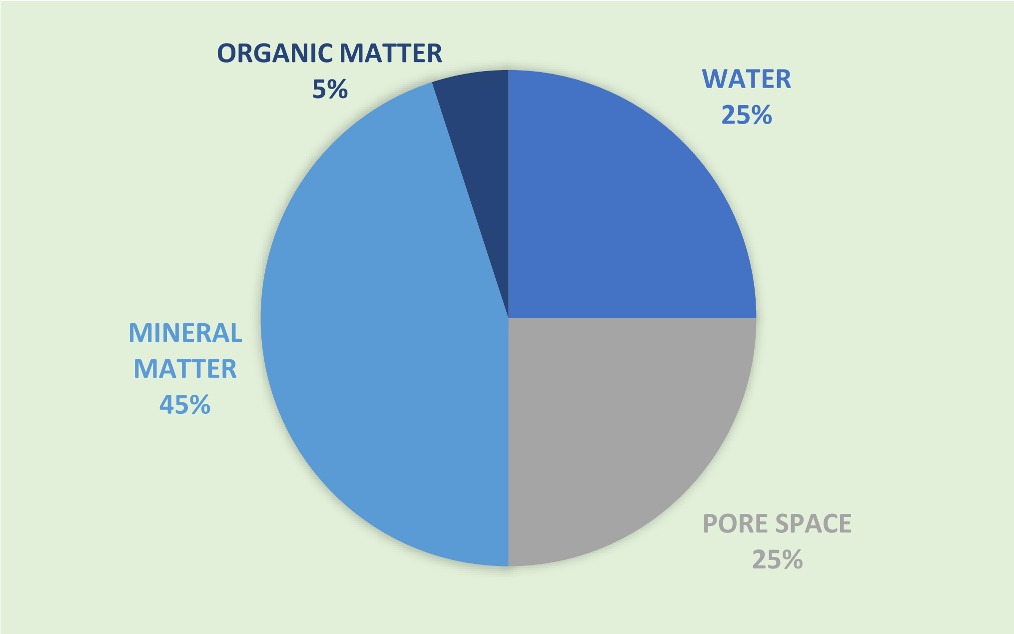

Figure 11 Approximate volume composition, Adapted source: Lal, 2013

Solids, liquids, and gasses, the three phases of matter, are always present in soil. Small mineral and organic particles comprise the solid fraction, and there are spaces (pores) between the solid particles. Some pores are large, and others are very small. Air and water, the gas and liquid phases, exist in the pores. The size of the soil particles and pores affects how much water a soil can hold, and how that water moves through the soil (Soil Science Society of America, 2020).

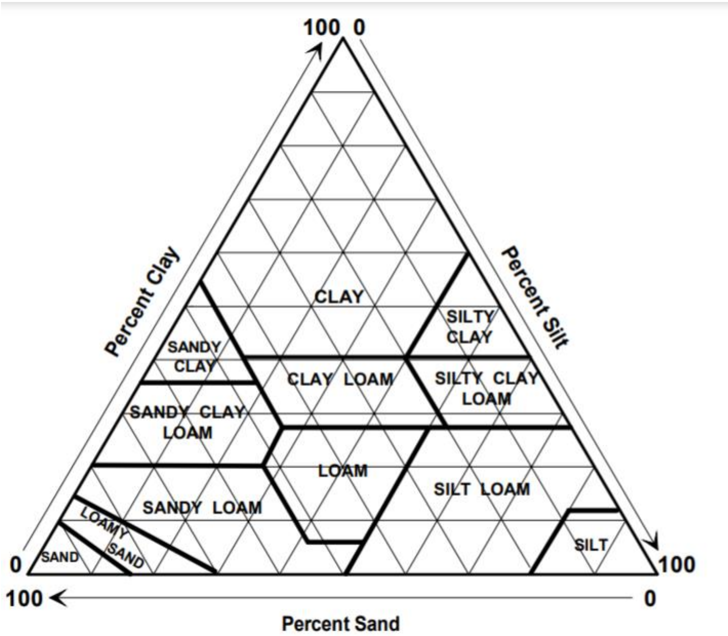

Figure 12 Soil textural triangle, Adapted Source: Lal, 2013

In terms of soil-water management, the classification of soil water potential (Ψm) is based on the availability of water to plants in the soil environment. All soils contain mineral particles, organic matter, water and air. The combinations of these determine the soil's properties – its texture, structure, porosity, chemistry and colour. The texture of the soil, whether silt loam, silty clay loam, or sandy loam, is determined by the amount of sand, silt, and clay in the soil. With experience, it is possible to determine soil texture by ribboning the soil between the fingers. However, for accurate determinations, the amount of sand, silt, and clay sized particles in a soil are determined in the laboratory. Once the percent of the three separates is known, soil texture is determined by the use of a "textural triangle" (**Figure 12**).

2.5.1 Forms of soil moisture

For purposes of relating soil moisture to crop growth and other relationships, soil scientists have grouped soil water into four classes:

- **Gravitational water**- Sometimes called "free water." This is the water in the soil which occupies the larger pores (or holes) and drains away under the influence of gravity. It occupies the space normally occupied by air in a well-balanced soil-water-air relationship. If this water drains away too slowly, injury to the plants may result.
- **Capillary water**- This is the water which is held by surface tension forces as films around the soil particles, in angles between them and in capillary pores. Water moves slowly in the capillary pores from the thicker to the thinner films. A soil holding the maximum amount of water it can retain against the force of gravity is said to be at its field capacity. Maximum soil compaction occurs at 80-100% of field capacity. When soil is saturated, pore space is totally filled with water which resists.
- **Hygroscopic water** – This is the water held very tightly in a thin film around the soil particles. It is held so firmly that it can move only in the form of vapour. The moisture remaining in air-dry soil is usually regarded 13 as hygroscopic water. It is unavailable for plant use.
- **Water vapour** – This is the water in the form of vapour which occurs in the soil atmosphere. It is not generally important to plant growth and development.

However, it may be an important means for desert plants survival. It can also help in the recovery of plants overnight after they have wilted under hot, dry conditions.

2.5.2 Major causes of Soil Pollution

Soil pollution is often caused by the uncontrolled disposal of sewage and other liquid wastes resulting from domestic uses of water, industrial wastes containing a variety of pollutants, agricultural effluents from animal husbandry and drainage of irrigation water and urban runoff. Among the most significant soil contaminants are hydrocarbons, heavy metals, herbicides, pesticides and chlorinated hydrocarbons.

Biodegradation of chemicals occurs through the activities of naturally-occurring microorganisms and biomass population. Soil factors, such as moisture content, pH, and temperature, also play an important role. The degradation is enhanced in the soil pH range of 5.5-8.0, with an optimal value of about 7, and tends to increase with temperature). Soil moisture is required for enhanced biomass activity. The rate of pesticide degradation under saturated soil conditions is also known to be very slow. The biodegradation of pesticides occurs at a higher rate on farms where soil moisture content is maintained at a higher level. In summers higher soil moisture content and soil temperature the pesticides may degrade rapidly, thus reducing the risk of water pollution(Jebellie, Prasher, & Clemente, 1996).

2.6 Cyclic contamination of land and water interlinkages

Land pollution means degradation or destruction of the Earth's surface and soil, directly or indirectly. Due to urbanization increasing of barren land plots and the decreasing of forest cover is ascending at an alarming ratio. This decreases the tree cover and impact the water cycle also known as hydrological cycle and affects a lot of factors and give rise to various concerns like Global warming, enhanced greenhouse effect, storm type rainfall and flash floods, among other climate risk.

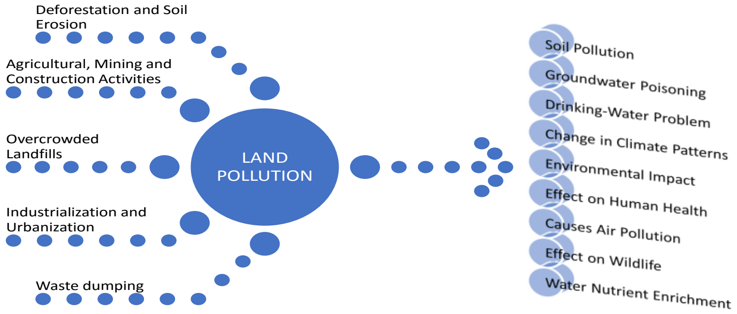

Figure 13 Land pollution cause and effect, Adapted Source: SPAE, 2012

Harmful substances from industries, like chemicals when improperly disposed on the land or are in an illegal landfills/storage, the chemicals and other substances tends end up in the groundwater cycle. This process is called leaching, it usually happens on farms, industrial sites, and landfills. The contaminated groundwater can flow into a water body.

This direct and indirect contamination of water when taken as a source of drinking water can cause health hazards. Increase in climate risk like increased temperature, unseasonal activity, acid rains, etc. causes discharge of chemicals on land makes it dangerous for the ecosystem too.

