Introduction to Sthapatya Vastu & Nirman Vidya and Arthashastra (IKS 60001)

Environment and Public Health Engineering

Module 16-18: IKS of Environment and PHE

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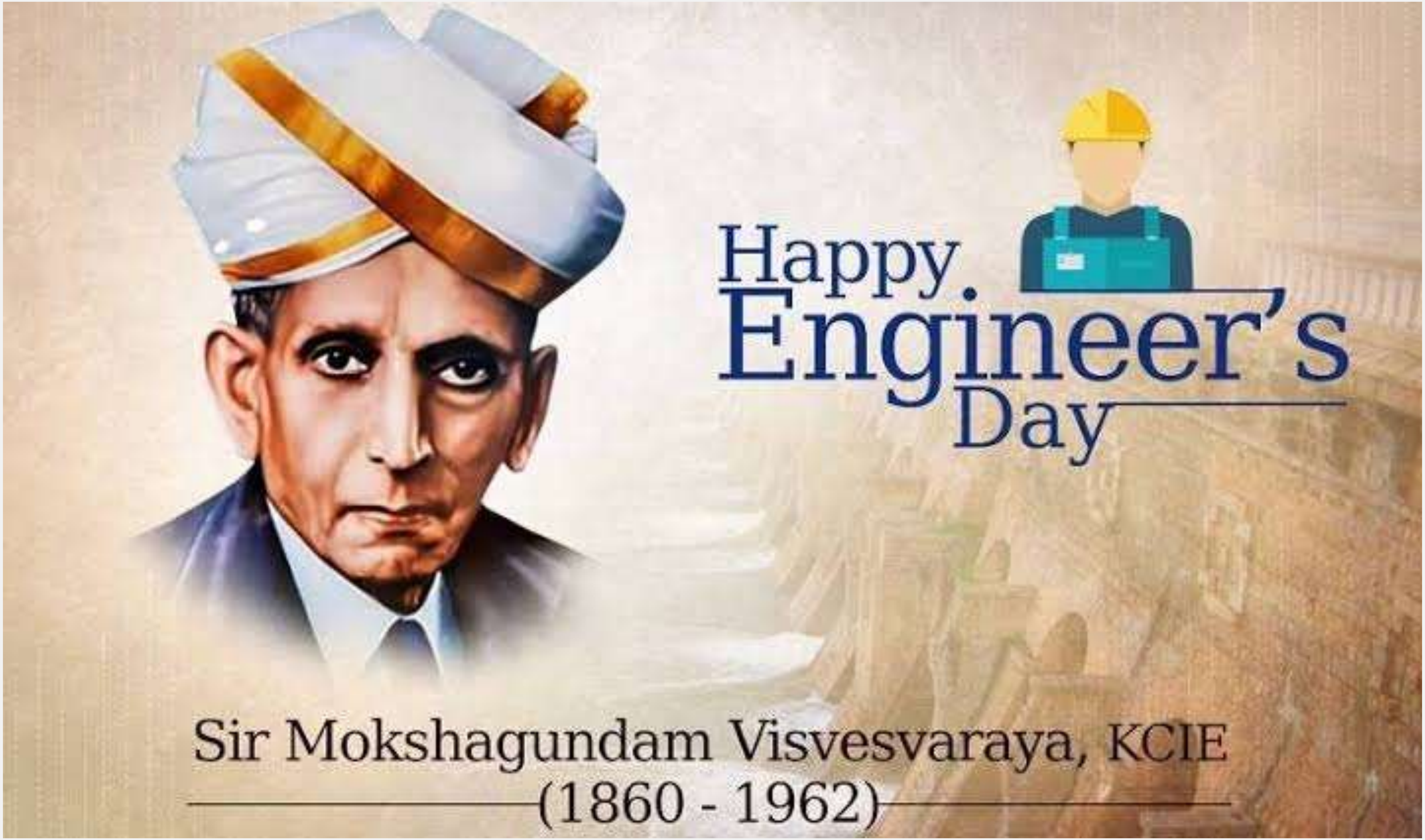
Environmental Engineering and Management Division

Department of Civil Engineering


Happy
Engineer's
Day
Sir Mokshagundam Visvesvaraya, KCIE
(1860 - 1962)

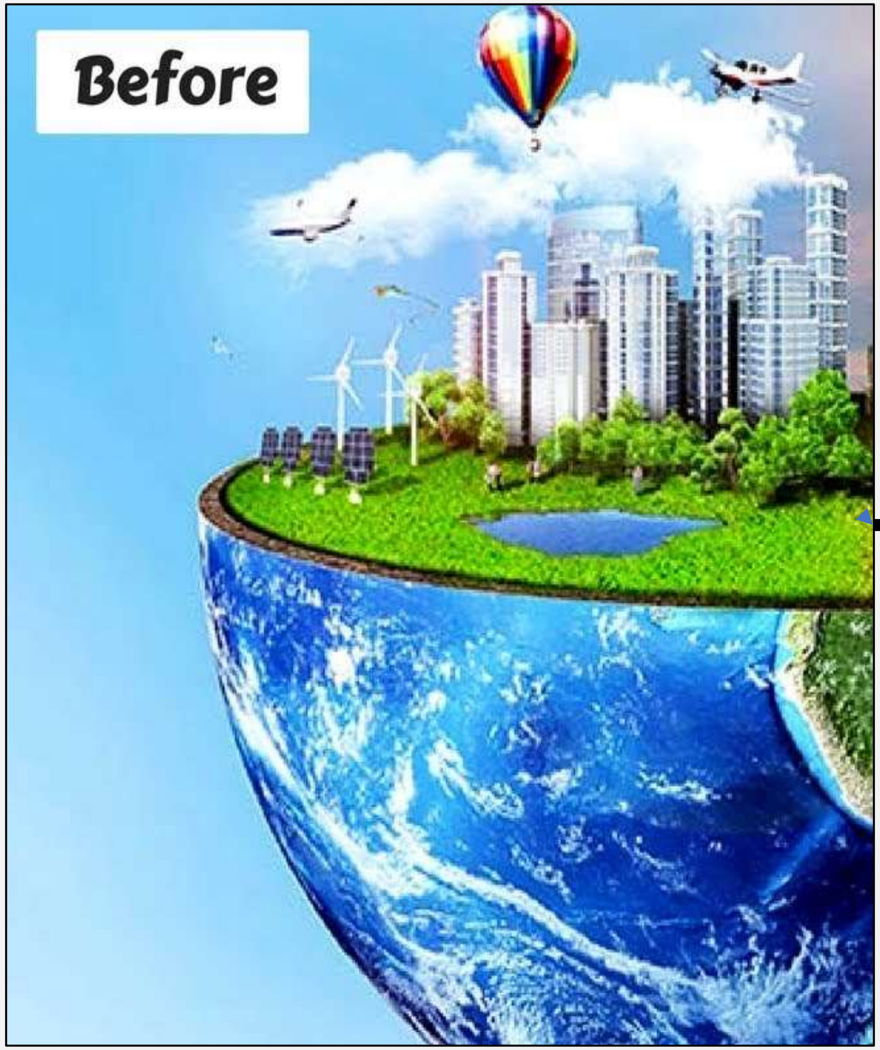
Module 16 – 18: Aranyak and Green conservation principles

- ✓ Water/ Energy Management in Ancient India - Review of the management systems from ancient practices, its application as on date
- ✓ Sustainable Water Management Practices from Ancient India - Afforestation, Rainwater harvesting, Ahar and Pyne System of Irrigation, Gabarband' and others;
- ✓ Indian Traditional Liquid and Solid Waste Management Systems - Wastewater management (from about 3000 BCE), Domestic grey water management and many others.
- ✓ Application of Traditional System in Modern Water, Environment and Energy Systems - Lessons from the past will be highlighted and case studies.

A bit about me…

- Brajesh Kumar Dubey, PhD, FIE, C.Eng
  - High School from Rly Boys' School and ISC from Rly Mixed School,KGP
  - B.Tech (Hons) in Civil Engg; **IIT Kharagpur**, India
  - Worked as a consulting engineer at **Engineers India Limited** for 4 years, based in New Delhi
  - Graduate work leading to PhD from **University of Florida** in Environmental Engineering Sciences
  - Worked as Research Scientist in Florida for 2.5 years
  - Taught and did research in **New Zealand** (at UOA) for nearly 2 years
  - Worked as a Professor in **USA** and **Canada** for 6 years
  - Presently at **IIT Kharagpur** since Mar 2015
  - http://scholar.google.ca/citations?user=gLXcah0AAAAJ
  - http://www.linkedin.com/pub/brajesh-dubey/0/883/716
  - https://twitter.com/wasteprof

Why Study Environment ?



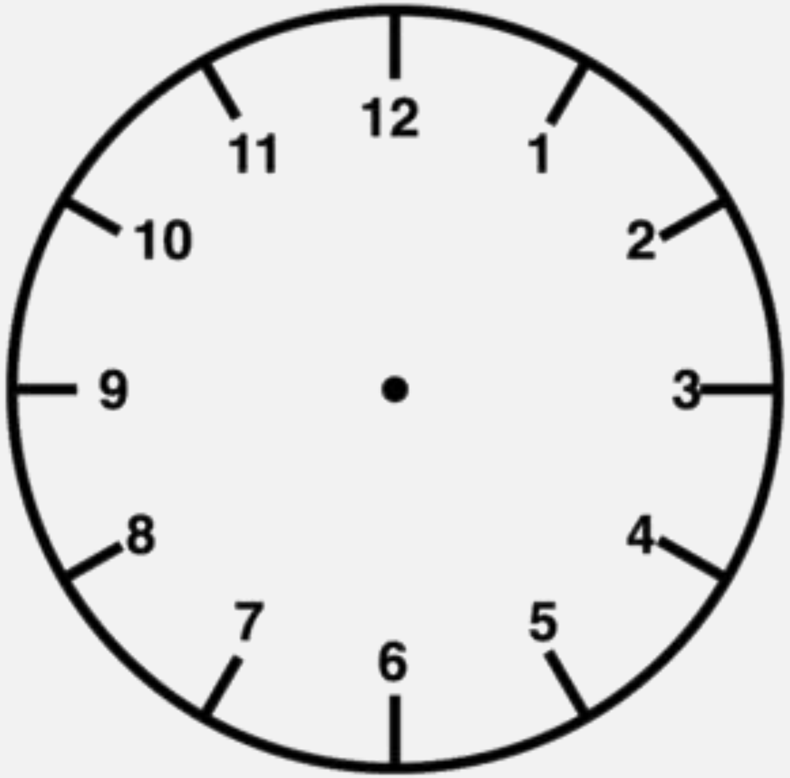
Fresh / Clean Resources
(Water, Air, Land, Minerals)

Human Activity

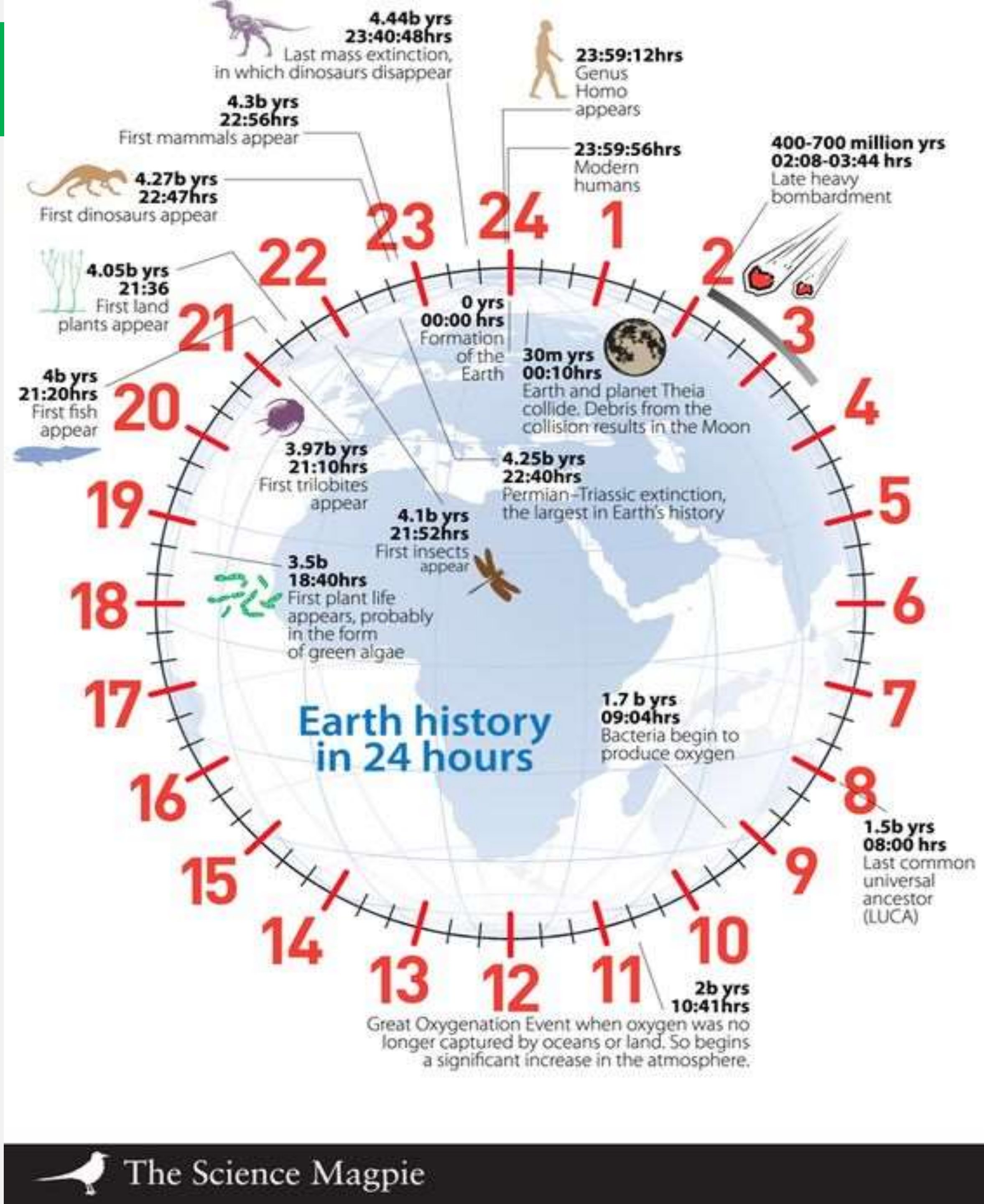
Resource Pollution
(Leads to severe impacts)

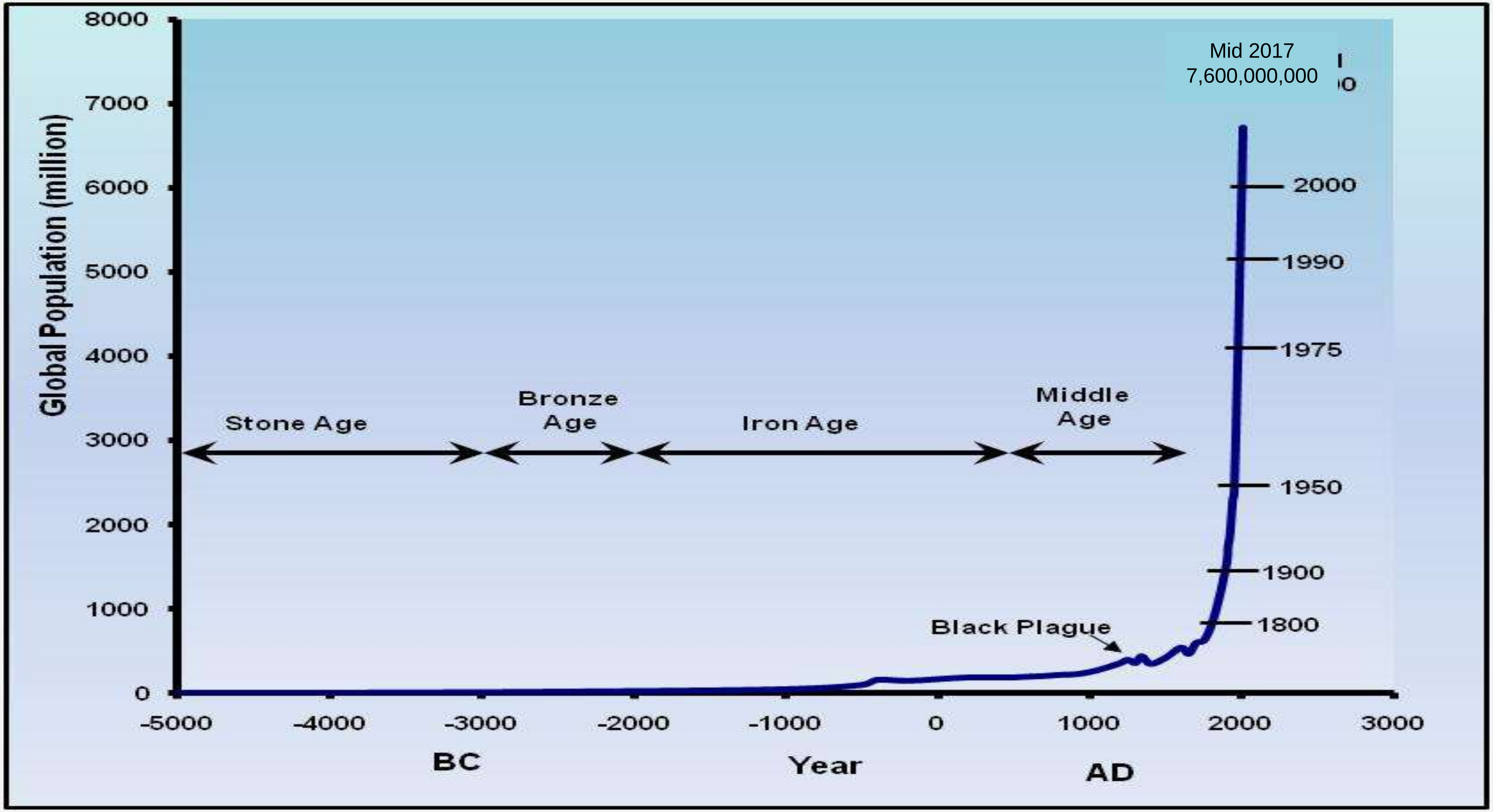
Humans on Earth

The Earth is 4.6 billion years old



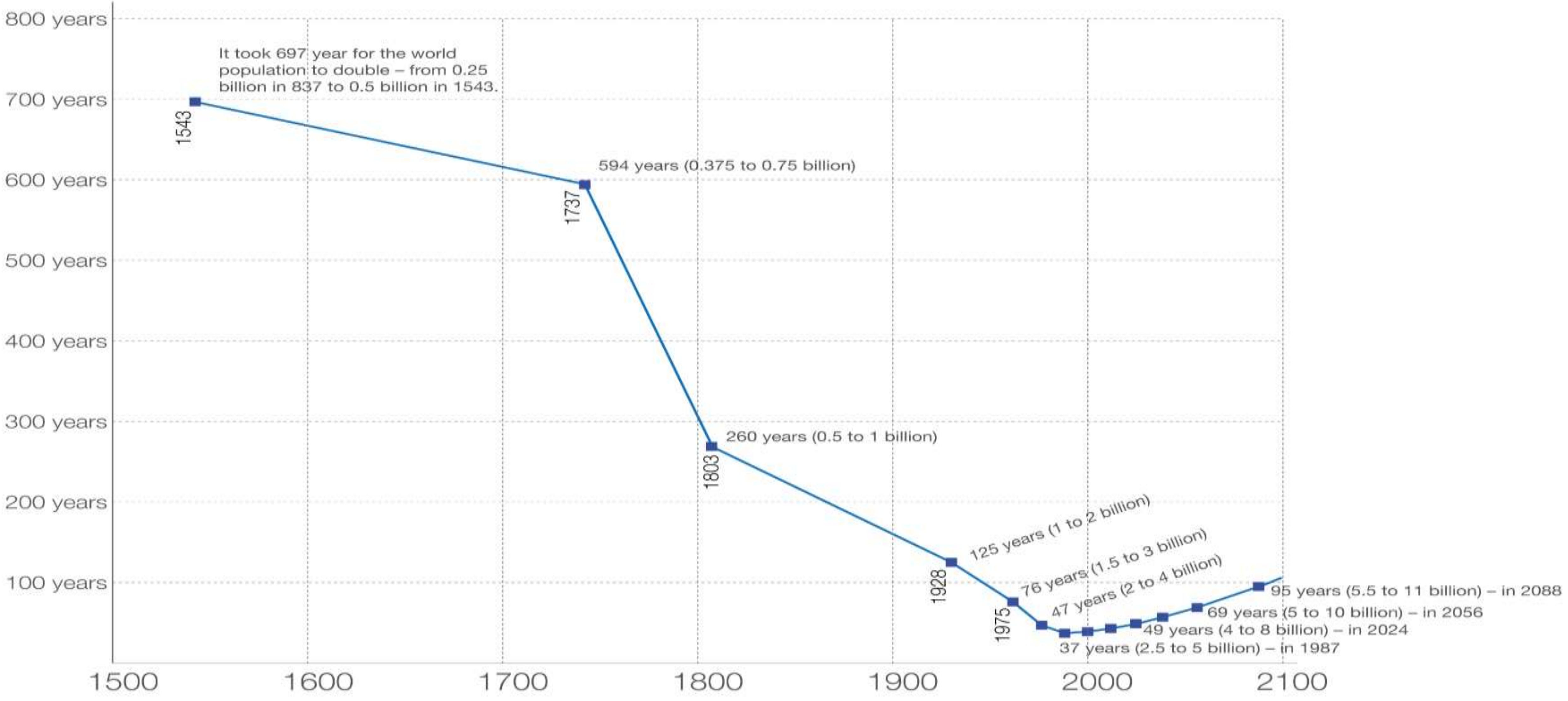
1 second = 52,000 yr
1 minute = 3.125 Myr
1 hour = 187.5 Myr




