SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

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SCHOOL OF BUILDING AND ENVIRONMENT

DEPARTMENT OFARCHITECTURE

Introduction

Traditional community wisdom regarding water management from ancient India

The oldest evidence of a plumbing system is the discovery of **copper water pipes** in palace ruins of India's Indus River Valley. These pipes date all the back to 4000-3000 B.C. In addition, earthen plumbing pipes dating around 2700 B.C. have been uncovered in the Indus Valley's ancient urban settlement

Hydrologic knowledge in India has a historical footprint extending over several millenniums through the Harappan civilization (∼3000–1500 BCE) and the Vedic Period (∼1500–500 BCE)

The **Mauryan Empire** (∼322–185 BCE) is credited as the first "hydraulic civilization" and is characterized by the construction of

- dams with spillways,
- reservoirs, and
- channels equipped with spillways (Pynes and Ahars);

they also understood water balance, development of water pricing systems, measurement of rainfall, and knowledge of the various hydrological processes

A typical Harappan well built with trapezoidal bricks to prevent inward collapse is as below:

Figure 1 Typical Harappan well

Civilisations

Civilisations began at places where water required for agricultural and human needs was readily available, i.e., close to springs, lakes, rivers and at low sea levels

Also, water cisterns for harvesting rainwater, canals and ground water wells were practiced since the Bronze Age (ca. 3200–1100 BC).

Sources of water could be seen as follows as we all know:

Figure 2 Sources of water

Civilizations in India were the following, showing the geographical extent of the indus valley civilisation

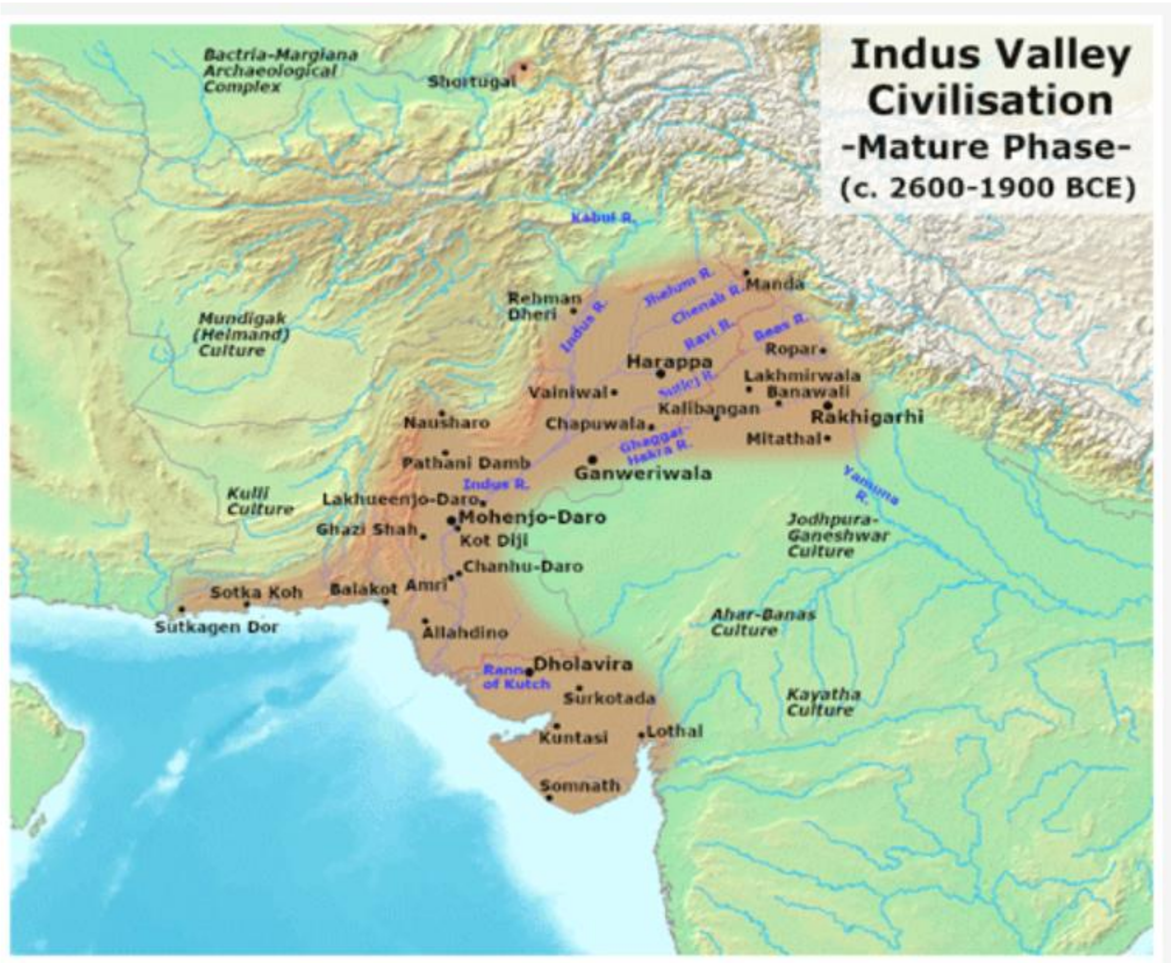

Figure 3 Extent of Indus valley civilization

Two major cities of the Indus Valley,

- Mohenjo-Daro
- Dholavira

These are the best examples of advanced water management and drainage systems

Rivers

Rivers played such a pivotal role in the life and living of those people that their civilizations came to be known as river valley civilizations.

Prominent among these were the

- Nile valley civilization in Egypt,
- the Tigris valley civilizations in Mesopotamia,
- the Howang-Ho valley civilization in China and the
- Indus valley civilization in India.

Most of these civilizations existed from 3500 to 300 BC. There are historical evidences to show that certain engineering measures were adopted by them to sustain as well as enhance benefits from rivers and also to protect against damages due to floods and droughts.

Indus Valley civilisation

It is also known as the Harappan Civilization, was a Bronze Age society extending from modern northeast Afghanistan to Pakistan and northwest India.

- The civilization developed in three phases:
  - Early Harappan Phase (3300 BCE-2600 BCE),
  - Mature Harappan Phase (2600 BCE-1900 BCE),
  - Late Harappan Phase (1900 BCE-1300 BCE).

Sir John Hubert Marshall led an excavation campaign in 1921-1922, during which he discovered the ruins of the city of Harappa. By 1931, the Mohenjo-daro site had been mostly excavated by Marshall and Sir Mortimer Wheeler. By 1999, over 1,056 cities and settlements of the Indus Civilization were located. In fact, The Partition of India, in 1947, divided the country to create the new nation of Pakistan. The bulk of the archaeological finds that followed were inherited by Pakistan.

Harappa: Indus valley developed the earliest known systems of flush toilets in the world. sculpted houses with flat roofs made of red sand and clay. It was home to as many as 23,500 residents. The city spread over 150 hectares (370 acres) and had fortified administrative and religious centers of the same type used in Mohenjo-daro

Mohen-joDaro: It was built in the 26th century BCE. It was the largest city of the Indus Valley Civilization. It was one of the world's earliest, major urban centers. It had sophisticated engineering and urban planning. It was was abandoned around 1900 BCE when the Indus Civilization went into sudden decline. Images below are typical features of Indus valley civilization.

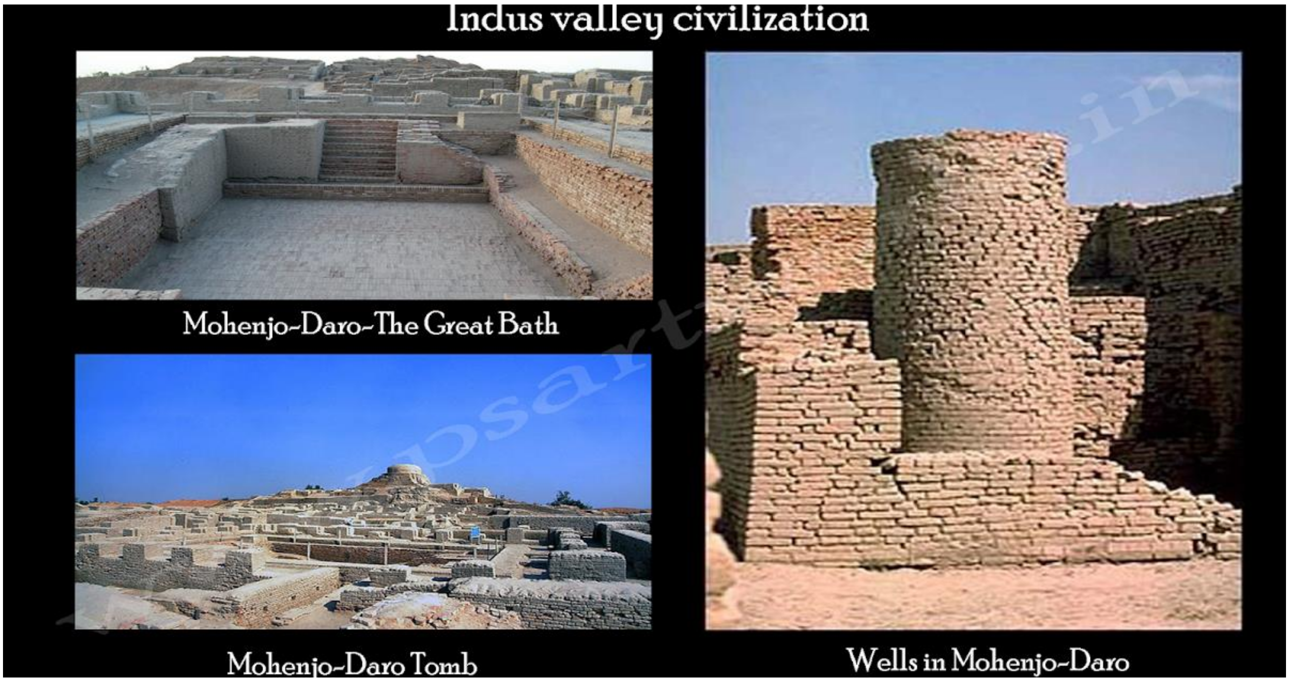

Figure 4 Typical features of Indus valley civilization

Water Management System- Mohenjo-Daro

A typical Mohenjo-Daro street with drain is as seen below:

Figure 5 Typical drainage system of MohenjoDaro

- The drainage system- one of the most remarkable features of the Mature Harappan city.
- All the streets and lanes across neighbourhoods in Mohenjo-daro had drains.

- In addition there was also provision for managing wastewater inside the houses with vertical pipes in the walls that led to chutes opening on to the street, as well as drains from bathing floors that flowed towards the street drains.
- The most remarkable feature was the high underground water table.
- The street drains were typically made of baked brick, with special shaped bricks to form corners.
- The bricks were closely fitted and sealed with mud mortar.
- Over time, the same drains were reused by raising the walls with more bricks.
- The drains were mostly covered and hidden underground.
- They were covered by a layer of baked bricked which was laid flat across the side walls of the drain.
- Wider drains were covered with limestone blocks.These were then covered with a layer of mud
- Small settling pools and traps were built into the system of drainage to allow sediment and other material to collect while the water and smaller particles flowed.

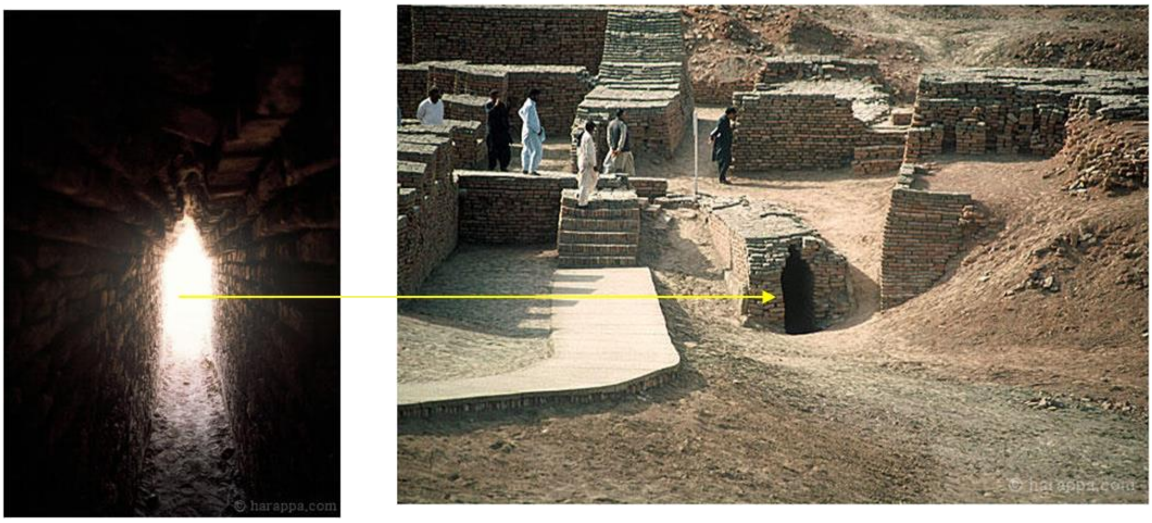

Figure 6 Drainage system showing an entry passage way

Wider drains were covered with extra long bricks, and for culverts, such as that at the Great Bath, a corbelled arch was used.

Note : The Indus Valley Civilization contained more than 1,000 cities and settlements. Although there were large walls and citadels, there is no evidence of monuments, palaces, or temples.

The Great Bath of Mohenjo-Daro of the Indus Valley is considered the “earliest public water tank of the ancient world” as seen below

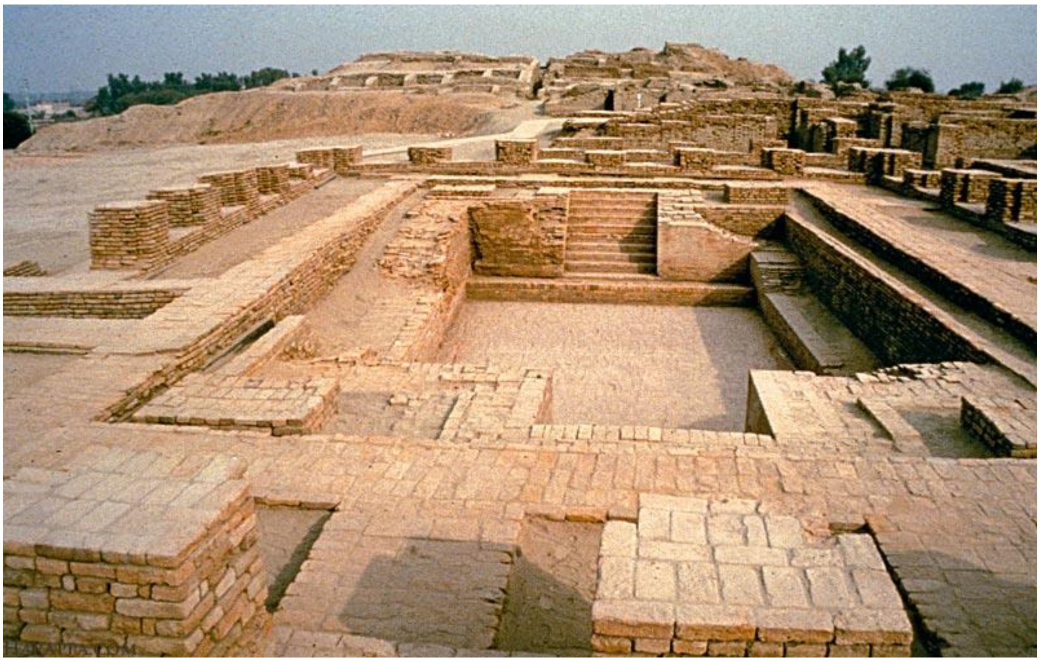

Figure 7 The great bath of MohenjoDaro

- India is known as the land of culture and spiritualism.
- Water has always had a pervasive influence on the cultural and the religious life of Indian people.
- The Great Bath of Mohenjo-Daro is a great testimony to this .
- The bath is considered by scholars as the "earliest public water tank of the ancient world".
- Although, the exact significance of the structure is unknown, most scholars agree that this tank was used for special religious functions.

Figure 8 The great bath of MohenjoDaro

Civilizations- Dholavira

Dholavira is an important city in the Indus Valley civilization. The Dholavira city was located between the ephemeral nullahs (streams) Mansar in the north and Manhar in the south (Fig. 4) and was equipped with a series of small check dams, stone drains for diverting water, and bunds to reduce the water velocity and thus to reduce siltation in the main reservoirs (eastern and western reservoirs). It has complex system for collecting and storing rain water within several reservoirs. It has a prolonged history of droughts, thus the Harappans were aware of the possibility of and were consciously practicing water management.

These helped in collecting rainwater in the catchment areas and bringing it to the reservoirs. This was achieved through an ingenious system involving stone bunds of dams that were raised across the streams at suitable points. From these the monsoon runoff was carried to a series of reservoirs, gouged out in the sloping areas between the inner and outer walls of the Harappan period city, through inlet channels. These water reservoirs were separated from each other by bund-cum-causeways, which also served to facilitate access to different divisions of the city.

This is reflected in the occurance of several rock-cut reservoirs. To fill these, there were two local , seasonal rivulets - the Mansar (to the north-west of Dholavira) and the Manhar (to the south-eastern part of the walled area).

Figure 9 Location of Dholavira

It had 16 large reservoirs (7 m deep and 79 m long). These storage structures account for about 10 % of the area of the city.

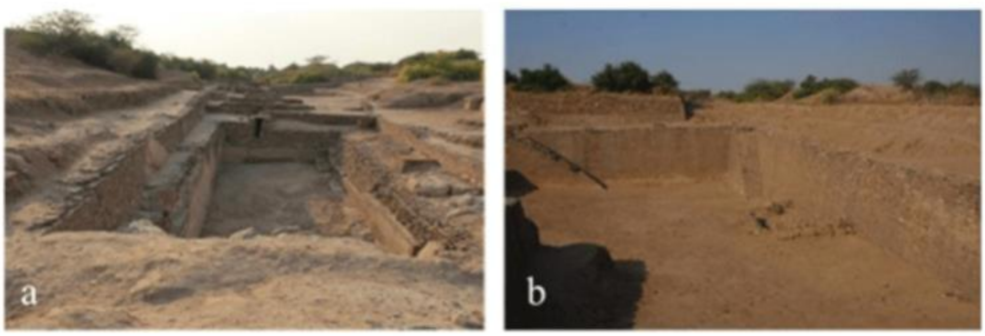

Figure 10 Souther (a) and Eastern (b) reservoir of Dholavira

It is Sandwiched between 2 different rivers. Water was directed through dams to flow in through the city

The layout of Dholavira is as can be seen below:

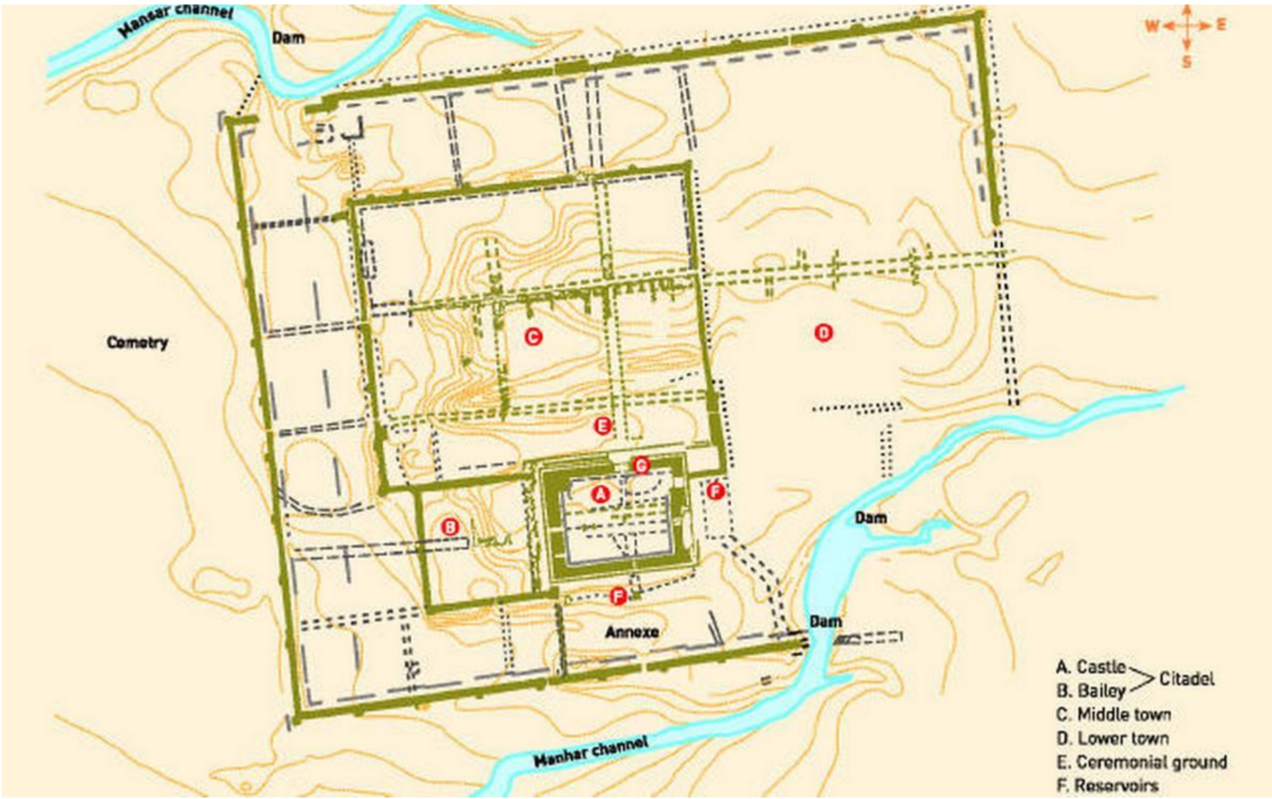

Figure 11 Layout of Dholavira

A typical storm water drain of Dholavira is as follows:

Figure 12 Typical storm water drain of Dholavira

Recently, a rectangular step well was found at Dholavira which measured 73.4 m long, 29.3 m wide, and 10 m deep, making it 3 times bigger than the Great Bath of Mohenjo-Daro

To summariza about Dholavira, the water management system at Dholavira is based on highly advanced hydraulic engineering, which is preferred and employed by even modern day technicians. Also, development of water resources and its conservation in this town was not only the responsibility of the higher authority but also the duty of the local community.

Lothal

It is claimed by the archeologists to be the first known dockyard of the world. The "Lothal" (meaning "mound of the dead"), known as the harbor city of the Harappan civilization (Bindra, 2003), is located at the doab of the Sabarmati and Bhogavo rivers. Lothal is an example of advanced maritime activities in those old days. Images below show the (a) Dockyard and ancient Indus port (b) Dockyard of Lothal

Figure 13 (a)Dockyard and ancient Indus port (b) Dockyard of Lothal

The existence of the massive protective wall (thickness of up to 18 m) around the Dholavira city indicates that the ancient Indians were aware of oceanic calamities such as tsunami and storms. A roughly trapezoidal structure having dimensions of • 212.40 m on the western embankment,

• 209.30 m on the eastern one,

• 34.70 m on the southern one, and

• 36.70 m on the northern one (Rao, 1979)

at Lothal is an example of advanced maritime activities in those old days. it is claimed by the archeologists to be the first known dockyard of the world

Water transport

Water transport over long distances was based on gravity. Thus, long aqueduct systems (indeed, sometimes exceeding 100 km) were used to convey water over large distances, using gravity. Water cisterns for harvesting rainwater, canals and ground water wells were practiced since the Bronze Age (ca. 3200–1100 BC). A roman aqueduct is as seen below

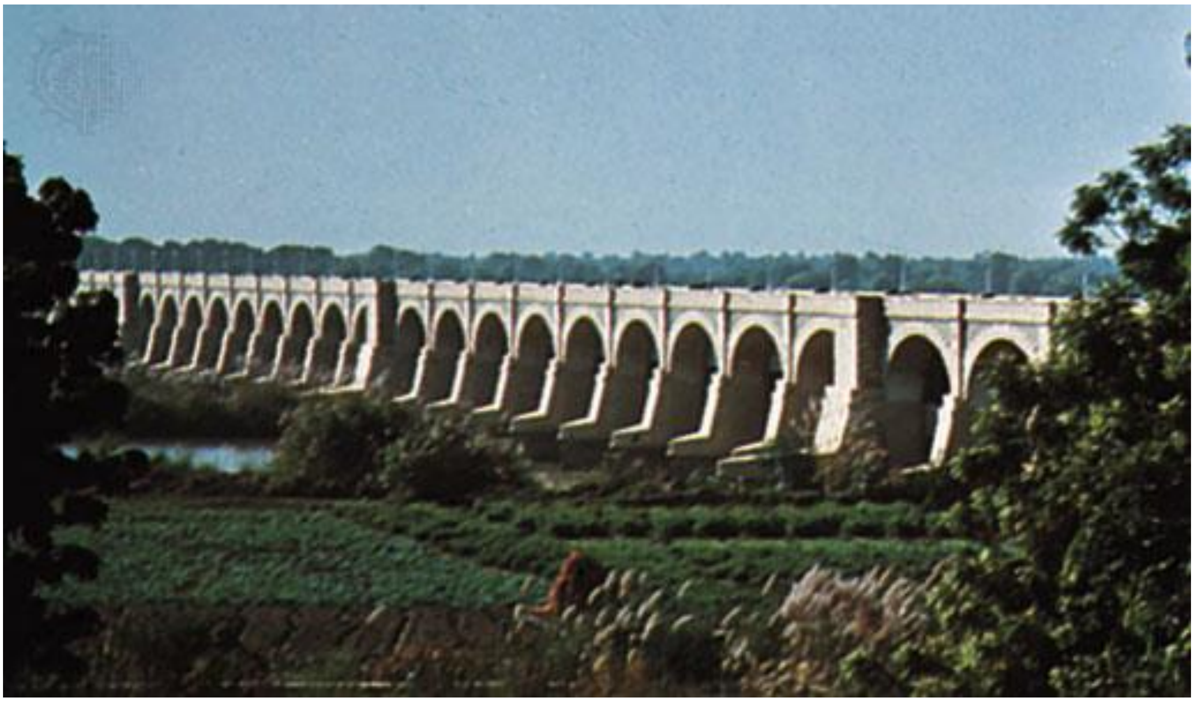

Figure 14 Typical roman aqueduct

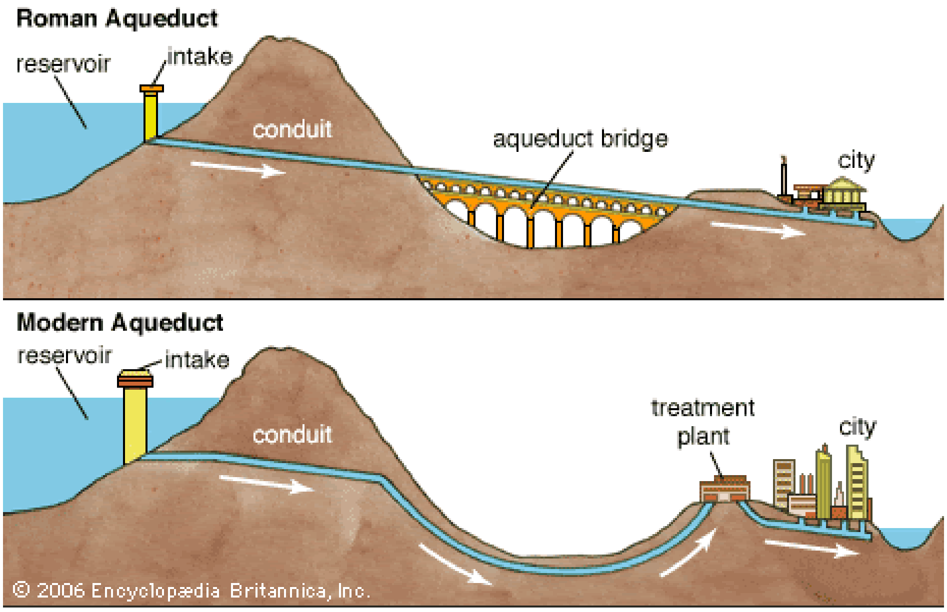

Figure 15 Roman aqueduct vs modern aqueducts

The Roman aqueduct was a channel used to transport fresh water to highly populated areas. Aqueducts were amazing feats of engineering given the time period. Though earlier civilizations in Egypt and India also built aqueducts, the Romans improved on the structure and built an extensive and complex network across their territories. Evidence of aqueducts remain in parts of modern-day France, Spain, Greece, North Africa, and Turkey.