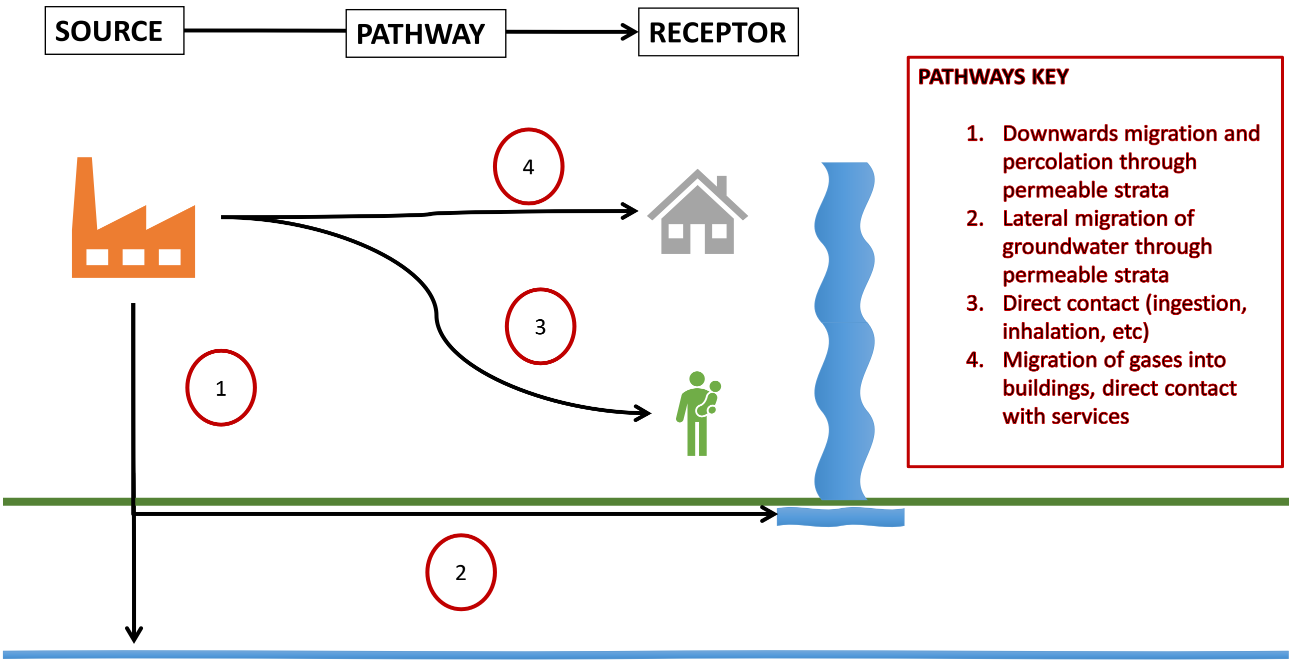

Figure 14 Significant harm and significant pollution, Adapted Source: SEPA, 2012

Module 3 Role of urbanization and industrialization

3.1 Rise of cities to mega-regions

Urbanization has been taking place since ancient times (USGS, 2020), we find mention of ancient city states from ancient times to medieval times, especially in Europe, Rome, Athens, Venice to name a few. As populations rose and people mastered techniques to grow food in fixed locations, settlements grew and with importance of trade on land and sea routes, towns and cities emerged. The urban shift over time led to emergence of megacities albeit after the second world war.

Urbanization in India primarily meant the four metropolitan cities of Delhi, Mumbai, Chennai, and Kolkata until recent times, other than Delhi which has been a city since ancient times, the other three emerged during British times as port cities. The population residing in urban areas in India, according to the 1901 census, was 11.4%, increasing to 28.53% by the 2001 census, and is now currently 34% in 2017 according to The World Bank. According to a survey by UN, in 2030 40.76% of country's population is expected to reside in urban areas (**Figure 15**). Rapid rise in urban population, in India, is leading to many challenges like increasing slums, decrease in standard of living in urban areas, and environmental damage caused by loss of green cover, urban flooding, air pollution.

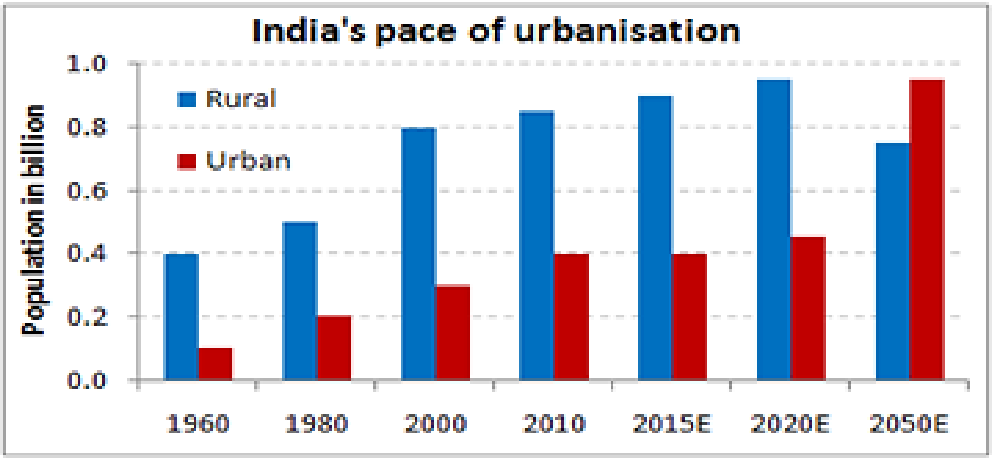

Figure 15 Urbanization, Sources: USGS,2018

3.1.1 Beginning of urbanization

Two major changes occur during the process of urbanization:

a) Change in Land Use

Removal of trees and vegetation, concretization increases with houses having plumbing system, some cities develop sewer network and others continue with septic tanks. Groundwater use in Indian towns and cities has a common practice, with the advent of boring technologies; the wells accessing groundwater went deeper into the aquifer.

b) Effect on Water System

More storm runoff and erosion occur because there is less vegetation to slow down water flow from higher elevations. More sediment is washed into streams, flooding can occur because hydrological drainage patterns are altered in urban areas.

3.1.2 Continuing urbanization

a) Change in Land Use

As cities grow, the landscape of the city changes by the addition of more roads, flyovers, residential, commercial and industrial buildings. New water supply and distribution systems are built to supply the growing population in cities. Reservoirs are built to supply water from rivers sometimes more than 100 KM away from the city. Cities like Bangalore and Delhi are a few examples. Water extraction from aquifers present at various depths have been carried out through large-capacity wells(USGS, 2020). Besides, to accommodate buildings, industries, and other infrastructure, often wetlands, low lying areas and hydrological channels have been altered.

Improvements in the storm drainage system can be made incorporating sustainable green infrastructure for reducing flood hazards and simultaneously improving the liveability of the city. Wells are drilled to recharge underground aquifers, projects to reuse wastewater targeted at industrial and institution buildings and residences will reduce the need to access water from faraway places. Ecological-designed recharge ponds allow dispersion of storm water and drainage to artificially recharge shallow aquifers.

b) Effect on Water System

More pavement means less water will soak into the ground, meaning that the underground water table will have less water to recharge it. This will lower the water table further in unconfined aquifers. Some existing wells will not be deep enough to get water and might run dry in the future. Since less rainwater seeps in the ground, increased runoff from the roads goes into storm sewers, which then goes into streams. This runoff, which used to soak into the ground, now goes into streams, causing flooding and it becomes a resource going waste. Changing a stream channel can cause flooding and erosion along the stream banks, there are many examples of this in all cities, this is cited as a major cause of Chennai floods of 2013. More sewage is discharged into streams that were not "designed by nature" to clean that much water.

The use of too many large wells can lower the underground water table. This can cause other wells to run dry, can cause saltwater to be drawn into drinking-water wells, and can cause land subsidence(USGS, 2020). Saline water intrusion in coastal cities is a challenge specially when freshwater levels are going down regularly. Sustainable new storm-drainage systems reduce flooding during storms and help reduce the impact of extreme events through green corridors, rain gardens and restoration and rejuvenation of lakes and ponds. Consequently, there will be less damage to basements, backyards, and streets. Storm water injected into recharge wells and abandoned wells to return water underground aquifers will improve the sustainability of groundwater use.

Reusing treated wastewater means less pollution, more water conservation, and additional water for recharging aquifers if done through proper monitoring and inspection. According to USGS 2016 report, engaging local communities can help us bring down the negative impacts of urbanisation.

3.2 Peri urban regions

According to the paper "Water Security in Peri-Urban South Asia (Prakash & Singh, 2014), "Urbanization has been an important trend of the 20th century. More than 50 per cent of the world's population currently lives in urban areas, a figure that is expected to increase to 70 per cent by 2050". Asian cities are likely to account for more than 60 percent of this increase, in several South Asian cities, growth and expansion picked up after the 1990s. This growth was led by neo-liberal economic policies, policies favouring the growth of special economic zones, followed by a real estate boom. Both local and global actors have had a role to play in this expansion. Most of these cities in South Asia expanded horizontally over space, changing the use of land and more rural areas have been annexed to urban areas, and the transformation of land and water resources at this urban periphery is an integral part of this physical expansion. The peripheral areas serve the urban centre as the sinks of its wastes too, while providing the much-needed land and water resources for the urban residents. With changes in land use supporting urban expansion, changes in water use followed suit.

Within a short period, water resources in peri-urban locations succumbed to the growing pressures from ever-expanding cities as new and emerging claimants compete for limited amounts of water (**Figure 16**). At the same time, the disposal of urban and industrial wastes and wastewaters into peri-urban water resources further compromises peri-urban water security. The effects of these are aggravated by climate variability and change. Climate change exacerbates the effects of the above through various noticeable changes in precipitation, incidents of storm surges and extreme events, sea level rise and salinity intrusion.

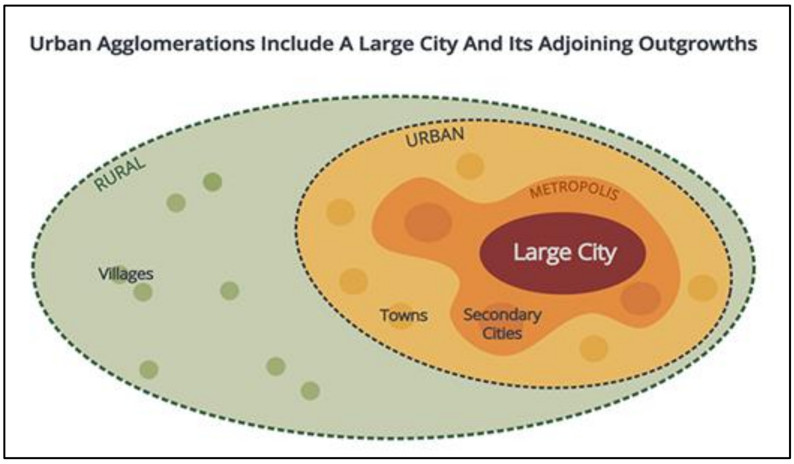

Figure 16 Peri-urban cities, Source: World bank,2009

Peri-urban water security is seen as being shaped by the twin processes of climate change and urbanization. These processes act as multiple stressors on peri-urban water resources and create a situation of uncertain water supply for peri-urban communities. The effects of urbanization occur from changing land-use patterns that endanger changes in water use through the links between land tenure and water security. The expansion of the city through new buildings, business centres, commercial districts and roads, railways change the water flows and increase pressure on the current water resources available. Moreover, the use of lakes and ponds to dispose urban wastes further compromises peri-urban water security as wastewater treatment facilities have rarely kept pace with urbanization. Land acquisition and land use change, essential features of peri-urban contexts, directly affect the access of peri-urban residents to water, as they lose access to water sources located on those lands. Urban and industrial actors may be able to employ expensive technologies for water extraction such as submersible pump-sets that cannot be afforded by the local population, who lose out in the race for appropriating water. Rural-urban water flows to quench urban thirst, acquiring common property water resources for urban expansion and discharge of urban wastes into rural water bodies are other manifestations of peri-urban water insecurity.