Mid 2017
7,600,000,000
Global Population (million)
8000
7000
6000
5000
4000
3000
2000
1000
0
Stone Age
Bronze Age
Iron Age
Middle Age
Black Plague
2000
1990
1975
1950
1900
1800
-5000
-4000
-3000
-2000
-1000
0
1000
2000
3000
BC
Year
AD

Time it took for the world population to double

Historical estimates of the world population until 2015 – and UN projections until 2100

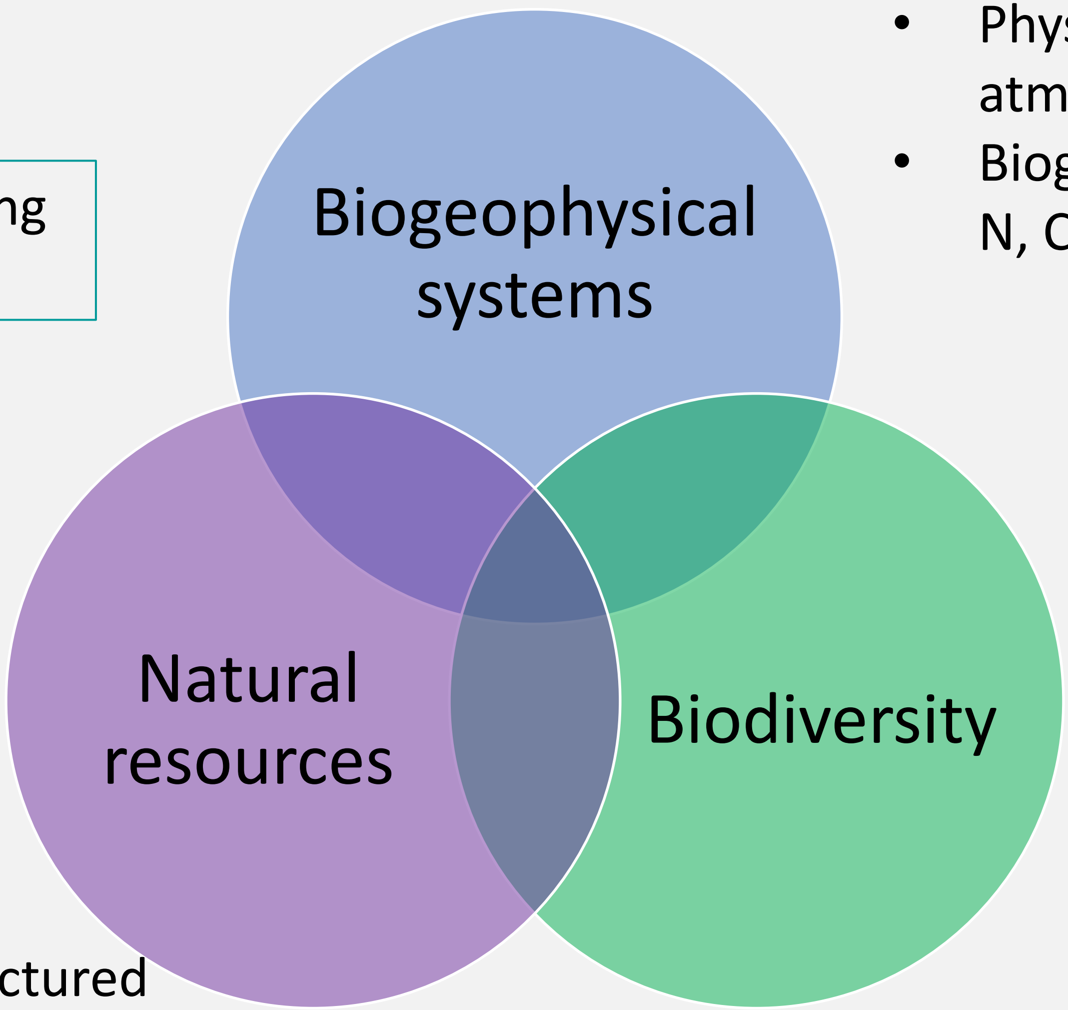


Data source: OurWorldInData annual world population series (Based on HYDE and UN until 2015. And projections from the UN after 2015 ('Medium Variant' 2015 Revision)).
The data visualization is available at OurWorldinData.org. There you find the raw data, more visualizations, and research on this topic.

Human Impacts on Environmental Systems

Complex & interacting components

- Physical systems – atmosphere/climate
- Biogeochemical cycles – N, C, P, Fe



- Water
- Minerals
- Fossil fuels
- Land productivity
- Pollution/manufactured products

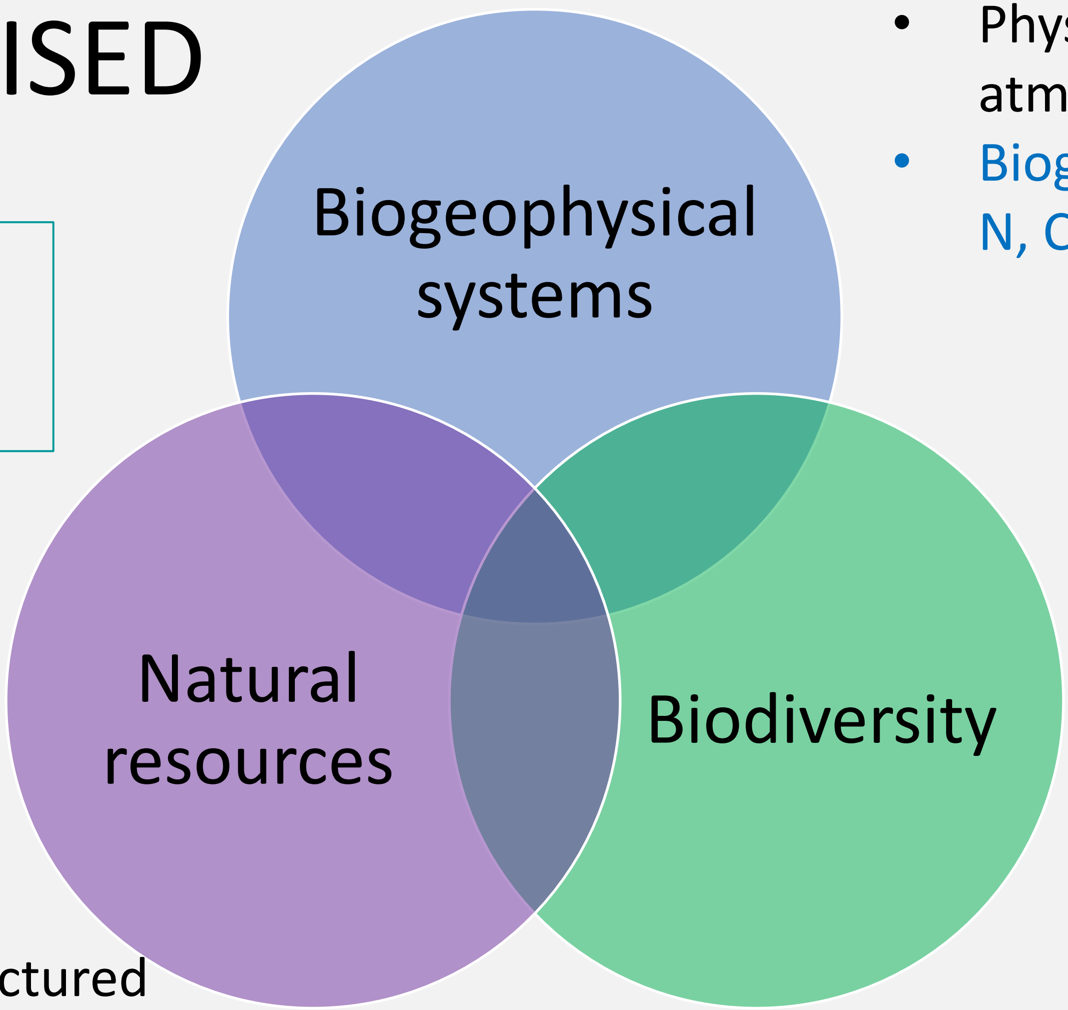
- Mass extinctions
- Biodiversity loss
- Invasive species

Human Impacts Pre-Common ERA

LOCALISED

impact = population × affluence × technology
$(I = P \times A \times T)$

- Physical systems – atmosphere/climate
- Biogeochemical cycles – N, C, P, Fe



- Water
- Minerals
- Fossil fuels
- Land productivity
- Pollution/manufactured products

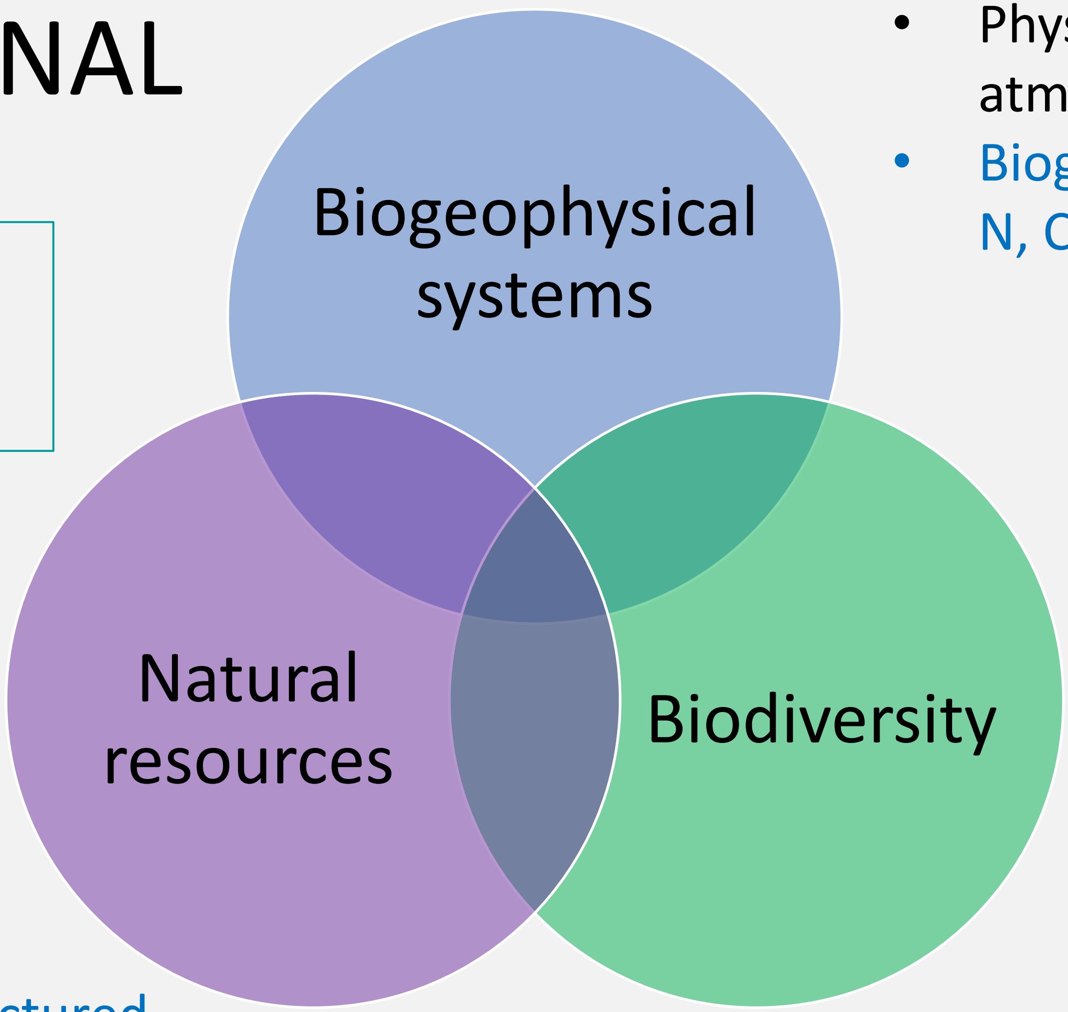
- Mass extinctions
- Biodiversity loss
- Invasive species

Global population steadily growing to ~200 million

Human Impacts in the Common ERA (PRE 1800)

REGIONAL

impact = population × affluence × technology
($I = P \times A \times T$)



- Physical systems – atmosphere/climate
- Biogeochemical cycles – N, C, P, Fe

- Water
- Minerals
- Fossil fuels
- Land productivity
- Pollution/manufactured products

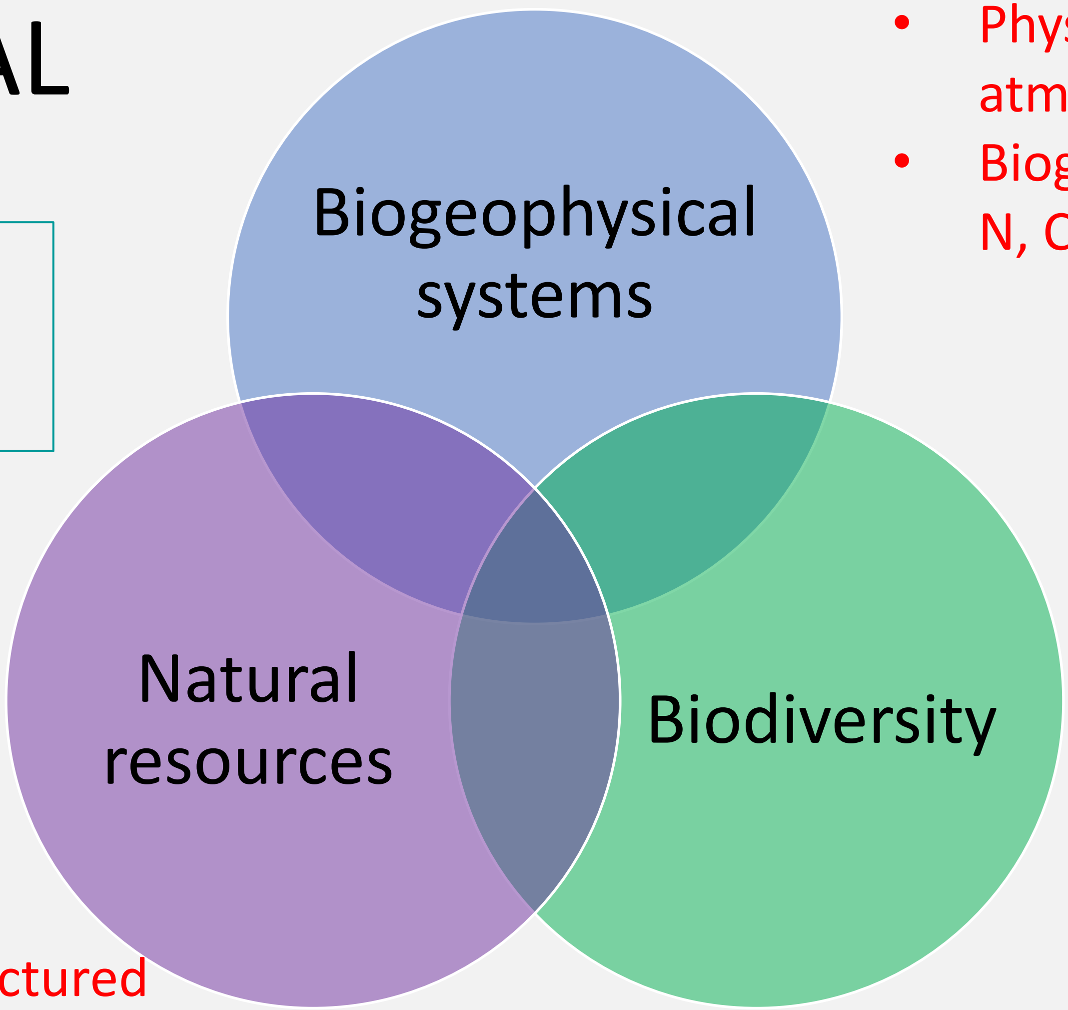
- Mass extinctions
- Biodiversity loss
- Invasive species

Global population growing steadily to ~500 million

Human Impacts Since 1800

GLOBAL

impact = population × affluence × technology ($I = P \times A \times T$)



- Physical systems – atmosphere/climate
- Biogeochemical cycles – N, C, P, Fe

- Water
- Minerals
- Fossil fuels
- Land productivity
- Pollution/manufactured products