Aqueducts required a great deal of planning. They were made from a series of pipes, tunnels, canals, and bridges. Gravity and the natural slope of the land allowed aqueducts to channel water from a freshwater source, such as a lake or spring, to a city. As water flowed into the cities, it was used for drinking, irrigation, and to supply hundreds of public fountains and baths.

Roman aqueduct systems were built over a period of about 500 years, from 312 B.C. to A.D. 226. Both public and private funds paid for construction. High-ranking rulers often had them built; the Roman emperors Augustus, Caligula, and Trajan all ordered aqueducts built.

The most recognizable feature of Roman aqueducts may be the bridges constructed using rounded stone arches. Some of these can still be seen today traversing European valleys. However, these bridged structures made up only a small portion of the hundreds of kilometers of aqueducts throughout the empire. The capital in Rome alone had around 11 aqueduct systems supplying freshwater from sources as far as 92 km away (57 miles). Despite their age, some aqueducts still function and provide modern-day Rome with water. The Aqua Virgo, an aqueduct constructed by Agrippa in 19 B.C. during Augustus' reign, still supplies water to Rome's famous Trevi Fountain in the heart of the city.

Decline of civilisations

Dholavira presents a classic case for understanding how climate change can increase future drought risk as predicted by the IPCC working group. Harappan Dholavira was near-synchronous to the decline at all the Harappan sites in India as well as societal collapse of Mesopotamia, Greece, China and the Old Kingdom of Egypt. There were many theories on the decline as follows:

1. Drying up of Saraswati river around 1900 BCE

2. Malaria evidences found on skeletons

3. Shift of monsoon towards east direction leading to droughts

4. Hit by a great flood

5. Invaded by Indo-European group – the Aryans

Inspite of all these theories, the Indus Valley Civilization declined around 1800 BCE due to climate change and migration.

The Newer era

The newer era began with the De-urbanization phase (~1900–1500 BCE) of the Harappan civilization

Vedic Period in the Indian subcontinent can be bracketed between ~1500 and 500 BCE.

- Early Vedic Period" (~1500–1100 BCE) •
- Late Vedic Period" (~1100–500 BCE)

By the beginning of 300 BCE, a firm administrative setup had taken shape.

• The Vedic texts and other Mauryan period texts such as Arthashastra mention other hydrologic processes such as infiltration, interception, streamflow, and geomorphology, including the erosion process. It mentions a manually operated cooling device referred to as **"Variyantra"** (revolving water spray for cooling the air). The Variyantra was similar to the water cooler. The ***Arthashastra*** also gives an extensive account of hydraulic structures built for irrigation and other purposes during the period of the Mauryan Empire. This suggests that the technology of the construction of the dams, reservoirs, channels, measurement of rainfall, and knowledge of the various hydrological processes existed in the ancient Indian society.

The Mauryan Empire

The Mauryan Empire (~322– 185 BCE) is credited as the first "hydraulic civilization" and is characterized by the construction of dams with spillways, reservoirs, and channels equipped **with** spillways (Pynes and Ahars); they also had an understanding of water balance, development of water pricing systems, measurement of rainfall, and knowledge of the various hydrological processes.

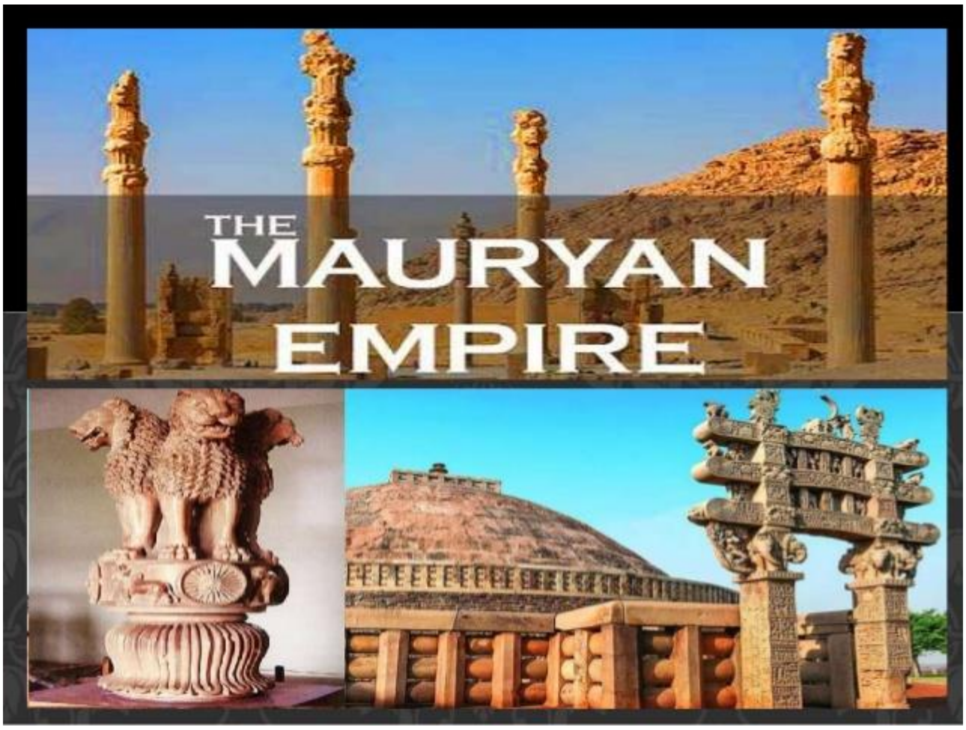

Figure 16 Mauryan empire main characteristics

It had departments concerned with the rivers, excavating, and irrigation along with a number of regional and other superintendents such as the superintendent of

• rivers;

• agriculture;

• weights and measures; • store house;

• space and time; • ferries,

• boats, and ships; • towns;

• pasture grounds; • road cess;

• and many others along with other strata of the associated officers such as head of the departments (adhyakshah), collector general (samahartri), and chamberlain (sannidhatri), etc.

Water pricing

Water pricing was also an important component of the water management system in the Mauryan Empire. According to *Arthashastra*, those who cultivate through irrigation:

(i) by manual labor would have to pay one-fifth of the produce as water rate (ii) by carrying water on shoulders- one-fourth of the produce;

(iii) by water lifts -one-third of the produce; and

(iv) by raising water from rivers, lakes, tanks, and wells one-third or one-fourth of the produce.

The superintendent of agriculture was responsible for compiling the meteorological statistics by using a rain gauge and for observing the sowing of the wet crops, winter crops or summer crops depending on the availability of the water.

The Arthashastra of Kautilya give an extensive account of dams and bunds that were built for irrigation during the period of the Mauryan Empire. The water supply systems were well managed within the framework of strict rules and regulations. Different type of taxes was collected from the cultivator depending upon the nature of irrigation. The tax rate was 25 per cent of the produce in respect of water drawn from natural sources like rivers, tanks and springs. For water drawn from storages built by the King the tax rate varied according to the method of drawing water. For instance, it was 20 per cent of the produce for water drawn manually, 25 per cent for water drawn by bullock and 33 per cent for that diverted through channels. Exemptions from payment of water rates were given for building or improving irrigation facilities. The period of exemption was 5 years for new tanks and bunds, 4 years for renovation old works and 3 years for clearing he works over gown with weeds.

Developments can be mapped to the following:

• Drier climates and water scarcity in India led to numerous innovations in water management. • Since Indus valley civilization, the following techniques were developed throughout the region:

• Irrigation systems,

• different types of wells,

• water storage systems and

• low cost and sustainable water harvesting

• The reservoir built in 3000 BC at Girnar and the ancient step-wells in Western India are examples of some of the skills.

Traditional well designs of India

For centuries, stepwells—which incorporated a cylinder well that extended down to the water table—provided water for drinking, washing, bathing, and the irrigation of crops

• Stepwells were excavated several stories underground in order to reach the water table, the level at which the soil or rock is always saturated with water.

There are two common types of stepwells.

- The first one is the step pond with a large-mouthed apex and modified sides that meets at a moderately low profundity.
- The second one would be the actual step well category that generally includes a tapered shaft, guarded from direct sunbeams by full or partial covering that ends with a curved, profound 'well-end'.

Rudimentary stepwells first appeared in India between the 2nd and 4th centuries A.D., born of necessity in a capricious climate zone bone-dry for much of the year followed by torrential monsoon rains for many weeks. It was essential to guarantee a year-round water-supply for drinking, bathing, irrigation and washing, particularly in the arid states of Gujarat (where they're called *vavs*) and Rajasthan (where they're *baoli, baori*, or *bawdi*) where the water table could be inconveniently buried ten-stories or more underground. Over the centuries, stepwell construction evolved so that by the 11th century they were astoundingly complex feats of engineering, architecture, and art.

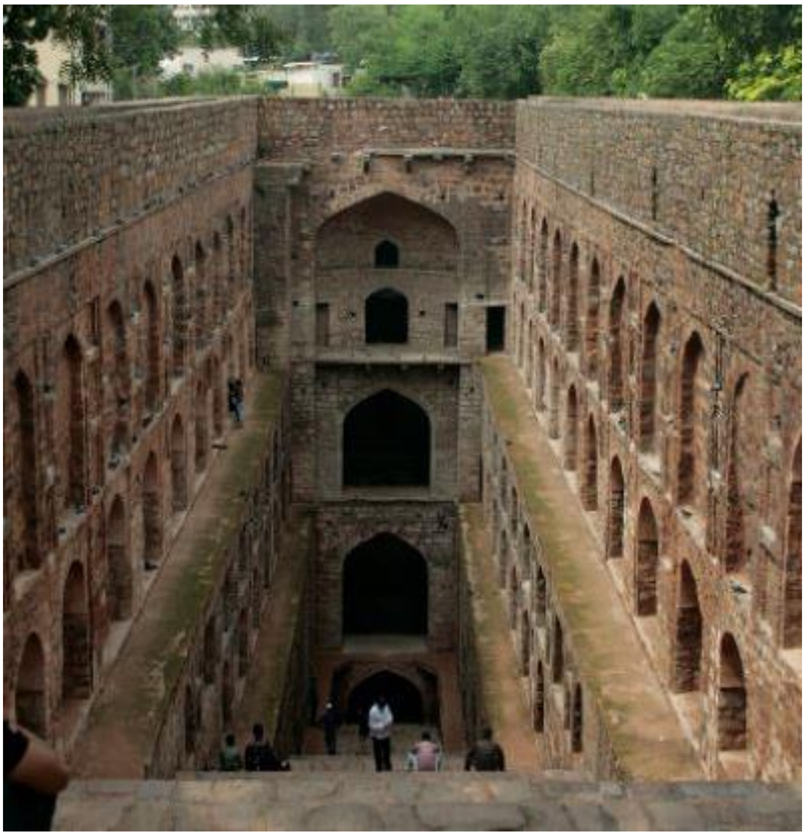

Figure 17 Typical stepwell

Construction of stepwells involved not just the sinking of a typical deep cylinder from which water could be hauled, but the careful placement of an adjacent, stone-lined "trench" that, once a long staircase and side ledges were embedded, allowed access to the ever-fluctuating water level which flowed through an opening in the well cylinder. In dry seasons, every step – which could number over a hundred - had to be negotiated to reach the bottom story. But during rainy seasons, a parallel function kicked in and the trench transformed into a large cistern, filling to capacity and submerging the steps sometimes to the surface. This ingenious system for water preservation continued for a millennium. In many wells – particularly those in Gujarat – covered "pavilions" punctuated each successive level, accessed by narrow ledges as the water level rose, and providing vital shade while also buttressing walls against the intense pressure. For this same reason, most stepwells gradually narrow from the surface to the lowest tier underground, where the temperature is refreshingly cool. By building down into the earth rather than the expected "up", a sort of reverse architecture was created and, since many stepwells have little presence above the surface other than a low masonry wall, a sudden encounter with one of these vertiginous, man-made chasms generates both a sense of utter surprise and total dislocation.

By the 19th-century, several thousand stepwells in varying degrees of grandeur are estimated to have been built throughout India, in cities, villages, and eventually also in private gardens where they're known as "retreat wells". But stepwells also proliferated along crucial, remote trade routes where travelers and pilgrims could park their animals and take shelter in covered arcades. They were the ultimate public monuments, available to both genders, every religion, seemingly anyone at all but for the lowest-caste Hindu. It was considered extremely meritorious to commission a stepwell, an earthbound bastion against Eternity, and it's believed that a quarter of these wealthy or powerful philanthropists were female. Considering that fetching water was (and is still) assigned to women, the stepwells would have provided a reprieve in otherwise regimented lives, and gathering down in the village vav was surely an important social activity.

Stepwells fall into similar categories based on their scale, layout, materials, and shape: they can be rectangular, circular, or even L-shaped, can be built from masonry, rubble or brick, and have as many as four separate entrances. But no two are identical and - whether simple and utilitarian, or complex and ornamented - each has a unique character. Much depends on where, when, and by whom they were commissioned, with Hindu structures functioning as bona-fide subterranean temples, replete with carved images of the male and female deities to whom the stepwells were dedicated. These sculptures formed a spiritual backdrop for ritual bathing, prayers and offerings that played an important role in many Hindu stepwells and despite a lack of accessible ground water, a number continue today as active temples, for instance the 11th-century Mata Bhavani vav in Ahmedabad.

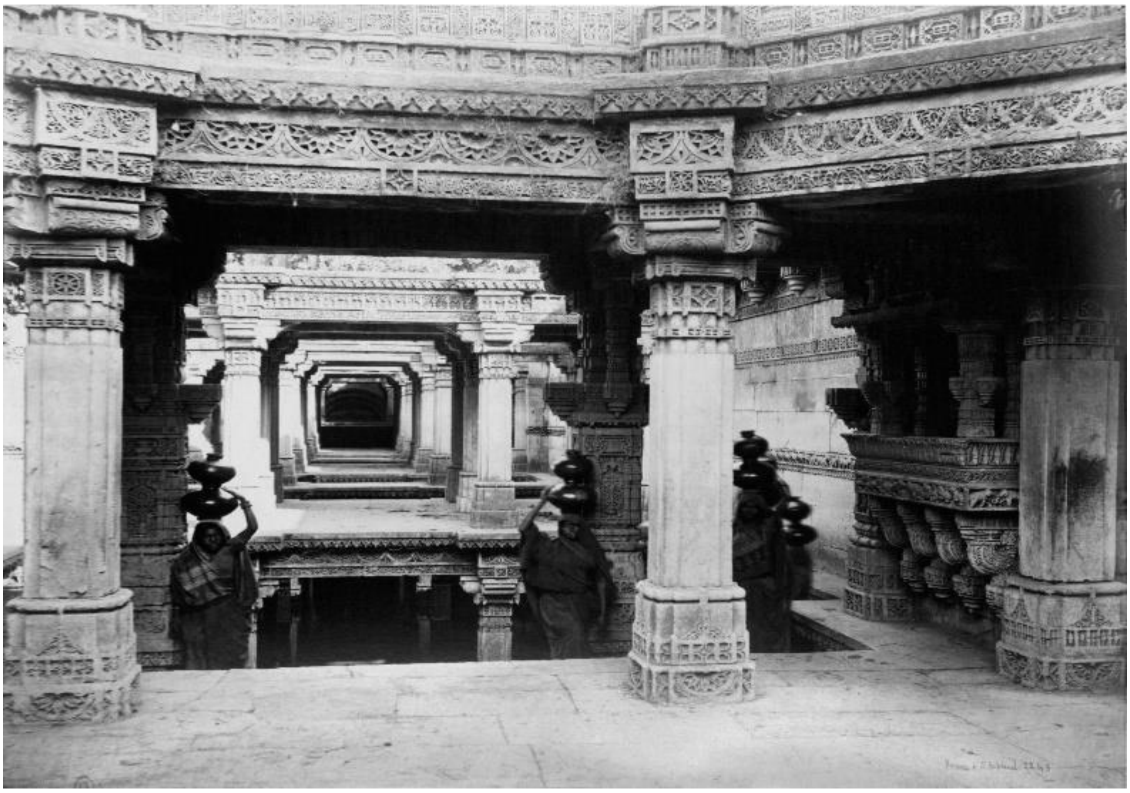

Figure 18 Stepwell Adalaj of Gujarat

Nowhere was a more elaborate backdrop for worship planned than at India's best-known stepwell, the Rani ki vav (Queen's Well) two hours away in Patan. Commissioned by Queen Udayamati around 1060 A.D. to commemorate her deceased spouse, the enormous scale – 210 feet long by 65 wide – probably contributed to disastrous flooding that buried the vav for nearly a thousand years under sand and mud close to its completion. The builders realized they were attempting something risky, adding extra buttressing and massive support walls, but to no avail. In the 1980's, the excavation and restoration of Rani ki vav (which is hoped to achieve UNESCO World Heritage status soon) were completed but by then, long-exposed columns on the first tier had been hauled off to build the nearby 18th-century Bahadur Singh ki vav, now completely encroached by homes.

Summarizing some main features of the step wells:

- First basic step wells first appeared in India in the 3rd century CE
- As deep as the water table

- Places of religious and social activities
- During summer, water level may be as low as the lowest point in a water table. IN monsoon, it can be quite high
- Many wells were commissioned by women philanthropists
- Usually made of stones
- Constructed in different shapes- circular, rectangular, l-shaped
- A long, deep flight of staircases were constructed
- Ledge along the perimeter for accessing water in case of rise of water levels
- Began as a community-level structure and started developing in various places as personal wells as well

Baoris

- Baoris are community wells that are used mainly for drinking purposes. Most of them are very old and were built by Banjaras (nomadic communities) for their drinking water needs.
- They can hold water for a long time because of almost negligible water evaporation.
- Baori may refer to: a Stepwell, as baori is one of the Hindi and Urdu terms for a stepwell.
- Chand Baori is one of the few stepwells that has "two classical periods of water building in a single setting“.
- Chand Baori consists of 3,500 narrow steps over 13 stories. It extends approximately 30 m (100 ft) into the ground, making it one of the deepest and largest stepwells in India.

Figure 19 Chand Baori at Rajastan

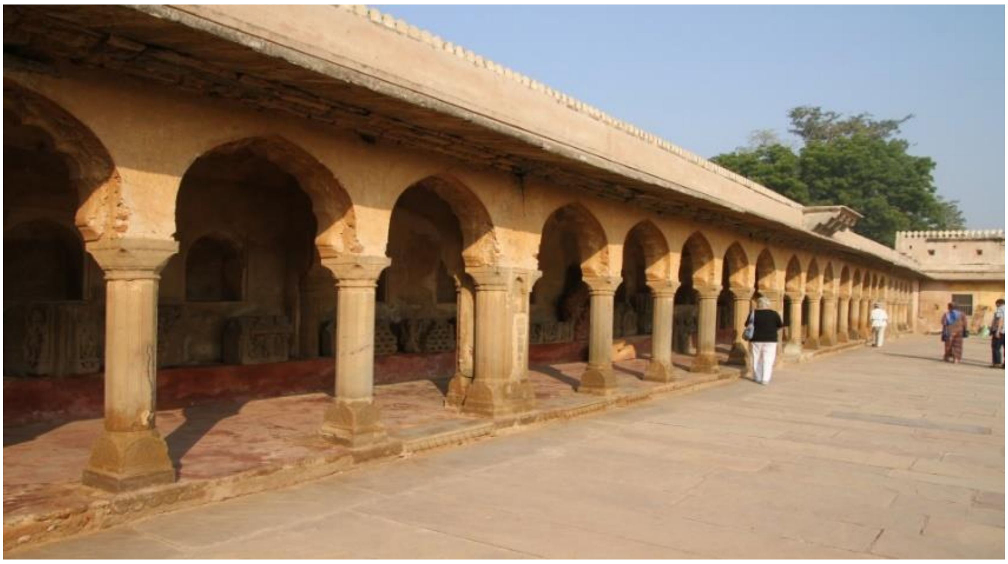

Figure 20 Baoris

Swastika well, Tamil Nadu

Swastika well, also known as Marpidugu Perunkinaru, was dug by King Kamban Araiyan. One inscription found in this well is in poetical form and describe the immortal life of man.

Figure 21 Swastika well at Tamil Nadu

- This unusually designed well located at the back of the premises. This swastika shaped well is surrounded by hedges and bushes. It has four stepped gateways. The peculiar feature of the well is that it ensures privacy for those taking bath in the four enclosures. Hence local people call it as Mother-in-law – Daughter - in – law Tank.

Figure 22 Swastika well at Tamil Nadu

Tankas

- A taanka, are also known as a tanka or kunds, is a traditional water storage technique, common to the Thar desert region of Rajasthan, India.
- It is meant to provide drinking water for and water security for a family or a small group of families.
- A tanka is composed of a covered, underground, impermeable cistern on shallow ground for the collection of rainwater.

Figure 23 A typical Tanka

A taanka is composed of a covered, underground, impermeable cistern on shallow ground for the collection of rainwater. The cistern is generally constructed out of stone or brick masonry, or concrete, with lime mortar or cement plaster. Rainwater or surface run-off from rooftops, courtyards, or artificially prepared catchments (locally called *agor*) flow into the tank through filtered inlets in the wall of the pit. The water stored day task to fetch water from long distance, often contaminated, water sources. The water in a taanka is usually only used for drinking. If in any year there was less than normal rainfall and household taankas do not get filled, water would instead be obtained from nearby wells and tanks to fill the taankas.

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UNIT – II – Water Management-Macro Level

Introduction

- Water is often envisioned as bloodstream of biosphere.
- It is a universal medium that is crucial for sustainability of both ecological and human societies.
- More than 70% of the earth surface is covered by water. However, only 3% of this reserve is fresh water that can be used for human consumption.
- 90% of the earth's fresh water resources is contained in groundwater and ice, and only 10% is water is contained in surface reservoirs as rivers, lakes, wetlands and streams

To plan sustainable utilization of water resources, we must understand how the water cycle works at the global and local scales. The amount of water on earth is finite, and the natural water cycle is a system that controls the circulation and redistribution of that resource.

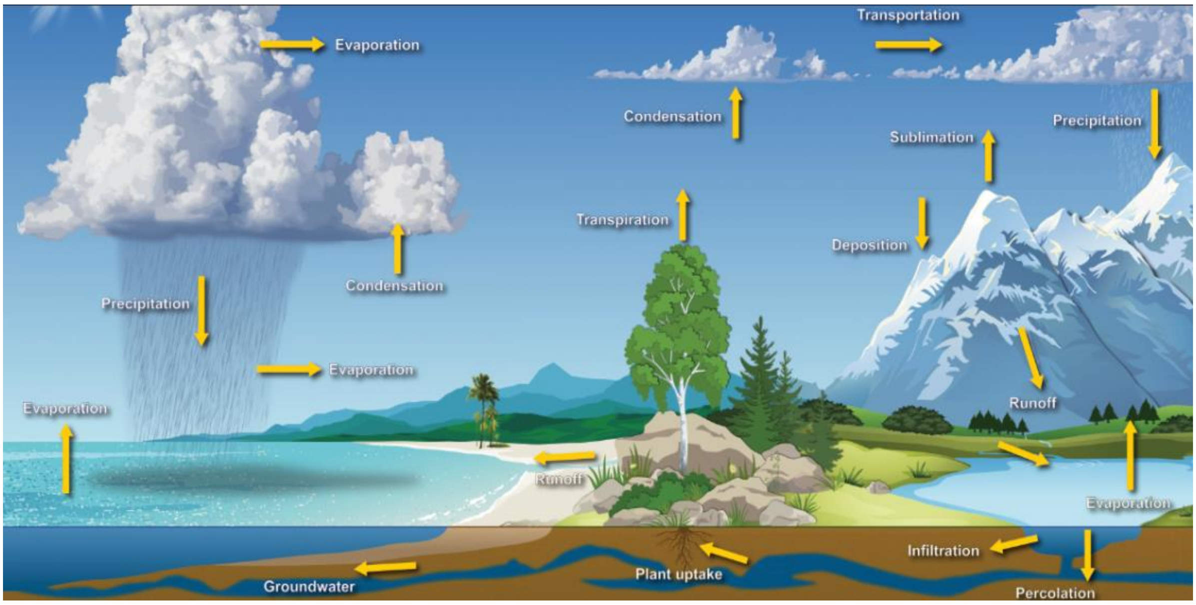


Figure 24 Water cycle depiction

Stages of water cycle are as follows:

The complete water cycle is carried into four stages which are as follows: Evaporation, Condensation, Precipitation and Collection.