The effects of these pressures on peri-urban water resources are aggravated by climate change and variability. However, peri-urban residents are not passive recipients of these change processes affecting their water security. They sometimes adapt to the situation using a mix of technologies and institutions at both the household and collective levels. Their differential vulnerabilities are shaped by their exposure to these processes as well as their access to resources, technologies and institutions that help mitigate the effects. Moving towards eco sensitive, sustainable solutions are needed, aligned with sustainable development goals will be the way forward. There cannot be one solution fits all approach, as each area with need climate sensitive solutions (Prakash & Singh, 2014).

3.3 Industrial clusters

”Environmental pollution remains a serious issue in the developing world, affecting the lives of billions of people, reducing their life expectancy, and damaging children’s growth and development (CPCB, 2009). The World Health Organization (WHO) estimates that 25% of all deaths in the developing world can be directly attributed to environmental factors. The problem of pollution and its corresponding adverse ecological impacts have been aggravated due to increasing industrial and other developmental activities. India, among other developing nations of the world, is facing the challenge of industrial pollution at an alarming rate. This has made the constant surveillance of environmental characteristics a necessary task. There is an urgent need to identify critically polluted areas and identify their problematic dimensions.

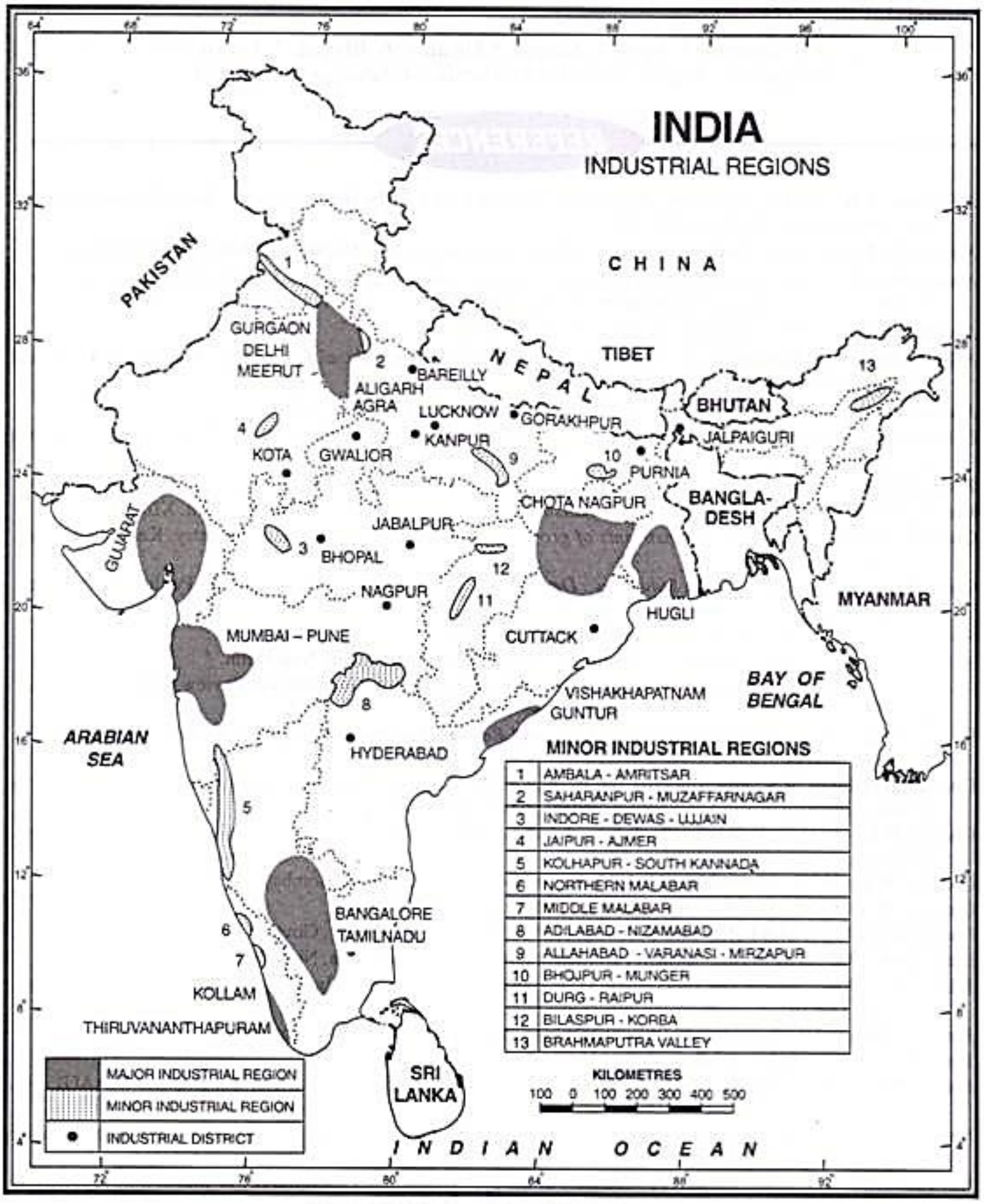

Figure 17 Industrial zones of India (Source: Maps of India)

Accordingly, measures are devised to make our process of industrial development and economic growth more sustainable. The biggest hindrance in this task is the lack of tools to identify the problematic areas and the lack of an objective criterion to rank these areas in order of their needs for mitigation measures and, hence, the protection of natural resources. This has led to the realization of the need for an objective method to analyse the environmental conditions of the identified industrial clusters, areas. To accomplish this, it is required, at the first instance, to process the base level information and develop a robust methodology for identification and ranking of the selected industrial clusters/areas based on various dimensions of pollution. Critically polluted industrial areas/clusters are environmental challenges, and they pose public health challenges. Indeed, only a fraction of national and international efforts has been made, so far, for remediation of critically polluted areas, despite their significant threat to environmental and public health (CPCB, 2009).

Isolated events of chemical spills, gas emissions get attention and are mitigated but the long-term effects of surface water and groundwater pollution through contaminant tracing has been undertaken only in a few river basins. Many times, the industrial clusters and thermal power plants are located near riverbanks to allow easy access to water to the industries. This helps the industries meet the water demands of their produce, however, the effluent discharge through these industrial clusters remains a cause of concern. The amount of water intake and kinds of effluent released varies from industry to industry, so wastewater treatment plants need to adopt different types of treatment technologies. The concept of zero liquid discharge (ZLD) from industries makes the industries take onus for their treated effluent reuse which is a step forward in good water management practices.

3.4 Landfills, municipal sewage, industrial effluent

3.4.1 Landfills

The EPA estimates that 250 million tons of household waste, or more than 1,300 pounds of trash per every person in America, was disposed in 2011. Though humans rarely see it, much of this trash gets deposited in landfills which use a complex system of liners and waste treatment to keep the liquid form of decomposing trash, leachate, from contaminating natural resources. Understanding the different types of water pollution that can come from landfills is important for knowing how take appropriate steps to limit this contamination.

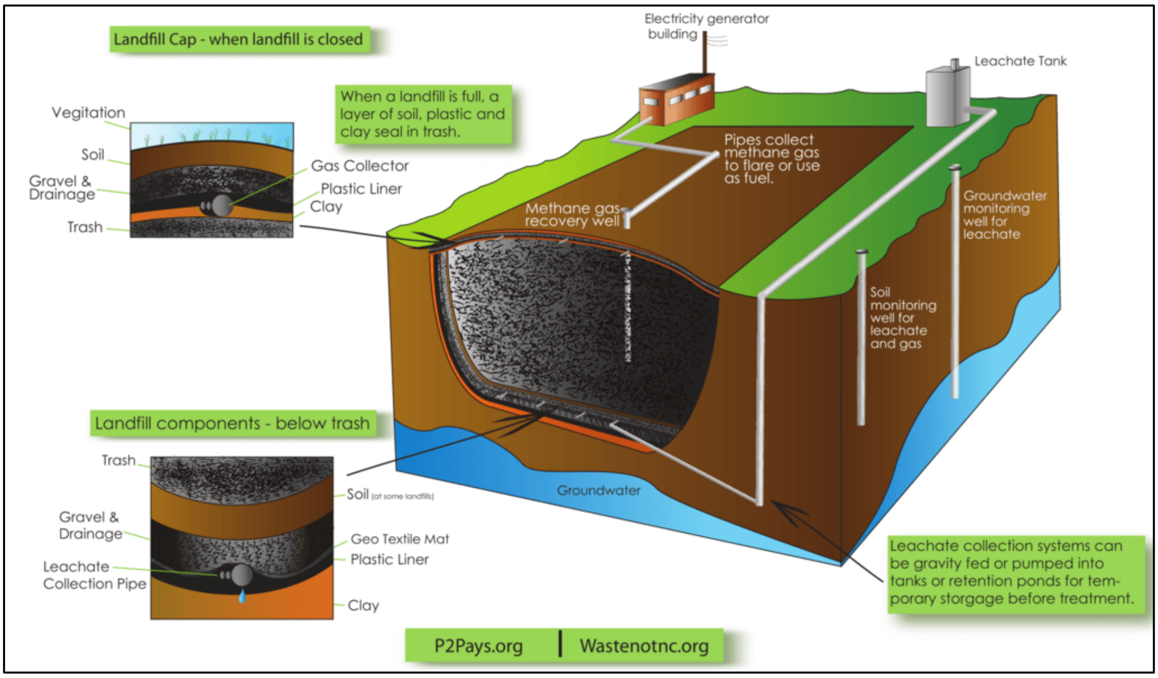

Figure 18 Parts of a solid waste landfill, source: Wastenotnc.org

a) Direct Leachate Contamination

The most serious form of water pollution from landfills is direct leachate contamination, considered to be a major environmental and human-health hazard. Leachate is a highly odorous black or brown liquid that commonly contains heavy metals, such a lead, and volatile organic compounds or VOCs. This form of contamination is rare because modern landfills contain leachate treatment systems and thick protective barriers to prevent leachate from meeting ground or surface water. The older landfills which are still in operation which were not designed as engineered landfills are a cause of concern.

b) Waste Transportation- Contamination

Landfills are often developed away from dense residential areas, industrial zones, which means there is often a long process for transporting waste from its source to a landfill. Most U.S. states carefully regulate waste transportation, but trucks carrying large quantities of solid and hazardous wastes may leak small quantities during transport or be involved in accidents that cause a release of waste material into surface water. The U.S. Department of Transportation reports that more than 5,000 hazardous materials trucks are involved in accidents every year. In 2013, a truck carrying hazardous sewage sludge to a landfill site in Colorado spilled an estimated 22,000 pounds of waste in the vicinity of a nearby stream;

response crews struggled to clean up the spill before it reached the water source. Such problems exist in developing countries too and they are less equipped to handle these challenges currently.

c) Stormwater Runoff Contamination

Landfills commonly cover a large area of land, have a design life of 50 years, which means large quantities of rainwater and snow melt will run down landfills and collect in large stormwater basins. Unlike leachate treatment systems, rainwater basins only collect water, and once the basins are full the water drains into the surrounding environment. Environmental specialist laboratories test this stormwater throughout the year, but the system's lack of secondary treatment presents the possibility for water pollution. The National Resources Defence Council, USA argues that hazardous wastes can also collect in these drainage basins due to improper containment of waste on landfill surfaces. In 2011, a San Jose landfill was fined more than $800,000 for leaking leachate condensate into a nearby stream from storm water basins. In a city like Delhi, India where the city population has increased tremendously, landfills like the one at Gazipur catch fire often and in recent years has witnessed landfill waste flow to the streets at least once during a heavy rainfall episode.