- Mass extinctions
- Biodiversity loss
- Invasive species

Global population growing exponentially to ~8 billion

Urbanization

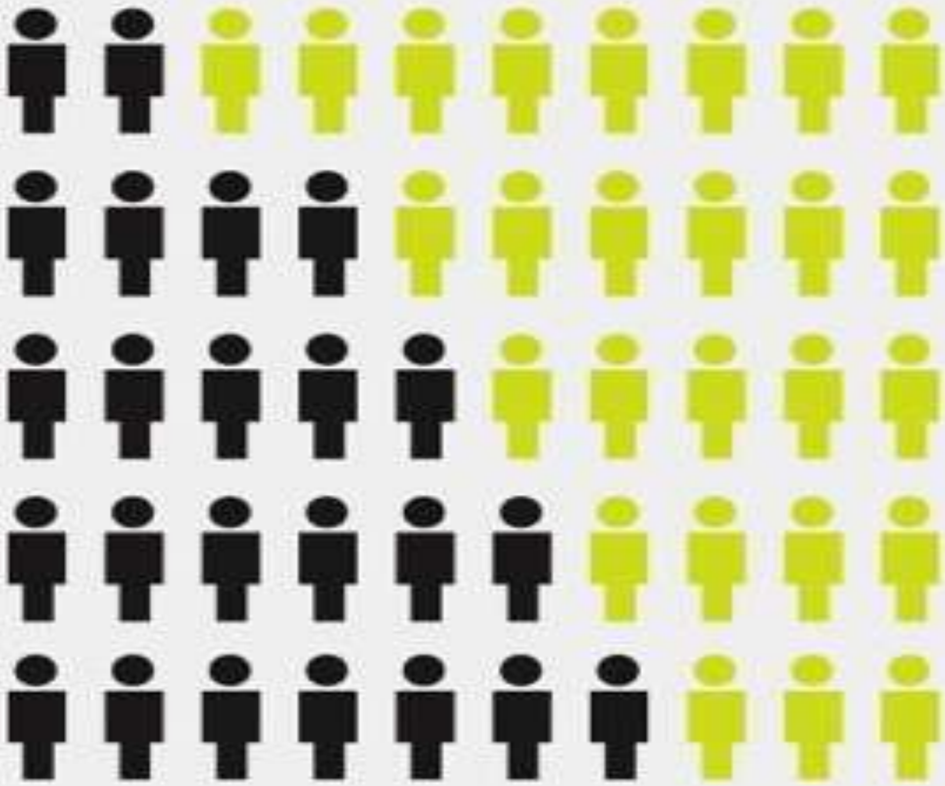
1900 | 2 out of every 10 people lived in an urban area

1990 | 4 out of every 10 people lived in an urban area

2010 | 5 out of every 10 people lived in an urban area

2030 | 6 out of every 10 people will live in an urban area

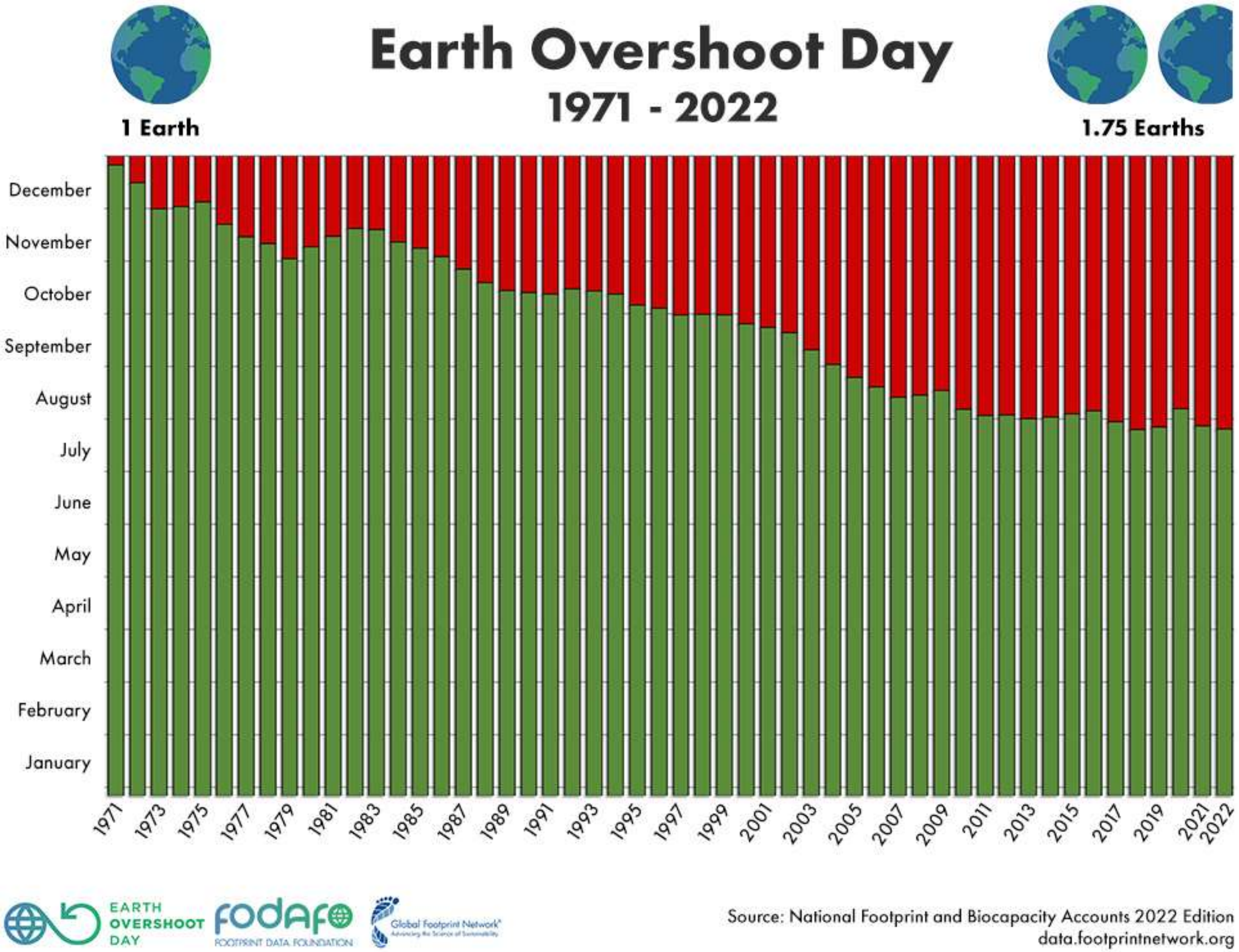
2050 | 7 out of every 10 people will live in an urban area



Defined by UN HABITAT as a city with a population of more thar

Why Environmental Issues Matter?

- Supreme Court directive
- Sustainable Development
- India/Developing country
  - Demand of resources for development activity
  - Need to have a balanced approach with minimum impact on environment
- As a future professional in the country, our students will have to make critical decisions related to development activities



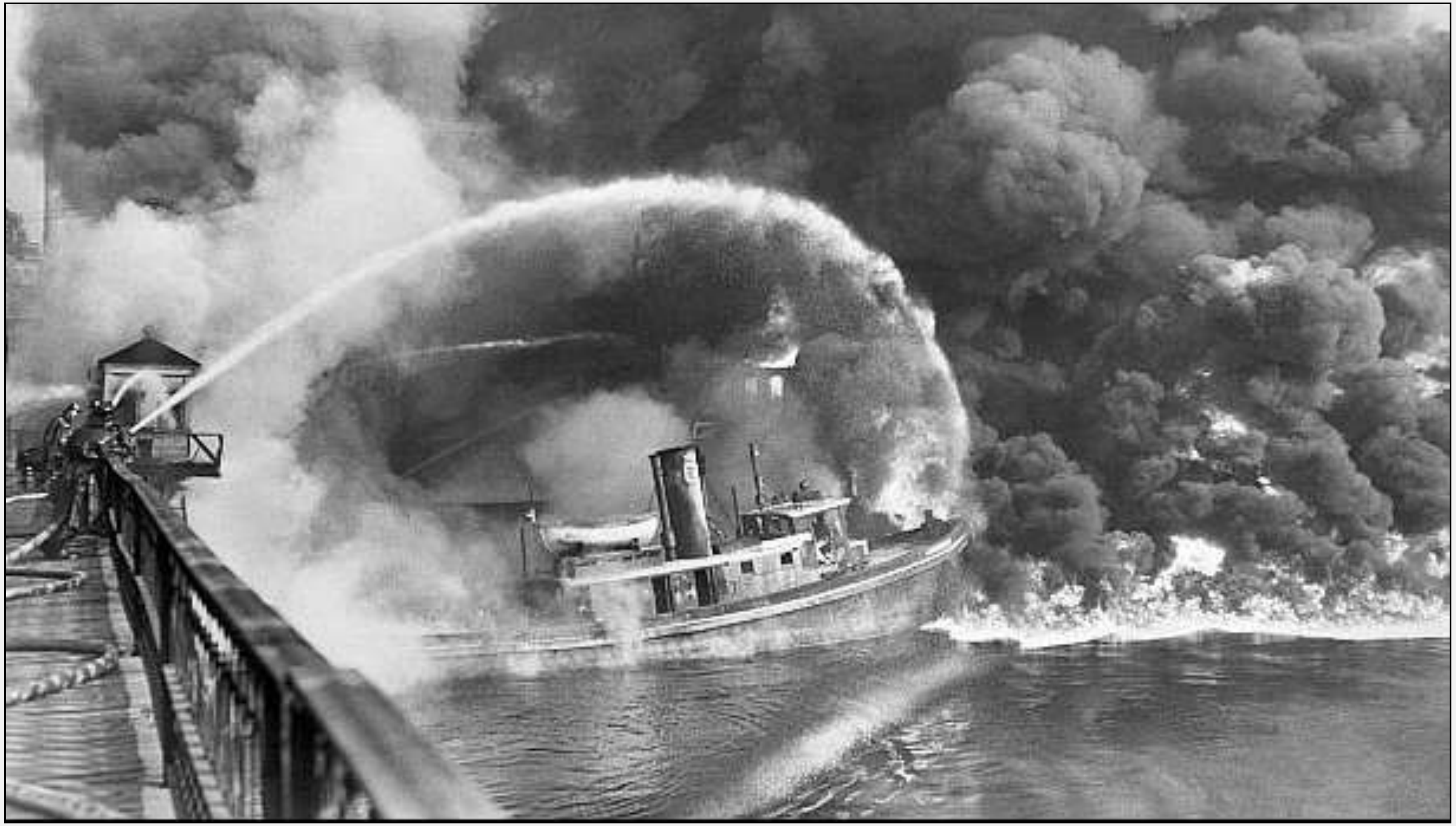
July 28th 2022

The Great Smog of London (1952)

The Great Smog of London, or Great Smog of 1952, was a severe air-pollution event that affected the British capital of London in early December 1952.

Cuyahoga River Fire (How a burning river helped create the clean water act)

The 1969 Cuyahoga River fire helped spur an avalanche of water pollution control activities, resulting in the Clean water act and the creation of the federal Environmental Protection Agency (EPA)- 1970 -1972



The Love Canal Tragedy

One of the most famous and important examples of groundwater pollution in the U.S. is the **Love Canal tragedy** in Niagara Falls, New York.

1980 :Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), better known as the Superfund Act. Love Canal became the first entry on the list

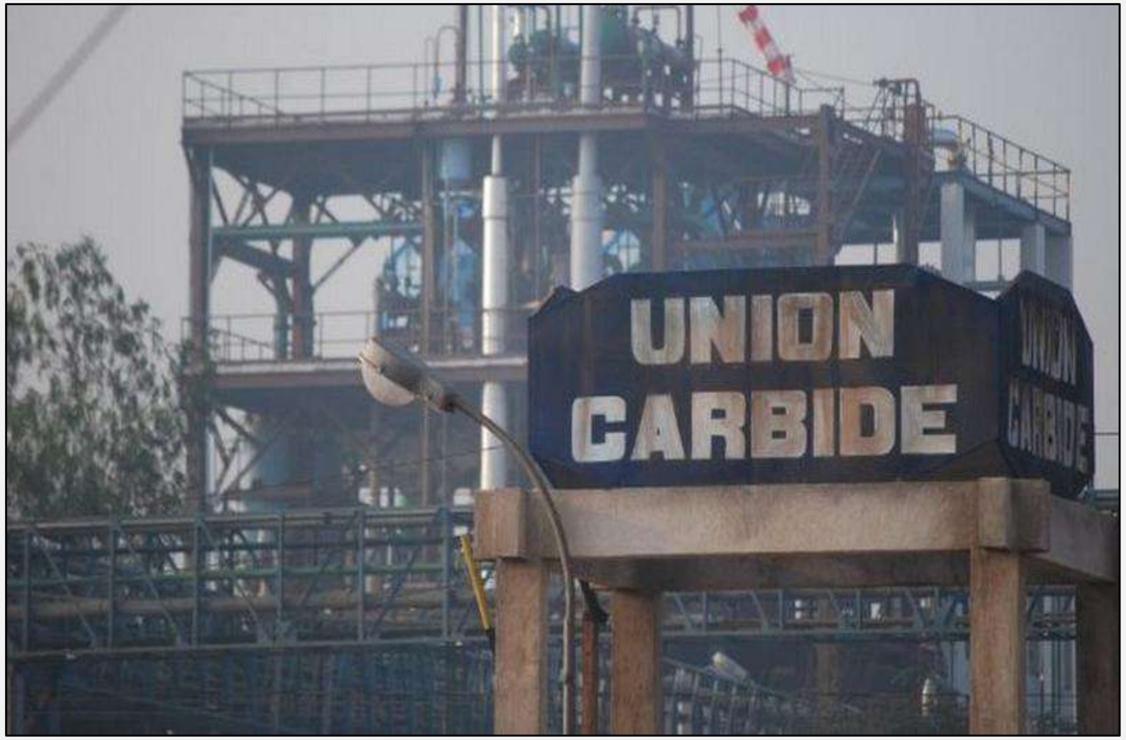
Resource Conservation and Recovery Act

1976 : The Resource Conservation and Recovery Act (RCRA) is enacted by Congress

-with primary goals of protecting human health and the environment from the potential hazards of waste disposal, conserving energy and natural resources, reducing the amount of waste generated, and ensuring that wastes are managed in an environmentally sound manner.

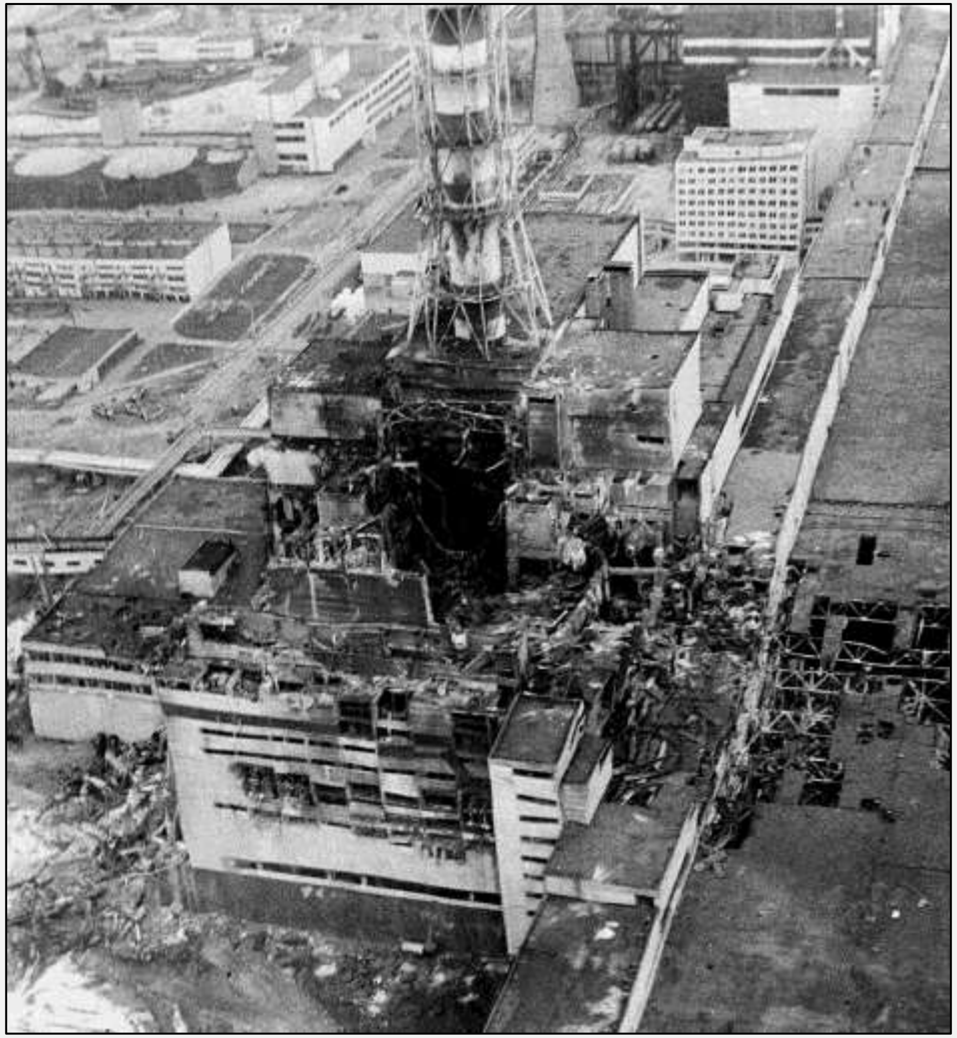
Bhopal Gas Tragedy (1984)

- An estimated 10,000 people are killed and many more injured when Union Carbide's pesticide plant in Bhopal, India, leaks 40 tons of methyl isocyanate gas into the air and sends a cloud of poison into the surrounding city of 1 million.



Chernobyl tragedy(1986)

The Chernobyl disaster was a nuclear accident that occurred on 26 April 1986 at the No. 4 nuclear reactor in the Chernobyl Nuclear Power Plant, near the city of Pripyat in the north of the Ukrainian



Surat Plague (1994)

The **1994 plague** in **India** was an outbreak of **bubonic** and **pneumonic plague** in south-central and southwestern **India** from 26 August to 18 October **1994**.