Evaporation

This is the initial stage of the water cycle.

The process by which water from its liquid state changes to vapour, a gaseous state, is termed as evaporation. During the water cycle, water in the water bodies get heated up and evaporates in the form of vapour, mixes with the air and disappears.

Condensation

When the evaporated water vapour loses its thermal energy, it becomes liquid through the process of condensation. Formation of clouds are examples of condensation.

Precipitation

Rain, snow, sleet, or hail are all examples of Precipitation. After the condensation, atmospheric water vapour forms sufficiently large water droplets and falls back to the earth with the help of gravity.

Deposition or Collection

This is the final stage of the water cycle. Deposition occurs when evaporated water vapour falls back to earth as precipitation. This water may fall back into the different water bodies, including oceans, rivers, ponds, lakes and even end up on the land, which in turn becomes a part of the groundwater.

Overall, the water cycle process describes how water is balanced in the atmosphere. It also plays an important role in ensuring the availability of water for all living organisms and also it has a great impact on our environment.

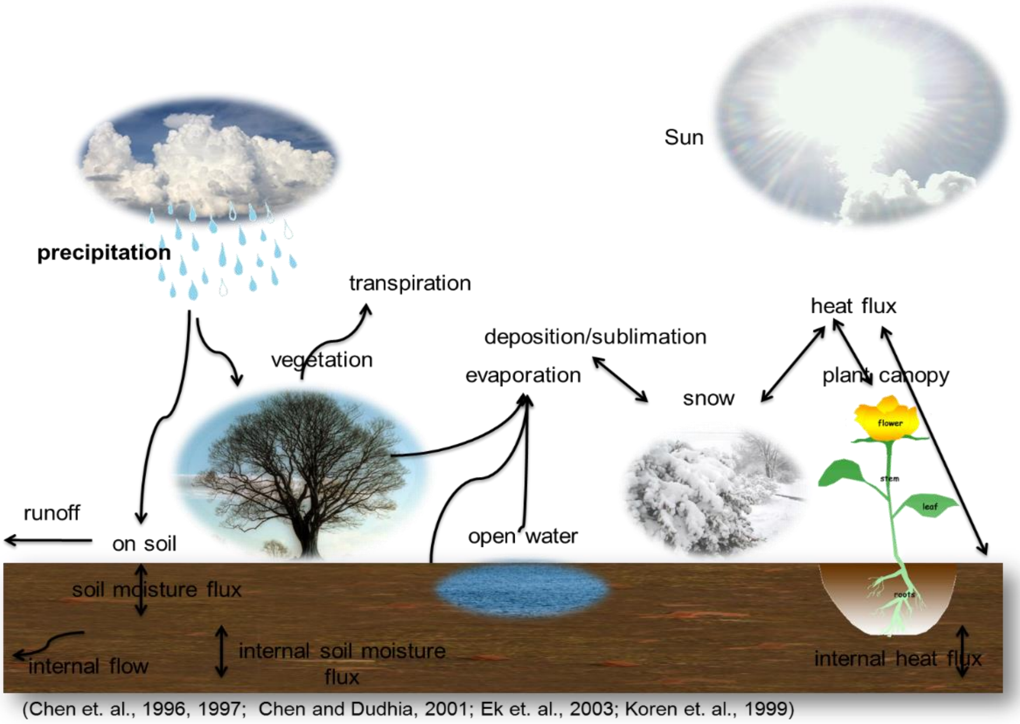


Figure 25 Water cycle process typical depiction

The effects on climate are as follows

- The water cycle is powered from solar energy. 86% of the global evaporation occurs from the oceans, reducing their temperature by evaporative cooling.

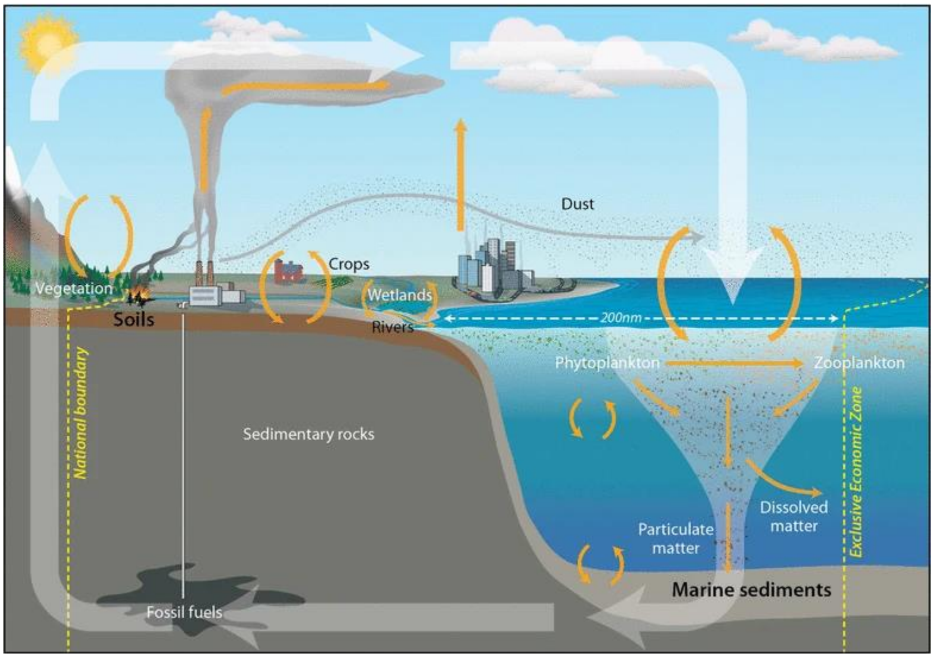


Figure 26 Effects of water cycle

- Without the cooling, the effect of evaporation on the greenhouse effect would lead to a much higher surface temperature of 67 °C (153 °F), and a warmer planet.
- Aquifer drawdown or over drafting and the pumping of fossil water increases the total amount of water in the hydrosphere, and has been postulated to be a contributor to sea-level rise.
- While the water cycle is itself a biogeochemical cycle, flow of water over and beneath the Earth is a key component of the cycling of other biogeochemicals.

The effects on surfaces are as follows:

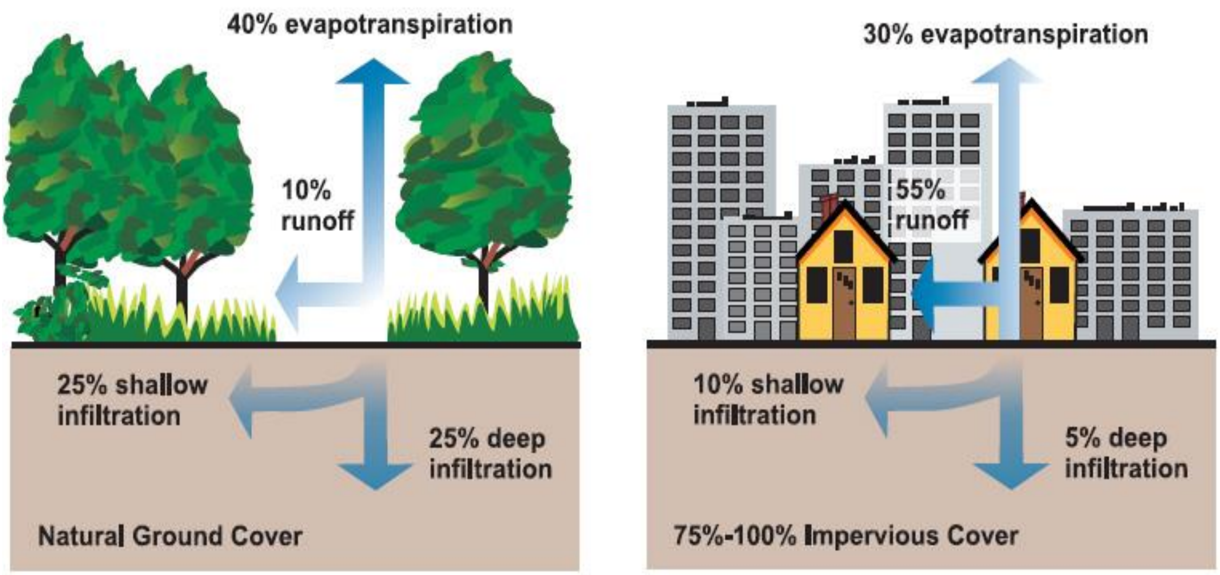


Figure 27 Effect of water run off on surfaces

It can be seen that in areas with natural ground cover, there is only 10% runoff and 25% shallow infiltration with 25% deep infiltration. However in the case of an urban area, the run off is quite high to the range of 55%, and only 10% shallow infiltration with 5% deep infiltration.

Management of water supply, sanitation and drainage.

- Earth is currently confronted with a relatively new situation, the ability of humans to transform the atmosphere, degrade the biosphere, and alter the lithosphere and hydrosphere.
- The challenges of our current decade—resource constraints, financial instability, religious conflict, inequalities within and between countries, environmental degradation.

Freshwater stress:

Today everyone is concerned about the potential water scarcity in the face of increasing, mainly:

- Population-driven
- Water demands
- Its consequences on our energy and food production.

By 2050, the world will have to feed and provide energy for an additional 2–2.5 billion people as well as meet the current unsatisfied power needs of a billion. India placed 13th among the world's 17 ‘extremely water-stressed’ countries, according to the Aqueduct Water Risk Atlas released by the World Resources Institute (WRI). To meet the nutritional needs of this additional population, we should consider the amount of water that is consumed in the production of different goods and, in particular, energy and food

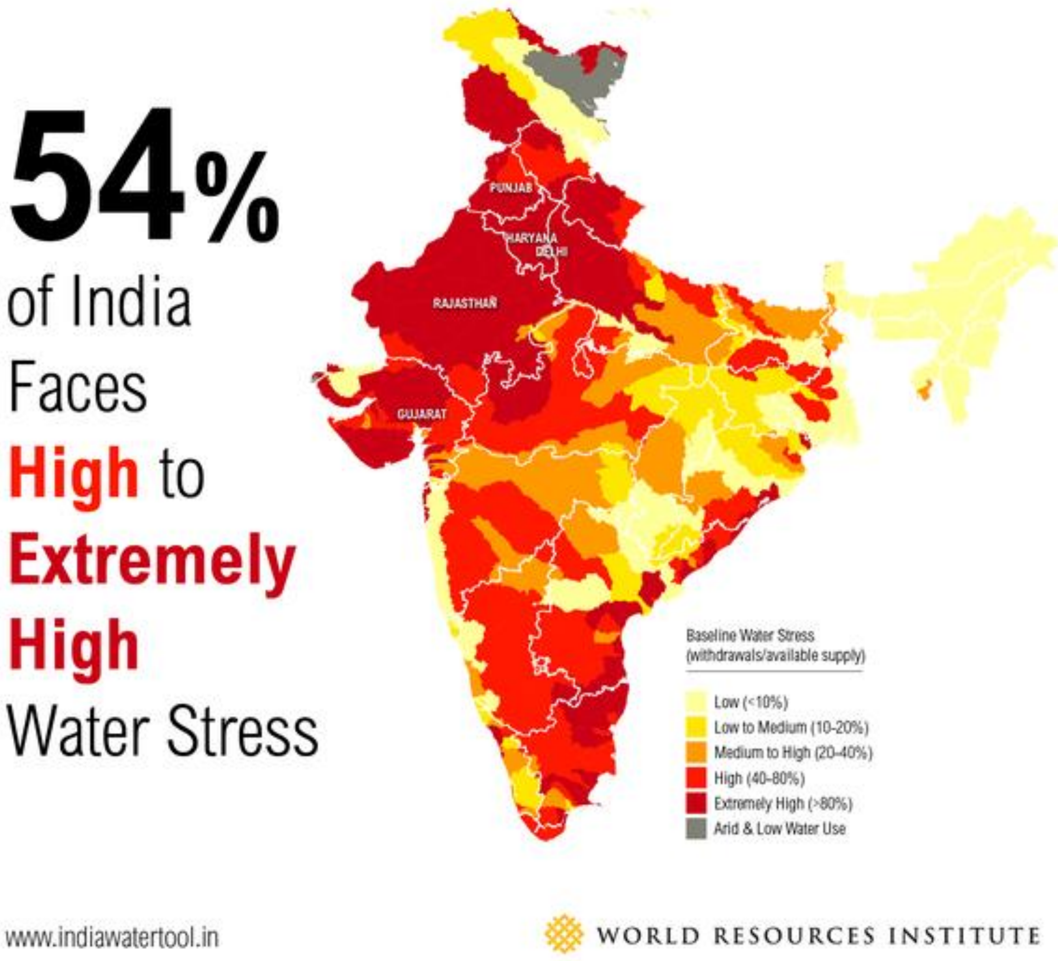


Figure 28 Water stress on India

Water supply in rural and urban areas:

Principal source of drinking water:

- 42.9% of households in rural areas use hand pumps a
- 40.9% of households in the urban areas use piped water
- There is a need to remove the large disparity between stipulations for water supply in urban areas and in rural areas. Efforts should be made to provide improved water supply in rural areas with proper sewerage facilities.

The solutions for water management systems mainly include

- engineering and construction services,
- operations and maintenance services,
- performance contracts,
- major maintenance and refurbishment, and
- collecting and treating waste water for safe discharge or recycling.

Important - to cover the whole water cycle, from collection to discharge, together with network and customer management, to meet the needs of cities

Figure 29 Water usage in rural and urban areas

The aim should be to reduce the amount of raw water extracted and to encourage cities to recycle and reuse water.

- The World Health Organization (WHO, n.d.) defines sanitation as: the provision of facilities and services for the safe disposal of human urine and faeces, the maintenance of hygienic conditions, through services such as garbage collection and wastewater disposal.
  - ‘facilities’ = structures that are used to provide sanitation.
  - ‘services’ = whole scheme for providing sanitation.

Below is a map showing percentage of population served by different types of sanitary systems

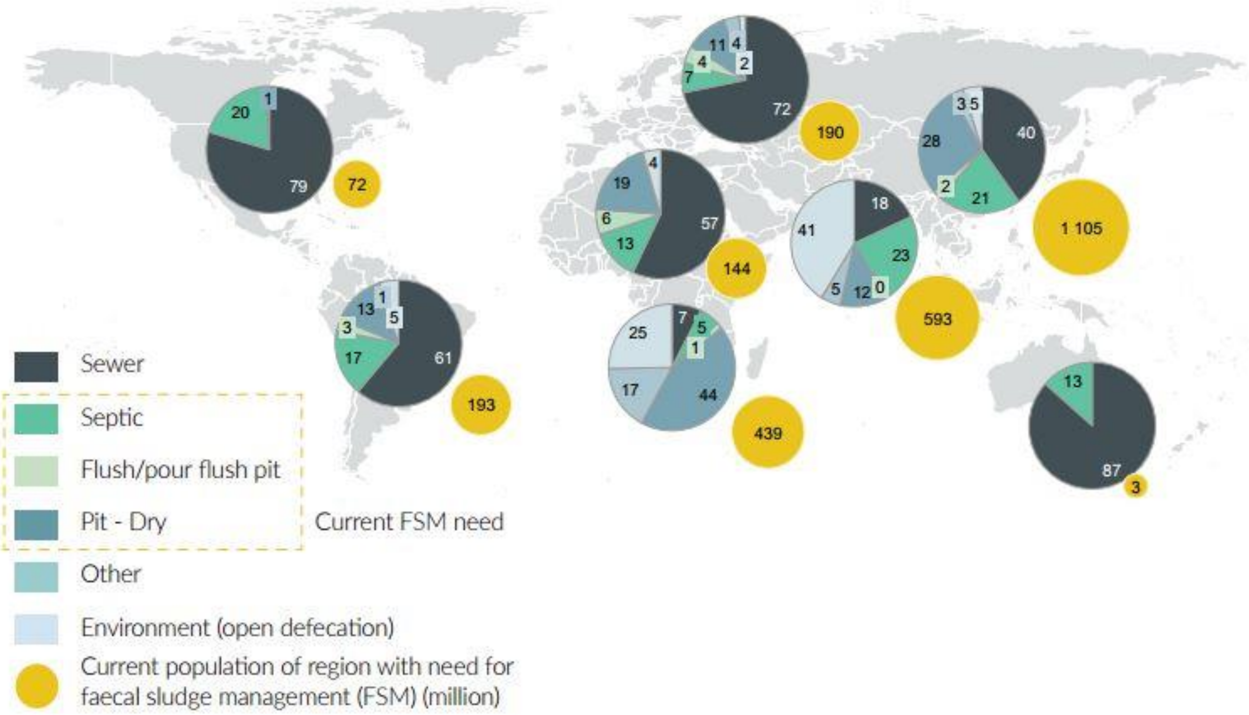


Figure 30 Percentage of population served by different types of sanitary systems

Challenges of sanitation in India

- Low infrastructure

- Population
- Growing water scarcity
- The potential for water reuse and conversation.
- Implementing innovative low-cost sanitation systems.
- Maintaining the sewage treatment plants and sanitation systems

Figure 31 Lack of sanitation scenario in India

Sustainable sanitation

Sustainable sanitation is needed to protect and promote human health. This can be done by providing a clean environment and breaking the cycle of disease.

The main objective of a sanitation system is to protect and promote human health by providing a clean environment and breaking the cycle of disease.

To qualify as sustainable sanitation, a sanitation system has to be economically viable, socially acceptable, technically and institutionally appropriate, and protect the environment and natural resources.

Most sanitation systems have been designed with these aspects in mind, but they fail far too often because some of the criteria are not met. In fact, there is probably no system which is absolutely sustainable. The concept of sustainability is more of a direction than a state to reach. Nevertheless, it is crucial that sanitation systems are evaluated carefully with regard to all dimensions of sustainability.

Since appropriateness to the context is such a core criterion for sustainable sanitation, there is no one-size-fits-all sanitation solution. However, taking into consideration the entire range of sustainability dimensions, it is important to observe some basic principles when planning and implementing a sanitation system

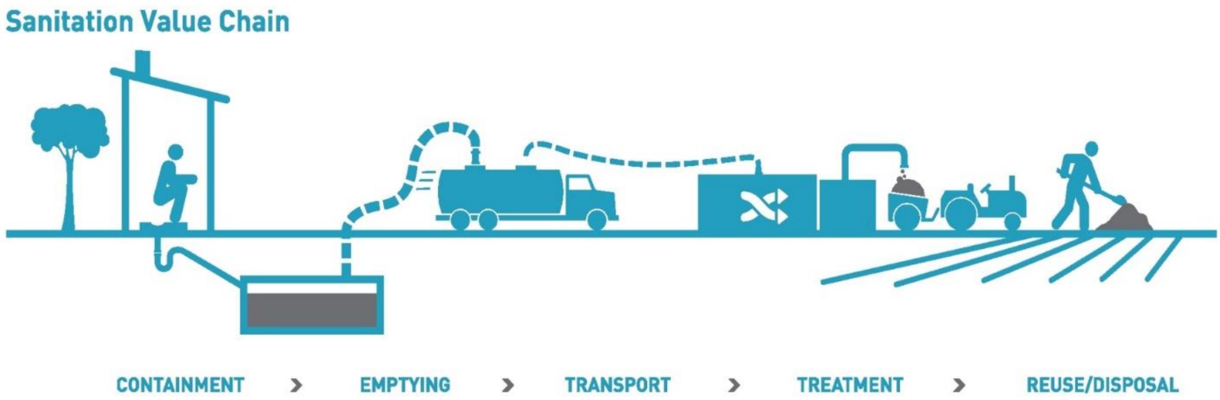


Figure 32 Sanitation value chain

The scheme shows the value chain of excreta: containment, emptying, transport, treatment, reuse or disposal. It is used to illustrate the Water, Sanitation and Hygiene (WSH) program of the Gates Foundation. The idea is to recover resources and to improve sanitation in areas with no centralized sewerage systems in order to contribute to sustainable sanitation services for the poor.

Drainage

The Indus Valley Civilization had advanced sewerage and drainage systems. All houses in the major cities of Harappa and Mohenjo-Daro had access to water and drainage facilities. Waste water was directed to covered gravity sewers, which lined the major streets. Below is the remains of a drain at Lothal, Circa.

Figure 33 Typical drain of ancient times

- The conventional engineering-based techniques most commonly used to drain excess water from land are:
    - Surface drainage
    - Horizontal subsurface drainage
    - Vertical subsurface drainage

Development of river systems and drainages

The water that comes in the form of rain is partly absorbed by the ground, partly evaporated and some of its parts flows in the form of streams, brooks and tributaries of the river. The water flowing through the surface has the capacity to transform the earth surface through denudation

River patterns

The source is mostly an upland region where there is high precipitation and have steep slope through which water can run down and move forward. Therefore, uplands are said to be the catchment areas of the river.

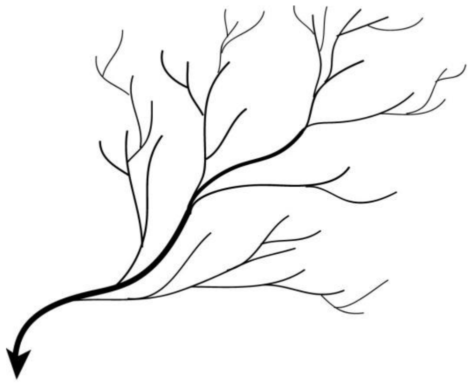
A divide or watershed is formed at the crest of the mountain. From this divide, the rivers flow down the slope and start its journey to reach the ocean.

The initial and mainstream that develops due to the slope of the mountain, is called consequent stream.

The consequent stream moves on the surface and is joined by several other streams or tributaries either at right angles or obliquely depending on the resistance offered by rocks and their alignment.

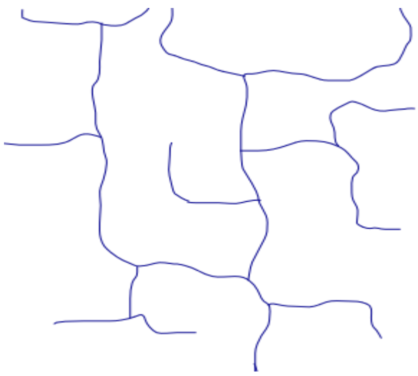
Formation of river patterns on the basis of rocks:

- **Dendritic drainage –** if the rocks are homogeneous in structure and offer same resistance throughout the surface, the nearby tributaries will join the consequent tributary at an oblique angle as an insequent stream. The pattern of drainage evolved like will appear in the shape of a tree with numerous branches. This is called dendritic drainage. Dendron means tree-like.



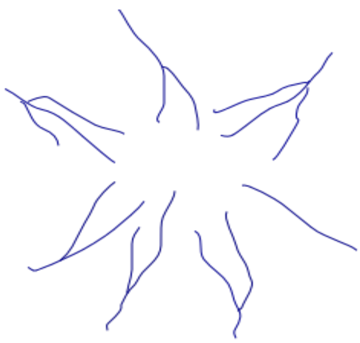
- **Trellised drainage** – If the rocks are not homogeneous and are made of an alternate layer of hard and soft rocks. So, when the streams join the main river by eroding the soft rocks at a right angle, it is called trellised drainage.

- **Rectangular drainage –**



- When streams join the main river through the space between the hard rocks without any erosion at a right angle, then it is called rectangular drainage. In this, the tributaries flow through faults i.e between the spaces provided by hard rocks

Radial drainage

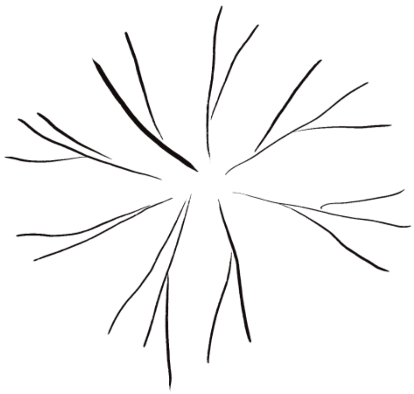


When the streams move in an outward direction from a high central point, it forms a radial pattern. Usually, this kind of pattern is seen in the flow of volcanoes as the lava emerge from one central point or crater. Laccoliths and domes also form radial patterns. It is formed when a stream of water flows in different directions starting from a centre point (usually a dome-like structure or a peak).

Amarkantak range, situated in India is one of the best examples of this kind of drainage pattern.

Centripetal drainage

It is almost identical to a radial drainage system. The only difference is that in radial drainage water flows out while in centripetal drainage water flows in a centre point.



Deranged drainage

It occurs in **drainage basins** where there is no consistent pattern of rivers and lakes. The region in which this pattern occurs is usually geologically disrupted. For example – Canadian Shield. In this area, the topsoil has been scraped off during the ice age and only bare rocks are present. Further, the melting of glaciers leads to irregular elevation of land and collection of water in low areas forming a large number of lakes. This is also the reason, there are so many lakes found in Canada. The drainage basin is at a young stage and will take time to mature and stabilize.

Annular drainage pattern

When streams follow a rough concentric or circular path along a belt of weak rock and form a ring-like pattern, it is called an annular drainage pattern. It can be seen in the regions where streams flow through the maturely dissected basin or structural dome where the sedimentary strata vary in hardness. The nest example is the Red valley which encircles the structure of Black Hills of South Dakota.