3.4.2 Municipal Sewage

[Based on envirotechwhitepapers (Source: Envirotech, 2016)]

Sewage is an important consideration for every part of the world. What is it? Simply put its water-carrying waste. Whether it’s the stuff that leaves your toilet or the vast amounts of wastewater that flow out of industrial plants – we all contribute to it and collectively we all have to deal with it. But what exactly is ‘dealing’ with sewage? And what is the impact of sewage on the environment?

a) Sewage and wastewater

Unfortunately, the effects of sewage on the environment are largely negative. It needs to be properly treated before it can be disposed of – usually into the ocean at the end of chain through various river systems. The rivers carry raw sewage, partially treated sewage and sewage treated until secondary treatment level. Therefore, downstream of where it is disposed, it can contaminate water and harm huge amounts of wildlife(Envirotech, 2016).

Alternatively, leaking or flooding can cause completely untreated sewage to enter rivers and other water sources, causing them to become polluted. In September, a large part of the River Trent was polluted by sewage in Staffordshire, United Kingdom. Over 15,000 fish were killed, and it would have been worse if the sewage had reached another water source. Contamination of water sources can cause diseases to spread, such as e-coli, diarrhoea and hepatitis A.

Even properly treated sewage can have its problems. Researchers have recently found that microscopic plastic fibres, released when certain clothes are washed, can make it through wastewater treatment plants and into marine ecology systems. Like the more common contaminants, they can harm animals and damage the food chain.

b) Utilizing sewage

As well as pollutants, human sewage contains a pool of information that can be used to monitor a range of areas. While most research has focused on monitoring the use of illegal drugs, it is now being extended to the other potential fields of research. Determining the presence of pesticide metabolites, for instance, can be beneficial for the food and agricultural sector.

Analysing wastewater can detect markers of oxidative stress in collective samples. This is essentially an indication that bodies are unable to neutralize certain diseases. It can help researchers determine the effects of environmental pollution on particular communities.

But how does it work? Because wastewater is so diverse and complex, targeted analysis requires more advanced methods. 'The utility of municipal wastewater analysis for drug epidemiology, food safety and environmental monitoring: From targeted analysis of biomarkers to non-target screening' is an eLearning course which explores the world of wastewater-based epidemiology. It looks at the different analytical techniques and technology required for analyses, but also where the field is heading with current and future developments. Treatment of wastewater is expensive, specially, in centralised sewage treatment plants (STP), the power requirements, sewerage networks all need investments by the government which often is the reason why construction of wastewater treatment infrastructure are lacking in the developing world.

3.4.3 Industrial Effluent

(Source: Breida, Alami Younssi, Ouammou, Bouhria, & Hafsi, 2020)

Industrial wastewater is a generic term involving a wide array of wastewater discharged out of various industries. Indeed, there are many kinds of industrial wastewater, with complex composition, because water fulfils several roles and functions in all types of industries. Measurements of parameters like biochemical oxygen demand (BOD), COD, pH, and alkalinity can classify industrial pollution. Indeed, industrial effluents can be classified according to the dominant nature of pollution, and it may be characterized by a high concentration of organic/inorganic compounds. It should be noted that among the industries generating waste, certain of the most dangerous wastewater comes from sectors such as refineries, mining, tanneries, pharmaceuticals, pulp mills, and sugar production/distillery. The food and agriculture industries generate wastewaters with high BOD, which is estimated to 0.6–20 m^3 wastewater/ton of product (such as bread/butter/milk or fruit juice). For instance, the conventional process in distillery industry generates ~15 L of wastewater per litter of alcohol with a BOD level of about 90,000 mg/L. The most important contributor of wastewater volume (18%), COD (23%), and a major source of NH_4^{+}–N is the paper and paper products industry, while the raw chemical material and chemical products industry is the dominant source of NH_4^{+}–N (35.3%) and an important source of COD and petroleum hydrocarbons. Around 80% of the heavy metal discharges into water sources come from four industries, namely, the nonferrous metal manufacturing and processing industry (27.5%), the fur and leather products manufacturing industry (19.4%), the metal product manufacturing industry (17.7%), and the nonferrous metal ore mining industry (14.0%). This is also true for the Moroccan industrial activities and its discharges. According to the Moroccan federation of metallurgical, mechanical, and electromechanical industries, this industrial sector includes more than 1000 companies divided into four main sub-sectors, including iron and steel, metal transformation, coating, surface treatment, and services related to the metallurgical, mechanical, and electromechanical industries.

Module 4 Surface and Groundwater pollution

4.1 Extent of contamination

4.1.1 Emerging pollutants

Source: (Tang et al., 2019) - "Emerging pollutants in water environment: occurrence, monitoring, fate, and risk assessment"

Contaminants of emerging concern (CECs) are substances that are released in the environment for which no regulations are currently established. They are mainly organic compounds present as pharmaceuticals and personal care products, hormones, food additives, pesticides, plasticizers, wood preservatives, laundry detergents, disinfectants, surfactants, flame retardants, and other organic compounds in water generated mainly by anthropogenic activities.

Since the time when EPs attracted wide attention, many attempts have been made to shed light on the concern of EPs release into environment and further promote policymakers to take related measures to prevent the ecological risks. In 2018, several review papers provided meaningful overview of the research progress in this field. Sanganyado, Rajput, and Liu (2018) presented a review on the bioaccumulation of legacy pollutants and EPs in Indo-Pacific humpback dolphins (Sousa chinensis), which inhabit shallow coastal waters often impacted by anthropogenic activities. Philip, Aravind, and Aravinda kumar (2018) explored the stepwise progress of Indian research on EPs. Qi et al. (2018) comprehensively reviewed the contamination of EPs in landfill leachate in China. Starling, Amorim, and Leão (2019) gathered the studies performed in Brazil with regard to the occurrence, control, and fate of EPs in various environmental components and compared published data with observed data in developed and developing countries. Gong, Li, Wu, Wang, and Sun (2018) provided an overview of the application of typical passive samplers for monitoring polar organic pollutants. Gogoi et al. (2018) reviewed various treatment techniques with their removal efficacy pertaining to EPs and pointed out that future research perspective should focus on the development of risk-based screening models and framework. In view of the fact that microplastics are also classified as EPs, the interaction between microplastics and pollutants was reviewed by Barboza, Dick Vethaak, Lavorante, Lundebye, and Guilhermino

(2018) who summarized that marine microplastic debris may compromise human food safety and health, conventional sewage treatment processes are not capable of treating EPs at very low concentrations. Taheran, Naghdi, Brar, Verma, and Surampalli (2018) presented a review suggesting the secondary treatment be integrated with an advanced treatment scheme to polish the effluent and hence remove EPs.

4.1.2 Persistent organic pollutants

In "An Overview of the Persistent Organic Pollutants in the Freshwater System" (Mosharraf, Nazmul Islam, & M. Rahm, 2012), organic contamination was viewed as secondary and tertiary dispersions of organic compounds from various sources into global circulation across different spheres of the environment viz. hydrosphere, lithosphere, atmosphere and biosphere. Freshwater contamination occurs in diverse ways, of which, contamination by organic compounds of various kinds from a wide range of sources is a major concern due to their persistent nature and harmful biological impacts, sources of supply of freshwater. Fresh water reserves are shrinking in quantity and dwindling in quality forcing the modern city planners to recycle potable water from treated water coming from wastewater treatment facilities. It incentivises the need to release less and less untreated wastewater in the environment. Contaminants are coming into freshwater streams from different geogenic and anthropogenic sources of which the anthropogenic contribution is getting larger in volume and diversity. These contaminants are either attenuated naturally into less toxic or non-toxic forms, or they persist in the freshwater ecosystem for long, enter the food chain through bioaccumulation and bio magnification to cause cascading effect on terrestrial and aquatic biodiversity, the cyclic influence of one aspect of the environment on the other is depicted in figure 16. Presence of organic compounds and their harmful derivatives makes water unfit for consumption. Maintaining a supply of continuous freshwater for increasing population is already a daunting challenge all over the world in cities and with simultaneous increase in organic contaminants are aggravating the challenges further.

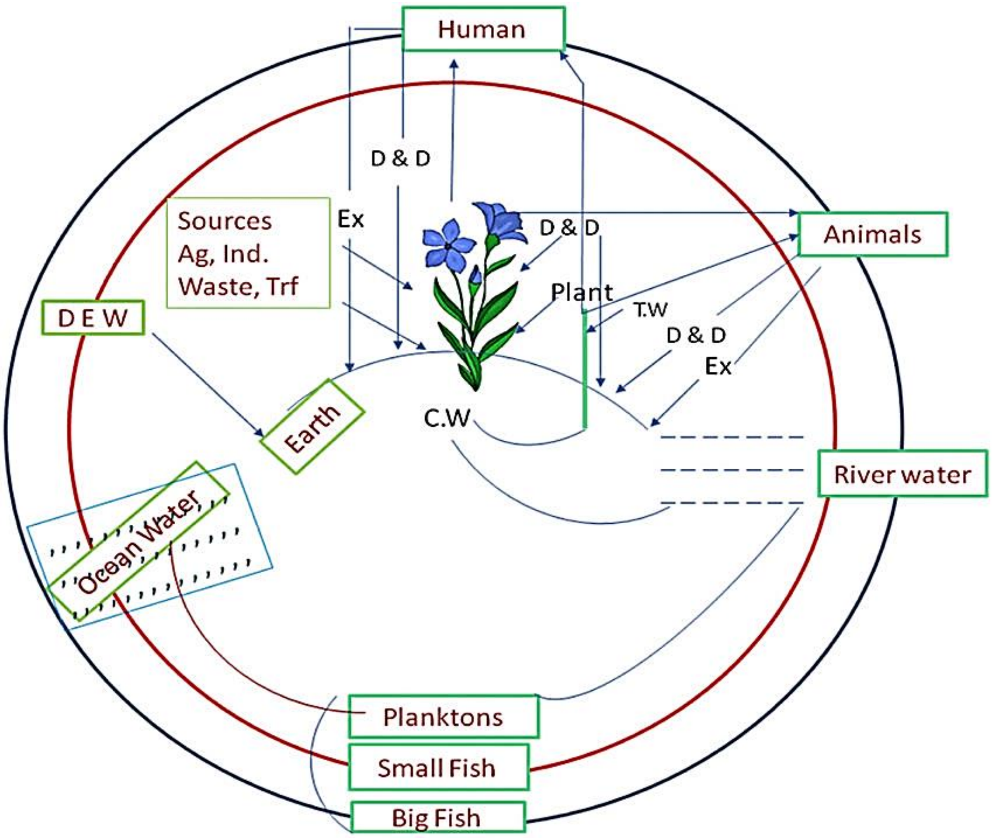

Figure 19 Organic pollutants (Source: Mosharraf et al., 2012)