The New York Times
In '94, 'Vote for Woman' Does Not Play So Well
REPORTS DESCRIBE WIDESPREAD ABUSE IN FARM PROGRAM
A YOUNGER COURT FACES OLD SPLITS AS ITS TERM OPENS
Upstate Forecast for Cuomo: Chilly Mood North and West
Searching for Pro-Aristide Guns, U.S. Raid Finds Dancers Instead
India's City of Plague: A Caldron of Urban Ills
From Repression to Respect, Russian Church in Comeback


The New York Times
With Eyes on Elections, Senate Finds an Impasse
BILL TO REVAMP COMMUNICATIONS DIES IN CONGRESS
Thousands Flee Indian City In Deadly Plague Outbreak
Report Finds Ames's Sabotage More Vast Than C.I.A. Admitted
U.N. Eases Curbs on Yugoslavia After Serbian Peace Concessions
Criticizing Pataki, Giuliani Seeks Details on His Plans to Aid City

Deepwater Horizon oil Spill (2010)

The Deepwater Horizon oil spill is an industrial disaster that began on April 20, 2010, in the Gulf of Mexico on the BP-operated Macondo Prospect, considered to be the largest marine oil spill

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एक कदम स्वच्छता की ओर

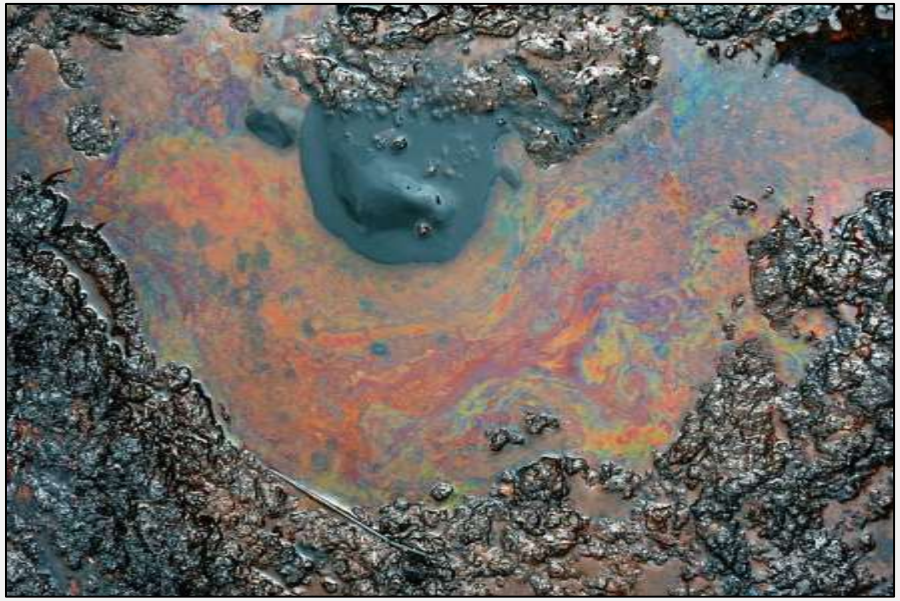
Air Pollution

Water Pollution



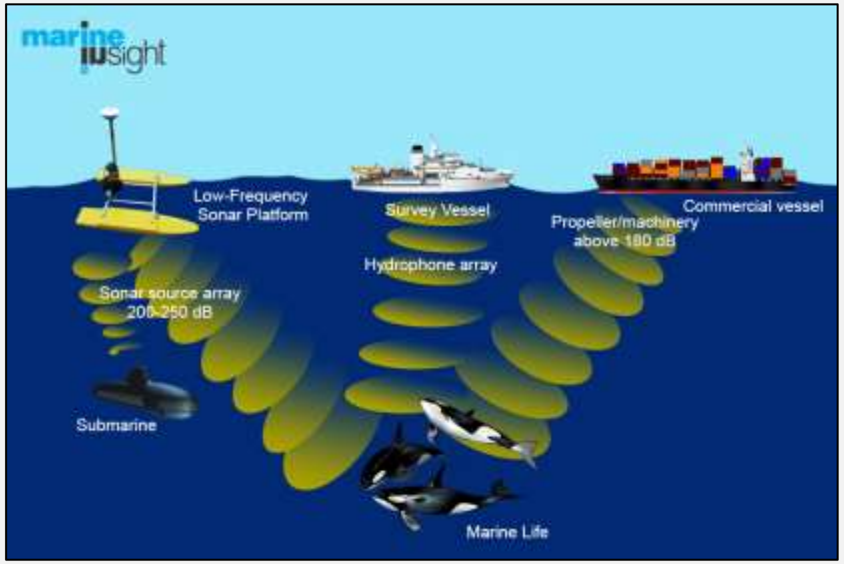


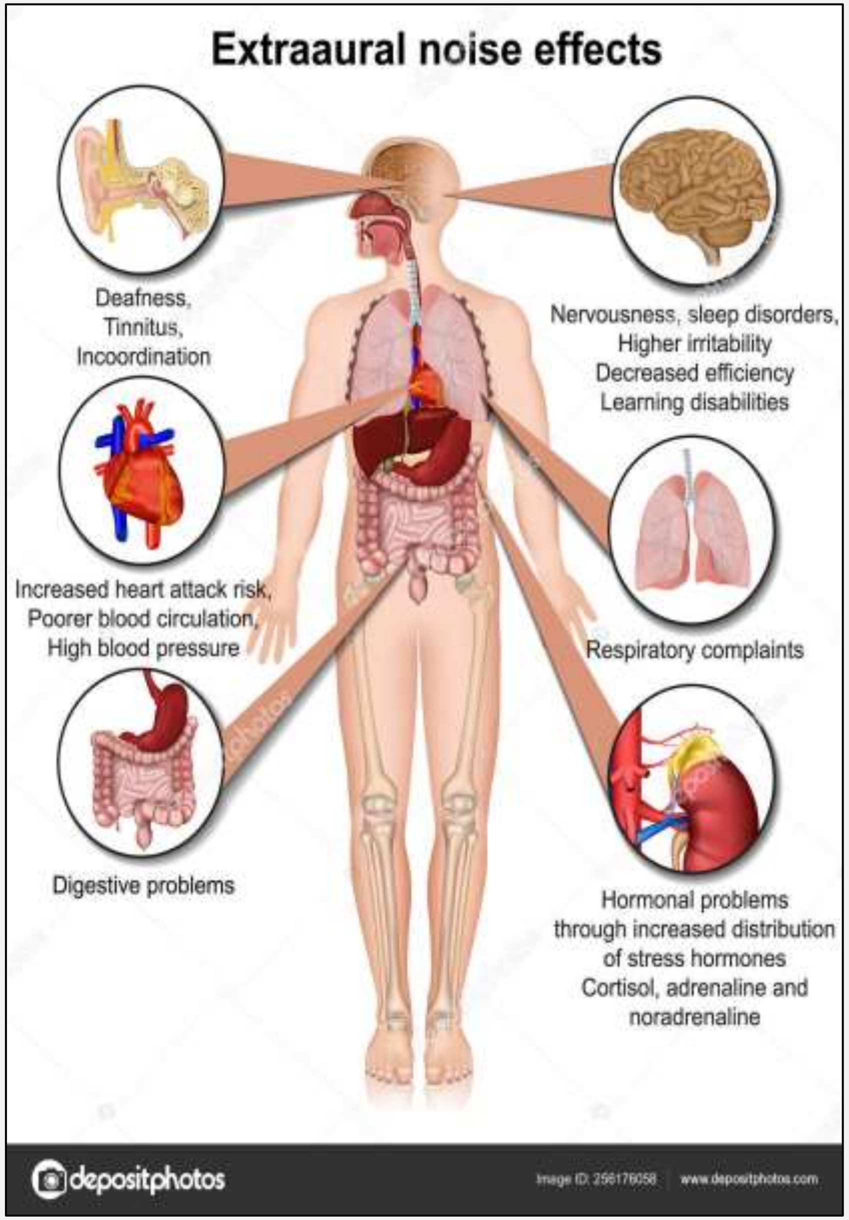

Soil Pollution



Solid Waste

Noise Pollution





Marine Pollution

Source: https://indianexpress.com/article/india/maharashtra-after-state-wide-plastic-ban-whats-allowed-whats-not-the-way-forward-5119185/ (Accessed on September 2018)

Source: https://www.dw.com/en/un-resolves-to-end-ocean-plastic-waste/a-41690999 (Accessed on September 2018)

Source: http://zeenews.india.com/news/sci-tech/maharashtra-to-target-manufacturers-stockists-of-plastic-bags_1551463.html (Accessed on September 2018)

Source: http://www.onegreenplanet.org/news/whale-filled-with-plastic-trash/ (Accessed on September 2018)

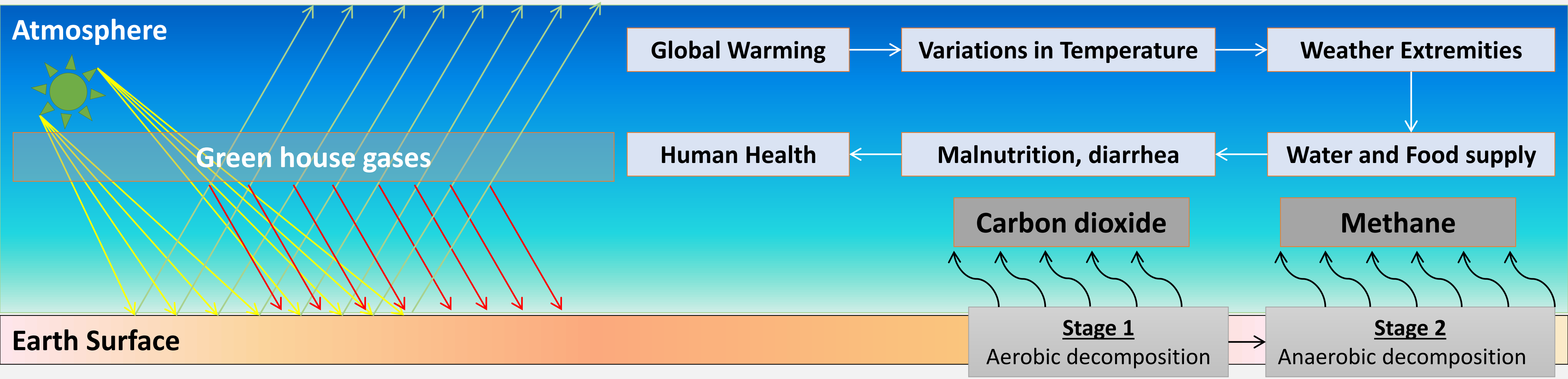
Source: https://www.dw.com/en/un-resolves-to-end-ocean-plastic-waste/a-41690999 (Accessed on September 2018)

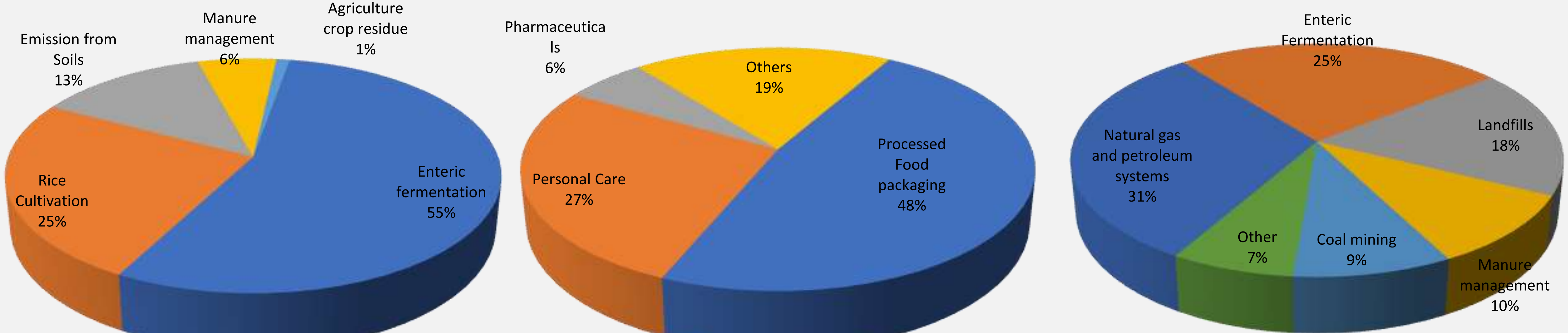
https://news.nationalgeographic.com/2015/09/15092-plastic-seabirds-albatross-australia/ (Accessed on September 2018)

https://www.indiatimes.com/news/india/80-kg-plastic-waste-removed-from-cow-s-stomach-after-3-hour-surgery-in-bihar-340046.html (Accessed on September 2018)

Source: http://www.technocrazed.com/international-study-reveals-269000-tonnes-of-plastic-waste-in-world-oceans (Accessed on September 2018)
Source: http://theconversation.com/what-animal-could-a-democracy-be-ape-fox-lion-how-about-jellyfish-48882 (Accessed on September 2018)

Global Warming

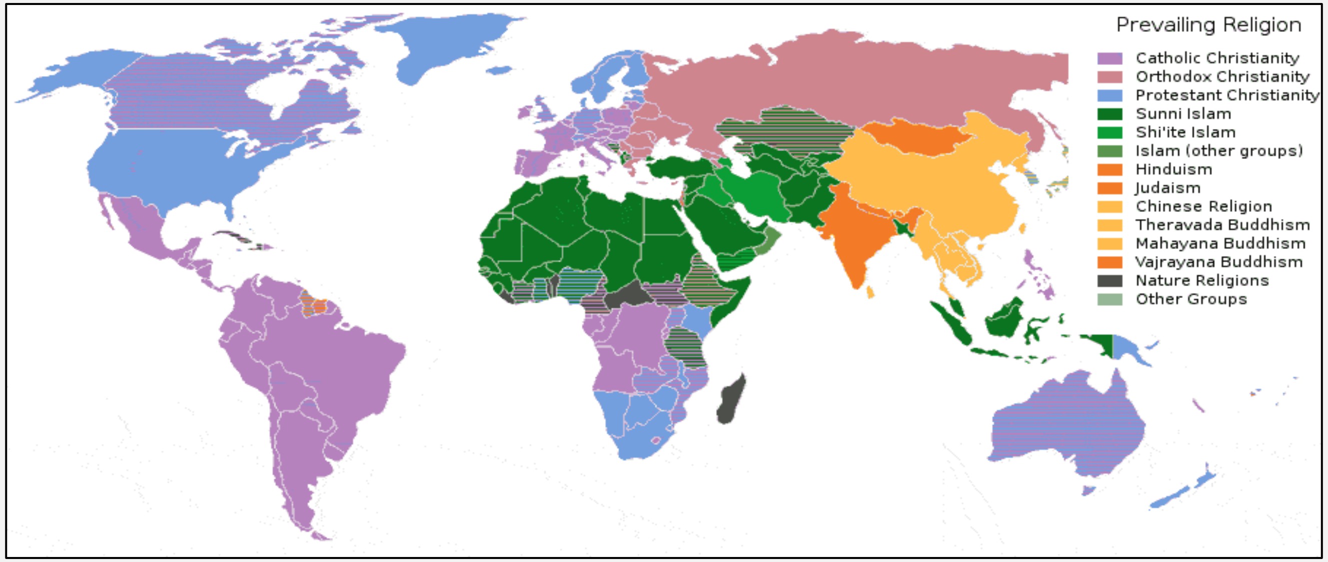


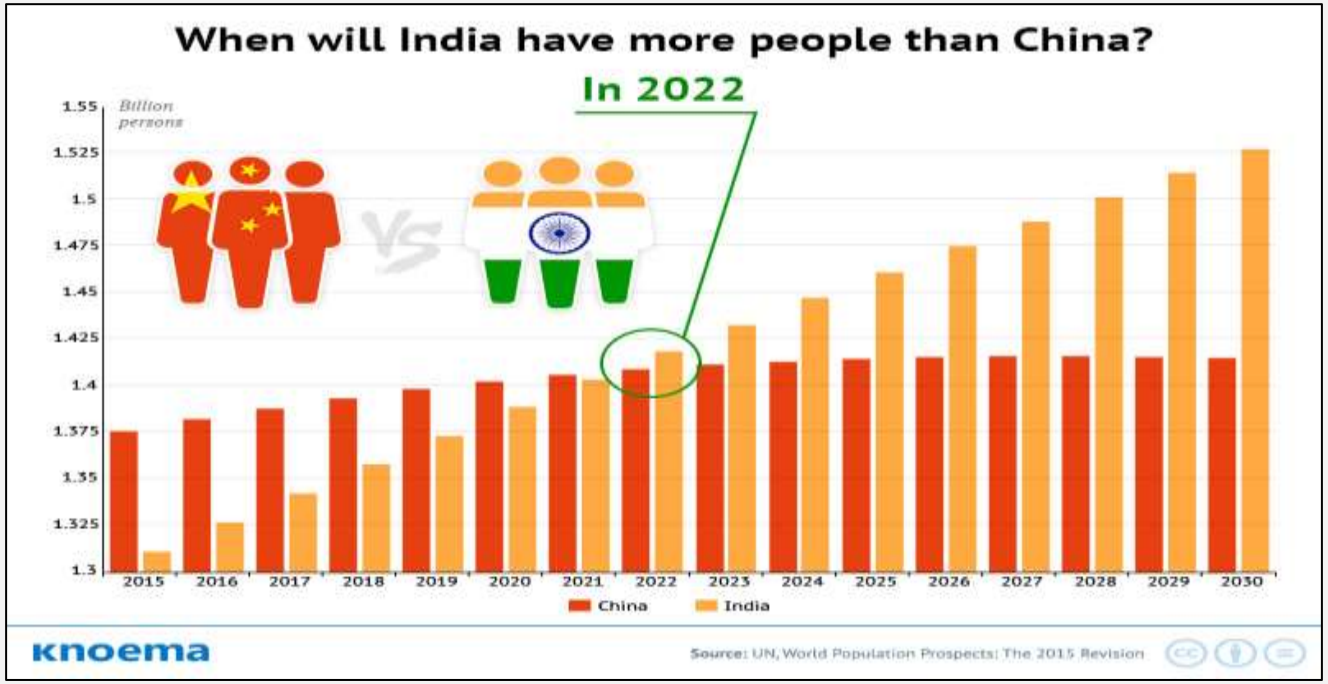


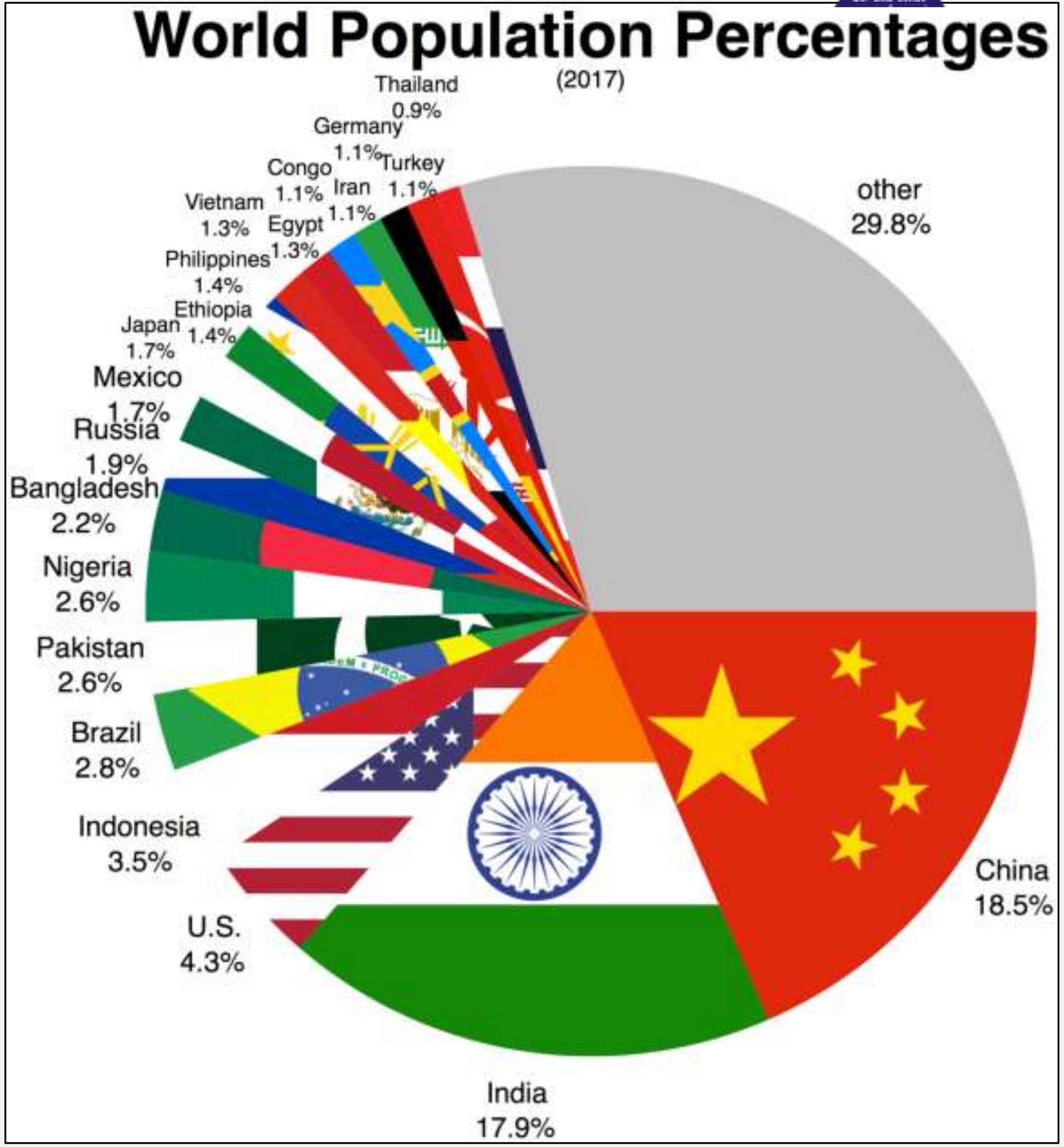
Agriculture Sector → **Packaging sector** → **Food waste management**