Angular drainage

When streams meet the main river at acute angles due to the presence of bedrocks and faults present at this angle, it is called angular drainage. The angle so formed is either more than 90 degrees or less than 90 degrees.

Discordant drainage

When a drainage pattern is formed which does not match the topography and geology of the region, it is called a discordant drainage pattern. It is further categorised as –

- **Antecedent –** Both vertical erosion and upliftment of land occur at the same force.
- **Superimposed –** It happens in two stages. First, a drainage system appears on the surface which is composed of young rocks. The denudation process of river removes the upper surface and continues to erode it and finally reaches the old rocks.
- **Ante-position –** When both antecedent and superimposed drainage combines, it is called ante-position drainage pattern.

Importance of water management from the Social, Environmental and Economic perspectives.

Large parts of India have already become water stresses. Rapid growth in demand for water due to population growth, urbanization and changing lifestyle pose serious challenges to water security.

Climate change also increase the sea levels. This may lead to salinity intrusion in ground water aquifers or surface waters and increased coastal inundation in coastal regions, adversely impacting habitations, agriculture and industry in such regions.

There is a wide temporal and spatial variation in availability of water, which may increase substantially due to a combination od water related disasters such as floods, increased erosion and increased frequency of droughts, etc.

Access to safe water for drinking and other domestic needs still continues to be a problem in may areas. Skewed availability of water between different regions and different people in the same region and also the intermitted and unreliable water supply system has the potential of causing social unrest.

Rapid growth in demand for water due to

- Population growth
- Urbanizations
- Changing lifestyle

pose serious challenges to water security.

The world’s total water use per capita by country is as follows:

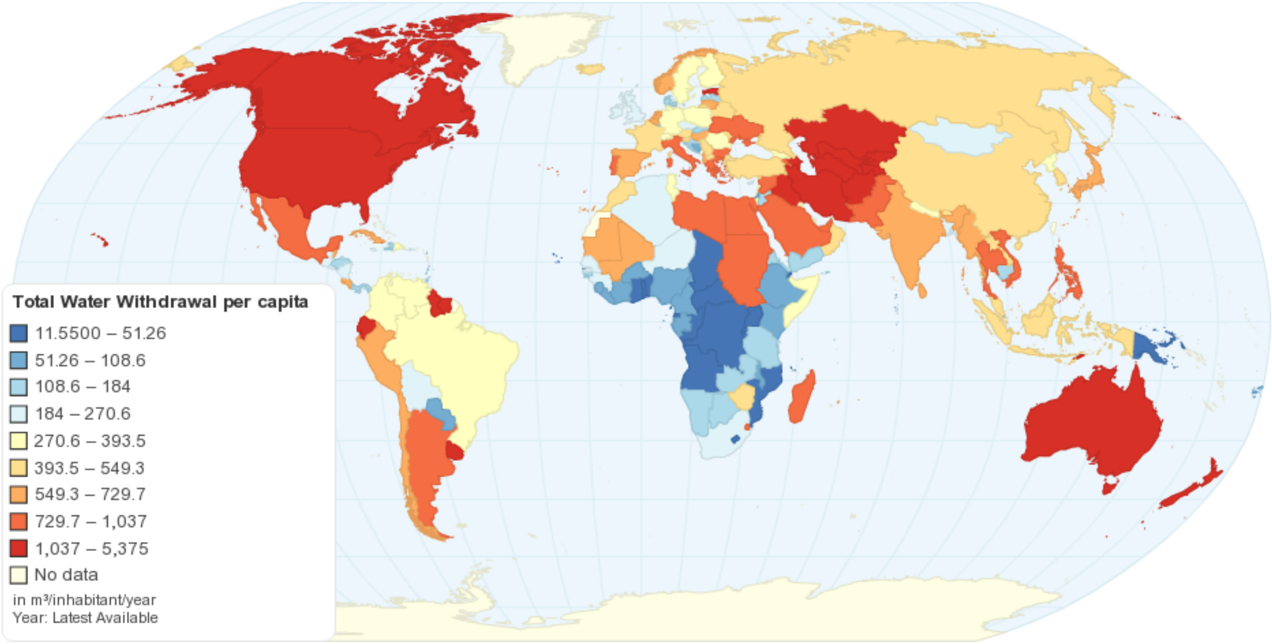
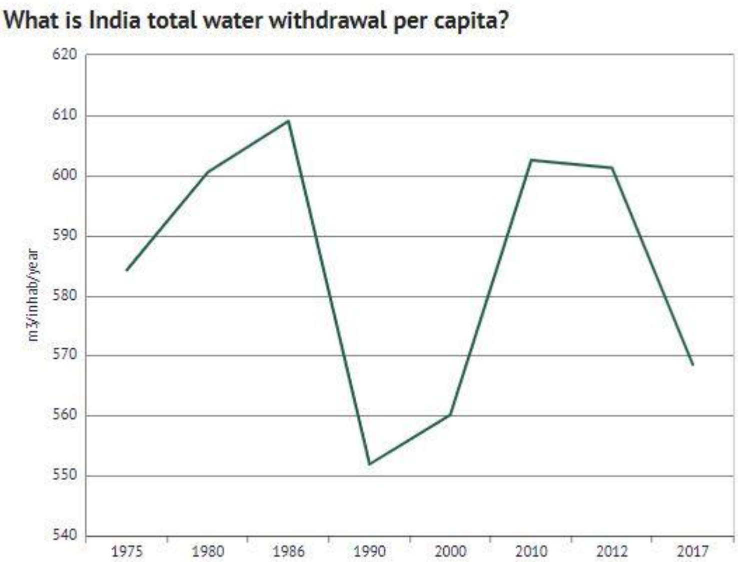


Figure 34 Total water withdrawal per capita in the world

India stands in the range where total water withdrawal per capita is of the order of 549-729 cu.m/ inhabitant.year.

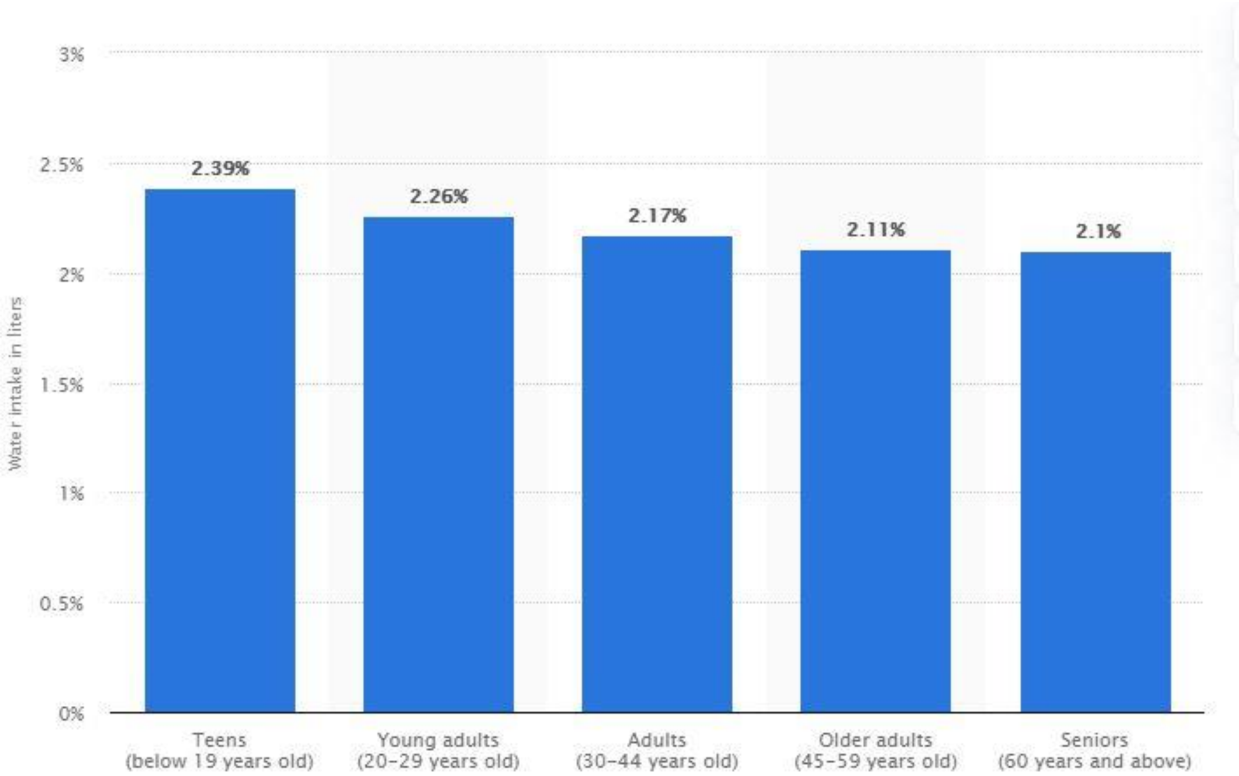
India's total withdrawal per capita is as follows:



DATE	VALUE	CHANGE, %
2017	568.47	-5.45 %
2012	601.21	-0.21 %
2010	602.50	7.57 %
2000	560.10	1.49 %
1990	551.90	-9.38 %
1986	609.00	1.42 %
1980	600.50	2.79 %
1975	584.20	

Figure 35 Water withdrawal per capita in India

The Average water consumption per person across India, by age group is as follows:



Water management scores, statewise are as follows:

State	Score (In %)	Performance
Gujarat	76	High
Madhya Pradesh	69	High
Andhra Pradesh	68	High
Karnataka	56	Medium
Maharashtra	55	Medium
Punjab	53	Medium
Tamil Nadu	51	Medium
Telangana	50	Medium
Chhattisgarh	49	Low
Rajasthan	48	Low
Goa	44	Low
Kerala	42	Low
Odisha	42	Low

Bihar	38	Low
Uttar Pradesh	38	Low
Haryana	38	Low
Jharkhand	35	Low
Tripura	59	Medium
Himachal Pradesh	53	Medium
Sikkim	49	Low
Assam	31	Low
Nagaland	28	Low
Uttarakhand	26	Low
Meghalaya	26	Low

Source: Composite Water Management Index, NITI Aayog

Table 1 Water management scores in India

Water management from Environmental perspective

- When surface and groundwater systems experience alterations to natural water movement, distribution, temperature, or quality, assets and ecosystems are impacted.
- Sometimes, those assets and ecosystems are pushed beyond their ability to rebound, resulting in the degradation of the system as a whole.
- Management of water for the environment must occur within a water resource planning framework that accounts for all water uses in a given basin, catchment or aquifer

Forest cover in India

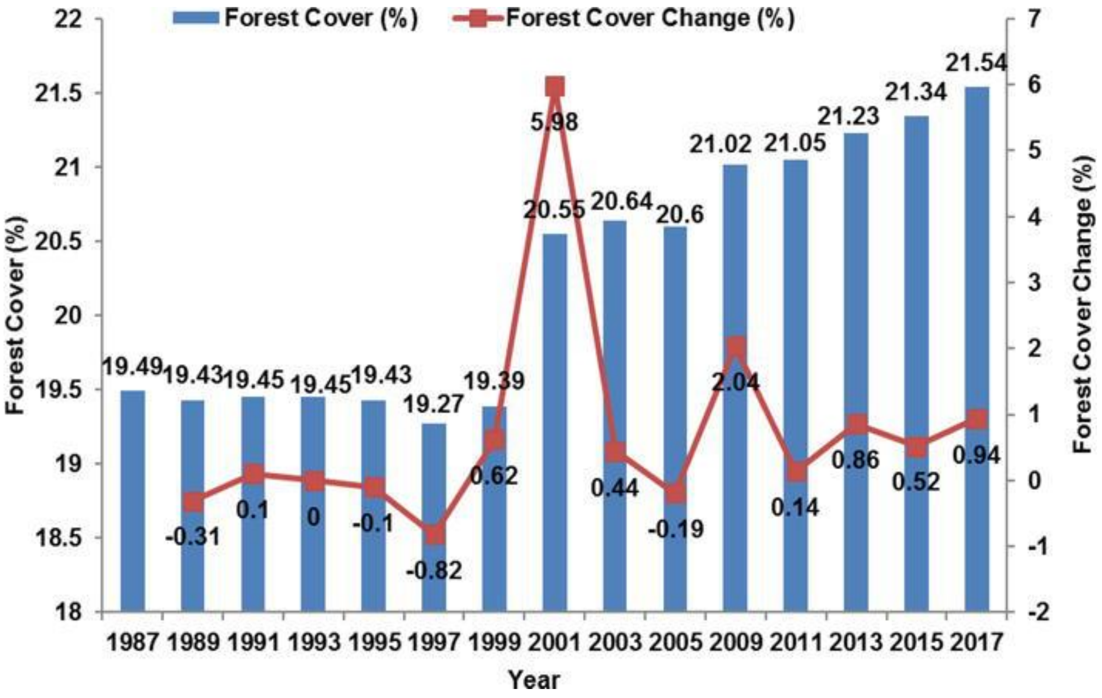


Figure 36 Forest cover in India

- Forests transport large quantities of water into the atmosphere via plant transpiration. When deforestation occurs, precious rain is lost from the area, flowing away as river water and causing permanent drying.

- The EPA report highlights potential vulnerabilities to drinking water and confirmed pollution events. Vulnerabilities include

  (1) inadequately cased or cemented wells resulting in below- ground migration of gases and liquids,

  (2) inadequately treated waste water discharged into drinking water resources, and

  (3) spills of hydraulic fracturing fluids, flowback, and produced water. Given these vulnerabilities and knowledge gaps highlighted by EPA, industry should not take too much comfort in the widely reported conclusion that the EPA found no evidence of widespread, systemic impacts.

  Water is precious natural resource for sustaining life and environment. Effective and sustainable management of water resources is vital for ensuring sustainable development. In view of the vital importance of water for human and animal life, for maintaining ecological balance and for economic and developmental activities of all kinds, and considering its increasing scarcity, the planning and management of water resource and its optimal, economical and equitable use has become a matter of the utmost urgency. Management of water resources in India is of paramount importance to sustain one billion plus population. Water management is a composite area with linkage to various sectors of Indian economy including the agricultural, industrial, domestic and household, power, environment, fisheries and transportation sector. The water resources management practices should be based on increasing the water supply and managing the water demand under the stressed water availability conditions. For maintaining the quality of freshwater, water quality management strategies are required to be evolved and implemented. Decision support systems are required to be developed for planning and management of the water resources project. There is interplay of various factors that govern access and utilization of water resources and in light of the increasing demand for water it becomes important to look for holistic and people-centered approaches for water management. Clearly, drinking water is too fundamental and serious an issue to be left to one institution alone. It needs the combined initiative and action of all, if at all we are serious in socioeconomic development. Safe drinking water can be assured, provided we set our mind to address it. The present article deals with the review of various options for sustainable water resource management in India.

The first central principle that is guiding the reform process is that all uses of water should be seen from the perspective of its economic value because the absence of an economic perspective in the past explains existing unsustainable uses of water. As a result, the emphasis is on water as a natural resource, which must be harnessed to foster the productive capacity of the economy, from irrigation water for agricultural production to water for hydropower. Thus, the National Water Policy laments the fact that an insufficient percentage of water is currently harnessed for economic development and even calls for 'non-conventional' methods of water utilisation such as inter-basin water transfers and seawater desalination as large-scale, high technology solutions to improve overall water availability. This message is also found in the recent draft World Bank report stressing out that India has not developed enough big water infrastructures.

Water management from Economic perspective

Beyond the relatively old characterisation of water as a natural resource, the underlying proposition for water sector reforms is that water is to be seen as an economic good. This implies an important shift in terms of the rights of control over and access to water. In fact, this leads to a complete policy reversal from the perspective that water is a public trust to the introduction of water rights and the possibility to trade water entitlements. As such, water-related rights are not new and there is already a vast corpus of law related to control over water. This includes, for instance, the absolute rights that the state may claim over water.[2] This also includes the rights and privileges that common law principles bestow over landowners. The novelty introduced by the reforms is that water rights are now created in favour of water users. These rights are the necessary premise for participation in the management of water resources, for the setting up of water user associations and for the introduction of trading in entitlements.

Another important change brought about by the notion that water is an economic good is that all water services must be based on the principle of (full) cost-recovery. In a situation where the provision of drinking and domestic water as well as irrigation water is substantially subsidised, this implies a significant policy reversal. At the national level, the policy is now to make water users pay at least for the operation and maintenance charges linked to the provision of water. This strategy is already being implemented in the context of irrigation water where farmers are made to pay for operation and maintenance costs. This has also been introduced under the Swajaldhara guidelines, which suggest that water users have to take up partial responsibility for the capital cost of new drinking water infrastructure and full responsibility for operation and maintenance.

The notion of cost recovery is directly linked to the environmental component of water sector reforms. Indeed, they are conceived as part of a single strategy. Further, cost recovery is, for instance, seen by the Asian Development Bank as the first instrument for conserving water.

- Water is used to extract

- Energy and mineral resources from the earth
- Refine petroleum and chemicals
- Roll steel
- Mill paper
- Produce uncounted other goods, from semiconductors to the foods and beverages that line supermarket shelves.
- Below is a sample calculation and illustration

Demand Side:

A. Household Requirement

1.	Size of Population in Chennai in 2019	-	90 lakh
2.	Per Capita Daily Water Requirement	-	135 litres
3.	Daily water requirement	-	1215 MLD
4.	**Annual water requirement for Households**	**-**	**15.66 T.M. Cft**

B. Industrial Water Requirement (15% of A-4) #- 2.35T.M. Cft

C. Service Sector Requirement (20% of A-4) # - 3.13T.M. Cft

So, Annual Water Requirement for Three Sectors (**100%**)- **21.14T.M. Cft**

Note: # Any additional water requirements of B & C may be met by RWH method.

Whether the government is ready to provide or not, it has to augment 21.14 T.M. Cft of water supply annually to match the annual requirements on a sustainable basis.

Water management from Social perspective

- Water scarcity disproportionately affects vulnerable people in low-income communities. In 2018, more than 600 million people in India did not have access to enough clean water. As the country's population is expected to grow by 300 million by 2050, while its groundwater sources dry up, this problem can only get worse.
- Societies directly and indirectly depend on the
    - Quantity
    - Quality
    - Reliability
    - Affordability of their water supplies
- Society's decisions are influenced by
    - Tradition (e.g., previous decisions)
    - History

- Education
- The current cultural, economic, natural, social, and political environment.

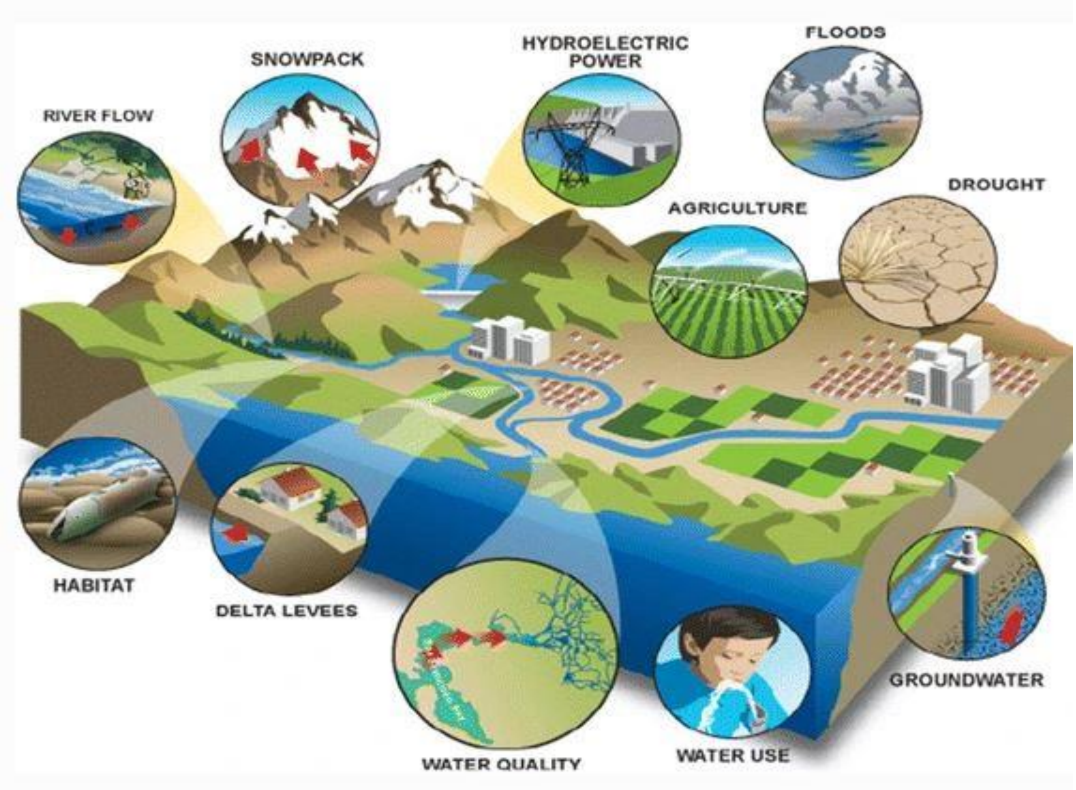


Figure 37 Challenges of water crisis

Drivers of increase in water demand:

- Direct increase in demand: Increase in population from 1.2 billion in 2010 to 1.6 billion in 2030
- Demand aggregation at some points due to increase in urbanization: Some cities may be away from areas where water is available
- Changes in lifestyle due to increase in per capita. Example: Present demand is 90lpcd and this increase significantly
- Increase in demand due to industrialization (power, steel and other heavy industries)
- 1700 cu.m/ year.person: Country is water stressed
- 1000 cu.m/ year.person: Country is water scarce

In cities, many people live on a relatively small area. Therefore, a lot of water is consumed, and a lot of wastewater is generated. Since the physical space in cities are valuable, the necessary infrastructure has to be accommodated on a small area. In addition, most of the surfaces in the city are sealed so that the rain drains and does not seep away. Especially in heavy rainfall periods, floods can occur. The topic is gaining acute importance bearing in mind that many people are still moving to the urban areas, especially in poorer countries, and advancement and progress of infrastructure cannot follow the fast phase of population growth in cities. Currently water scarcity is already a critical issue in many cities around the world.

Types of water management

1. **Irrigation water management**

It is the process of determining and controlling the volume, frequency and application rate of irrigation water in a planned, efficient manner.

2. Drinking water management

The amount of **drinking water required per day is variable**. It depends on physical activity, age, health, and environmental conditions.

3. Urban water management

About 30% of people in India live in cities that are expected to double in population by 2050. With a growing economy and changing lifestyles the pressure on already strained water resources is increasing.

4. Industrial water management

The development of new concepts and technical, digital, and nontechnical innovations together with priorities will continue to set the course for future integrated water management, particularly in the industrial environment.

Case study 1: Irrigation water management

Figure 38 Case study showing SWAR

- The innovation has been highly recognized by the Andhra Pradesh government.
- In 2015, this technique was also used to grow vegetables and flowers.
- This helped show immediate results in terms of both soil and plant health and farmers' incomes.

Takeaways:

- Suitable for the massive tree plantation programme.
- Agricultural innovations should be sustainable and offer improved incomes to smallholder farmers.

- Shift from rain dependent farming to harvesting and storing rain water and using it efficiently to cultivate crops.

Watershed

A watershed is an area that supplies water by surface or sub-surface flow to a given drainage system or body of water.

- Watersheds vary from a few hectares (or less) to millions of square kilometers (for example, Ganga river basin)
- Organizing eff orts and activities around watersheds are best pursued only when strictly necessary and relevant, such as when land or water-related externalities are of sufficient concern to drive development objectives and priorities
- Watershed management (WSM) is the integrated use and/or management of land, vegetation, and water in a geographically discrete drainage area.
- It is done for the benefit of its residents, with the objective of protecting or conserving the hydrologic services that the watershed provides and of reducing or avoiding negative downstream or groundwater impacts.