We need a clear understanding of the classes of organic compounds, which find their way into the fresh water system, their sources, and their transformation through physicochemical and biological processes in the freshwater system in order to control their entry and undesired transformation thereof. Moreover, we need to know the chemistry of these contaminants and their effects on the environment and impact on human health. Better understanding of these pollutants is needed for developing better techniques for purification of water from persistent organic contaminants. Substantial improvement has so far been achieved in all these aspects. This chapter is an effort to get a contemporary picture of our understanding about the organic contaminants in the freshwater system. After introducing the issue of freshwater pollution in the second section, we have focussed on different aspects of contamination of fresh water by persistent organic compounds in section three. This section will include a review of detection techniques available for the detection of organic contaminants in the freshwater system. The section will be concluded with two sub sections – one highlighting our understanding of the natural assimilation of persistent organic contaminants through normal aquatic ecological processes and the other focusing on the techniques that we have at our discretion for the removal of such contaminants from water in order to purify water. Different conventions and protocols are in place to reduce and control the issue of organic contamination of water. Before concluding the chapter, the current status of protocols and conventions regarding organic contamination of fresh water(Mosharraf et al., 2012) is presented.

This diagram from USGS (**Figure 20**) shows how groundwater contributes water to surface water (streams, rivers, and lakes). In case, of a "gaining stream", which generally gains water from the ground, it receives groundwater. Many lakes too are perennial for they receive groundwater supply continuously. In such cases if the groundwater is polluted, the stream or lake too gets polluted. Other streams are "losing streams", which lose water from the stream bed out into the ground. In such cases, if the river is polluted, the aquifer which receives river water also gets polluted. Rivers can be gaining and losing at different locations; they can be gaining one time of the year and losing in another time of year. And, as the yellow arrow shows, even a gaining stream will be losing some water, and the other way around. In this diagram, though, a gaining stream is shown where groundwater is entering the stream. The interlinkages between groundwater and stream water are very complex and need to be understood, once a chemical imbalance is created, restoring equilibrium conditions may be difficult.

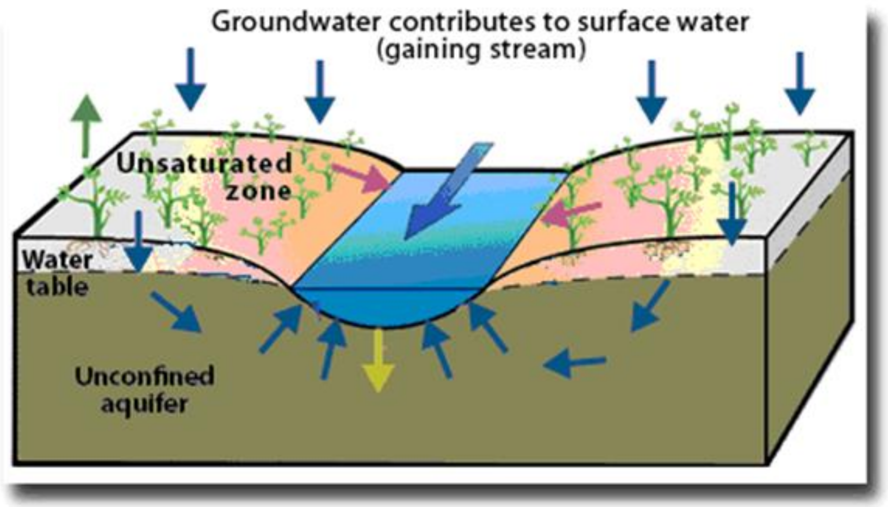

Figure 20 Groundwater contamination (Source: USGS)

4.2 Contaminated stretch of river and aquifer

Rivers are polluted in stretches whenever it passes through cities and industrial areas. Contaminants in aquifers too are in urban areas and industrial areas. However, agriculture return flow from irrigated fields are also a source of pollution in rivers and aquifers.

4.2.1 Fate of pollutants in water bodies

Montuelle & Graillot (2017) discusses the urban, agricultural and industrial developments which generate many pollutant emissions, in increasing quantities and of a highly variable nature, in aquatic environment (nutrients, pesticide residues, heavy metals, pharmaceutical residues). Sometimes alarming river pollution levels lead to hyper eutrophication and increase in toxicity which is mainly due to either complete lack of or low efficiency wastewater treatment plants. In Europe efficient wastewater treatment infrastructures, with strict regulations have been introduced through the European Water Framework Directive (WFD). Technical and financial resources have been given to various water utilities and city local governments to plan and carry out recovery and rejuvenation of rivers and groundwater.

In addition to chemical releases, other pressures also impact the river's quality: suspended solid and sediment from land erosion, hypoxia (or anoxia) during the microbial degradation of algal blooms and other organic matter, reduction of flows increasing pollutant concentrations and increase in water temperature. Lastly, the many interactions between contaminants/pollutants and environmental factors control the expected stresses and their effects on water uses and aquatic biodiversity.

Aquatic pollution, is the result of a complex mixture of substances and environmental factors, making risk assessment particularly difficult and uncertain. Except for heavy metals, organic pollutants and toxic compounds are degradable, though their half lifetime periods vary, so some of them exist as contaminants over a longer period in the water than others (this is due to various different natural attenuation processes that apply to different pollutants: photo degradation, biodegradation). These processes are likely to affect the bioavailability and toxicity of substances and globally reduce the toxic load over time. But for this to happen, the biodegradation potential of the river must not be exceeded by excessive pollutant loads, which is often the case given the continuous inputs along the river and the upstream-downstream transfer of pollution: a watercourse is not and should never be considered as an annexe of a wastewater treatment plant(Montuelle & Graillot, 2017). The seasonal water flow in rivers and changing temperatures with seasons also influence the pollutant properties in the river.

The induced environmental effects are multiple and can be of varying degrees on different specifies, depending on the different kinds of pollutant entering the river at any point location. From a scientific point of view, all these issues are brought together within a thematic/new discipline called stress ecology, making it possible to formalize pressure-impact relationships, and assess the causes of environmental stress. Numerous methods of bio indication and ecotoxicology are available, some are standardized and regulated that enable to classify hazardous substances, evaluate potential impacts, and highlight the deterioration and need for rejuvenation aquatic environments. Some European guidelines exist to assess the effect of substances and environmental quality (e.g., WFD) which help to assess the extent of pollution. One of the current challenges, despite the growing number of studies, is the development of in situ ecological assessment approaches especially those which enable to assess the effects of contaminants. These approaches are based on the weight of evidence, which report the state of the environment, however, a forward planning policy on such matters is yet to be in place in India(Montuelle & Graillot, 2017).

4.2.2 Impact on aquatic life

(Source: Denchak, 2018)

In order to thrive, healthy ecosystems rely on a complex web of animals, plants, bacteria, and fungi—all of which interact, directly or indirectly, with each other. Harm to any of these organisms can create a chain effect, putting the aquatic environment in peril. When water pollution causes an algal bloom in a lake or marine environment, the proliferation of newly introduced nutrients stimulates plant and algae growth, which in turn reduces oxygen levels in the water. This dearth of oxygen, known as eutrophication, suffocates plants and animals and can create “dead zones,” where waters are essentially devoid of life. In certain cases, these harmful algal blooms can also produce neurotoxins that affect wildlife, from whales to sea turtles.

Chemicals and heavy metals from industrial and municipal wastewater contaminate waterways, these contaminants are toxic to aquatic life—most often reducing an organism's life span and ability to reproduce—and make their way up the food chain. That's how tuna and other big fish accumulate high quantities of toxins, such as mercury.

Marine ecosystems are also threatened by marine debris, which can strangle, suffocate, and starve animals. Much of this solid debris, such as plastic bags and soda cans, gets swept into sewers and storm drains and eventually moves out to sea in coastal areas, turning oceans into trash soup and sometimes consolidating to form floating garbage patches. Discarded fishing gear and other types of debris are responsible for harming more than 200 different species of marine life. Plastic pollution is bound to affect life of marine organisms and vulnerable communities living near coasts.

Meanwhile, ocean acidification is making it tougher for shellfish and coral to survive. Though they absorb about a quarter of the carbon pollution created each year by burning fossil fuels and other sources, oceans are becoming more acidic. This process makes it harder for shellfish and other species to build shells and may impact the nervous systems of sharks, clownfish, and other marine life. The long-term impact of many pollutants is not yet completely understood, or the damage caused to the entire oceanic environment.

Module 5 Pollutant estimation and analysis-accounting

5.1 Identification of source and sink

A source is any process or activity through which a greenhouse gas is released into the atmosphere. Both natural processes and human activities release greenhouse gases.

A sink is a reservoir that takes up a chemical element or compound from another part of its natural cycle.