Floods

Population Growth





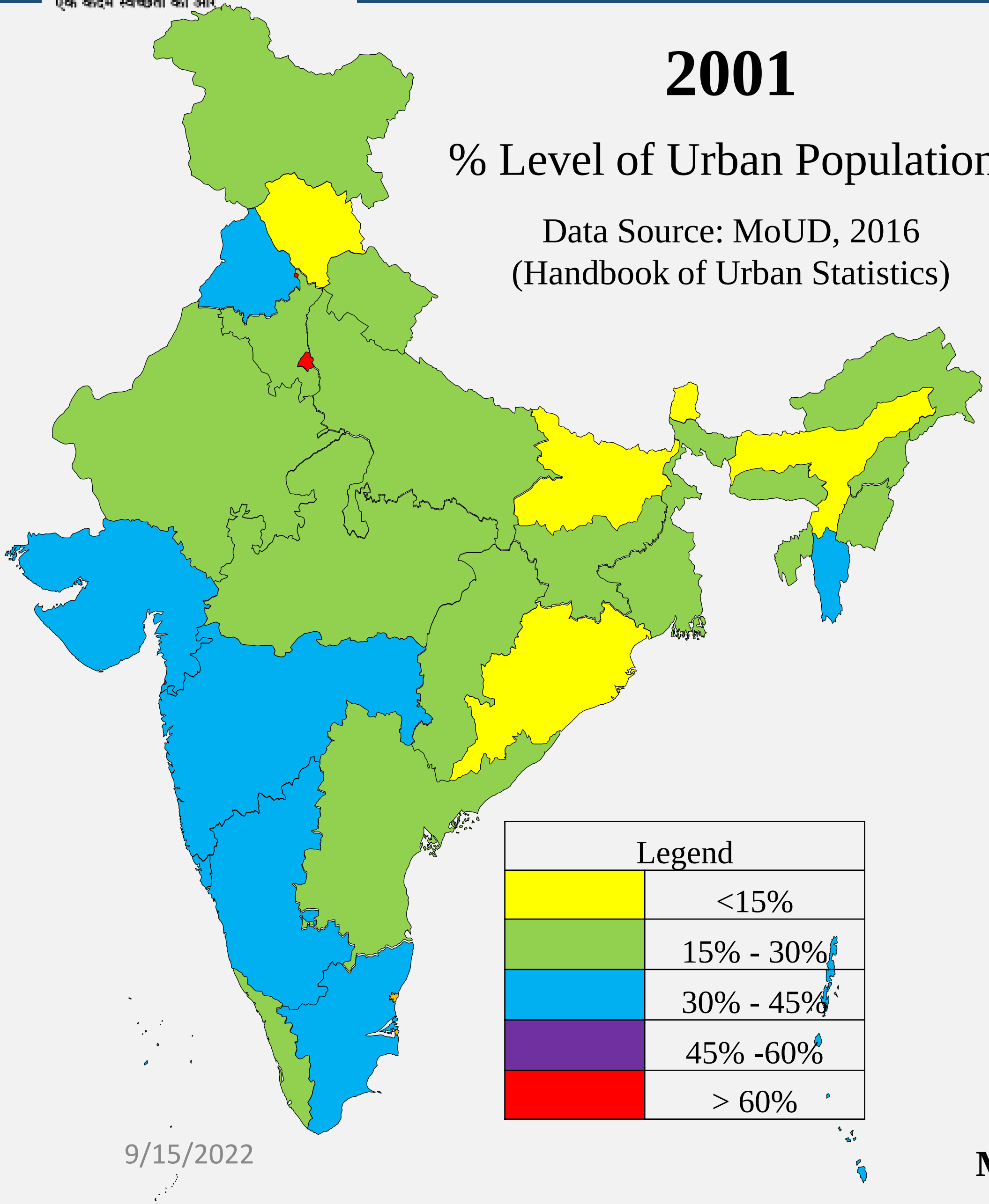


Urban Sprawl

2001

% Level of Urban Population

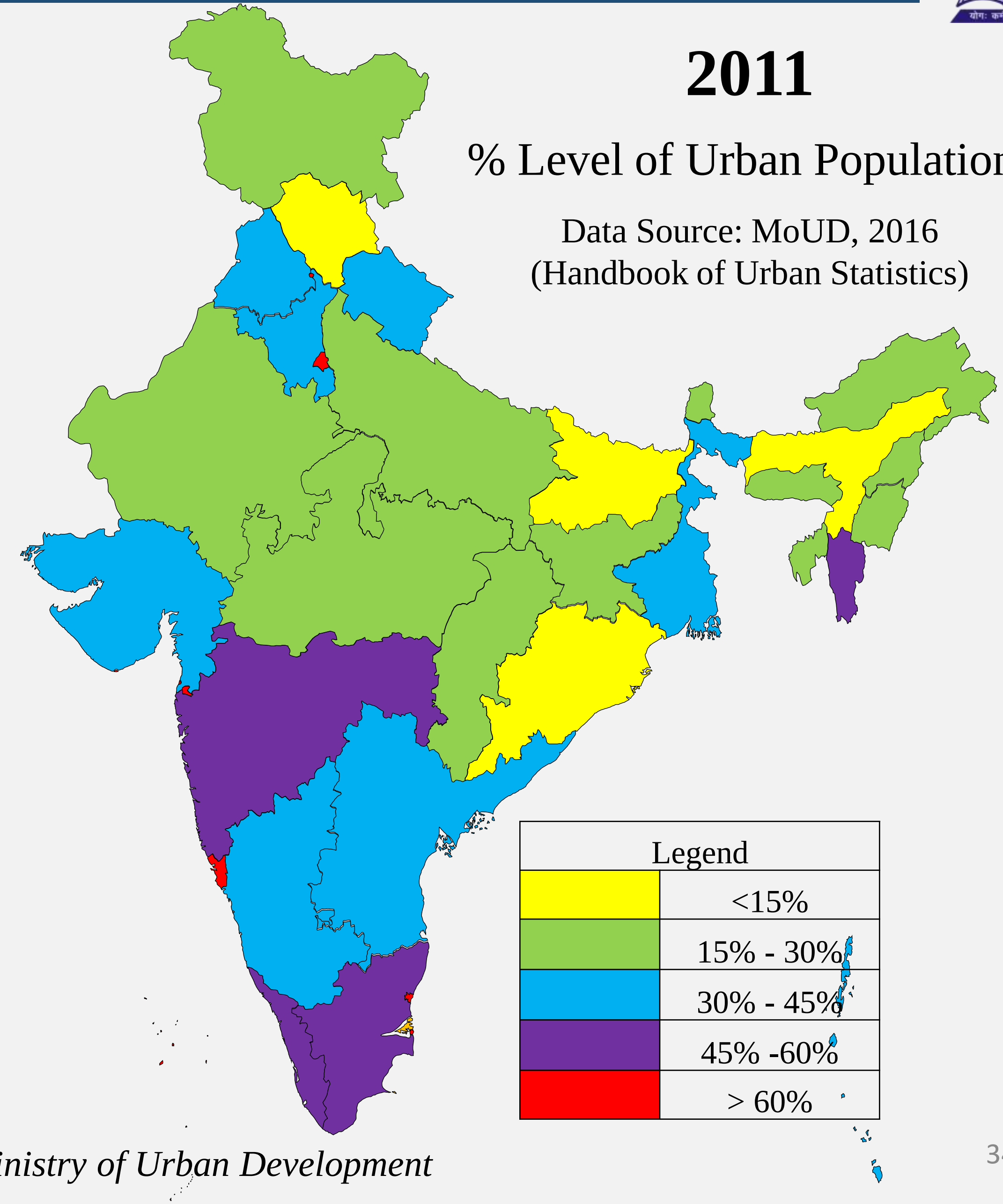
Data Source: MoUD, 2016
(Handbook of Urban Statistics)



2011

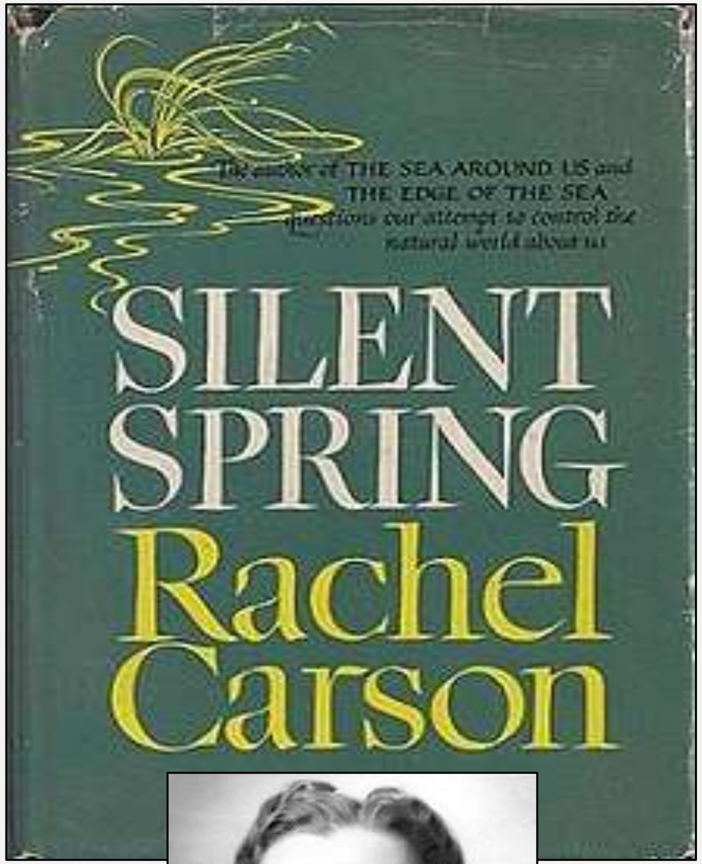
% Level of Urban Population

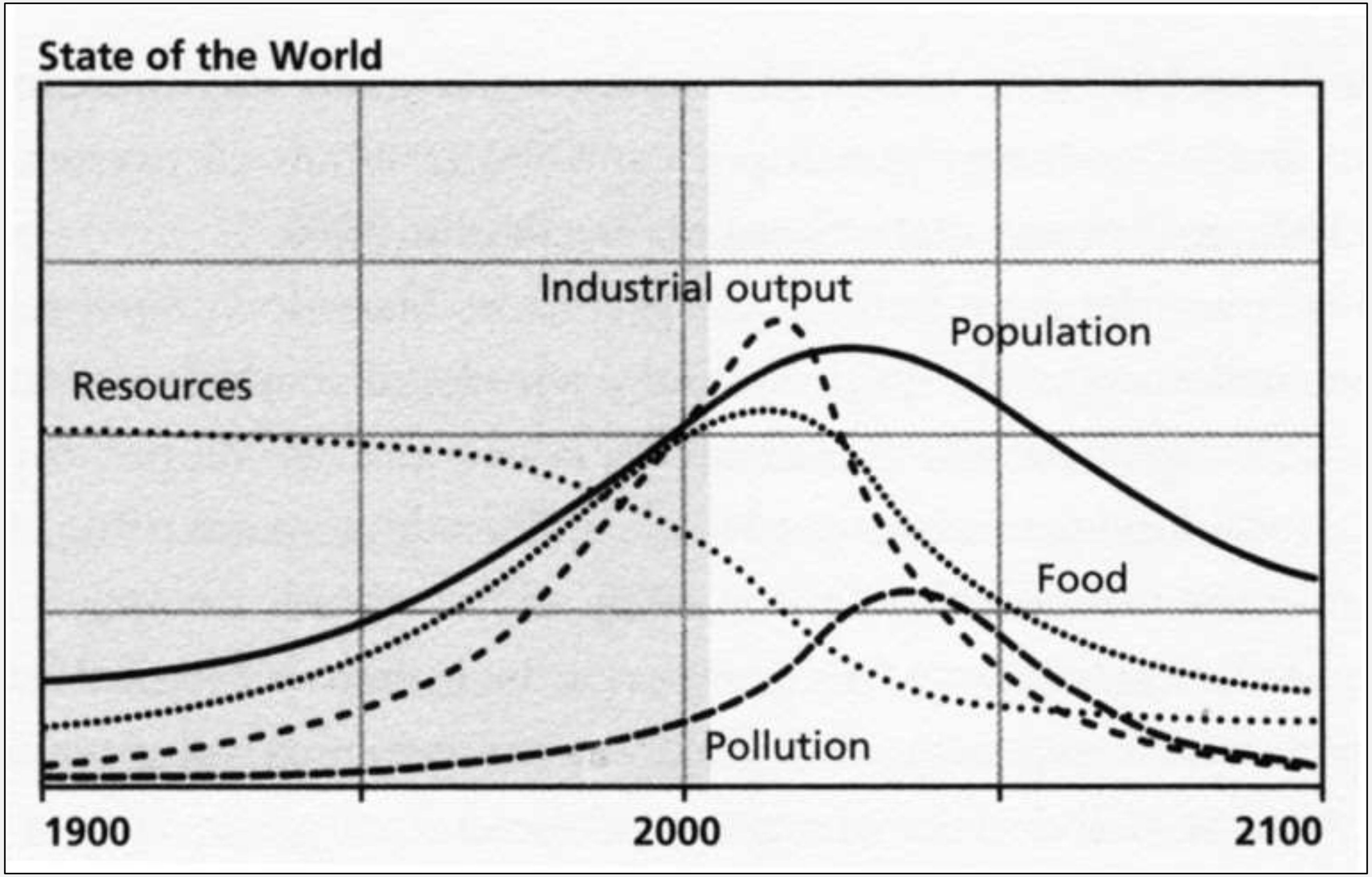
Data Source: MoUD, 2016
(Handbook of Urban Statistics)



MoUD: *Ministry of Urban Development*

Limits to Growth Model

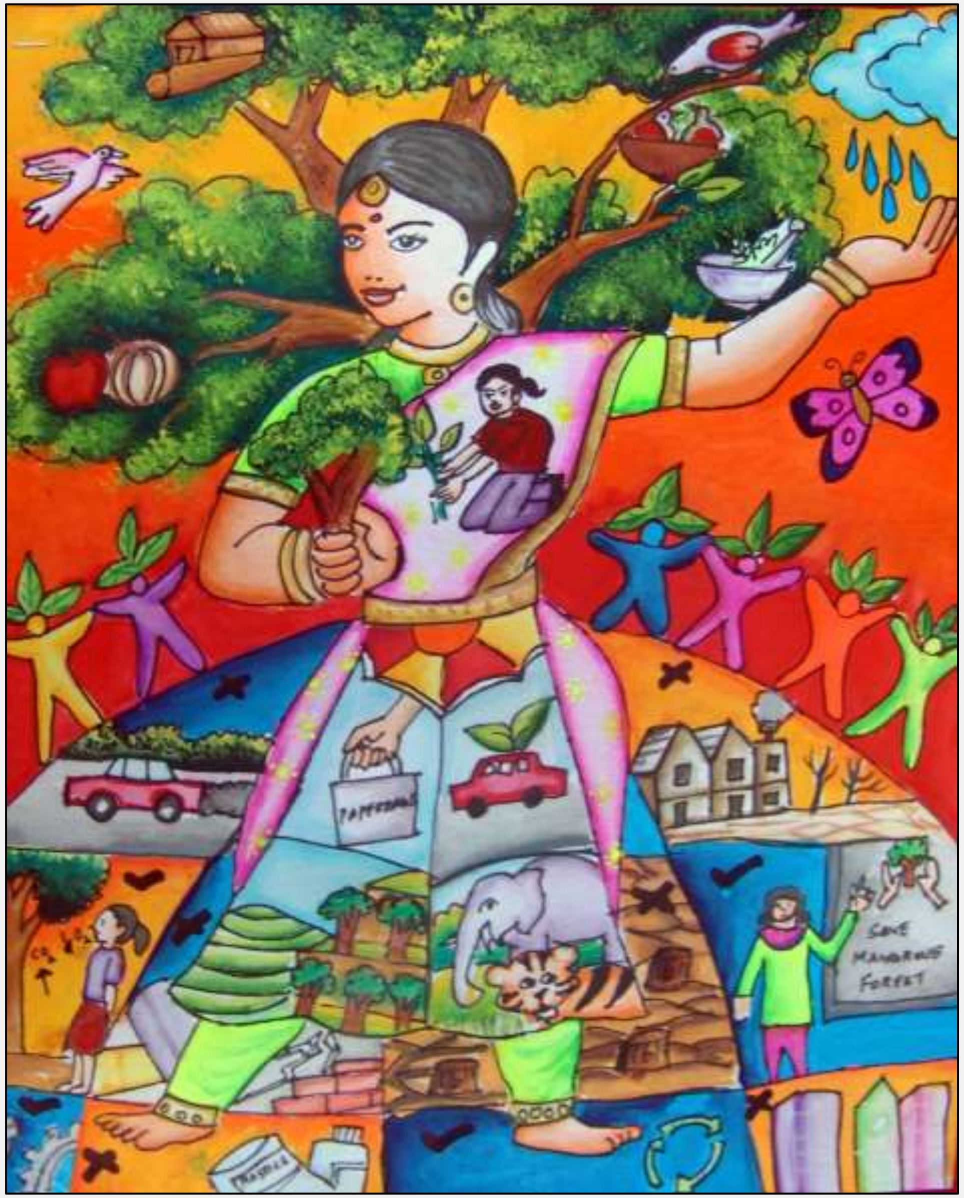




Source: Meadows, D.H., Meadows, D.L., Randers, J. and Behrens III, W.W. (1972)


SUSTAINABLE DEVELOPMENT GOALS
1 NO POVERTY
2 ZERO HUNGER
3 GOOD HEALTH AND WELL-BEING
4 QUALITY EDUCATION
5 GENDER EQUALITY
6 CLEAN WATER AND SANITATION
7 AFFORDABLE AND CLEAN ENERGY
8 DECENT WORK AND ECONOMIC GROWTH
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
10 REDUCED INEQUALITIES
11 SUSTAINABLE CITIES AND COMMUNITIES
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
13 CLIMATE ACTION
14 LIFE BELOW WATER
15 LIFE ON LAND
16 PEACE, JUSTICE AND STRONG INSTITUTIONS
17 PARTNERSHIPS FOR THE GOALS
SUSTAINABLE DEVELOPMENT GOALS

Indian Government Programs



Ministry of Skill Development And Entrepreneurship

DDU-GKY

Deen Dayal Antyodaya Yojana - NRLM

Aajeevika - NRLM
aajeevika.gov.in

Digital India
Power To Empower

Government missions, schemes and other key organizations in skill development, training and employment