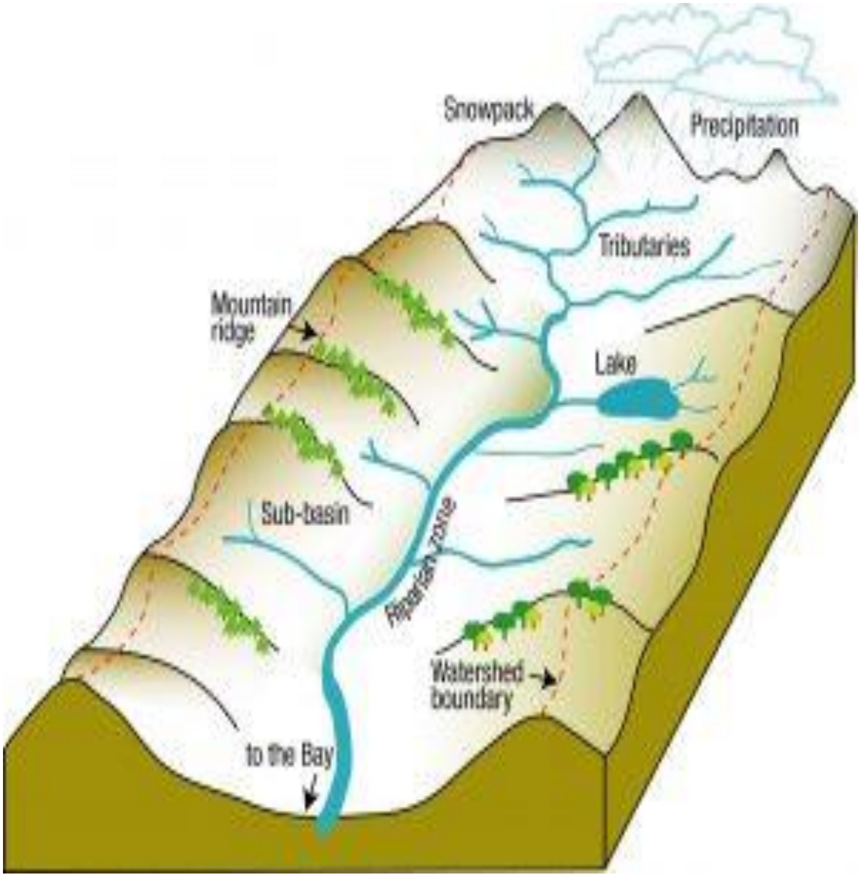


Figure 39 Watershed

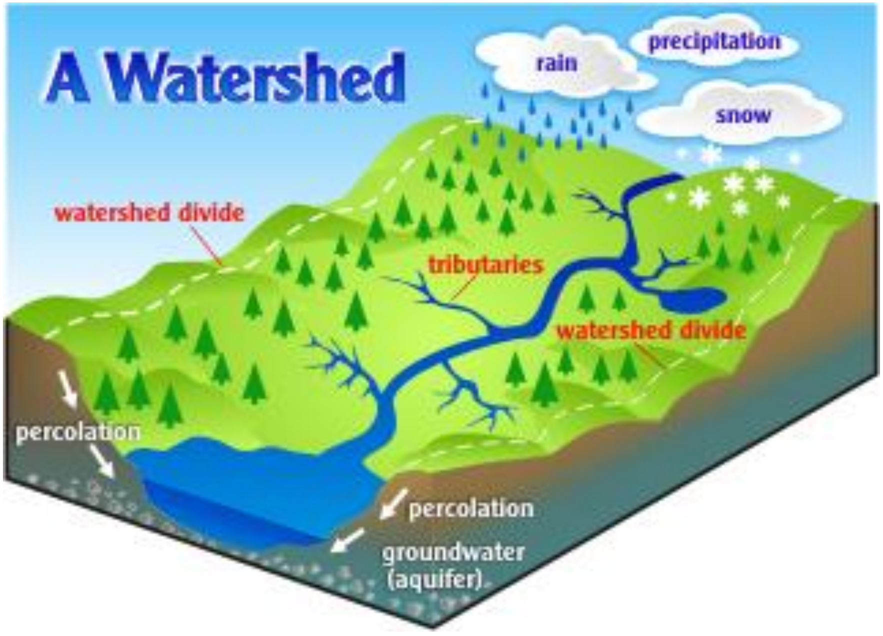


Figure 40 Watershed representation

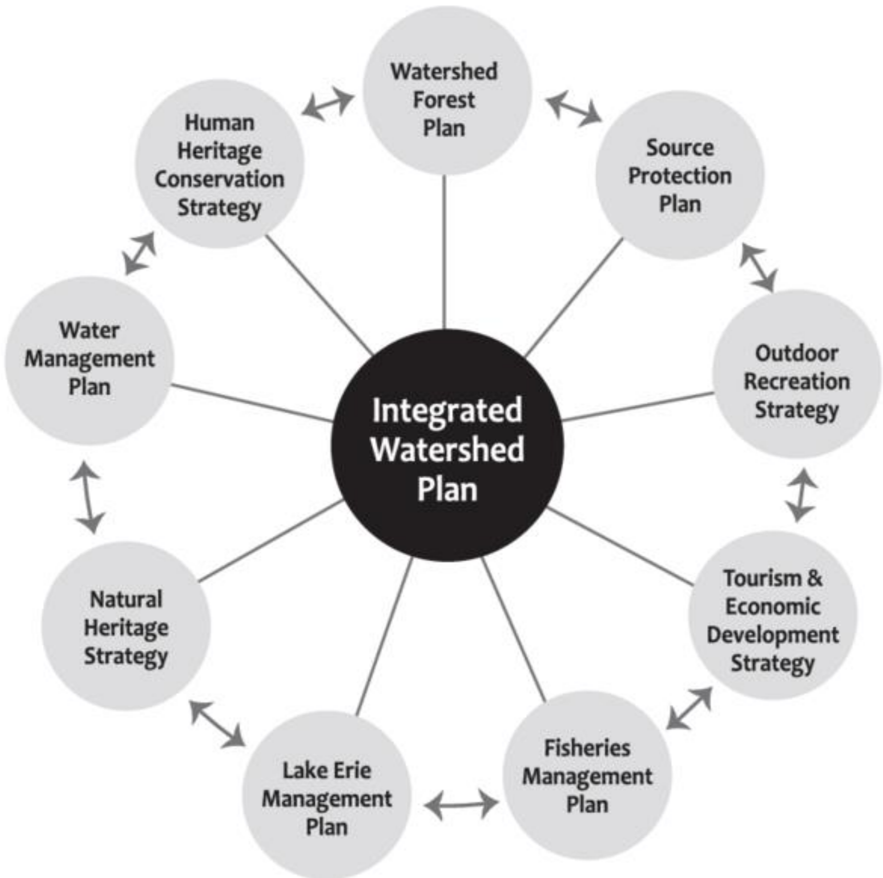


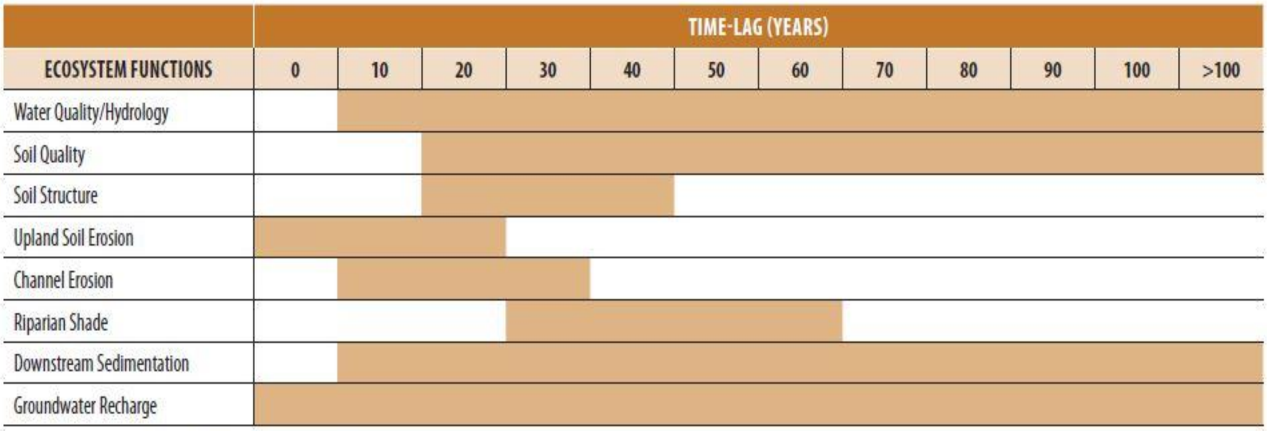
Figure 41 Integrated watershed plan

An Idealized Scheme of Changes in Watershed Management Approach and Focus with Scale

WATERSHED MANAGEMENT UNIT	INDICATIVE SIZE (ha)	INFLUENCE OF RURAL LAND USE ON WATERSHED HYDROLOGY	HIERARCHY OF POLITICAL STAKEHOLDERS	TYPICAL MANAGEMENT FOCUS/INSTRUMENTS
Micro-watershed	1–500	Very Strong	Those with land & resources rights (statutory & customary/traditional)	Participatory planning; best management practices; site design
Sub-watershed	500–5,000	Very Strong to Strong	Local government w/ principal local stakeholders	Stream classification; land use planning/zoning; land, water resources & stakeholder management
Watershed	5,000–25,000	Strong to Moderate	Local or multiple local governments with principal local & regional stakeholders	Watershed-based zoning; land use & water resources planning; stakeholder management; policy, norms, regulations & incentives
Sub-basin	25,000–250,000	Moderate to Weak	Local, regional or state governments with principal regional stakeholders	Basin planning; stakeholder mgmt.; policy, legal framework & incentives
Basin	>250,000	Weak to Very Weak	State, multistate, or federal governments with principal regional & state stakeholders	Basin planning; stakeholder management; policy, legal framework & incentives

Table 2 Scheme of Changes in Watershed Management Approach

Illustration of Time Lag for Ecosystem Response at Sub-Basin/Basin Scale



As adapted by J. Kerr, 2007 from Gregory et al, 2007.

Table 3 Time Lag for Ecosystem Response at Sub-Basin/Basin Scale

Principles of Sustainable Watershed Management

- Technical & socioeconomic measures -based on sound data & experimental investigation.
- Successful activities in a small watershed may lead to integration of achievements in a large river basin .
- Good coordination among t he institutions w ho are working towards fulfilling IWM goals.
- Avoid local politics to lead people in misuse, when designing policies and legislative measures.
- Community participation.

Estimation of water requirement for drinking and domestic use

Water Requirements for Buildings Other than Residences

Sl No.	Type of Building	Domestic litres per head/ day	Flushing Litres per head/ day	Total Consumption Litres per head/ day
1.	Factories including canteen where bath rooms are required to be provided	30	15	45
2.	Factories including canteen where no bath rooms are required to be provided	20	10	30
3.	Hospital (excluding laundry and kitchen):			
	a) Number of beds not exceeding 100	230	110	340
	b) Number of beds exceeding 100	300	150	450
	c) Out Patient Department (OPD)	10	5	15
4.	Nurses' homes and medical quarters	90	45	135
5.	Hostels	90	45	135
6.	Hotels (up to 3 star) excluding laundry, kitchen, staff and water bodies	120	60	180
7.	Hotels (4 star and above) excluding laundry, kitchen, staff and water bodies	260	60	320
8.	Offices (including canteen)	25	20	45
9.	Restaurants and food court including water requirement for kitchen:			
	a) Restaurants	55 per seat	15 per seat	70 per seat
	b) Food Court	25 per seat	10 per seat	35 per seat
10.	Clubhouse	25	20	45
11.	Stadiums	4	6	10
12.	Cinemas, concert halls and theatres and multiplex	5 per seat	10 per seat	15 per seat
13.	Schools/Educational institutions:			
	a) Without boarding facilities	25	20	45
	b) With boarding facilities	90	45	135

14.	Shopping and retail (mall) a) Staff	25	20	45
	b) Visitors	5	10	15
15.	Traffic Terminal stations a) Airports	40	30	70
	b) Railway stations (Junction) with bathing facility	40	30	70
	c) Railway stations (Junction) without bathing facility	30	15	45
	d) Railway stations (Intermediate) with bathing facility	25	20	45
	e) Railway stations (Intermediate) without bathing facility	15	10	25
	f) Interstate bus terminals	25	20	45
	g) Intrastate Bus Terminals/Metro Stations	10	5	15

Table 4 Water requirements for buildings other than residences

- Over the past few decades, several regions of the world have experienced notable progress in various aspects of water management, including improving access to water resources and related services.
- However, rapid population and economic growth, urbanization, and the underperformance of existing water assets mean that there are still significant shortfalls in meeting these needs.
- Today, half of the world's people live in urban areas, and urban populations are still growing rapidly in many regions.
- Integrated water resources management strategies, and strategies to respond to water-related risk, are vital.
- These growing urban human settlements cannot become sustainable without ensuring reliable access to safe drinking water and adequate sanitation. Messages for urban mayors, leaders and high-level decision makers

Best practices for water sustainability

- Pennsville water residents can save hundreds of gallons of water every week by following these water-saving tips:

<u>Bathroom</u>

- Do take shorter showers & save 3-5 gallons every minute.
- Do fill the tub halfway & save 10-15 gallons.
- Do install water-saving toilets, shower heads and faucet aerators. Place a plastic bottle filled with water in your toilet tank if you can't switch to a low flow toilet.

<u>Everywhere</u>

- Do check your water meter or bill to see how much water you are using. A good rule of thumb is 75-100 gallons per day, per person.

- Do repair leaky faucets and turn taps off tightly. Slow drips waste 15-20 gallons per day.

Table 5 Water metering

Kitchen and Laundry

- Do run the dishwasher and washing machine only when full. Save even more water by using the short cycle.
- Do install front-loading washing machines, which reduce water usage by about 40 percent.

Outdoor

- Do use a self-closing nozzle on your hose.
- Do position your downspouts so rain water runs onto the lawn or into the garden, not down the driveway.
- Do plant drought-resistant trees/flowers and use mulch to keep the soil moist.

Bad practices for water sustainability

Bathroom

- Keeping the water running while shaving or brushing your teeth. Using faucets at **2-3 gallons/minute.**
- Using the toilet as a wastebasket & don’t flush it unnecessarily.

Kitchen and laundry

- Letting the water run while washing dishes

Outdoor

- Watering the lawns during the heat of the day.
- Using water to clean sidewalks or driveways instead of sweeping them instead

Major problems faced in watersheds

Flooding

- Flood problems are caused by many different factors. Hydrologic and hydraulic modeling helps analyze effects of land cover, floodplain geometry, and rainfall intensity.

Figure 42 FLooding problem scores as per study in Canada

Erosion

- Erosion problems can stem from changing land use conditions that increase the quantity and velocity of storm water runoff.
- Stream channels react to these changes by widening and deepening, which can cause creek bank failures, threaten creek side structures, and degrade water quality.

Figure 43 Erosion problem score as per study in Canada

<u>Water Quality</u>

- Water quality problems are multifaceted and complex to study and control.
- Key concerns include increases in runoff and degradation of aquatic and riparian habitat.

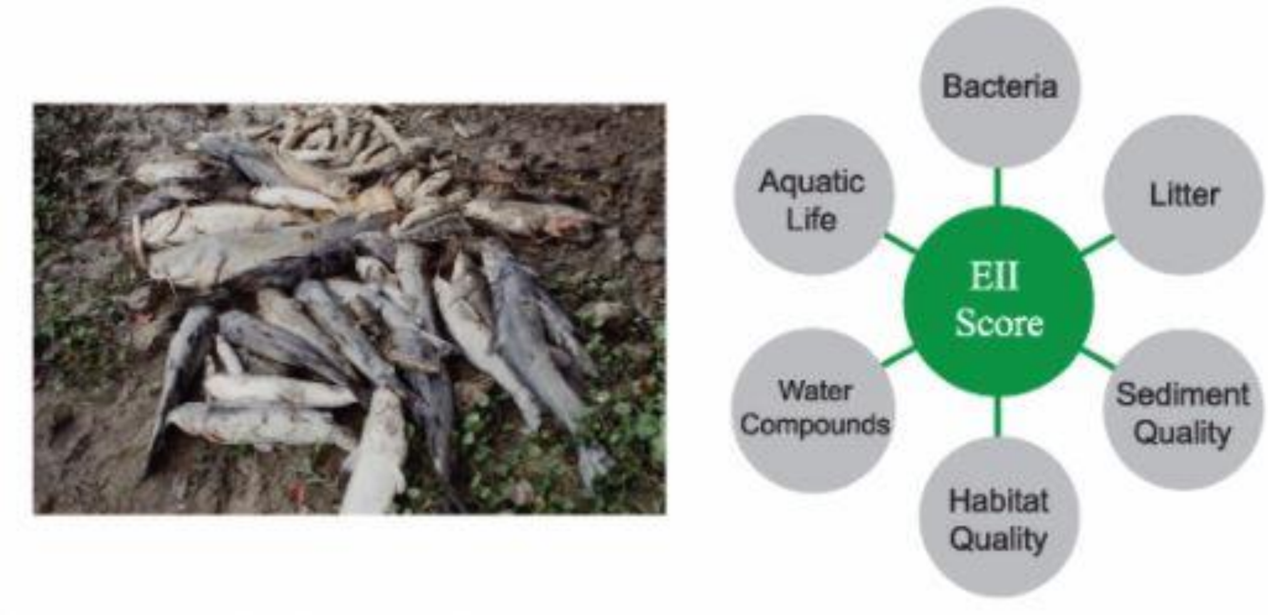


Figure 44 Water quality scores

Prevention of soil erosion into watersheds

- Avoiding sites susceptible to increases in surface erosion is the most effective and economical means to prevent surface erosion from occurring in the first place and, in doing so, to maintain the productivity of a watershed.

Figure 45 Most prone erosion features

- More specifically, sites most susceptible to increases in surface erosion are those with sloping surfaces, shallow soils, soils with low hydraulic conductivity, and a lack of a protective vegetation cover**.**

Here are 3 main sources of water pollution
Domestic / municipal

1. Agricultural
2. Industrial

Agriculture is by far the leading cause of water pollution, with pollutants such as sediment eroded from agricultural lands, fertilizers, pesticides, bacteria from livestock, food processing waste and excess salts from soils of irrigated crop lands all contributing to water pollution.

Industry is the second largest cause of water pollution with pollutants such as coal ash from power plants, toxic organic and inorganic chemical waste, oil and natural gas during drilling contributing to water pollution.

Domestic/ municipal pollution usually includes sewage or waste water from homes or businesses. Pollutants usually include household cleaning agents, detergents, grey water and also the dumping of garbage into waterways.

Point source versus Non-point source pollution

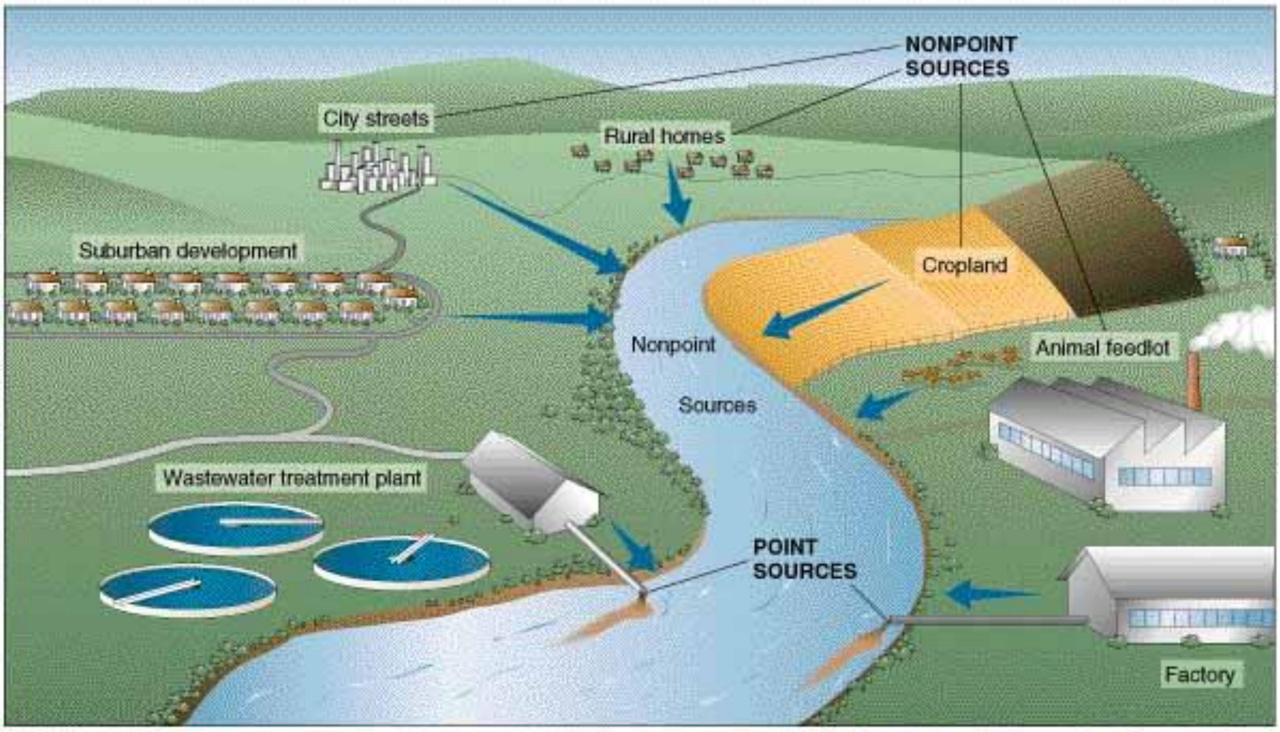


Figure 46 Point and non point sources of pollution

<u>Point source water pollutants</u>: pollutants that are discharged from specific/ known locations.

<u>Non point source pollutants</u>: water pollutants that are discharged over a large area.
Note: Non-point source pollution is hard to control because the perpetrators cannot be easily traced.

Case study: Harvesting Water Harnessing Life

<u>A case study of Amba Township, Gandhinagar, Gujarat</u>

Introduction:

- Rain water harvesting is the accumulation/ deposition of rainwater for reuse before it reaches the aquifer.
- Rain water harvesting means collecting rain water from the top of roof or building, open spaces surrounding the buildings, farm-areas, etc. And then storing it for a later use or diverting it to an existing well for recharging.

Rainwater harvesting is an environmentally sound solution to address issues brought forth by large projects utilizing centralized water management approaches

Figure 47 Amba township location in Gandhinagar, Gujarat

Description of study area:

- Amba Township is located at distance of 10kms from Gandhinagar, state-Gujarat (India).
- It lies between latitude 23°11’17” N and longitude 72° 34’32” E.
- Amba Township is just on the outskirts of Gandhinagar.
- The population of township is around 1000.
- Entire Amba Township contains 100 acres. Entire Township is divided in five sector. But, currently we are studying only on sector-3 (A, B).

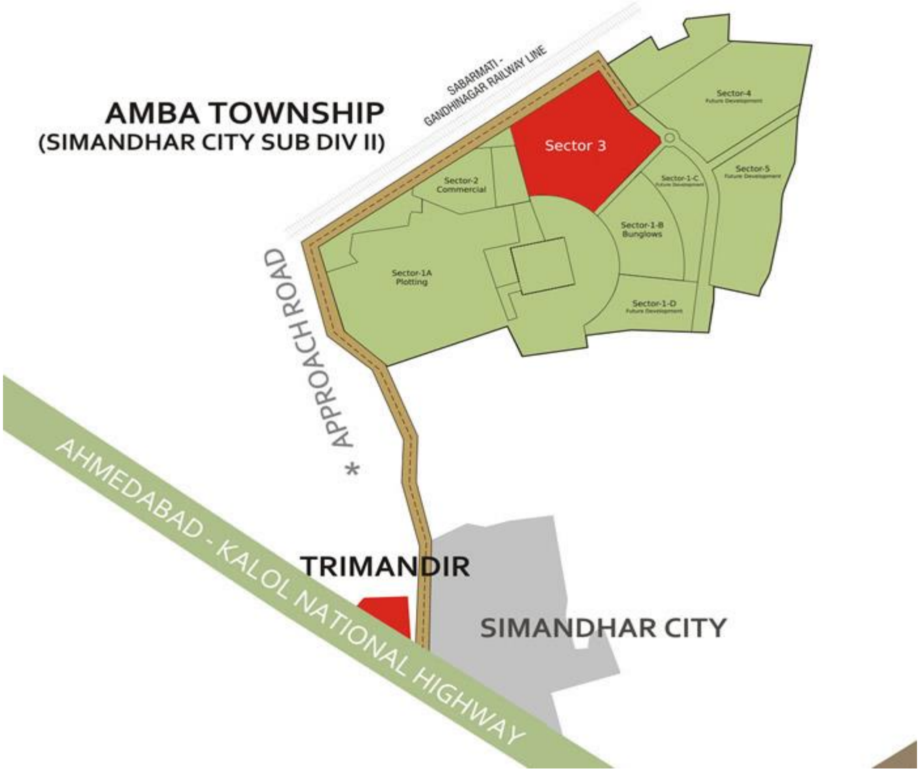


Figure 48 Layout of Amba Township

Figure 49 SIte plan of Amba Township

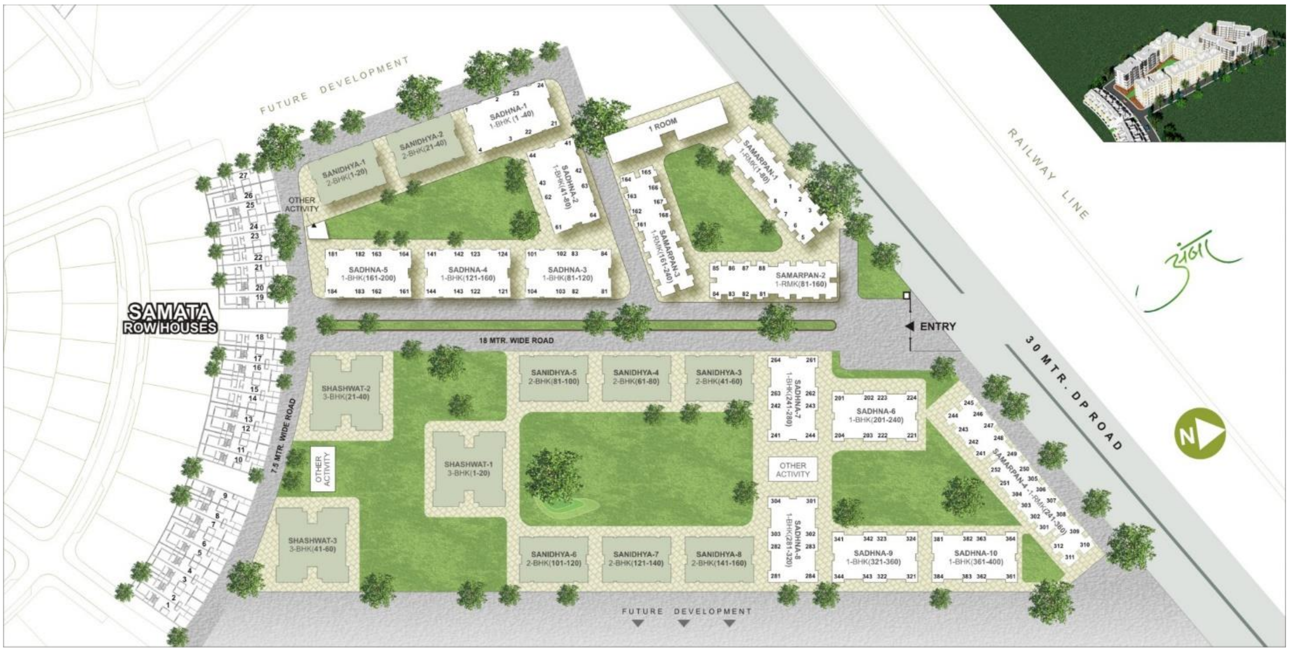


Figure 50 One sector detailed plan Amba township

Description of study area:

Total Terrace Area of Sector-3(A, B)	=	22011 Sq.m
Total Road Area of Sector-3(A, B)	=	8000 Sq.m
Total Landscape Area of Sector-3(A, B)	=	14011Sq.m
Total Area of Sector-3(A, B)	=	44022 Sq.m

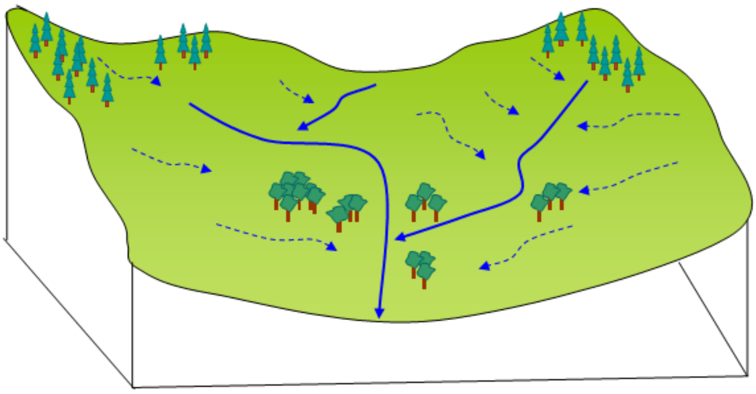
- The total area of roof top of all buildings in Amba Township is 22011 Sq.m and average annual rainfall in Gandhinagar is 740.3mm.
- Amba Township is 10kms away from the Gandhinagar, so there is no any water supply from Municipal of Gandhinagar.
- There is no any reliable source of water in Amba Township. So there is need to dug a private bore wells in Amba Township. But day by day buildings are constructed and population of city are increasing as faster way. Due to this, water demand is also increase.