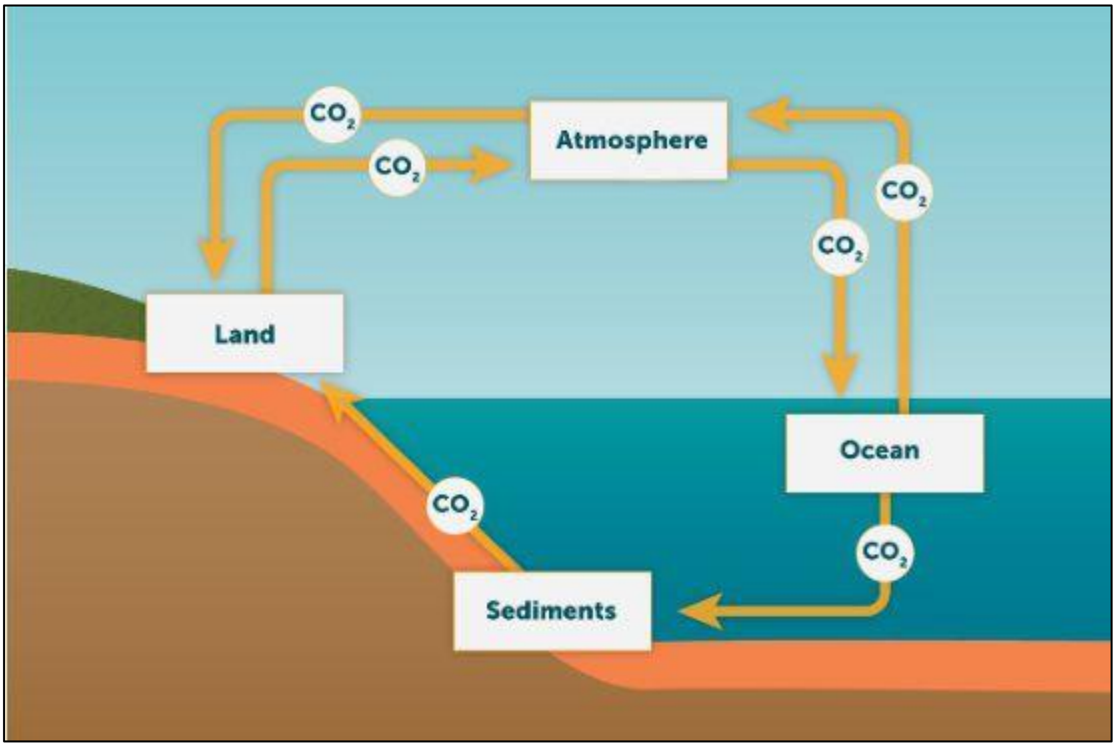

Figure 21 Source and sink flow (Source: NGS, 2018)

Sinks are a fundamental factor in the ongoing balance which determines the concentration of every greenhouse gas in the atmosphere. If the sink is greater than the source of pollution, the pollution concentration will decrease; if the source is greater than the sink, the concentration will increase (European Environmental Agency, 2019).

There are many causes for water pollution but two general categories exist: direct and indirect contaminant sources.

5.1.1 Direct sources

Include effluent outfalls from factories, refineries, and waste treatment plants etc. that emit fluids of varying quality directly into urban water supplies. In the United States and other countries, these practices are regulated, although this doesn't mean that pollutants can't be found in these waters.

5.1.2 Indirect sources

include contaminants that enter the water supply from soils/groundwater systems and from the atmosphere via rain water. Soils and groundwater contain the residue of human agricultural practices (fertilizers, pesticides, etc.) and improperly disposed of industrial wastes. Atmospheric contaminants are also derived from human practices (such as gaseous emissions from automobiles, factories and even bakeries)(GRDC, 2015).

5.2 Material flow analysis in city

Effective 'sustainable' cities should be sustainable and their use of natural resources and waste production should be commensurate with the potential of local, regional and global biodiversity. It is increasingly suggested that the Urban Metabolism (UM) approach, can help city decision-makers (e.g. planners) look at many of the major contributing factors related to the external flow of natural resources (e.g. food, water and energy) and waste collection. Mass Flow Analysis - MFA can contribute to the measurement, assessment and understanding of life, defined as 80% carbon reduction (from levels 1990); secure service (ethos of One planet living) with well-maintained or improved well-being (**Figure 22**).

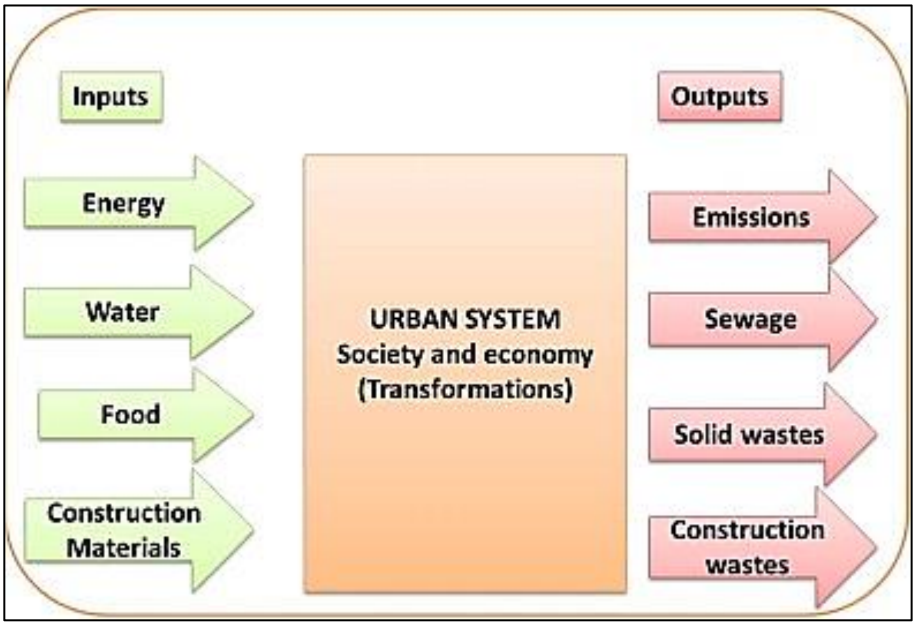

Figure 22 Material flow analysis, Source: William, 2018

Material flow analysis, determines the flows of inputs (water, energy, food and others) and outputs (wastewater, air pollution, wastes and others) to determine the relationship between demand for resources and the environmental impact of outputs.

Material flow analysis contains the following main steps (BRUNNER & RECHBERGER, 2004):

I. Identification of the key (material flow related) issues.
II. System analysis (selection of the relevant matter, processes, indicator substances (elements), and system boundaries).
III. Quantification of mass flows of matter and indicator substances.
IV. Identification of weak points in the system.
V. Development and evaluation of scenarios and schematic representation, interpretation of the results.

With the focus given to the distribution of each resource (e.g. water) on multiple scales (city to individual) it is shown that MFA can be used as a starting point to develop real engineering solutions. However, more work is needed to truly reflect the broader aspects of urban life. MFA can be used for environmental impact assessments, development of environmental policy for hazardous substances, nutrient management in watersheds, waste management and for sanitation planning.

5.3 Zero Liquid Discharge (ZLD)

Zero liquid discharge (ZLD) is an engineering approach to water treatment where all water is recovered and contaminants are reduced to solid waste. While many water treatment processes attempt to maximize recovery of freshwater and minimize waste, ZLD is the most demanding target since the cost and challenges of recovery increase as the wastewater gets more concentrated. Salinity, scaling compounds, and organics all increase in concentration, which adds costs associated with managing these increases. ZLD is achieved by stringing together water treatment technology that can treat wastewater as the contaminants are concentrated.

5.3.1 Benefits of ZLD

There are a number of benefits to targeting zero liquid discharge for an industrial process or facility (**Figure 23**):

a) Lowered waste volumes decrease the cost associated with waste management.

b) Recycle water on site, lowering water acquisition costs and risk. Recycling on-site can also result in less treatment needs, versus treating to meet stringent environmental discharge standards.

c) Reduce trucks associated with off-site waste water disposal, and their associated greenhouse gas impact and community road incident risk.

d) Improved environmental performance and regulatory risk profile for future permitting.

e) Some processes may recover valuable resources, for example ammonium sulphate fertilizer or sodium chloride salt for ice melting.

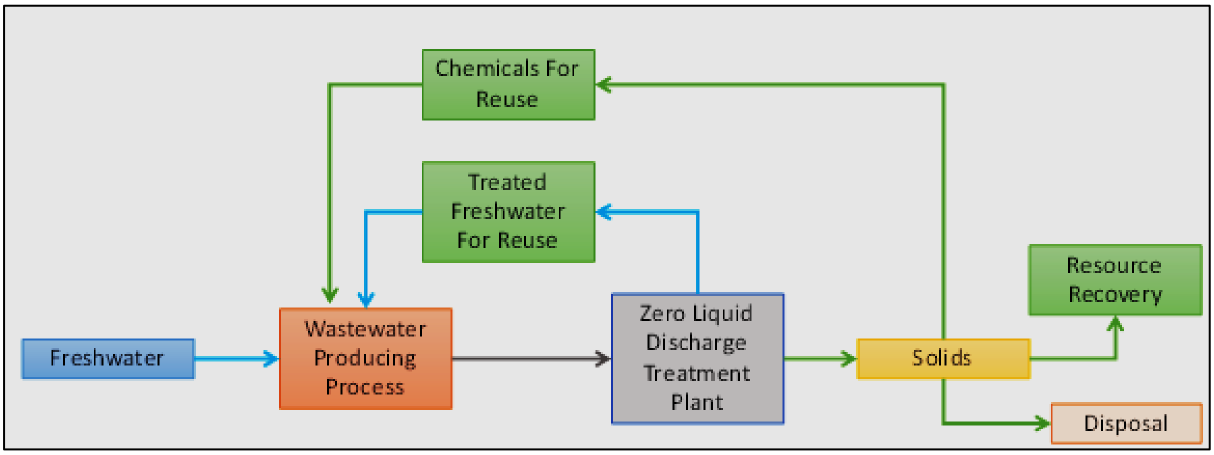

Figure 23 ZLD flow (Adapted Source: Saltworks Technologies Inc., 2020)

Several methods of waste management are classified as zero liquid discharge, despite using different boundaries to define the point where discharge occurs. Usually, a facility or site property line that houses the industrial process is considered the border or ‘boundary condition’ where wastewater must be treated, recycled, and converted to solids for disposal to achieve zero liquid discharge.

Certain facilities send their liquid waste off-site for treatment, deep well disposal, or incineration and they consider this to qualify as zero liquid discharge. This approach to zero liquid discharge eliminates continuous discharge of liquids to surface waters or sewers, but can significantly increase cost.

5.3.2 Importance of ZLD

In a world where freshwater is an increasingly valuable resource, industrial processes threaten its availability on two fronts, unless the water is treated. Many industrial processes require water, and then reduce the availability of water for the environment or other processes, or alternately contaminate and release water that damages the local environment.

Although the history of tighter regulations on wastewater discharge can be traced back to the US Government's Clean Water Act of 1972, India and China have been leading the drive for zero liquid discharge regulations in the last decade. Due to heavy contamination of numerous important rivers by industrial wastewater, both countries have created regulations that require zero liquid discharge. They identified that the best means to ensure safe water supplies for the future is to protect rivers and lakes from pollution. In Europe and North America, the drive towards zero liquid discharge has been pushed by high costs of wastewater disposal at inland facilities. These costs are driven both by regulations that limit disposal options and factors influencing the costs of disposal technologies. Tong and Elimelech suggested that, "as the severe consequences of water pollution are increasingly recognized and attract more public attention, stricter environmental regulations on wastewater discharge are expected, which will push more high-polluting industries toward ZLD" (Saltworks Technologies Inc., 2020).