Ministry of Rural Development

GOVERNMENT OF INDIA
MINISTRY OF LABOUR & EMPLOYMENT

MAKE IN INDIA

N·S·D·C
National Skill Development Corporation
Transforming the skill landscape

PMKVY

Skill India
कौशल भारत - कुशल भारत

www.nationalskillsnetwork.in

बेटी बचाओ बेटी पढ़ाओ

स्वच्छ भारत
एक कदम स्वच्छता की ओर

प्रधानमंत्री उज्ज्वला योजना

सॉयल हैल्थ कार्ड
स्वस्थ धरा, खेत हरा

Skill India
कौशल भारत - कुशल भारत

Smart City
MISSION TRANSFORM-NATION

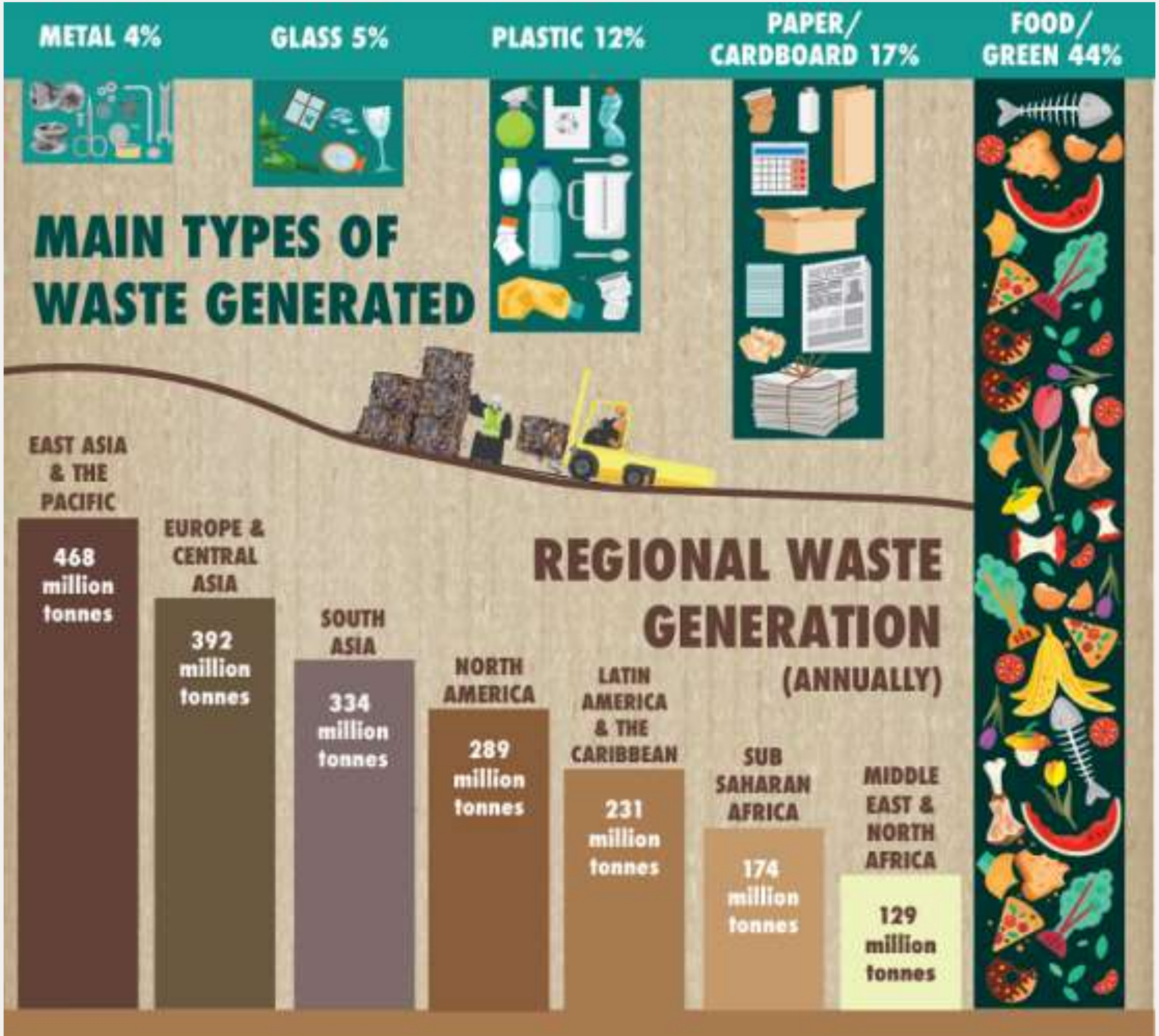
Digital India
Power To Empower

WHAT A WASTE 2.0

A Global Snapshot of Solid Waste Management to 2050

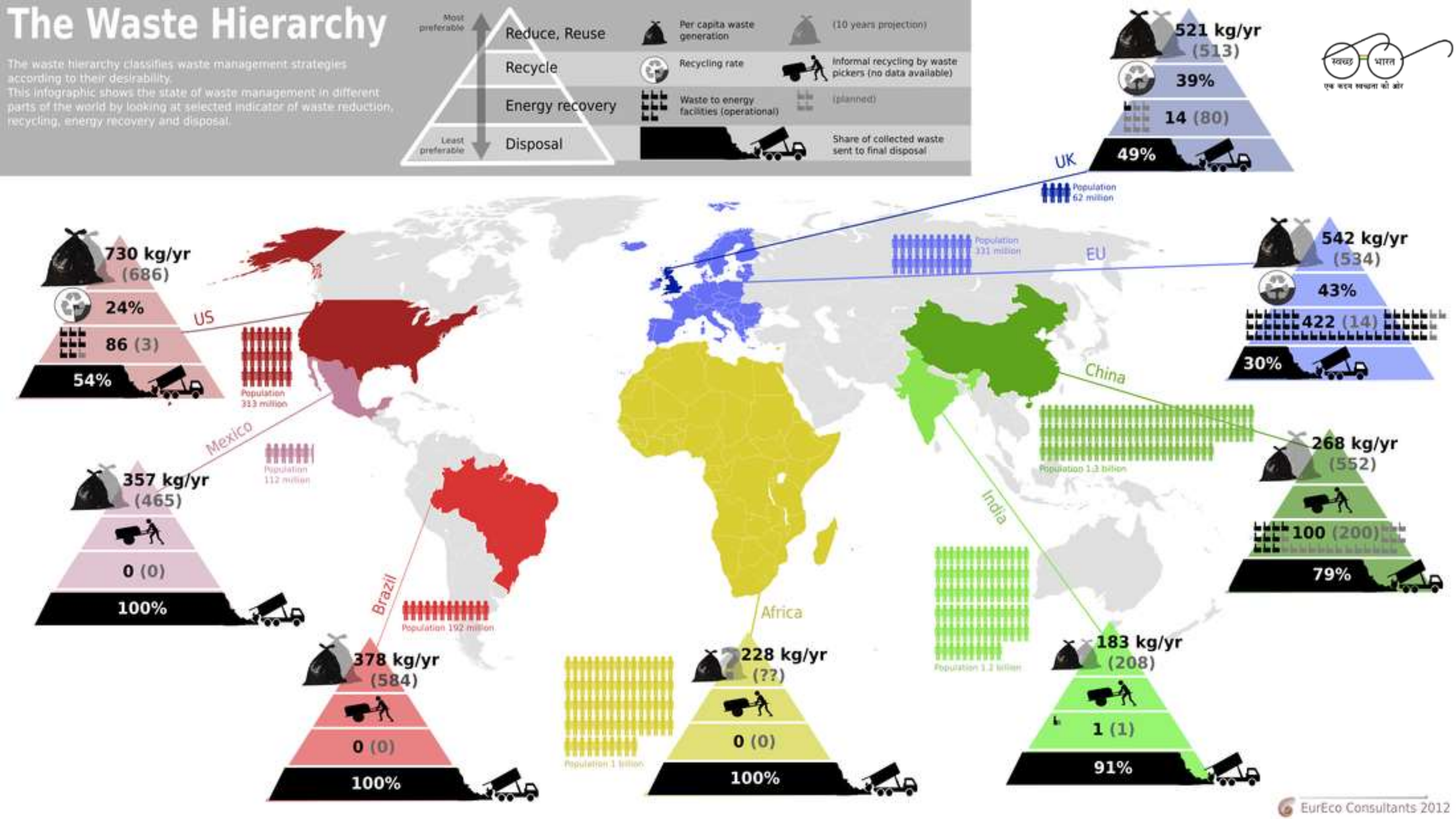
The world generates **2.01 BILLION TONNES** of municipal solid waste annually.

Unless urgent action is taken, global waste will increase 70% to **3.4 BILLION TONNES** by 2050!



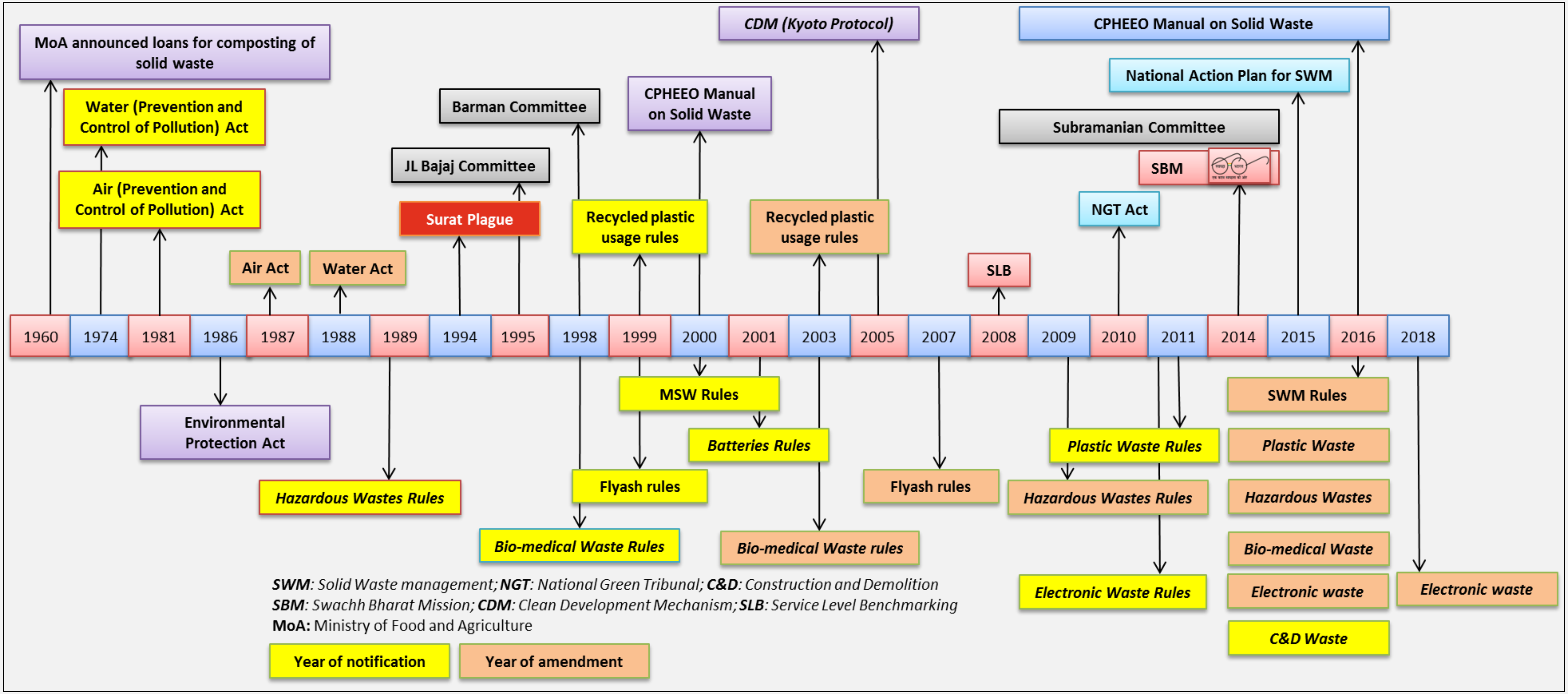
METAL 4%
GLASS 5%
PLASTIC 12%
PAPER/ CARDBOARD 17%
FOOD/ GREEN 44%
MAIN TYPES OF WASTE GENERATED
REGIONAL WASTE GENERATION (ANNUALLY)
EAST ASIA & THE PACIFIC
468 million tonnes
EUROPE & CENTRAL ASIA
392 million tonnes
SOUTH ASIA
334 million tonnes
NORTH AMERICA
289 million tonnes
LATIN AMERICA & THE CARIBBEAN
231 million tonnes
SUB SAHARAN AFRICA
174 million tonnes
MIDDLE EAST & NORTH AFRICA
129 million tonnes


In low-income countries, over 90% of waste is mismanaged.
This increases emissions and disaster risk,
which affects the poor disproportionately.
1/3 (extremely conservative) of
solid waste is openly dumped or burned
In low-income countries,
waste management costs comprise
20% of municipal budgets on average
We will LITTERally be living in waste
if nothing is done.
What can we do?
worldbank.org/what-a-waste
#WhatAWaste2
Data Source: World Bank (2018)
Images: Lois Goh, World Bank, Shutterstock



The Waste Hierarchy
The waste hierarchy classifies waste management strategies according to their desirability.
This infographic shows the state of waste management in different parts of the world by looking at selected indicator of waste reduction, recycling, energy recovery and disposal.
Most preferable
Least preferable
Reduce, Reuse
Recycle
Energy recovery
Disposal
Per capita waste generation
(10 years projection)
Recycling rate
Informal recycling by waste pickers (no data available)
Waste to energy facilities (operational)
(planned)
Share of collected waste sent to final disposal
स्वच्छ भारत
एक कदम स्वच्छता की ओर
UK
521 kg/yr
(513)
39%
14 (80)
49%
Population 62 million
EU
Population 331 million
542 kg/yr
(534)
43%
422 (14)
30%
US
730 kg/yr
(686)
24%
86 (3)
54%
Population 313 million
Mexico
Population 112 million
357 kg/yr
(465)
0 (0)
100%
China
Population 1.3 billion
268 kg/yr
(552)
100 (200)
79%
India
Population 1.2 billion
183 kg/yr
(208)
1 (1)
91%
Brazil
Population 192 million
378 kg/yr
(584)
0 (0)
100%
Africa
Population 1 billion
228 kg/yr
(??)
0 (0)
100%
EurEco Consultants 2012

Timeline chart of waste management policies and activities in India



Comprehensive Integrated Solid Waste Management Planning Process

Start here

Identify the needs
What types of waste are generated and in what quantities?

Review the existing system
How is the waste currently managed?

Review the existing Regulations
Are the existing laws adequate for ISWM?

Organize Decision Making Frame Work
Who will make the decision?

Establish Objectives
What are the short and long term goals?

Identify Potential Components
Which waste management activities will help you in achieving your goals?

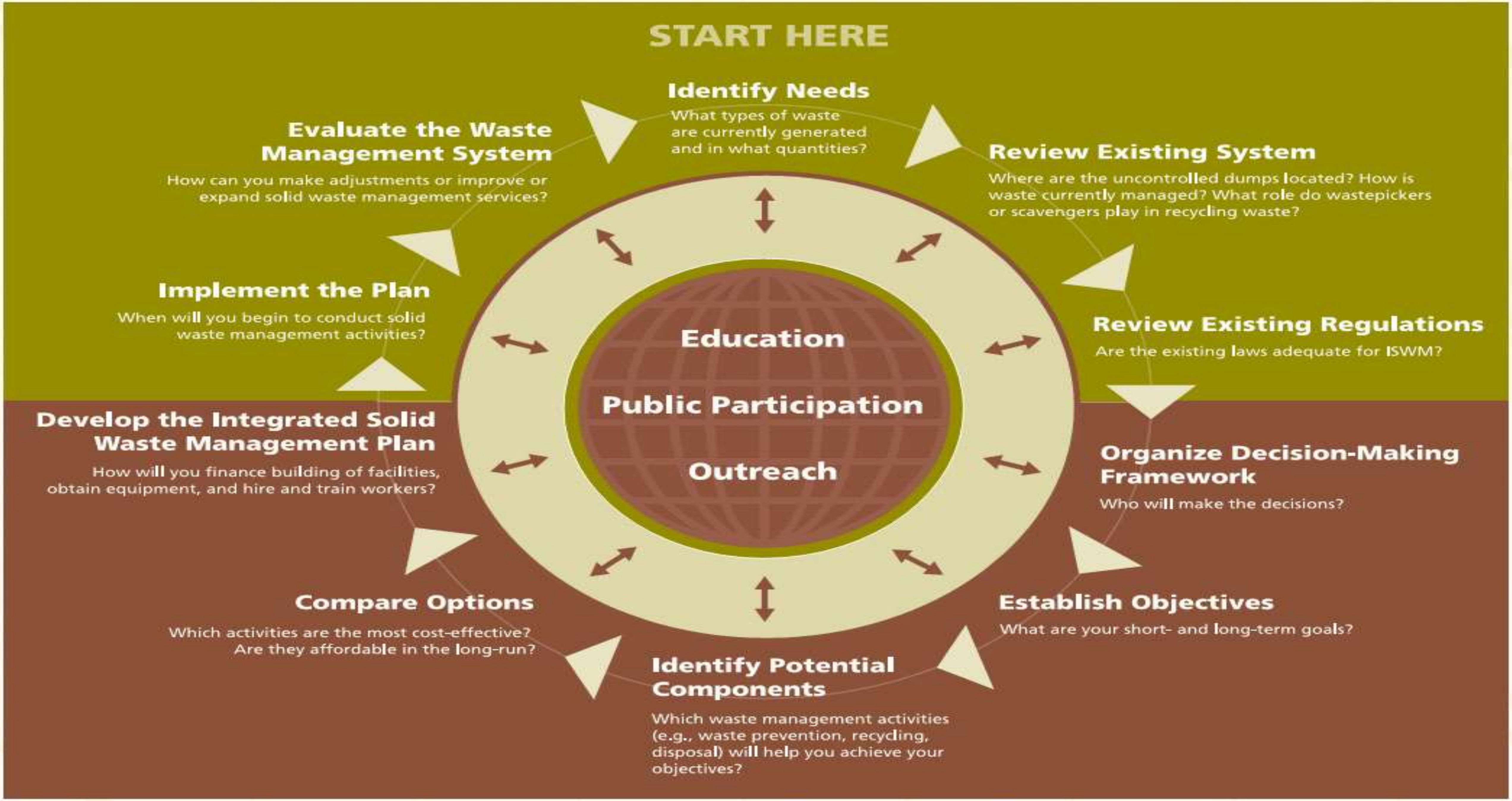
Compare Options
Which activities are most cost-effective?
Are they affordable in long run?

Develop the ISWM Plan
How will you finance building of facilities, obtaining equipment, and hire and train workers?

Implement the plan
When will you conduct SWM activities?

Evaluate the Waste management System
How can you improve of expand SWM services?