Description of study area:

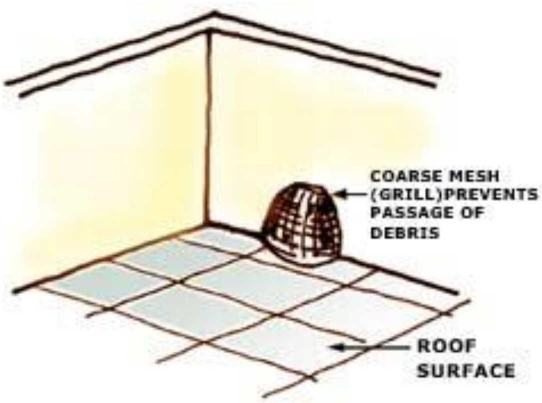
- Total average annual rainfall of Gandhinagar = 740.3mm.
- Water Demand:- As per IS Specification (IS 1172: 1993),
- Total water demand for one person = 135 lit/day
- Total water demand = 135*1000
- Annually total water demand = 365*135*1000
- Annually total water demand = 4,92,75,000 lit
- **Description of study area:**

Rain water harvesting system:-

1. **Catchment area**: It is the surface on which the rain Water falls. In this study all building's roof and all roads are taken as catchment area. This water can be used for recharging ground aquifers after proper filtration.



2. **Coarse mesh / leaf screen**: It is used to prevent the entry of leaves and other debris in the system.



3. **Conduits: Conduits are pipelines or drains that carry rainwater from the catchment or rooftop area to the harvesting system. Conduits can be of any material like polyvinyl chloride (PVC) or galvanized iron (GI), materials that are commonly available.**

Sizing of rainwater pipe for roof drainage

Diameter Of pipe (mm)	Average rate of rainfall in mm/h					
	50	**75**	**100**	**125**	**150**	**200**
50	13.4	8.9	6.6	5.3	4.4	3.3
65	24.1	16.0	12.0	9.6	8.0	6.0
75	40.8	27.0	20.4	16.3	13.6	10.2
100	85.4	57.0	42.7	34.2	28.5	21.3
125	-	-	80.5	64.3	53.5	40.0
150	-	-	-	-	83.6	62.7

mm/ h - millimeters per hour; m - meters

Source: National Building Code

4. **Percolation well:** Percolation tanks are artificially created surface water bodies, submerging a land area with adequate permeability to facilitate sufficient percolation to recharge the ground water. These can be built in big campuses where land is available and topography is suitable.

Calculation:

Area description	Runoff coefficient (K)	Area description	Runoff coefficient (K)
Residential:-		Industrial:-	
Single-Family	0.30-0.50	Light	0.50-0.80
Multiunit, detached	0.40-0.60	Heavy	0.60-0.90
Multiunit, attached	0.60-0.75	Parks, cemeteries	0.10-0.25
Residential (suburban)	0.25-0.40	Play grounds	0.20-0.35
Apartment	0.50-0.70	Railroad yard	0.20-0.35
Pavement:-		Lawns, sandy soil:-	
Asphaltic and concrete	0.70-0.95	Flat, 2 percent	0.05-0.10
Brick	0.70-0.85	Average, 2-7 percent	0.10-0.15
Roofs	0.75-0.95	Steep, 7 percent	0.15-0.20

Runoff coefficient table as below:

Rain water Harvesting by Terrace:-

Total Terrace Area of Sector-3 (A, B) A = 22011 Sq.m
Average Annual Rainfall in mm R = 740.3 mm
= 0.740 m
Runoff co-efficient for a flat terrace C = 0.60

Annual water harvesting potential through total terrace = A * R * C
= 22011 * 0.740 * 0.60
= 9772.884 Cubic meter
= 97, 72,884 lit

Rain water Harvesting by Surface Drainage:-

Total Road Area of Sector-3(A, B) A = 8000 Sq.m
Average Annual Rainfall in mm R = 740.3 mm
= 0.740 m
Runoff coefficient for a R.C.C road C = 0.82

Annual water harvesting through total Surface drainage = A * R * C
= 8000 * 0.740 * 0.82
= 4854.4 Cubic meter
= 48, 54,400 lit

Annually Total Rain water Harvesting:-

Annually Total Rain water Harvesting = (Total Rain water harvesting By Roof-top) + (Total Rain Water harvesting By Surface drainage)

= (97, 72,884) + (48, 54,400)

Annually Total Rain water Harvesting = 1, 46, 27, 284 lit

Conclusion:

- We can see that, we can obtain 1,46,27,284 lit of water annually.
- One of the most logical steps towards this goal would be acknowledging the importance of rainwater harvesting.
- We have to catch water in every possible way and every possible place it falls. It can be concluded from above findings that rainwater, if conserved and utilized using the rainwater harvesting technology, can be an effective tool of replenishing ground water resources.
- We can harvest total annually 1,46,27,284 lit water which is 29.68% of total water demand. So by using Rain water harvesting methods we can harvest and store the rain water into ground aquifer or into percolation well.

Control of soil erosion into watersheds

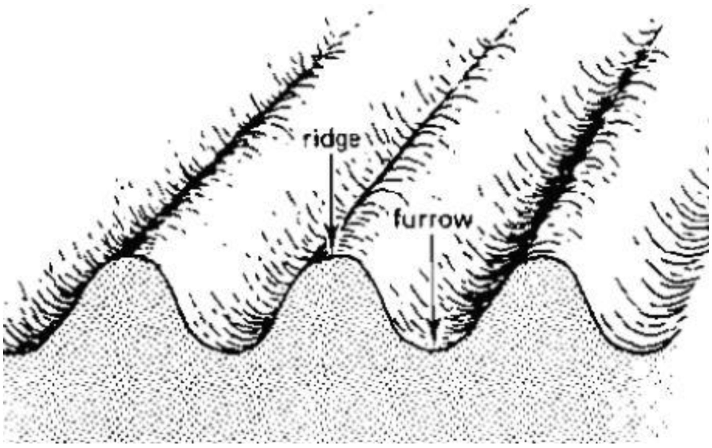
- The key here is to maintain the surface soil in a condition that readily accepts water. The more water that infiltrates the soil, the better the chance of reducing the erosive effects of surface runoff and sustaining plant growth becomes.

a. Vegetative measures:

- Maintaining a vegetative cover on the soil surface protects against the energy of rainfall impact and, therefore, reduces the surface erosion.
- The plants also increase the roughness of the soil surface that increases the tortuosity of the flow path and reduces the velocity (energy) of surface runoff.

b. Mechanical methods:

- **Contour furrows** - small ditches 20 to 30 centimeters deep that follow the contour-forming depressions and terraces that hold the water in place until it infiltrates into the soil.



- **Contour trenches** - large furrows on slopes too steep for contour furrows to hold greater amounts of runoff and have potential for groundwater recharge depending on soil.

Other mechanical methods:

- **Fallow strips -** vegetation strips about 1 meter wide along contours on level to gently rolling land to break the slope length until vegetation can become established.

- **Pitting -** shallow depressions 20 to 30 centimeters wide and 45 to 60 centimeters long dug into the soil surface to create depression storage for surface runoff and to provide soil water for re-vegetation measures.
- **Basins -** larger pits about 2 meters long, 1.8 meters wide, and 15 to 20 centimeters deep to store a greater amounts of water and, furthermore, create pockets of lush vegetation. Basins are more costly to construct and are not as widely used as pitting methods.

Pollutions affecting watersheds

It is classified under two categories:

1. **Point source pollution:** Direct contamination of waterways, such as industrial waste pouring from a factory drain into a river, is an example of point source pollution.

2. **Non point source pollution:** Pollutants such as motor oil leaked on parking lots, plastic grocery bags, pesticides, fertilizers, detergents, and sediments are known as nonpoint source pollutants.

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UNIT – III – Water Management-Micro Level

DESIGN FOR WATER CONSERVATION

Water conservation technologies and strategies are often the most overlooked aspects of a whole-building design strategy.

- The planning for various water uses within a building is increasingly becoming a high priority.
- This is due to a number of reasons, namely that new and existing water resources are becoming increasingly scarce in a number of regions throughout the country; per capita water consumption is increasing annually.
- Water and sewer rates have increased dramatically over the last decade (100–400%); and new water supply options are too costly or altogether unavailable—often resulting in stringent water use requirements in new construction applications.
- In addition, there is the increasing recognition of the water, energy, and O&M savings that can be realized through the implementation of water saving initiatives.

WATER CONSERVATION STRATEGIES

There are a number of strategies that can be employed to reduce the amount of water consumed at a facility. In general terms, these methods include:

- System optimization (i.e., efficient water systems design, leak detection, and repair);
- Water conservation measures; and
- Water reuse/recycling systems.

More specifically, a wide range of technologies and measures can be employed within each of these strategies to save water and associated energy consumption. These include:

- Water-efficient plumbing fixtures (ultra-low-flow toilets and urinals, waterless urinals, low-flow and sensored sinks, low-flow showerheads, and water-efficient dishwashers and washing machines)
- Irrigation and landscaping measures (water-efficient irrigation systems, irrigation control systems, low-flow sprinkler heads, water-efficient scheduling practices, and Xeriscape)
- Water recycling or reuse measures (Gray water and process recycling systems), and
- Methods to reduce water use in HVAC systems.

DESIGNING EFFICIENT PLUMBING SYSTEM

- A building layout that has been optimized for mechanical/electrical/plumbing (MEP) services will not only have a lower construction cost, but it will also be cheaper to design.

- A thoughtfully designed building layout will have a direct impact on the complexity of its plumbing system, which in turn will have a direct impact on savings among all design teams involved. Helping the design team minimize coordination efforts and delivering a successful building design without exceeding the project budget starts with a close cooperation between the plumbing engineer and the architect early in the design process.

Figure 51 Plumbing joints

- Plumbing over operating rooms; food preparation areas, (serving and storage areas); and electrical rooms containing main distribution panels or motor control centres shall be avoided.

- Piping over such areas can be made only after approval from the medical centre or VA Project Manager. When piping is necessary in these areas, indicate leakage protection, such as drain pans on drawings and in specifications. Plumbing riser or stack floor (not floor drains) penetration sleeves shall extend 50 mm [2 inches] above the floor and 1 inch [25 mm] below the floor and include a built-in water stop and appropriate seal.

WATER REUSE AND RECYCLING

Many facilities have water use requirements that may be met with non-potable water. Using non-potable water to meet these requirements can result in significant water and dollar savings from avoidance of potable water purchases and sewerage costs. The use of non-potable water resources is often more cost-effective if applicable end-uses are identified early on in the building design process.

Figure 52 Water recycling plant

There are four general strategies that can be employed for utilizing reused or recycled water.

1. **On-site water reuse or recycling***:* This process relies on reusing water from the same purpose at the same location, and usually involves minimal treatment or filtration to make it acceptable for its intended reuse. Examples include rinse water that is filtered from car washing and laundry uses and then used in the next wash cycle.

2. **Reclaimed/treated water***:* this non-potable water resource is developed by treating used water to wastewater treatment standards and then redistributed for on-site use. This strategy can be costly, but may still be cost-effective due to offsets of potable water purchases and sewerage costs. Non-potable water meeting wastewater treatment standards can be used for end uses such as landscape irrigation, decorative fountains, cooling tower makeup water, toilet flushing, fire sprinkler systems, and other on-site industrial processes.

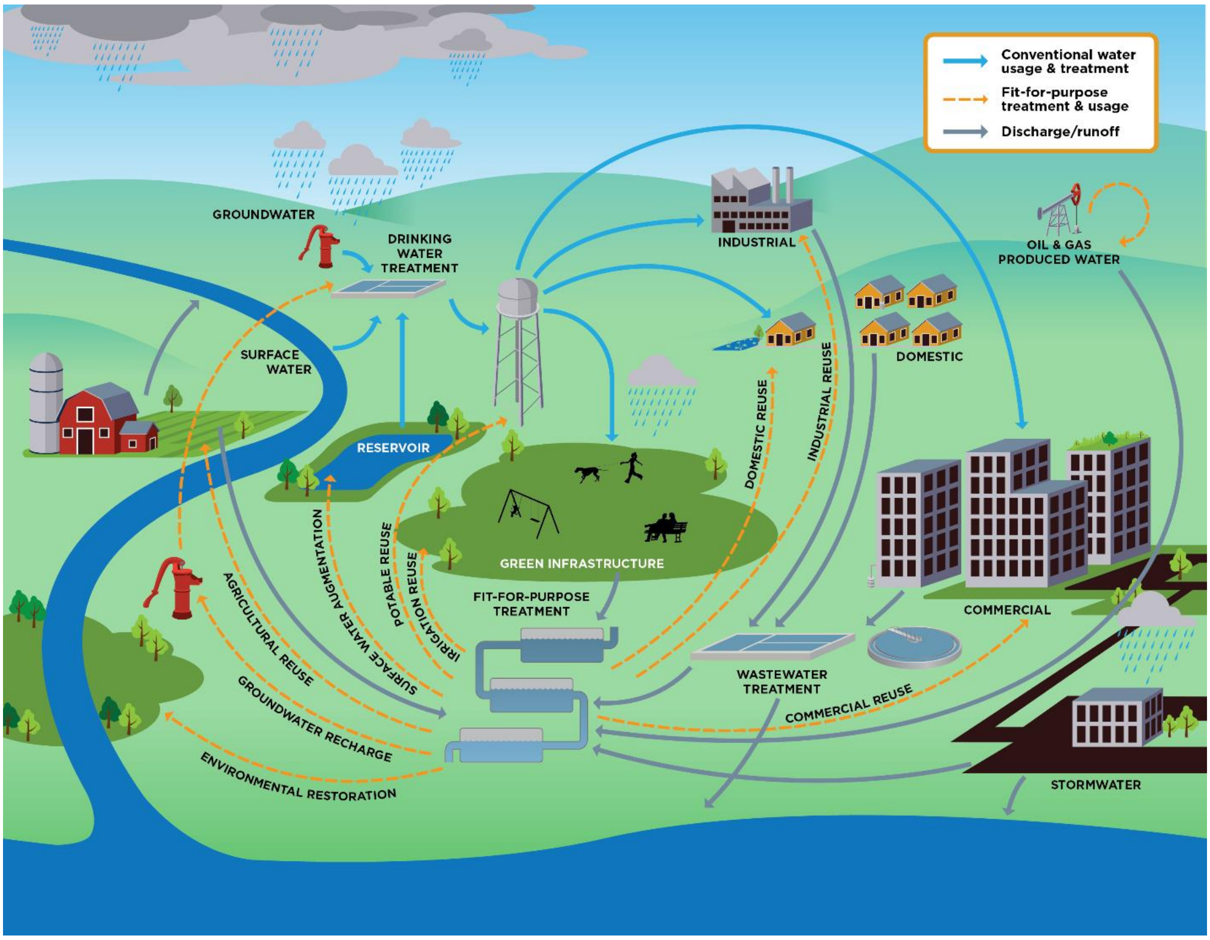


Figure 53 Water usage cycle- use, reuse and recycle

Uses of recycled water:

- Irrigation for agriculture
- Irrigation for landscaping such as parks, rights-of-ways, and golf courses
- Municipal water supply
- Process water for power plants, refineries, mills, and factories
- Indoor uses such as toilet flushing
- Dust control or surface cleaning of roads, construction sites, and other trafficked areas

- Concrete mixing and other construction processes
- Supplying artificial lakes and inland or coastal aquifers
- Environmental restoration

Water Recycling Treatment Process

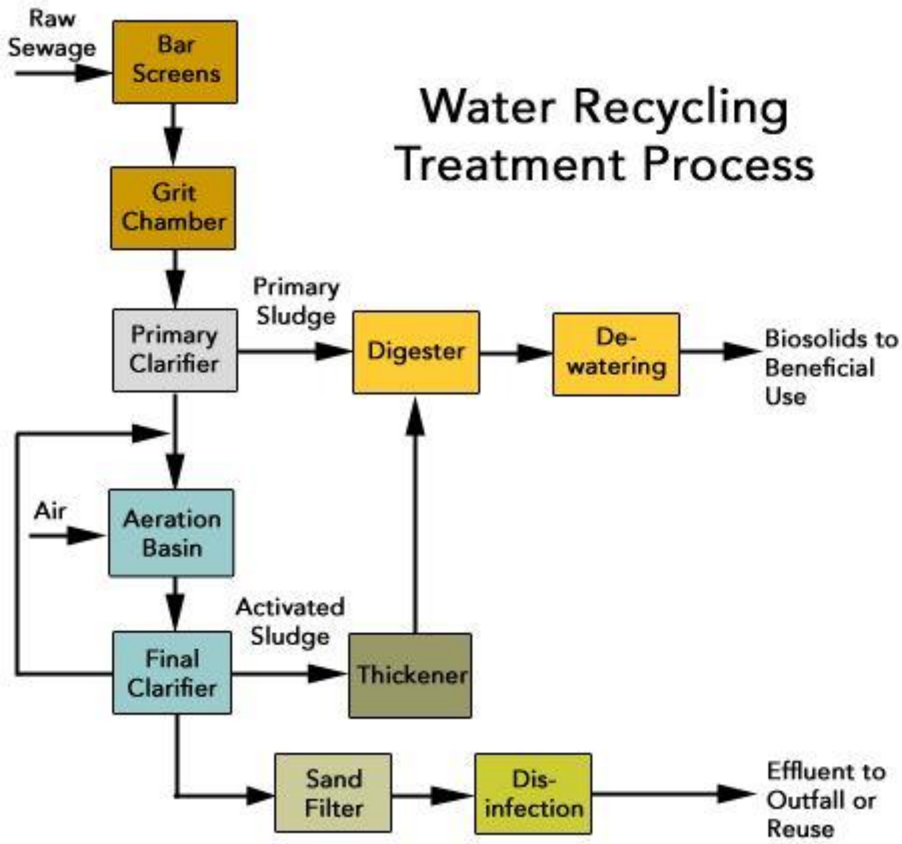


Figure 54 Water recycling treatment process

Primary Treatment

- Primary treatment uses simple mechanical and physical processes to remove approximately half of the contaminants from wastewater.

- **Bar screens**: To begin the water recycling process, incoming raw sewage is routed through mechanical bar screens, removing large solids such as sticks, rags, and plastic material from the wastewater stream. A horizontal rake on a toothed gear drive rakes the bars and removes the captured material to a conveyor that deposits the material into a dumpster for removal to the sanitary landfill.

Grit chamber: As wastewater flow enters aerated grit chambers, the stream is saturated with fine air bubbles to encourage the settling of fine grit particles.

Primary clarification: The wastewater continues to primary clarifiers, where the flow velocity is slowed to promote solids settling. Bio solids removed at this point are digested, dewatered, and used for beneficial purposes like conditioning soil or composting.

Secondary Treatment

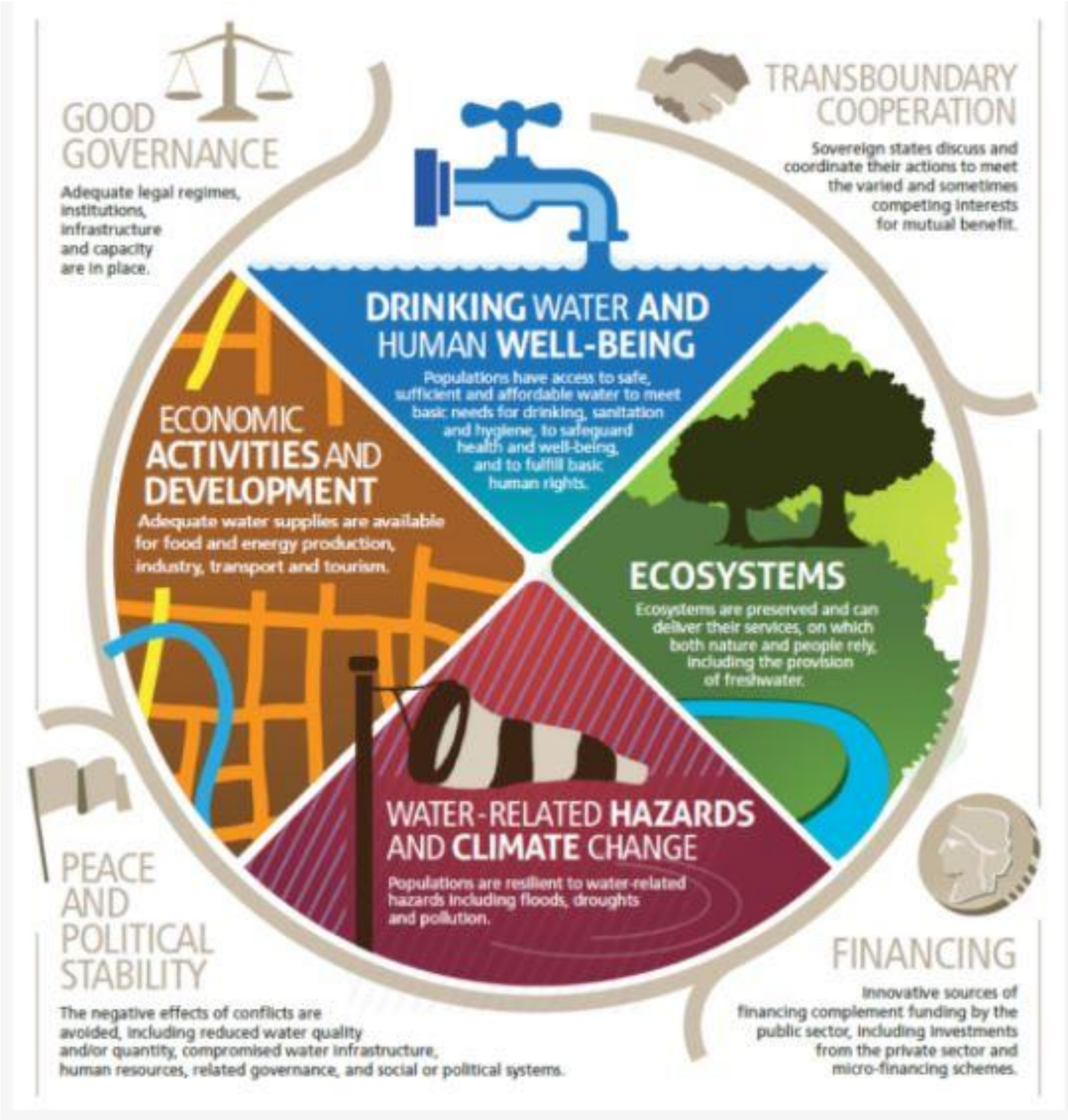
Secondary treatment uses biological processes to remove most of the remaining contaminants. Many operators of WRC's consider themselves "bug farmers" since they are in the business of growing and harvesting a healthy population of microorganisms.

Aeration Basins: Water flows into aeration basins where oxygen is mixed with the water. Bacterial microorganisms consume the organic material as food. They convert non-settleable solids to settleable solids and are later themselves captured in final clarifiers.

Final Clarifiers: Most of the solids that settle out in final clarifiers are thickened and digested, but some are returned to the aeration tank to reseed incoming water with hungry microorganisms.

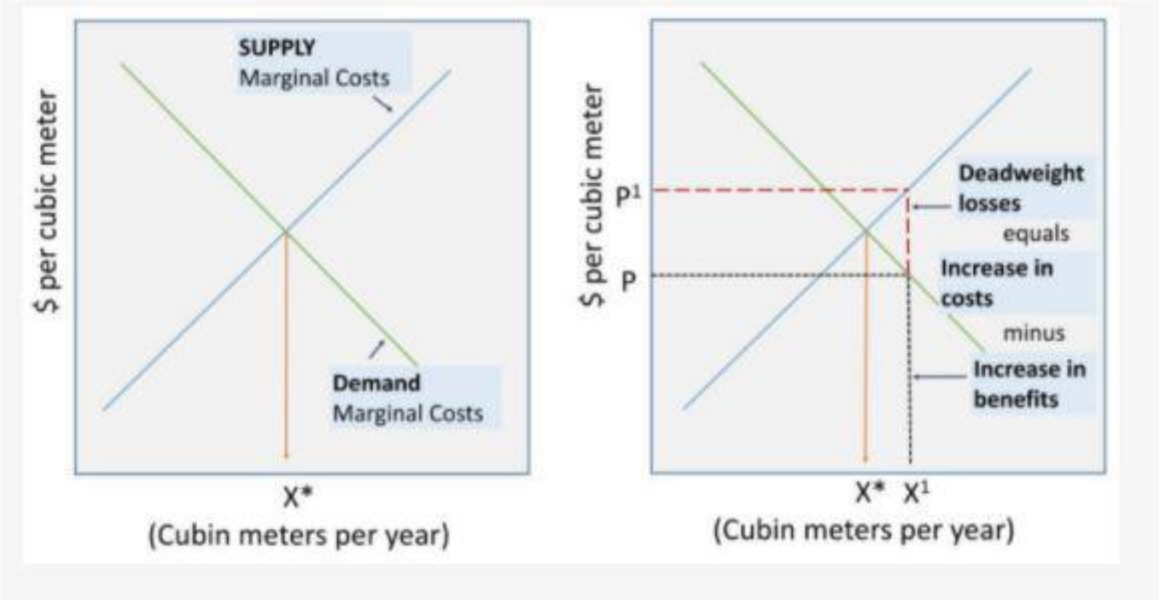
Water Pricing and its Regulations

Water pricing is a means of exercising a public policy about water. Water prices have been steadily rising in the past years due to the high demand and the fact that water quality has deteriorated and demands additional processing before it is provided to consumers. Today's water consumers have been bequeathed (from their ancestors) water sources containing a lot of accumulated pollutants, which have not been there as a result of the current consumers' activities, but of the past generations. Less progress toward efficient water pricing has taken place in agriculture compared to domestic and industrial sectors. Agriculture water is still heavily subsidized, transmitting distorted messages to farmers.