Another important reason to consider zero liquid discharge is the potential for recovering resources that are present in wastewater. Some organizations target ZLD for their waste because they can sell the solids that are produced or reuse them as a part of their industrial process. For example, lithium has been found in USA oil field brines at almost the same level as South American scalars. In another example, gypsum can be recovered from mine water and flue gas desalinization (FGD) wastewater, which can then be sold to use in drywall manufacturing. Regardless of an organization's motivations to target zero liquid discharge, achieving it demonstrates good economics, corporate responsibility and environmental stewardship. By operating an in-house ZLD plant, disposal costs can be reduced, more water is re-used, and fewer greenhouse gases are produced by off-site trucking, which minimizes impact on local ecosystems and the climate.

5.4 Circular economy

Circular economy is an economic system aimed at eliminating waste and sustainable use of resources(Ellen MacArthur Foundation, 2020). Circular systems employ reuse, sharing, repair, refurbishment, remanufacturing and recycling to create a closed-loop system, minimising the use of resource inputs and the creation of waste, pollution and carbon emissions(Geissdoerfer, Savaget, Bocken, & Hultink, 2017). It aims to keep products, equipment and infrastructure in place for a long time, thus improving the productivity of these resources. All "waste" must be "food" in one process: either a third-party product or a recycled material or other renewable resource (e.g., compost). This method of self-renewal contradicts the traditional economy, which has a productive method of Looking beyond the current take-make-waste extractive industrial model, a circular economy aims to redefine growth, focusing on positive society-wide benefits (Ellen MacArthur Foundation, 2018). It entails gradually decoupling economic activity from the consumption of finite resources, and designing waste out of the system. Based on the transition to renewable energy sources, the circular model creates economic, environmental and social capital. Based on three principles:

i. Create waste and sanitation protocols
ii. Keep products and equipment in check
iii. Revitalization of environmental systems and recycling

Module 6 Role of Policies in positive interventions

6.1 Policies related to land-based water pollution

Laws comprise of Acts and Rules. One of the acts that directly concern water pollution in India is the Water (Prevention and Control of Pollution) Act, 1974. This is complemented by the Water (Prevention and Control of Pollution) Rules, 1975. The Water Act aims to prevent and control water pollution; and to maintain or restore wholesomeness of water (**Table 6**).

Table 6 Summary of Constitutional provisions and Laws related to water quality

Provisions	Name	Features	Remarks
Constitutional	**Article 21**	Right to life – interpreted as pollution free water	Focus on water quality and pollution prevention
	Article 48-A	State's responsibility to protect and improve the environment – includes water bodies	
	Article 51-A(g)	Fundamental duty of all citizens to protect the environment	
	Directive Principles	State shall improve public health and environment through control of water pollution	
Laws	**Water (Prevention and Control of Pollution) Act**	Clauses that target prevention and control of pollution and to maintain and restore wholesomeness of water. Standards are defined that need to be achieved for discharge into water bodies. Recent revisions (2016) include aspects for reuse. Pollution Control Boards for monitoring and enforcement of the Act	Focus is on industrial pollution. Pollution due to sewage has also been addressed. Pollution due to agriculture is not addressed, though mentioned.
	Water (Prevention and Control of Pollution) Rules	For supporting the implementation of the Water Act	
	Water (Prevention and Control of Pollution) Cess Act	Revenue generating legislation for ensuring financial resources for the Pollution Control Boards	Does not restrict the consumption of water
	Environment (Protection) Act	Addresses protection of environment due to water pollution (in addition to other environmental pollution)	Focus on industrial pollution
	Environment (Protection) Rules	For supporting the implementation of the Environment Act	
	Municipality Act	Sewage disposal into sewer networks based on permissions and fee Reuse of treated effluent for irrigation needs prior approval In areas without sewer networks – appropriate on-site systems to be implemented post approval	
	Water Supply and Sewerage Act		
	Sec 277-Indian Penal Code	Offense to foul public springs or reservoir	
	Sec 133-Code of Criminal	Removal of any nuisance at a public place (include in water bodies or creating a problem	

Provisions	Name	Features	Remarks
	Procedure	for a water body)	
	Solid Waste Management Rules	All solid waste should be collected and treated appropriately	This entails that solid waste should not enter water bodies causing pollution
	Plastic (Management and Handling) Rules	Plastic needs to be used only as per specifications and waste should be recycled and reused. Only rejects can be disposed in scientific landfills	Does not address water pollution directly but entails that it should not enter water bodies casing pollution

The Water Act establishes the Central Pollution Control Board (CPCB) (at the national level) and the State Pollution Control Board (SPCB) or the Pollution Control Committee (at the State/Union Territory level) to carry out the objectives defined under the Act. Pollution control boards at the central and state levels are empowered to prevent, control, and abate water pollution, and to advise governments on matters pertaining to such pollution. CPCB is to coordinate the activities of the state boards.

In order to augment the financial resources of the CPCB and SPCBs, the Water (Prevention and Control of Pollution) Cess Act, 1977 (and amended in 1988) was enacted. The Act levies a cess on water consumed by persons carrying on certain industrial activities and local authorities. It is a revenue-generating legislation and not a measure to restrict the consumption of water by industrial units.

The Environment (Protection) Act or EPA (1986) provides for environmental protection and improvement, associated with different types of environmental pollution, including water pollution. The EPA is designed to fill the gaps still remaining in the legal framework for the control of industrial pollution. The Water Act and Rules as well as the EPA and Rules define the standards (limits of concentration) for discharge of effluents that may pollute water.

The Central Government has also issued a number of notifications, which are relevant for the prevention and control of water pollution. These include:

i. Environment Impact Assessment Notification, 2006
ii. Different Eco-Sensitive Zone notifications
iii. Coastal Regulation Zone Notification, 2011

Most of the States in India have formulated and enacted a state level as well as state capital-city level water supply and sewerage act along with the Municipality Act that makes adequate provisions for the management of sewerage and disposal of sewage. As per the Act, connection with the existing sewers cannot be made without prior permission from the body (state or city level Water Supply and Sewerage Board) constituted to administer and manage water supply and sewerage management. Rules under the said Act says that any owner, lessee, or occupier of trade or industrial premises who desires to discharge effluents directly or indirectly into the sewer needs to make application to the Board with particulars on the quantity and quality of the effluent. The Rules also state that no sewage or industrial effluent shall be used for irrigation purposes without the written approval. In areas where underground drainage lines are not laid suitable septic tanks / soak pits shall be provided as approved. No septic tank or soak pit shall be constructed within six meters from any water pipelines.

Fouling of water bodies is considered as a nuisance under criminal laws. Section 277 of the Indian Penal Code, 1860 penalizes voluntary corruption or fouling of the water of any public spring, reservoir so as to render it less fit for the purpose for which it is ordinarily used. However, this provision does not apply to river pollution and private wells. Further, the punishment, which is imprisonment of a maximum term of three months and/or a maximum fine of Rs500 does not have the required deterrent effect. Under section 133 of the Code of Criminal Procedure, 1973, a speedy and summary remedy is available, among other situations, where 'any unlawful obstruction or nuisance should be removed from any public place or from any way, river or channel which is or may be lawfully used by the public'. However, the injunctive relief under section 133 must not interfere with an order of the SPCB under the Water Act (if any).

Solid Waste in water ways and leachate from collected solid waste causes ground water and surface water contamination. In the recent years this has become a major source of water pollution. It is well known today that with development, the quantities of solid waste generation have also increased. The 'From Waste to resource- World Waste Survey, 2009 report' states that in the next two generations, the world will be saturated by its population and by the virtue of being richer, and more "developed", they will also produce more waste, perhaps twice as much as we can measure at the present time. since 2007-2008, the market has also realized the economic potential of recycling waste. However, this market is still to be explored and established completely. As per the 'From waste to resource-World Waste Survey 2009 Report' the worldwide municipal waste generation was estimated to be 1.9 billion tons of which only 1.24 billion tonnes were collected. India was estimated to be producing 67.5 million tons of municipal waste. Urban India is estimated to be collecting 34.5 million tonnes (2004 estimates). Rural India produces 50% of waste compared to urban India per person per year. Most of the waste generated ends up in unsanitary landfills that create large quantities of leachates moving into ground water and neighbouring water bodies contaminating it. A large quantity of waste ends up in water streams (due to poor user behaviour, collection practices and services and indiscriminate dumping). These waste material causes pollution due to its degradation and also by causing blockages in the flow of water reducing its natural ability to rejuvenate.

The Municipal Solid Waste Management Rules 2016 encourages segregation and collection of waste and resource recovery. The Plastic Waste Management and Handling Rules, 2011 (amended in 2016) in its efforts to reduce the generation of waste has introduced rules that prevent the generation of plastic and packing material that is not suitable for the environment (increasing the thickness of plastic, making use of plastic bags an expense) and support recycling through the Extended Producers Responsibility.

Segregation and collection of solid waste and its disposal at sanitary landfills has also been made compulsory however, most of the landfills in India are not sanitary and leachate from the insanitary landfills is going into the ground water and surface body causing serious water pollution issues. Collection is still not effective resulting in solid waste accumulating in water ways causing pollution issues. Appropriate and effective Solid Waste Management practices will directly impact the quality of water sources.

6.2 Innovative interventions

India has only about 4 per cent of the world's renewable water resources but is home to nearly 18 per cent of the world's population. And as the country continues to urbanize, its water bodies are getting toxic. Around 70 per cent of surface water in India is unfit for consumption, and almost 40 million litres of wastewater enter rivers and other water bodies daily.

The cost of environmental degradation in India is estimated to be Rs 3.75 trillion a year, and the health costs are alone approximately Rs 470-610 billion. Keeping in mind these facts, conscious citizens across India are making attempts at the local and national level to prevent water pollution, revive the polluted water bodies and thereby eradicate water-related diseases.

a) Turning Sewage Water into Drinkable Water

This organic water filter developed by Anton P Biju and Thomas Cyriac, is the size of an index finger, costs just Rs 10, and can convert up to 30 litres of impure water into freshwater within a few hours using activated carbon.