Source:
https://nepis.epa.gov/Exe/ZyPDF.cgi/P1000L3W.PDF?Dockey=P1000L3W.PDF


START HERE
Identify Needs
What types of waste are currently generated and in what quantities?
Review Existing System
Where are the uncontrolled dumps located? How is waste currently managed? What role do wastepickers or scavengers play in recycling waste?
Review Existing Regulations
Are the existing laws adequate for ISWM?
Organize Decision-Making Framework
Who will make the decisions?
Establish Objectives
What are your short- and long-term goals?
Identify Potential Components
Which waste management activities (e.g., waste prevention, recycling, disposal) will help you achieve your objectives?
Compare Options
Which activities are the most cost-effective? Are they affordable in the long-run?
Develop the Integrated Solid Waste Management Plan
How will you finance building of facilities, obtain equipment, and hire and train workers?
Implement the Plan
When will you begin to conduct solid waste management activities?
Evaluate the Waste Management System
How can you make adjustments or improve or expand solid waste management services?
Education
Public Participation
Outreach


Waste Prevention
Recycling and Composting
Disposal (Landfilling and Combustion)
=
Integrated Solid Waste Management

Waste Generation Trends → Physical Characterization → Chemical Characterization → Seasonal Characterization

Population forecasting

Population data was collected form the statistics department

↓

Growth characteristics of the study area were determined

↓

Suitable forecasting method was determined

↓

Population forecasting was estimated for three decades

Determination of waste quantity

Waste quantities were determination at city level (Study was performed at the dump yard)

↓

The net weight of the waste was determined

↓

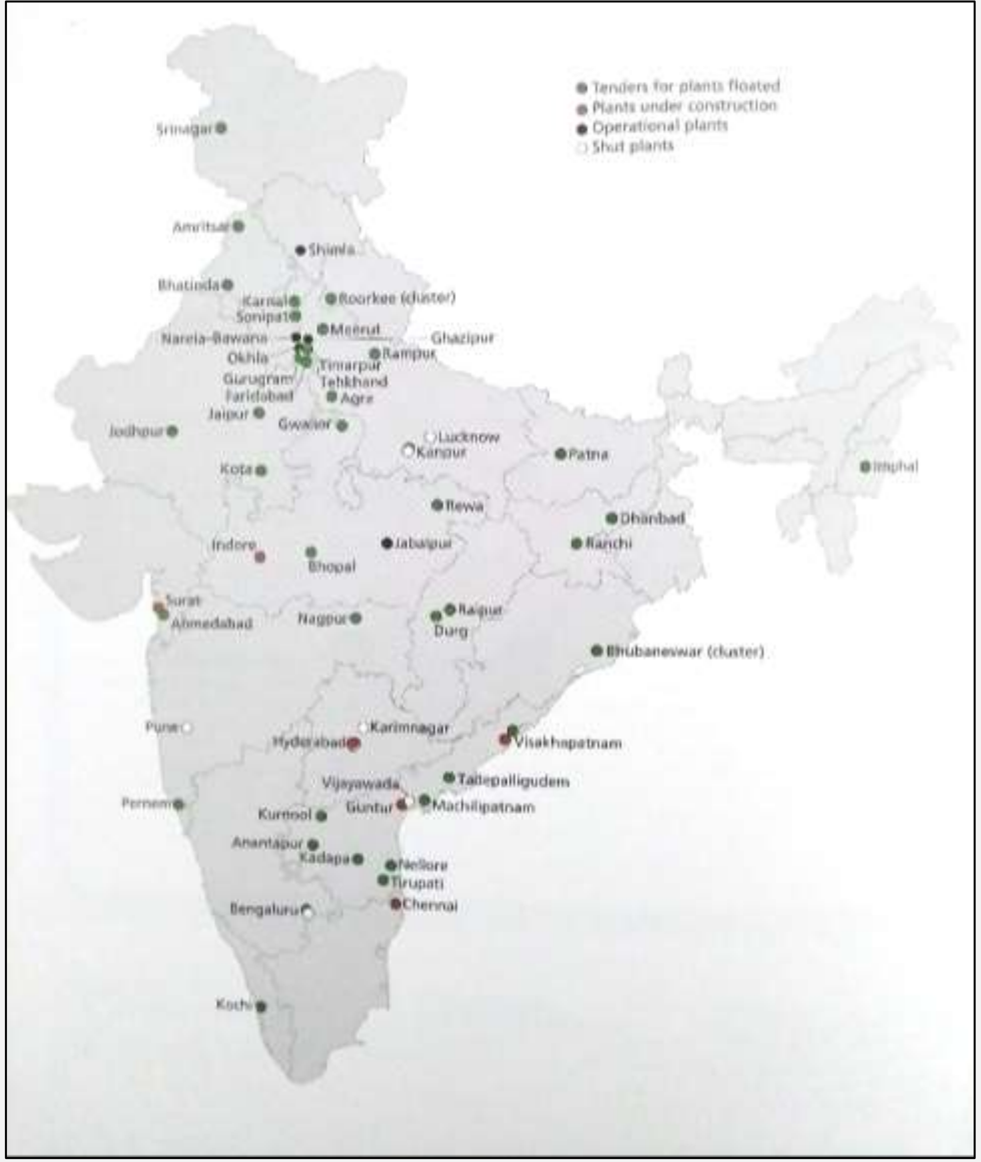
Zone wise amount of waste generation was determined

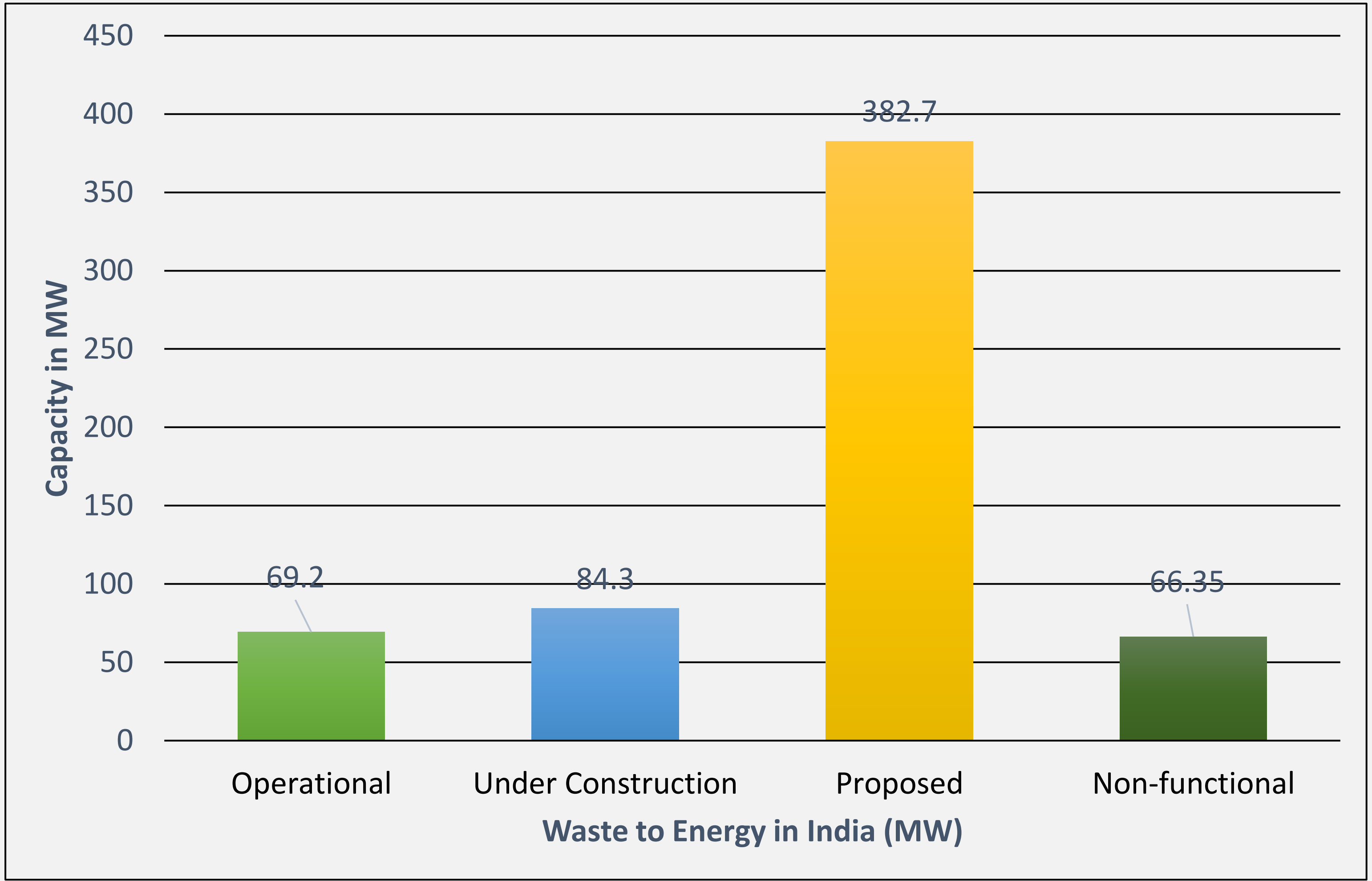
↓

The cumulative weight of the waste generated was determined.

Quantity of waste generated in a ULB	**Population * Per capita waste generation**

Waste to Energy in India





Source: *Sambyal, S. S., and Richa, A. 2018. To burn or not to burn: Feasibility of Waste to Energy Plants in India. CSE Publishers, India*