Managing Water Resources: Conceptualization and Pricing Structures

In 1992, the Fourth Dublin Principle established under principle (1) and (4) that water is a finite and vulnerable resource that has an economic value and should be recognized as an economic good. In addition to this, the Rio Principle expressed that water is a social good and that humans are entitled to, at least, a minimal quantity and quality of safe water. However, the emerging pluralism in the valuation and interpretation of water could lead to scenarios of competing and conflicting conceptualizations.

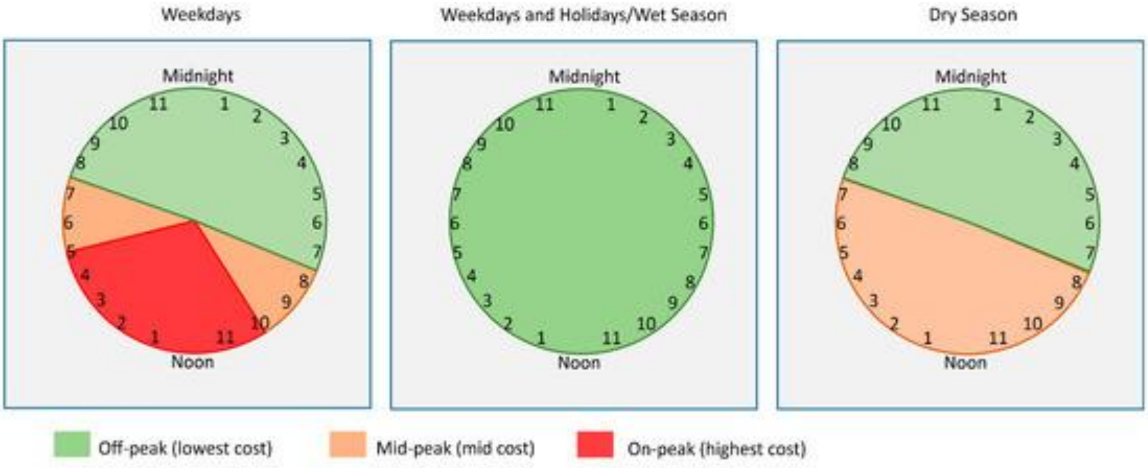


The emerging concepts influence the existing debate by experts from various disciplines over water pricing. When water is priced as an economic good, its economic value can vary depending on buyer and seller willingness to pay. However, if the concept of social good is applied to the pricing structure, then water should be affordable to the poor, benefiting the largest number of people in the best possible way. To add further complexity with respect to the economic principles, the true “economic” value of a good and its “financial” value seldomly correspond; hence, the competitive market prices reflect only the financial and not necessarily the economic values of water.

From the previous explanation and in order to continue this analysis, we must consider water as a special economic good (discussed below). However, water utilities are usually a natural monopoly and the marginal costs are usually lower than average costs. Such pricing would lead to a unit price that is less than the average cost and the utility will not generate enough funds to cover all costs (operational, management, quality, maintenance, or future events).

Potential of Water Pricing as a Tool for Water Security

As previously described in the case studies, the power of water pricing as a policy of regulation for water consumption is quite relevant, as it implies that, as a water policy, pricing can control the demand sector. Therefore, water pricing is considered a crucial issue for decision makers, water utilities managers, and consumers. Water security can be severely affected if innovations in water pricing are not developed and implemented efficiently to improve and ensure the effectiveness of another strategy already in place. Efforts have commenced to address this issue in some parts of the world. For example, the European Union Water Framework Directive (WFD) created a pricing structure that taxes water users to reflect the scarce value of water.



(e) Alternative Structures: Time of Day or Seasonal rates.

The European Commission report states that water pricing should be used as a key tool to support water management decisions, and that under-priced water may lead to its unsustainable use. The report goes on to state that water pricing should be discussed within social policies to help ensure that they are fair to all sections of society and environmentally sustainable (i.e., ensuring that developing populations do not suffer from high water pricing policies). Applying a participatory approach to water-related decision making is recommended. In contrast, other case examples reflect how water prices could lead to social conflicts and increase government reluctance to adopt this approach, since the different views regarding government's role in water regulation are based on cultures, religions, and political interests. Moreover, negotiation principles demonstrating different and often heavily asymmetric bargaining positions of partners are related to water pricing of existing cross-border utilities. Consequently, to establish whether water pricing could serve as a tool for water security, from the case studies, we concluded that the price of water as a strategy is highly sensitive in societies with problems of scarcity. Therefore, its application must be carefully studied, considering the understanding as well as who is in charge under different scenarios, and commitments of the water allocation, distribution, and overall management.

Materials and Methods

The complexity of applied water pricing policy reflects the efforts of governments and utility service providers put into effect actions that will address water demand. Thus, we completed a systematic review of academic and grey literature on the subject. During our review, we accessed 112 studies, with 40 being excluded due to their irrelevance to objective of this paper.

For the case studies, agriculture and urban water consumption were considered for analysis because of their complexity and diversity with respect to water pricing. Both national and municipal/district level examples were chosen. The paper focuses on the agriculture and urban drinking water sectors because 86% of the total global water consumption is due to agricultural activities and given the importance urban water access to societal development.

Rainwater Harvesting

Rainwater harvesting systems consists of the following components:

- Catchment- Used to collect and store the captured Rainwater.

- Conveyance system – It is used to transport the harvested water from the catchment to the recharge zone.
- Flush- It is used to flush out the first spell of rain.
- Filter – Used for filtering the collected Rainwater and remove pollutants.
- Tanks and the recharge structures: Used to store the filtered water which is ready to use.

The process of rainwater harvesting involves the collection and the storage of rainwater with the help of artificially designed systems that run off naturally or man-made catchment areas like- the rooftop, compounds, rock surface, hill slopes, artificially repaired impervious or semi-pervious land surface.

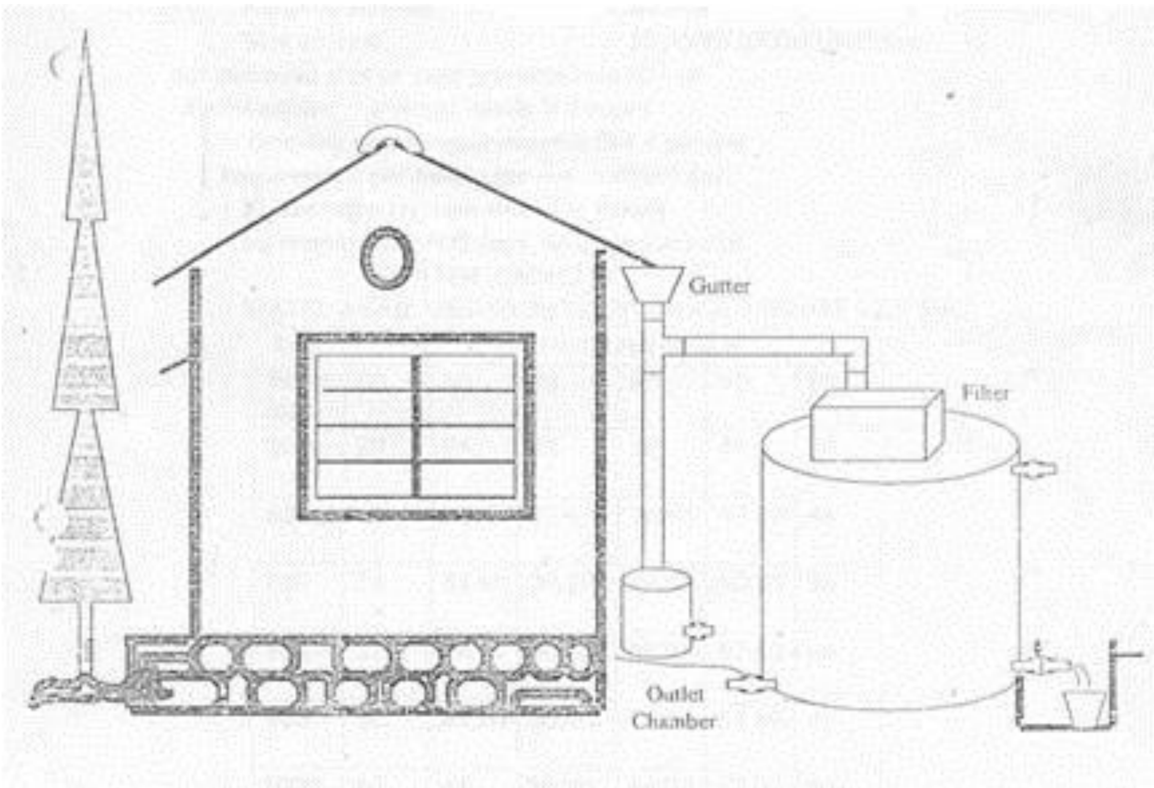


Figure 55 Rain water harvesting

Several factors play a vital role in the amount of water harvested. Some of these factors are:

- The quantum of runoff
- Features of the catchments
- Impact on the environment
- Availability of the technology
- The capacity of the storage tanks
- Types of the roof, its slope and its materials
- The frequency, quantity and the quality of the rainfall
- The speed and ease with which the Rainwater penetrates through the subsoil to recharge the groundwater.

Rain Barrel

The easiest way to harvest rain is through a rain barrel (make your own from a large trash can or an old drum) linked to a pipe fitted to collect rainwater from the rooftop and veranda of the house. To prevent the barrel from becoming a mosquito breeding ground, fasten a tight-fitting top to it, and screen the ends of the downspouts leading into the barrels. Or simply add a tablespoon of vegetable oil to the stored rainwater. It coats the water's surface and kills larvae by depriving them of oxygen.

Figure 56 SImple filtration at home

Rain Garden

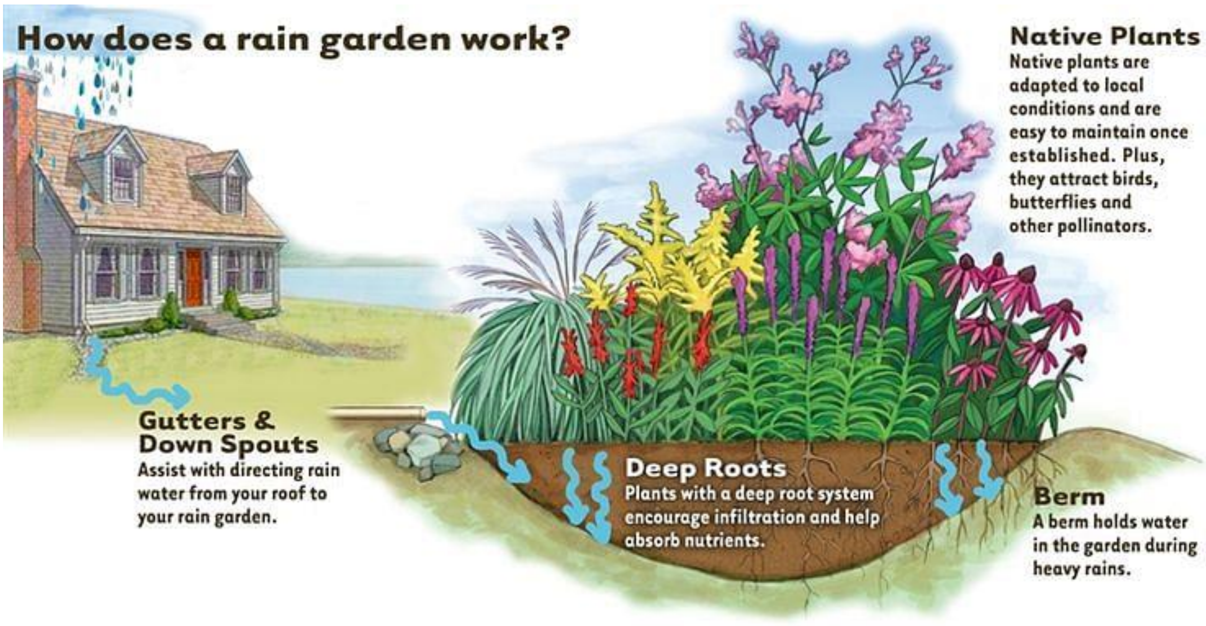


Figure 57 Rain garden

A rain garden is a sunken landscape that uses native plants, local soil, and mulch to remove pollutants from water, and allows it to percolate into the ground. It’s easy to create, looks good all year-round and has a positive impact on the environment. Here’s how to make a rain garden in your own backyard.

Naturally recharge your wells and bore wells

Figure 58 Natural recharge of wells

Rooftop rainwater is led through pipes with a filter at the end to open dug wells for replenishing underground aquifers. Based on this idea, the ‘Mazhapolima’ (bounty of rain) Recharge Project of Thrissur was born. As a result, today, not only is there abundant water in summer, there is also reduced salinity, turbidity, and colour in the well water.

A recharge pit for bore wells is also a good idea as it pushes back the surface water into the groundwater system. Usually, a recharge pit is one metre in diameter and six metres deep, lined with concrete rings having perforations. These perforations let filtered and de-silted water seep from the sides increasing the groundwater table.

Piping connections

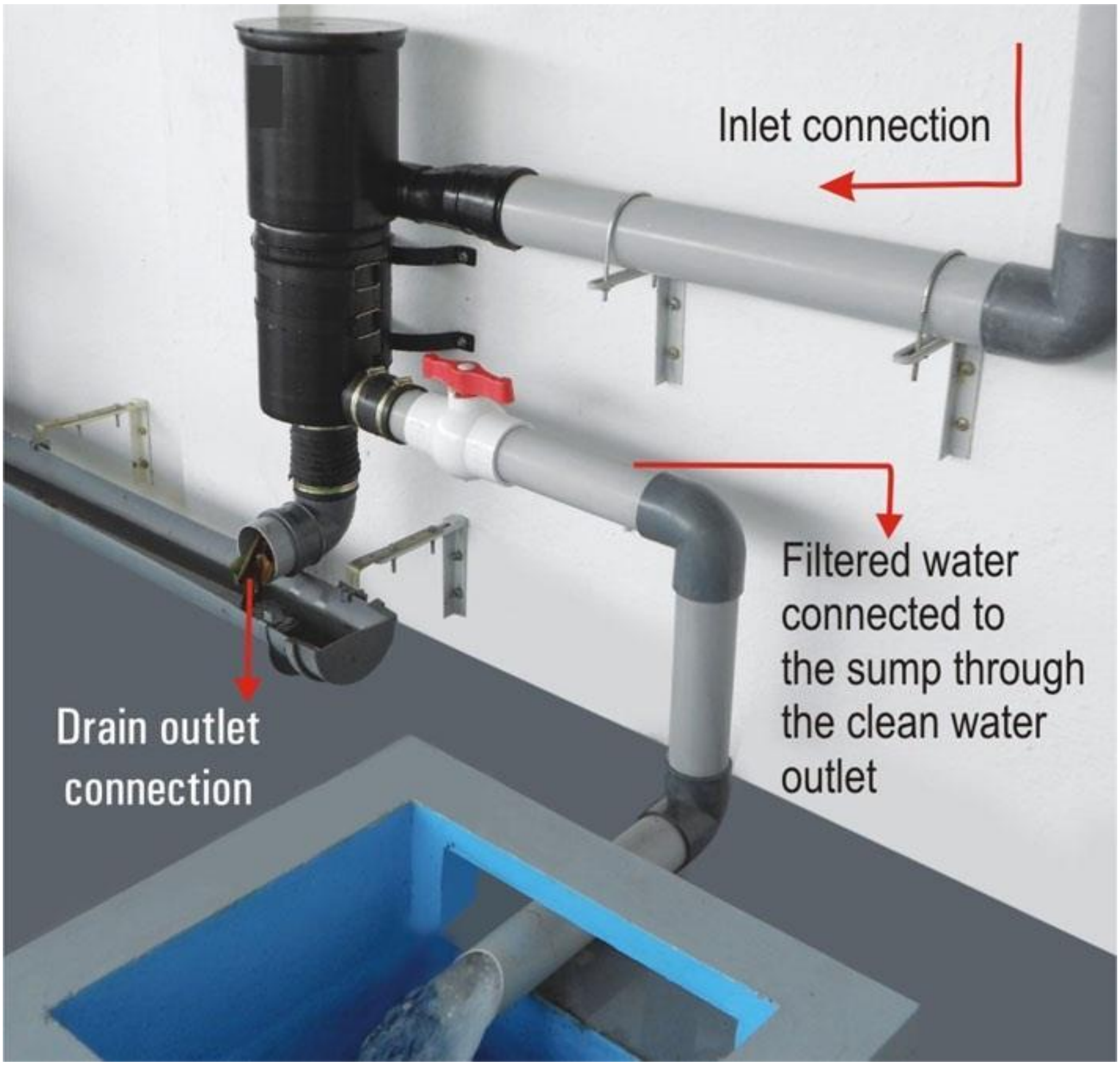


Figure 59 Collected rainwater being used

What Are The Uses Of Collected Rainwater?

You can essentially use rainwater anywhere you use tap water. The idea of using drinking water to flush our toilets and water our lawns is wasteful and irresponsible, especially in light of population growth and water shortages across the country.

Rainwater collection is a technique to green your home and to lessen your environmental footprint.

There are basically three areas where rainwater can be used: Irrigation use Indoor, non-potable use Whole house, potable use Here are some ideas for specific uses of rainwater:

- Hand water your lawn and garden
- Connect rainwater collection system to irrigation/sprinkler system
- Wash your vehicles
- Wash your pets
- Refill your fountains and fish ponds

- Refill your swimming pool
- Replace the use of tap water with rainwater to wash your driveways and sidewalks (if you don't use a broom)
- Use it for all indoor non-potable fixtures (toilets and clothes washer)
- Use it for all potable needs when properly filtered and disinfected
    - Use it for industrial processes instead of municipally treated water.

Technical Designs for Ground Water Recharge

1. **Recharge pit method:**

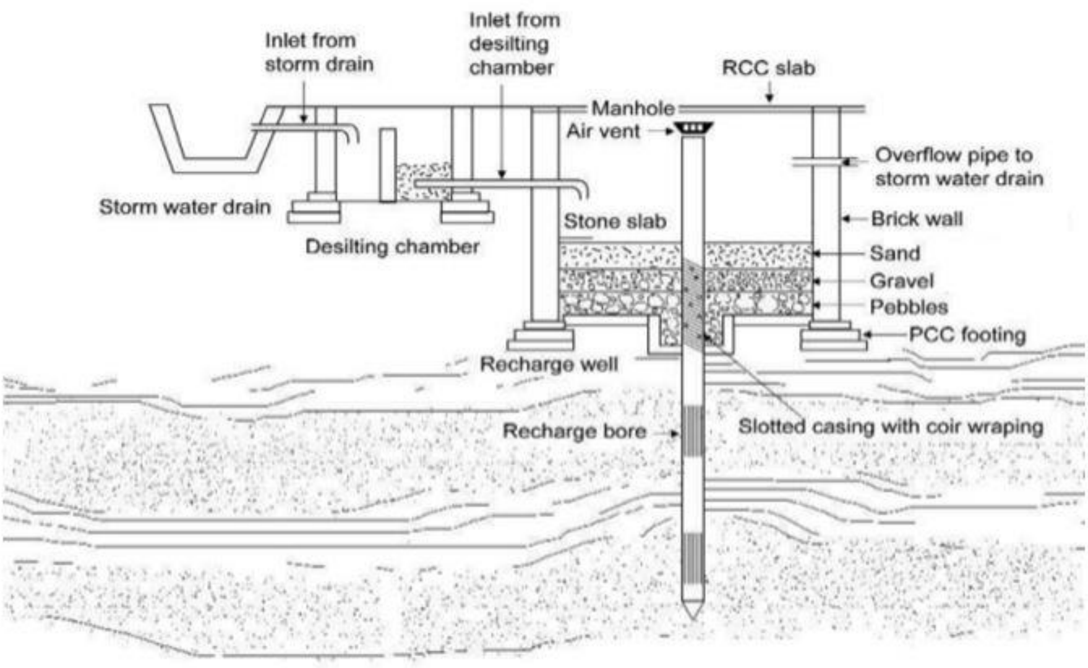


Figure 60 Recharge pit

- Recharge Pit Method is most suitable for such alluvial areas (plains) where permeable strata are not below than 2 to 2.5 meter deeper from the ground surface.
- This technique is generally considered suitable for the roof having 100 SQM areas and it is constructed to recharge shallow aquifers.
- Recharge pits can be constructed after calculating the quantum of rain water that can be available on the bigger rooves.
- Recharge pit may be of any size and shape and this is constructed generally with the width of 1– 2 M, 1.5 to 2 M deeper or according to the availability of permeable strata.
- This pit is filled with layers in graded form with the boulders of 5-20mm, gravels of 5– 10mm, thick sand/Morang (1.5 to 2mm).
- Boulders are placed on bed of the pit, gravels in middle and thick sand is filled on top so that the silt coming in with run off is deposited above thick sand or Morang which can be removed later.
- Recharge/percolations pits for the rooves comparatively of smaller size can be filled in with brick pieces or pebbles etc.

- A mesh should be put at the drainage point on the roof so that leaves or other solid materials can be prevented to fell in the pit.
- A desilting/collection chamber can also be constructed on the surface to stop silt which can further prevent the flow of small molecules towards the pit.
- "Over Flow" system should be integrated for each recharge pit to counter the situations of heavy rains. Upper layer of sand/Morang should be cleaned time to time to maintain the recharge rate.
- A separate by-pass system should be there to allow over flowing the very first rain water before it enters water collection chamber. Construction of recharge pit is easier and cheaper.
- If the same is provisioned at the time of construction of building, it takes very less cost and suitable recharging can be managed with better planning. This is safer in comparison with other technics. So it should be widely adopted.

2. **Recharge Trench Method:-**

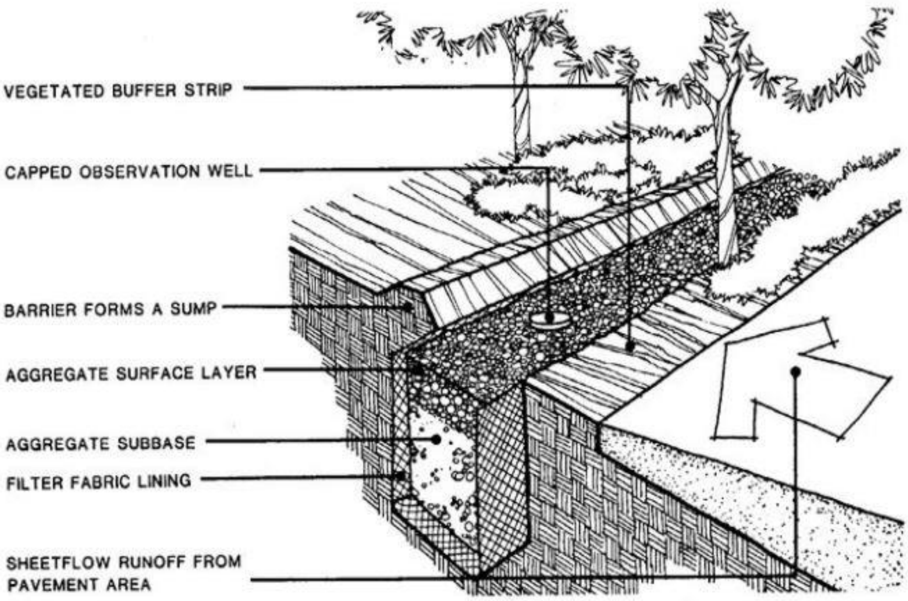


Figure 61 Recharge trench

- Recharge trench is also a simple method like recharge pit. Difference is only of shape and size. Recharge trench is suitable for the buildings having roof size from 200-300 SQM.
- This method will also suit those areas where permeable strata are available on shallow depth. Measurement of trench may be according to the availability of water that can be recharged, it may 0.5-1M wider, 1 – 1.5M deeper and 8-10M longer or it may be variable according to local needs.
- Recharge trench is filled with boulder (5 to 20 C.M.), Gravel (5-10M.M.) and thick sand/Morang (1.5 – 2 M.M.) in sequence.
- Filling of recharge trench is also like the pit as boulders on bed, gravels in middle portion and thick sand/Morang on the top so that silt coming with run-off is deposited on very upper layer and can be removed easily.
- A wire mesh should be put on the on drainage point on roof to avoid entrance of leaves and other material into the trench.

- A desilting or collection chamber should also be constructed on ground surface to stop entry of smaller materials into the trench.
- A by-pass system should be there to prevent entry of very first rain water before it enters water collection chamber.
- A separate by-pass system should be there to allow over flowing the very first rain water before it enters water collection chamber.
- Upper layer of thick sand/Morang should be cleaned before every monsoon season to maintain recharge rate.
- To counter the heavy rain, an "over flow" system should be integrated with recharge trenches.