On putting the purifier in any water container, pores from contaminated water that act as micro-reservoirs are fixed over a disc inside the cartridge. It eliminates foul smell, harmful metals and colours from the water. Moreover, the technology adds minerals that improve the immune system. The best part? The cartridge in the purifier that costs around Rs 60 has to be replaced every five years, which means there is no maintenance or recurring cost. A from Palai town, who developed the device, had used 200 such purifiers during the 2018 Kerala floods in the relief camps that provided safe drinking water to thousands of displaced victims.

b) Using Floating Wetlands to Make Water Bodies Pollutant-Free

Tarun Sebastian Nanda, an ecological engineer, is using a natural way to clean water bodies in Delhi through his 'Adopt an Island' initiative. He is constructing floating wetlands by using aquatic plants. These plants are placed on buoyant mats made from drainage pipes and discarded soda bottles. When the island is placed on the surface water, they absorb manganese, iron, aluminium and other contaminants through their roots and foliage, thus purifying the polluted water. These wetlands also discourage the growth of algae and help improve the overall ecosystem.

c) Purification of Groundwater Within 30 Minutes

Anjan Mukherjee assisting locals with installing Taraltec Disinfection Reactor. (Source: Taraltec Solutions). Most farmers are heavily dependent on groundwater to fulfil their water needs to grow food. However, using polluted groundwater can lead to water-borne diseases. To address this issue, Anjan Mukherjee, a former marine chief engineer, has developed the Taraltec Disinfection Reactor. It is a device that can be installed inside a hand pump or motorized borewell, and it will purify the contaminated water in 30 minutes by killing 99% of the microbes present in it. The device does not require electricity or fuel to function and hence, there are no maintenance costs. "The device converts the kinetic energy of the fluid into millions of targeted microbubbles each acting as localized reactors. This generates extreme heat, pressure and turbulence that releases intense energy packets during the collapse of bubbles. The resultant shockwave, marked by a bang sound, lacerates and kills the microbes. The water, which is 99% safer than it was earlier, then emerges from the borewell or pump into the hands of those drawing it," explains Mukherjee.

d) Treating Water with Human Hair

Human hair removed over 90 percent of the oil influence from water in its first experiment. At just 13, Nikhilesh Das from Assam came up with an indigenous way to use human hair to clean oil spills in water. He mixed motor oil and lubricant with water in a beaker. As the oil formed a layer on top, he deposited human hair and saw how it absorbed 90 per cent of the oil from water within 30 seconds. His innovation even won an award from former President, Pratibha Patil, in 2009.

e) Using AI and Robotics to Solve Water Woes

Using artificial intelligence and robotics, Asim Bhalerao and Nidhi Jain have been instrumental in diverting 600 MLD (Million Litres a Day) of raw sewage from entering water bodies and prevented over 5,600 hours of manual scavenging. The couple has developed a robot that can map and inspect underground pipelines. The collected data identifies structural defects, operations and maintenance failure modes that makes it easier for the authorities to fix them. "Solutions are expected to be cost effective, relevant, while being highly scalable and intrinsically safe to operate, in extremely hazardous conditions. Robotics and AI based solutions, that are developed with a deep understanding of problems on the ground, will be key in improving water treatment and water reuse," explains Asim. They have also come up with a drone that identifies similar problems in buildings, slums, pipelines, roads and villages. "We use AI and robotics to automate pipeline mapping and health assessment. We also use drones and AI for crop pattern analysis, identifying different crops and water sources for effective farm management," shares Nidhi. (Kerlia, 2018)

6.3 Ecosystem-soil and water conservation

Soil is a basic resource that allows the earth to provide a variety of benefits. Humans and animals depend on the land for food and life. Soil is important for the community because it supports plants that provide food, fibres, life-saving drugs and other essentials and because it filters water and recycles waste.

Forest water walls provide water purification, flood and drought mitigation, soil conservation, and shelter care. The quality and abundance of freshwater in lakes, wetlands, streams, and rivers determine the aquatic and terrestrial diversity of life.

There are two types of measures for soil and water conservation, that is, mechanical/engineering/structural measures and biological measures. Mechanical measures are permanent and semi-permanent structures that involve terracing, bunding, trenching, check dams, gabion structures, loose/stone boulders, crib wall, etc., while biological measures are vegetative measures which involve forestry, agroforestry, horticulture and agricultural/agronomic practices(Kumawat, Yadav, Samadharmam, & Rashmi, 2020).

6.3.1 Soil and water conservation measures

a) Contour farming

Contour ploughing mitigates the impacts of floods, storms and landslides on the crops by reducing soil erosion up to 50 percent, controlling runoff water, increasing moisture infiltration and retention and thus enhancing soil quality and composition (FAO, 2015).

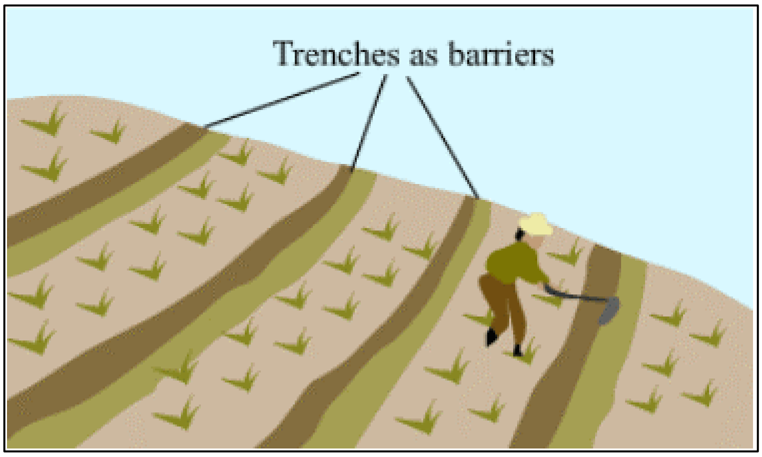

Figure 24 Contour farming (Source: edurev)

b) Choice of crops

Choosing the right crop is very important for soil and water conservation. Yield should be selected according to the intensity and the critical rainfall, market demand, climate, and the farmer's resources. Crops with good biomass, bed cover, and wide roots protect the soil from erosion and create barrier, thus reducing soil and nutrient losses(Kumawat et al., 2020).

c) Crop rotation

On sloping lands, **crop** rotations can help reduce **soil erosion**. Rotations with alfalfa and other legumes reduce fertilizer needs because these plants replace some of the nitrogen removed by corn and other grain **crops**. Rotations help improve **soil** health by adding diverse biological activity(USDA, 2015).

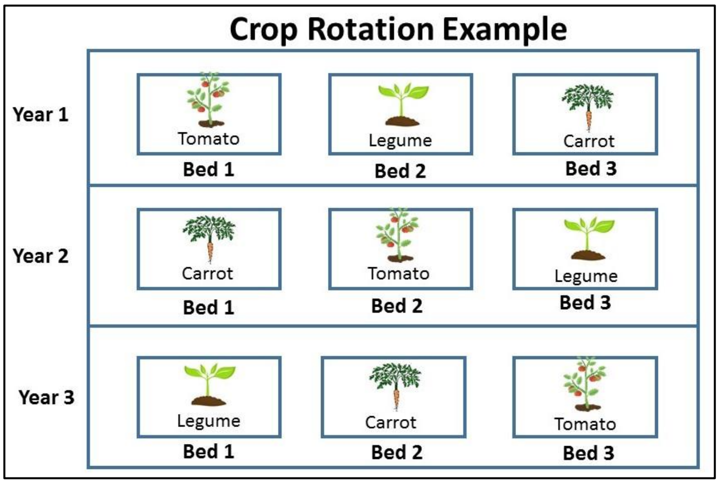

Figure 25 Crop rotation (Source: nwdistrict)

d) Cover crops

Nearby plants with high tower strength are planted to protect the soil from erosion, known as mulch. Legume plants have better biomass to protect the soil than successive plants.(Kumawat et al., 2020) The performance of the cover crop depends on the geometry of the plants and the construction of the bed for the prevention of raindrops which helps to reduce the exposure of soil erosion (Yousuf & Singh, 2019).

e) Intercropping

The planting of two or more plants simultaneously in the same field with a clear or distinct row pattern is known as intercropping. (Kumawat et al., 2020)It can be classified as linear, string, and re-distribution according to each crop, soil type, topography, and climatic conditions. Replanting involves time and space. Soil erosion that allows for plant resistance should be included. Plants should have different root growth patterns (Yousuf & Singh, 2019). Planting plants provides better soil, reduces the direct impact of raindrops, and protects the soil from erosion

f) Strip cropping

Growing some of the erosion pieces that allows for the erosion of plants with deep roots and the maximum size of the canopy in the same field is known as strip cropping.(Vanwalleghem, 2017) This practice slows down the running speed and monitors erosion processes and loss of nutrients from the field

g) Mulching

Mulch is any living or non-organic material used to cover the surface of the soil to prevent soil erosion, reduce evaporation, increase penetration, regulate soil temperature, improve soil composition, thereby maintaining soil moisture. (Kumar S, Meena RS, Yadav GS, 2017)Mulching prevents the formation of solid crust after each rain. The use of blade harrows between rows or cultural practices creates a "protective dust" on the surface of the earth by violating the continuity of capillary tubes of soil moisture and reduces evaporation losses (Jabran, 2019).

h) Conservation tillage

In this practice at least 30% of the soil should always be covered with crop residues before and after planting the next crop to reduce soil erosion and soil erosion, as well as other benefits such as C restoration (Sharma et al., 2019).

The term includes reduced cultivation, small-scale farming, non-tillage, direct piercing, vegetable gardening, ethnic farming, garbage farming, tillage farming, etc. The concept of conservation farming is widely accepted in large-scale crop production systems to reduce the drastic impact of raindrops and to conserve soil moisture by conserving soil carbon (Yousuf & Singh, 2019).

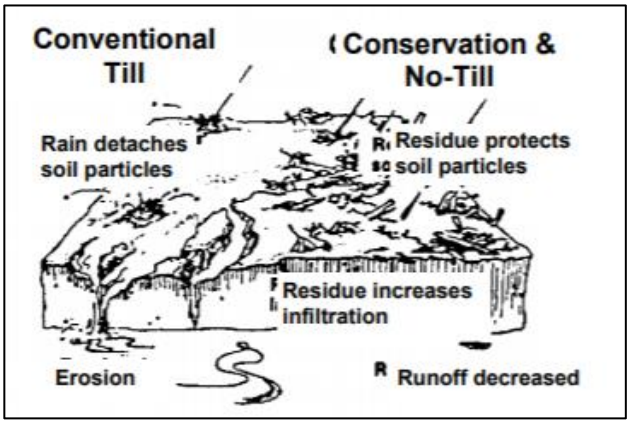

Figure 26 Conservation tillage (Source: Google)

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