3. Recharge Well Method:-

- In such areas where top layer clay is impervious and its thickness is comparatively more, aquifer is 25 to 30M deeper or more, adoption of "Recharge Well Method" will be most suitable.
- In the multi-storied buildings (roof area is 400 – 1000 SQM or more), this technique is generally suites better especially where the place is limited and water level is deeper.
- This method can also be used for the rooves having lesser area like 100, 200, 300 SQM. With the help of this technique, stressed aquifer can be recharged directly.

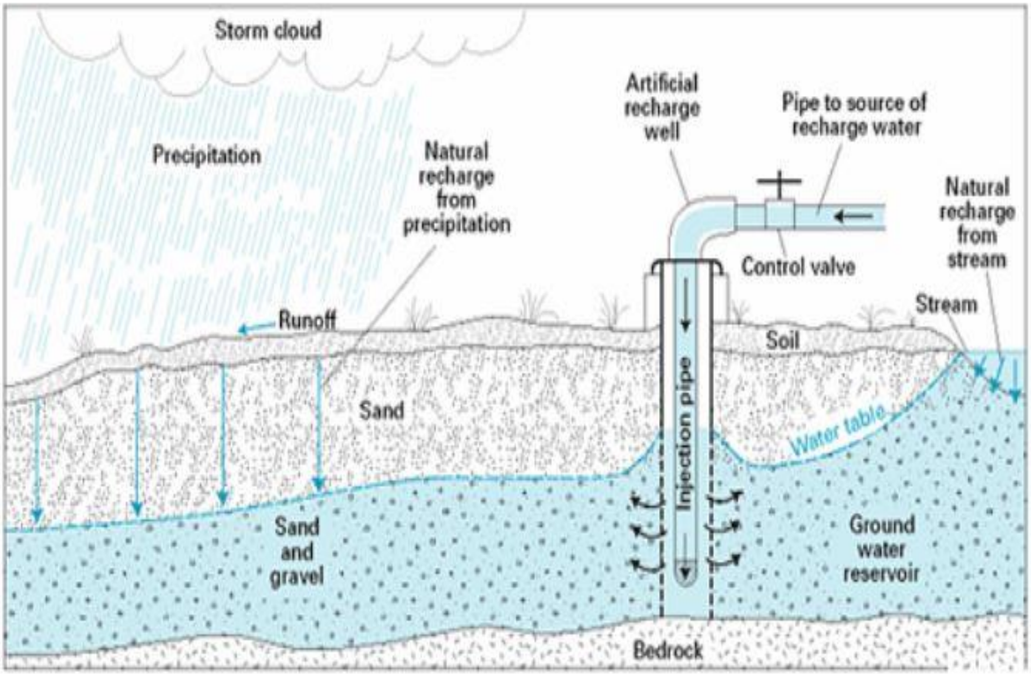


Figure 62 Recharge well

- By this method, rain water received from the rooves under recharge system, will reach at filter chamber first through piped conveyance network.
- The water will be stained here and will reach in the storage tank made from concrete.
- Rain water will enter through slotted pipe/strainer in the well, constructed within the chamber and recharge the aquifer directly.

- Determination of size of storage tank and filter will be depending on the availability of water from the roof.
- Storage capacity of these storage tanks and filter will also depend on the depth and diameter of recharge well, thickness of aquifer, granularity and recharge rate.
- The size of storage tank and filter can be increased or decreased based on these factors. Filter should generally be graded with the boulder/pebble at the bed, gravels in the middle and Morang should be on the top thus total three layers should be there.
- P-gravel can be used as major filtering material so that cleaning of filter can be ensured easily every year.
- This technique has been found practical with the view of long age and maintenance of recharge structure, thus the method is being implemented in maximum buildings.
- Special attention is paid on the requirement of wire mesh, over flow system, by-pass system, suitable screen/slot in this technique.
- To manage the rain water storage in the recharge/storage tank and filter chamber, count of water storage volume is done in the ratio of normal monsoon rain as per area of roof catchment and other parameters.

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UNIT – IV – Strategies to reduce water consumption in buildings

Low flow plumbing fixtures for water efficient appliances

Low-flow plumbing fixtures are those that limit the amount of water that is expelled per minute and line up with federal guidelines when it comes to water usage. They are available in multiple forms for different parts of your home in order to save you the most water.

Types of low flow plumbing fixtures

1. **Low flow toilets**

Traditional flow toilets can use up to 7 gallons of water per flush! Low flow toilets can lower the amount of water you use from an average of 3.5 gallons per flush to just 1.6, and they typically come in two models.

- **Gravity-Fed**: These use the traditional method of using the water's weight to flush. They tend to be cheaper and a bit quieter.
- **Pressure-Assisted**: This model tends to be a bit noisier but can help reduce your water usage by up to 45%.

2. **Low flow showerheads**

Most shower heads expel water at a rate of 2.5 gallons per minute, while low-flow showerheads can reduce that rate to 2.0. Since we know that some of us take much longer showers than others, reducing the amount of water that comes out of the showerhead can make a big difference in your water bill. You can usually choose from two main models.

- **Laminar Flow**: This model creates individual streams of water and allows for a bit more control of the water's temperature.
- **Aerating**: This model mixes air into the water to create a mist. Since this can lead to a lot of steam, it's not always a good option for humid climates.

a. **Low flow faucets**

Adding low fixtures to your faucets can lower the amount of water that use from 2.5 gallons per minute to 1.5 gallons per minute. This is very easily done by installing an aerator on your faucets.

Challenges in low flow fixtures

Low-flow plumbing can save homeowners from high water bills, but these fixtures come with potential drawbacks. Quality low-flow products will usually perform as expected, but users must be certain that the products will not change their water use habits. For example, efficient toilets will sometimes not be able to flush all the waste at once. If it takes two flushes, this defeats the purpose of having a low-flow toilet in the first place. Some toilets address this specific problem by having two flush volumes; one for solid and one for liquid. The thing to remember with these models is to use the correct volume for your needs each flush.

Another potential issue is that low-flow toilets rely more on gravity than older models. In some homes, the pipes were installed with high-volume toilets in mind, and they are at the wrong angle for low-flow models. This is another reason that low-flow toilets might require multiple flushes. Low-flow showerheads and faucets are less prone to such problems, but you should beware of taking longer showers than you did before the new head was installed or using more water to wash the dishes. Low-flow showerheads may have weaker water pressure, so longer showers may result. The change in water pressure is less noticeable in kitchen and bathroom faucets with low-flow aerators.

The IGBC Green Homes Rating system requires applicants to comply with the following thresholds:

Baseline Flow Rates / Capacity as per Uniform Plumbing Code of India (UPCI)

Fixture Type	Maximum Flow Rate / Capacity	Duration	Daily Uses per Person/ Day
Water Closets	**6 LPF (High flush)**	**1 Flush**	**1**
	3 LPF (Low flush)	1 Flush	1
Health Faucet/ Bidet, Hand-held spray*	6 LPM	15 Seconds	1
Faucet/ taps*	6 LPM	15 Seconds	8
Kitchen Sink*	6 LPM	15 Seconds	6
Urinal*	4 LPF	1 flush	2
Showerhead* / Hand-held Spray*	10 LPM	8 Minutes	1

Source: Uniform Plumbing Code – India, 2016 ** At a design pressure of 4 bar*

Table 6 Baseline flow rates/ capacity as per UPCI

Reuse of greywater for non-potable uses

Grey water is water that has been used for washing dishes, laundering clothes, or bathing. Essentially, any water, other than toilet wastes, draining from a household is grey water. Although this used water may contain grease, food particles, hair, and any number of other impurities, it may still be suitable for reuse.

Reusing Grey water serves two purposes: it reduces the amount of freshwater needed to supply a household, and reduces the amount of waste water entering sewer or septic systems.

Graywater is water that has been used for washing dishes, laundering clothes, or bathing. Essentially, any water, other than toilet waste, draining from a household is Graywater. Although this grey water may contain grease, food particles, hair, and any number of other impurities, it may still be suitable for reuse. Reusing Greywater serves two purposes: it reduces freshwater recruitment, and also reduces the quantum of waste water entering sewer or septic systems.

Grey water characteristics versus Black Water

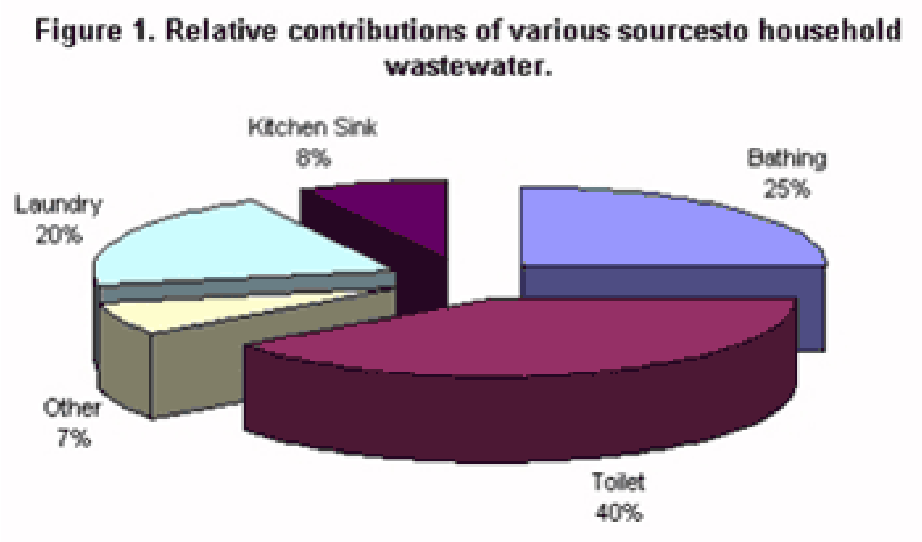

Figure 63 Relative contributions of various sources to household wastewater

• Low BOD concentration, 140 to 160 mg/L.
• Low suspended solids, 50 - 150 mg/L.
• Low nitrogen concentration, 5 - 10 mg/L.
• Low phosphorus concentration, 0.4 to 2mg/L.
• Presence of more Alkaline.
• High salt content.

Washing clothes and utensils, mopping dishes, bathing — mundane tasks like these contribute to around 60% of the wastewater generated from households each day. Contrary to popular opinion, only some of this waste is unusable; the rest, known as greywater, can be efficiently recycled and reused. Also known as sullage, greywater comprises most of the wastewater produced by households on an everyday basis. However, it does not include sewage and wastewater from toilets, which fall under the category of black water.
Greywater can be cleaned and utilised further for a variety of domestic use

Wetlands for natural waste water treatment

Wetlands are transitional areas between land and water. The boundaries between wetlands and uplands or deep water are therefore not always distinct. The term "wetlands" encompasses a broad range of wet environments, including marshes, bogs, swamps, wet meadows, tidal wetlands, floodplains, and ribbon (riparian) wetlands along stream channels

All wetlands - natural or constructed, freshwater or salt - have one characteristic in common: the presence of surface or near-surface water, at least periodically. In most wetlands, hydrologic conditions are such that the substrate is saturated long enough during the growing season to create oxygen-poor conditions in the substrate. The lack of oxygen creates reducing. (oxygen-poor) conditions within the substrate and limits the vegetation to those species that are adapted to low-oxygen environments. The hydrology of wetlands is generally one of slow flows and either shallow waters or saturated substrates. The slow flows and shallow water depths allow sediments to settle as the water passes through the wetland. The slow flows also provide prolonged contact times between the water and the surfaces within the wetland. The complex mass of organic and inorganic materials and the diverse opportunities for gas/water interchanges foster a diverse community of microorganisms that break down or transform a wide variety of substances. Most wetlands support a dense growth of vascular plants adapted to saturated conditions. This vegetation slows the water, creates microenvironments within the water column, and provides attachment sites for the microbial community. The litter that accumulates as plants die back in the fall creates additional material and exchange sites, and provides a source of carbon, nitrogen, and phosphorous to fuel microbial processes

Under appropriate circumstances. constructed wetlands can provide: water quality improvement flood storage and the desynchronization of storm rainfall and surface runoff cycling of nutrients and other materials habitat for fish- and wildlife passive recreation, such as bird watching and photography active recreation, such as hunting education and research aesthetics and landscape enhancemerit.

A constructed wetland system for domestic wastewater treatment is designed to mimic the natural wetland treatment processes by Mother Nature. This system uses plants and microbes to improve the wastewater quality.

A constructed wetland consists of a properly designed basin that contains water, a substrate, and, most commonly, vascular plants. These components can be manipulated in constructing a wetland. Other important components of wetlands, such as the communities of microbes and aquatic invertebrates, develop naturally.

Natural wetlands generally have visible water in the system. However, for those at homes, the water flows beneath the media surface, which limits contact between residents and wastewater.
The constructed wetland wastewater treatment system has three main components that work together to purify wastewater:

- A septic tank, which is an enclosed watertight container that provides primary treatment by removing the settling solids and floating solids (oils and greases) from the wastewater;
- A constructed wetland, which is a bed of graded stone, with water beneath the surface, where aquatic plants are grown. It removes nutrients, organic matter, suspended solids, and pathogens; and
- A final treatment and dispersal system, which disperses the wastewater into the soil for final treatment and dispersal/reuse.

Constructed wetland systems should be designed and built to blend into the home's landscaping. The best way to achieve this goal is to determine where the wastewater treatment system will be located before the house is built. Effective planning before building the house simplifies the system and helps you enjoy it.

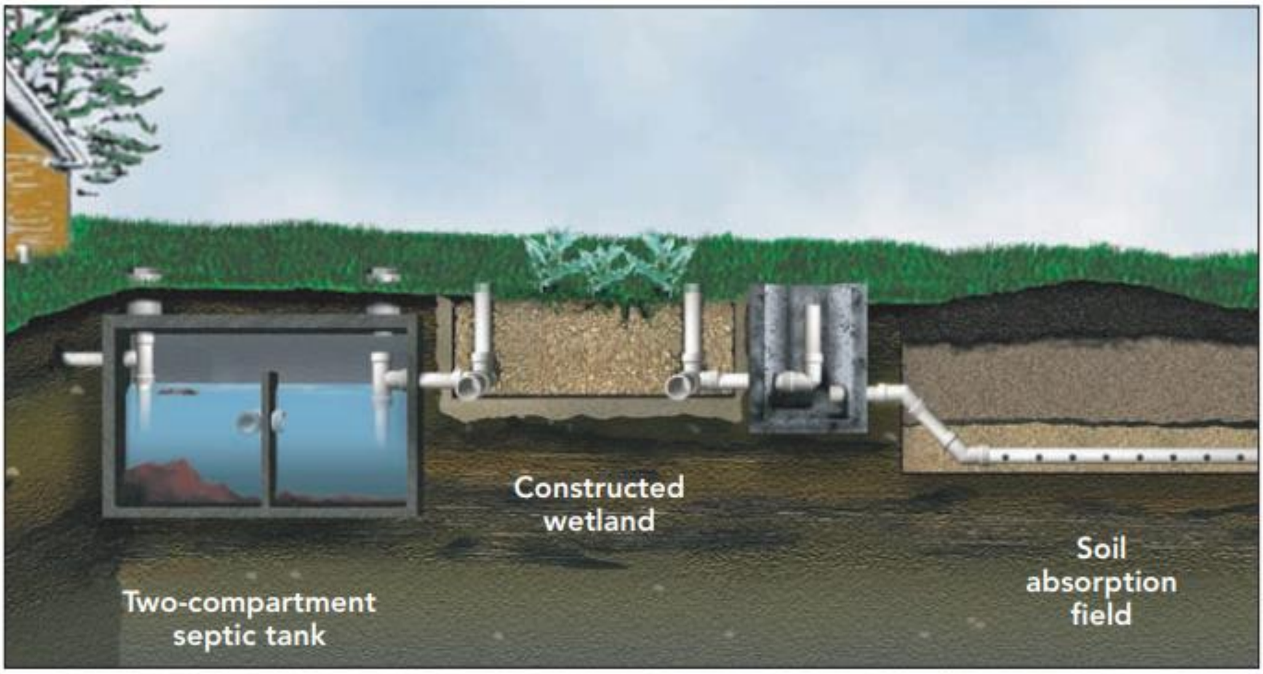

Figure 1: A constructed wetland system.

Figure 64 Wetland

For example, a key factor in determining whether or not your system uses gravity or a pump to move the water between the system components is the location and elevation of the plumbing exit from the house. If the plumbing exit is too low, you will need to install a pump to lift the wastewater back to near the ground surface to have a gravity flow system.

Also, the pipes transporting the wastewater must be installed with a slight slope to help wastewater flow through the system. If the yard slopes in the same direction as the wastewater flow, the wetland will be near the soil surface, thus increasing its aesthetic value. The wetland consists of a bed of graded stone where aquatic plants are grown.

The wetland cell is generally an earthen basin lined with compacted native clay, bentonite clay, concrete, PVC, hypalon, or PondGard Ethylene Propylene Diene Terpolymer (EPDM) Rubber. The media bed itself is usually washed rock but can be any porous material that resists being corroded or dissolved by wastewater.

The media bed has devices to distribute wastewater entering the system and to collect wastewater leaving it. The water to be treated flows horizontally through the bed, remaining below the media surface.

Plants in the wetland must be able to survive in a saturated medium. Although soft- and hard-tissue plants can be used, some experts believe that hard-tissue plants are better because they may provide a pathway for oxygen to enter the wetland during winter and reduce the need for plant maintenance. However, residents prefer soft-tissue plants because they generally have flowers and are colorful. Remember that if you use soft-tissue plants, your system may need more maintenance.

Treatment

Wastewater is treated by the septic tank first.

- The tank, which should have two compartments, should be sized appropriately to allow enough time for the settling solids to separate from the wastewater.
- Upon leaving the septic tank, wastewater enters the wetland. It is believed that pollutants entering the wetland are removed from the water by microbes living on the surfaces of the media and plant roots. The plants provide oxygen to the bed and remove some of the nutrients.
- Other processes such as filtering, microbial decomposition, and attachment to particle surfaces also help remove pollutants. The longer the water is detained in the wetland, the more pollutants are removed and the better the quality of water leaving the wetland.
- After flowing through the media, wastewater exits the wetland through a water-level control sump. The sump allows the water level to be adjusted, because the wetland water level must be lower than the media surface to prevent odors.
- The water then flows into the soil absorption field, the last treatment stage. If it cannot enter the field by gravity, it enters a pump tank and is pumped to the absorption field, where the soil absorbs it. Microbes and plants growing in the soil use the remaining nutrients in the water.

Design

All components of the wetland system must be designed properly. This fact sheet focuses on the wetland. For information on septic tank sizing and final treatment and dispersal systems, see the Extension publication L-5227, Septic Tank/Soil Absorption Field.
Wetland systems remove biological materials, suspended solids, nutrients and pathogens from the wastewater. To determine a wetland's size, consider:

- Temperature of the system, which affects how fast it removes nutrients; and
- Amount of waste. A wastewater treatment system must be designed to treat the most wastewater that a residence generates.

This information is used in an equation to determine the hydraulic detention time, which is the amount of time the wastewater needs to stay in the wetland. It is generally expressed in days. The longer the wastewater stays in the wetland, the more time that microbes and plants have to treat the water. Generally, the water needs to stay in the wetland system for 2 to 3 days.

HOW WETLANDS IMPROVE WATER QUALITY

A wetland is a complex assemblage of water, substrate, plants (vascular and algae), litter (primarily fallen plant material), invertebrates (mostly insect larvae and worms). and an array of microorganisms (most importantly bacteria). The mechanisms that are available to improve water quality are therefore numerous and often interrelated. These mechanisms include:

- settling of suspended particulate matter
- filtration and chemical precipitation through contact of the water with the substrate and litter
- chemical transformation l adsorption and ion exchange on the surfaces of plants, substrate, sediment, and litter
- breakdown and transformation of pollutants by microorganisms and plants
- uptake and transformation of nutrients by microorganisms and plants
- predation and natural die-off of pathogens.
- The most effective treatment wetlands are those that foster these mechanisms.
- The specifics for the various types of wastewater and runoff are discussed in the wastewater-specific volumes.

ADVANTAGES OF CONSTRUCTED WETLANDS

Constructed wetlands are a cost-effective and technically feasible approach to treating wastewater and runoff for several reasons:

- wetlands can be less expensive to build than other treatment options . operation and maintenance expenses (energy and supplies) are low
- operation and maintenance require only periodic, rather than continuous, on-site labor
- wetlands are able to tolerate fluctuations in flow. They facilitate water reuse and recycling. In addition:
- They provide habitat for many wetland organisms
- They can be built to fit harmoniously into the landscape
- They provide numerous benefits in addition to water quality improvement, such as wildlife habitat and the aesthetic enhancement of open spaces
- They are an environmentally-sensitive approach that is viewed with favor by the general public.

Water balance

The overall water balance for a constructed wetland is an account of the inflow, storage, and outflow of water. Water inflow to the wetland includes surface water (the wastewater or stormwater), groundwater infiltration (in unlined wetlands), and precipitation: Storage is the surface water plus that in the pore spaces of the substrate. Outflow comprises evaporation from the water surface, transpiration by plants, effluent discharge, and exfiltration to groundwater. During design and operation, the wetland water balance is important for determining conformance with desired limits for HLR, hydroperiod range, HRT, and mass balances. A simple water balance equation for a constructed wetland is expressed as:

$S=Q+R+I-O-E\ T$

Where:

S = net change in storage

Q = surface flow, including wastewater or stormwater inflow,

R = contribution from rainfall

I = net infiltration (infiltration less exfiltration)

O = surface outflow

ET= loss due to evapotranspiration

Natural renewable power source such as PV

Solar water heaters

Solar water heating system is a device that uses solar energy to heat water for domestic, commercial, and industrial needs. Heating of water is the most common application of solar energy in the world. A typical solar water heating system can save up to 1500 units of electricity every year, for every 100 litres per day of solar water heating capacity.

Parts of the solar water heating system

- A solar water heating system consists of a flat plate solar collector, a storage tank kept at a height behind the collector, and connecting pipes.

- The collector usually comprises copper tubes welded to copper sheets (both coated with a highly absorbing black coating) with a toughened glass sheet on top and insulating material at the back. The entire assembly is placed in a flat box.
- In certain models, evacuated glass tubes are used instead of copper; a separate cover sheet and insulating box are not required in this case.

Working of a solar water heater

- The system is generally installed on the roof or open ground, with the collector facing the sun and connected to a continuous water supply.
- Water flows through the tubes, absorbs solar heat and becomes hot.
- The heated water is stored in a tank for further use.
- The water stored in the tank remains hot overnight as the storage tank is insulated and heat losses are small.

Uses of solar water heater

- SWHs can be used at homes for producing hot water that can be used for bathing, cleaning, and washing. Solar water heaters (SWHs) of 100-300 litres capacity are suited for domestic application. Larger systems can also be used for a variety of industrial applications. Hot water at 60-80^{o}C could be obtained through use of solar water heaters.
- Fuel Savings: A 100 litres capacity SWH can replace an electric geyser for residential use and saves 1500 units of electricity annually.
- Saves cost on power generation - The use of 1000 SWHs of 100 litres capacity each can contribute to a peak load saving of 1 MW.
- Environmental benefits - A SWH of 100 litres capacity can prevent emission of 1.5 tonnes of carbon-dioxide per year.
- Pay back period - SWHs have a life span of 15-20 years. The pay back period is about 3-4 years when electricity is replaced, 4-5 years when furnace oil is replaced and 6-7 years when coal is replaced.

Solar water heating has the following advantages :
Solar water heaters save electricity and thus money; electricity is becoming more and more expensive and its availability is becoming unrelaiable;

- Solar water heaters are non-polluting.
- Solar water heaters are safer than electric geysers as they are located on the roof

Estimates of requirements of hot water- some useful thumb rules

Application	Typical Requirement of Hot Water at 60OC.
Household bathing using buckets	10-20 liters per person per bath.
Household bathing using shower with a mixing tap	20-30 liters for 10-15 minute bath
Shaving, while a tap runs	7-10 liters
Household bathing in bathtub (one filling)	50-75 liters
Wash basin with a mixing tap (hand wash, brushing of teeth, etc.)	3-5 liters per person per day.
Kitchen washing	2-3 liters per person per day.
Dishwasher	40-50 liters per wash cycle
Clothes washing machine	40-50 liters per cycle

Table 7Applications of water and typical requirements

Electricity and energy savings

The table below gives approximate likely electricity and money savings for typical 100 liters per day solar water heating systems located in different parts of the country. Likely savings of electricity and money by use of a 100 liters domestic solar water heater (using 2.0 sq.m collector area)

	Northern Region	Eastern Region	Southern Region*	Western Region*
Expected no. of days of use per year	200 days	200 days	250 days	250 days
Expected yearly electricity saving with use of full capacity, kwh	950	850	1200	1300
Monetary savings at different prices of electricity, Rs/year				
Rs. 4/kwh	3800	3400	4800	5200
Rs. 5/kwh	4750	4250	6000	6500
Rs. 6/kwh	5700	5100	7200	7800

Table 8 Electricity savings in various regions in India

The use pattern and savings for southern region pertains to the typical climate of Bangalore, while those for western region relate typically to Pune climate.

Operational requirements

Domestic solar systems do not require any special operational skills. However, if following are observed, the efficiency of the systems will be maintained at a high level:

- Try to consume most of the heated water at one time - either in the morning or in the evening. Frequent on and off of the hot water tap would lead to reduced electricity savings.
- If an electrical back up is provided in the tank, set the thermostat at the lowest acceptable temperature.
- In the north Indian climate, hot water may not be used for bathing in summers. If the system is to be put totally out of use, it should be drained of water and the collector should be covered.
- Alternatively, if the hot water requirement remains in summers also, though at a reduced level, cover the collector partially.
- Dust deposition on the collector would reduce its efficiency. Try to clean it at least once in a week.

Maintenance requirements

- Domestic solar water heating system does not need significant maintenance requirements. Occasional leakages in the plumbing could be easily repaired by common plumbers.
- In case quality of water is hard, scale deposition in the collectors may result over the years. This may require descaling with acids for which it is best to contact the suppliers.
- Broken glass may also have to be replaced by the suppliers.
- If outside exposed surfaces are painted, the paint may have to be redone every 2-3 years to prevent corrosion of the surfaces.

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