HTC of the organic fraction of MSW

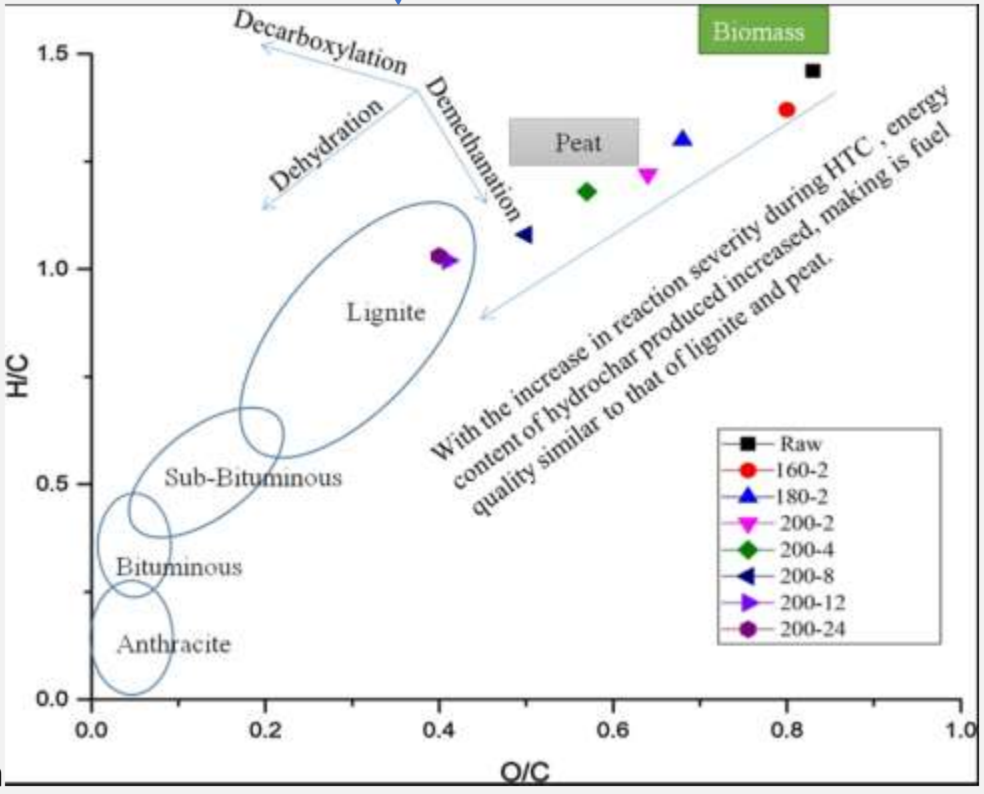
Yard Waste

Food

Reactor

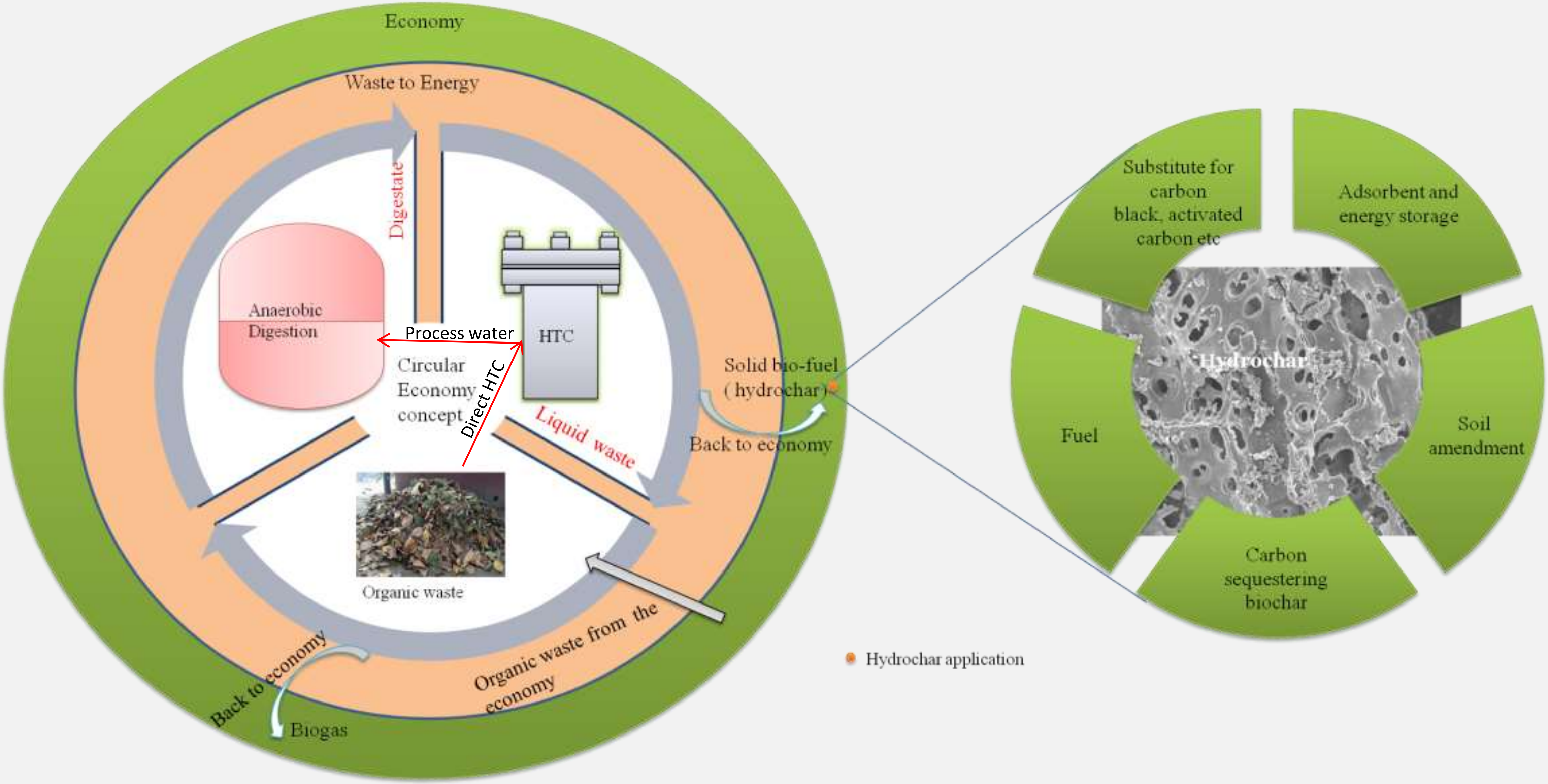
Hydrochar

Fuel Pellets

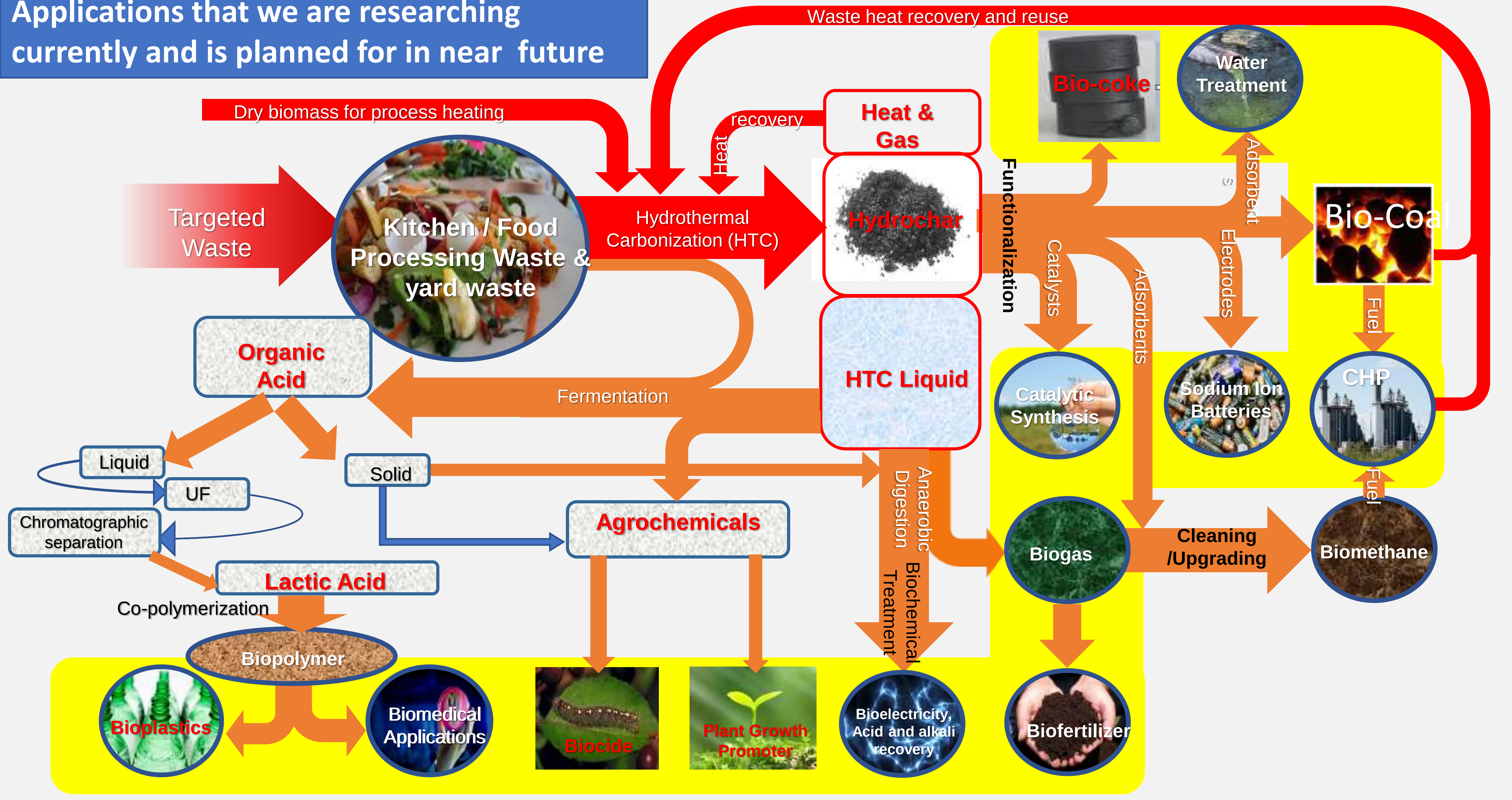


Van Krevelen diagram

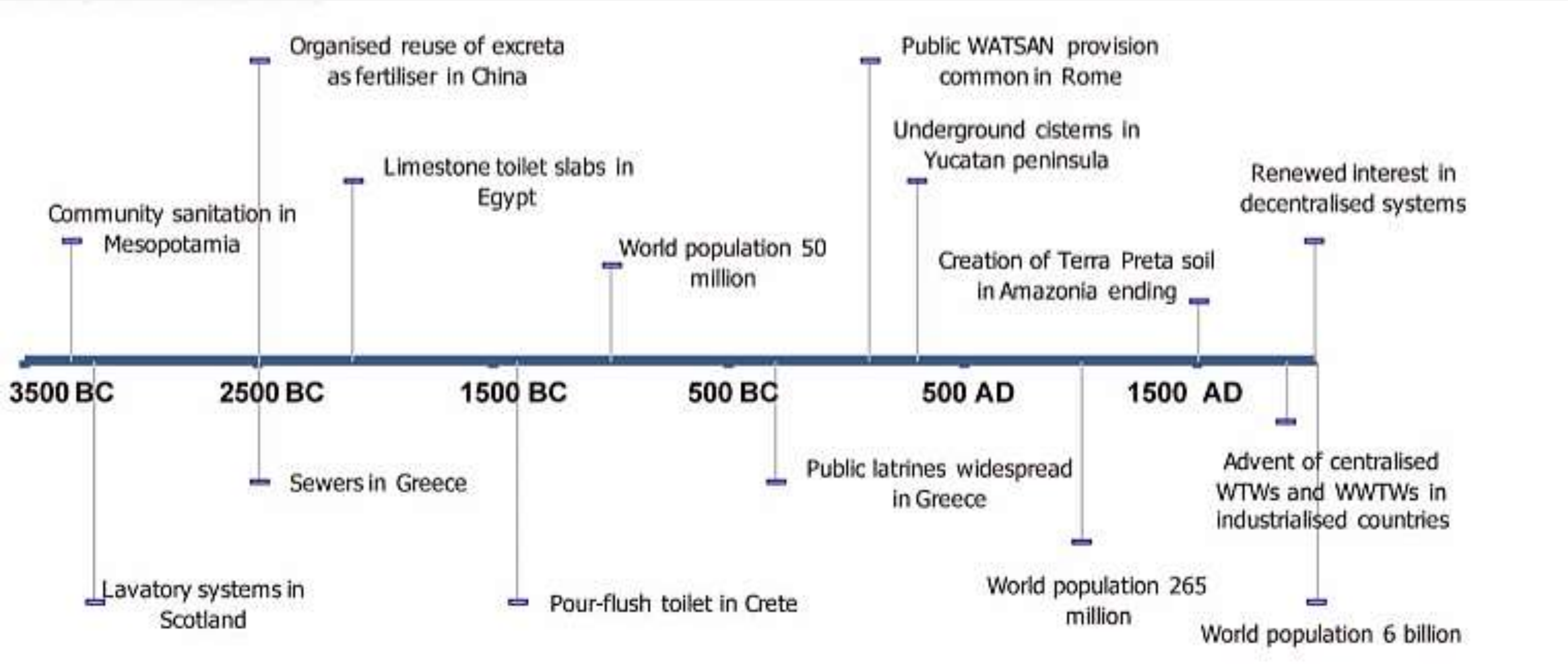
Zero loss process to treat organic fraction of MSW in a line of circular economy concept



Applications that we are researching currently and is planned for in near future



Water and Sanitation timeline from 3500BC to 2000AD



Source: https://www.researchgate.net/publication/235648775_Ancient_water_and_sanitation_systems_-_applicability_for_the_contemporary_urban_developing_world

Sanitary and drainage system in Indus cities

- The Harappan civilization developed a well-organized sewage network in a few urban agglomerations.
- While ***Harappa and MohenjoDaro*** covered about the same surface (around 100 ha during the Mature Harappan Period), ***Lothal*** was much smaller (around 25 ha).
- Interestingly, ***Dholavira***, which was a large city of about 100 ha as well, ***did not have a centralized sewage network*** at all: wastewater disposal was only about ***soak-pits and pierced jars***, whereas it has been demonstrated that this very site had stormwater drains.
- Conversely, the site of ***ChanhuDaro*** covered an area of only 6 ha, but had a ***centralized sewage system with drains***.
- Thus, it seems that Harappan centralized sewage system did not depend on the surface extent of the town, but most probably on ***socio-political factors***.

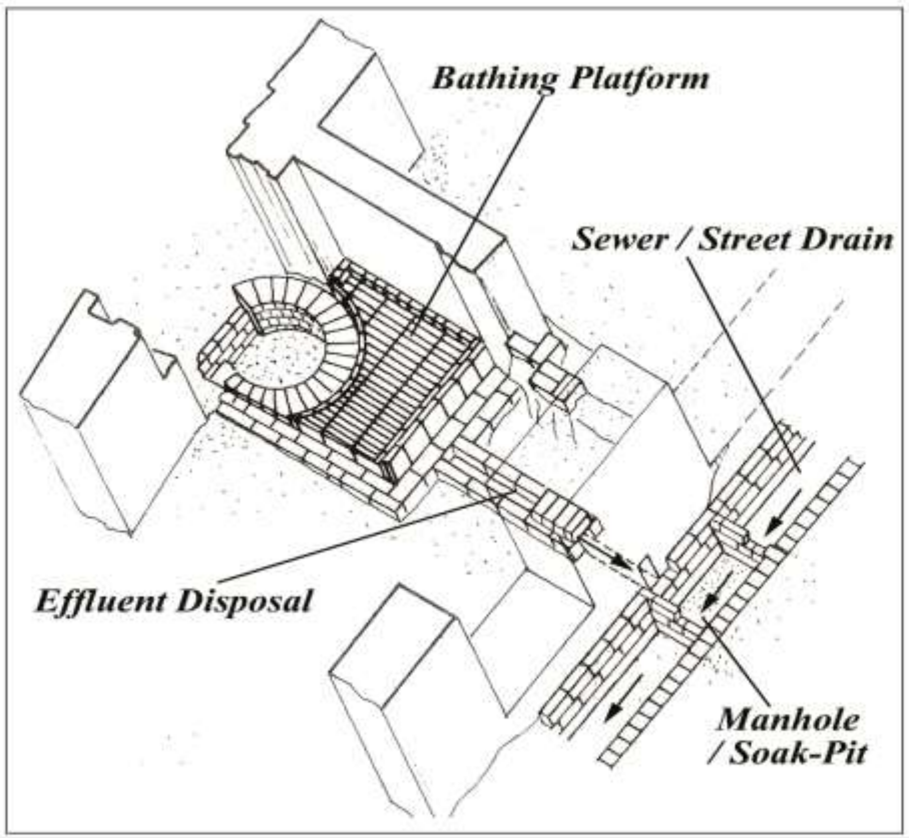
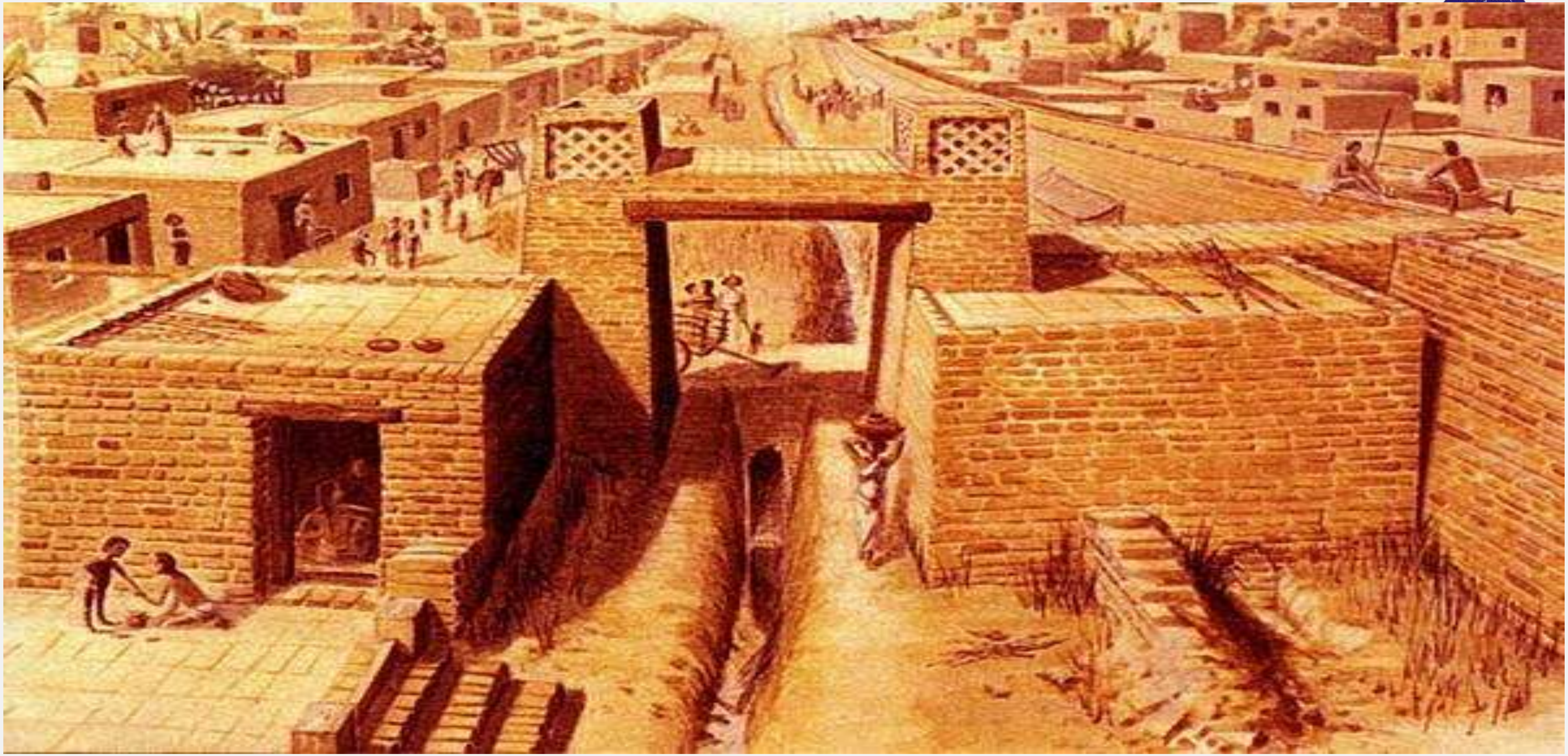


Figure. Scheme of domestic wastewater disposal of an urban agglomeration of the Harappan civilization

Source: https://www.mdpi.com/2071-1050/6/6/3936/htm

Water drains in the city of Harappa



Source: https://www.wonderslist.com/10-fascinating-facts-indus-valley-civilization/

An elaborate sanitary and drainage system (Indus cities)

- The Harappans have developed advanced sewerage and drainage systems.
- ***Wastewater management*** of the Harappan sites was of two types: one ***centralized***, with sewage and drainage networks, the other ***decentralized***, with soak-pits and/or pierced jars.
- But, in the sites where centralized wastewater management was implemented, as in Harappa, Mohenjo-Daro and Lothal, decentralized techniques were also used for the houses isolated from the existing sewage network.
- The sewage system of these three sites was made of ***standardized baked-bricks set in clay mortar.***
- ***Drains were covered with stone, wooden boards, or baked-bricks***, and in Mohenjo-Daro and Harappa sometime assembled in corbelled vault.
- Liquids entered brick-lined pits, having ***manhole function*** (control and cleansing) as well as ***sedimentation pits***. Then the effluent flowed into a larger drain.
- Bathrooms and lavatories were often located next to each other on the street side of the building, and wells were often in an adjacent room.

Source: https://www.tandfonline.com/doi/pdf/10.1080/00438243.1989.9980100?needAccess=true

Drainage system in Mohenjodaro

- An astonishing feat of civil engineering achieved over 4,000 years ago is the network of effluent drains built of brick masonry along the streets of ***MohenjoDaro***.
- The drains mostly ran along past the houses on one side of the normally unpaved streets, some 50 or 60cm below the surface.
- ***U-shape in cross-section***, the sides and bottom of the drains were built of ***bricks set in clay mortar*** while various coverings could be used for the open top.
- These covers, whether loose bricks, flagstones or wooden boards, ***could be removed for cleaning*** as required.

Source: https://www.tandfonline.com/doi/pdf/10.1080/00438243.1989.9980100?needAccess=true

Drainage system in Mohenjodaro

- The width of the open top depended on the size of the bricks which ranged from 25 X 13 x 5.75cm to 29.5 x 14.6 x 7.6cm.
- Thus a typical drain cross-section may be 17 to 25cm broad and 15 to 50cm high, i.e. between ***two and eight brick courses deep***.
- The ***drains sloped at a gradient of about 2cm per metre*** and met at different levels depending on their depth.
- Curved structures were sited in such a way that frictional loss was cut to a minimum.
- Wherever a drain had to traverse a longer distance or several drains met, a ***cesspool was installed***, this being the simplest method ***to avoid clogging by allowing solids to settle***.

Source: https://www.tandfonline.com/doi/pdf/10.1080/00438243.1989.9980100?needAccess=true

Corbelled Drains

- ***Corbelled Drains were the main source of collecting sewage and rain water***
- This drain cuts through the edge of the so-called granary. If the entire drain were constructed along with the Great Bath.
- The corbelled arch drain from the great bath is large enough to walk into. It has a small ledge on either side of the actual drain channel.

Source: https://www.harappa.com/sites/default/files/slides/greatbathdrain31.jpg
https://www.mauritius-images.com/en/asset/ME-PI-6363462_mauritius_images_bildnummer_12242119_%2522-;

Mohenjodaro Streets with Drains and Toilet system

Fig: Miniatures of pit and flush toilets of Mohenjo-Daro

- The drainage system was one of the most remarkable features of the Mature Harappan city.
- All the streets and lanes across neighbourhoods 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 ***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.

Source: https://izi.travel/de/0aa0-miniature-of-flush-toilet-of-mohenjo-daro/en

Toilets in Indus Valley Civilization

Fig: Miniatures of pit and flush toilets of Mohenjo-Daro

Fig: Public toilets of Mohenjo-Daro

- ***Toilets in the houses of Mohenjo-Daro were wither pit toilets or flush toilets.***
- Archaeologists have also depicted the presence of public toilets
- ***Indus Civilization can also be credited for the world's first automatic flushing toilets***
- Flush toilets were built in the form of brick boxes. Through ***vertical drainage channels*** sewage flowed down into sewers ***that extend outside the city or into cesspools.***
- The toilets of Indus valley civilization were different than the Roman and Greek Civilizations. This difference is the main evidence of the cultural difference between them.

Source: https://izi.travel/de/0aa0-miniature-of-flush-toilet-of-mohenjo-daro/en

Mohenjodaro Street with Drains

Fig: Mohenjodaro Street with Drains

- 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 away. These would be cleaned out periodically.
- Wider drains were covered with ***extra long bricks, and for culverts***, such as that at the Great Bath, a ***corbelled arch*** was used.

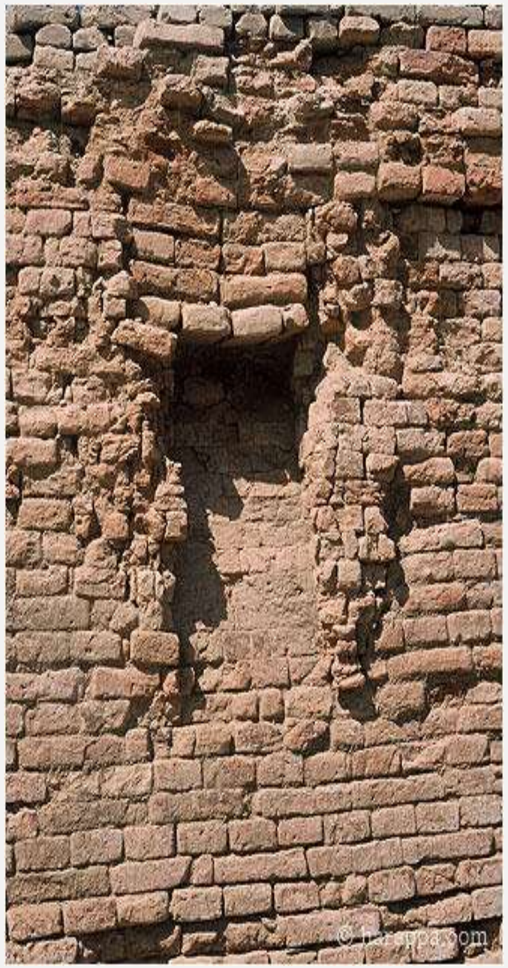
- The ***offensive odours*** emitted by the sewage chutes, soak pits, cesspools and sewers must have been a ***considerable public nuisance*** which could only have been relieved somewhat by a ***constant high rate of flow and frequent cleaning.***
- Both relief measures would have required a great deal of man power. In particular the maintenance of the drainage system must have been a ***labour-intensive public burden.***

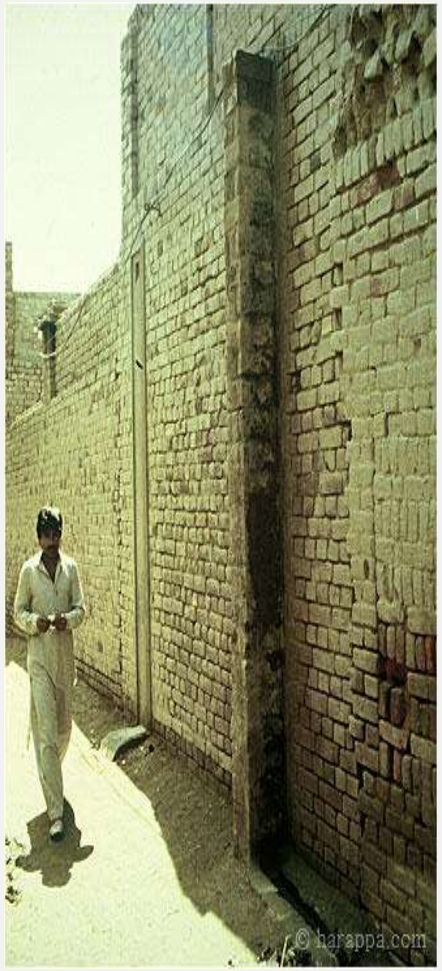
Source: https://www.tandfonline.com/doi/pdf/10.1080/00438243.1989.9980100?needAccess=true

Drains in multistorey buildings – Indus Valley

- Many of the buildings at Mohenjodaro had two or more stories. Water from the ***roof and upper storey bathrooms*** was carried through enclosed ***terracotta pipes or open chutes that emptied out onto the street.***

- In the modern town of Harappa, however, ***a covered drain built along the outside of a house*** takes sewage water from a second storey latrine and bathroom to the street level drain ***without splashing people passing by on the street.***





Figures. Drain chutes Open vs Closed

Source: https://www.harappa.com/indus6/uchsharifdrain100.html

Dholavira - Harappan Site

- Dholavira is a Harappan site located in the Rann of Kutch, Gujarat.
- This 47 hectares (120 acres) quadrangular city is one of the largest mature Harappan sites.
- Its incredible water management system and hydraulic engineering that contains at least ***16 reservoirs and an elaborate systems of drains and sewers***.
- In the citadel area there is an intricate ***network of storm water drains***, all connected to an arterial one and furnished with *slopes, steps, cascades, manholes (air ducts / water relief ducts), paved flooring and capstones.*

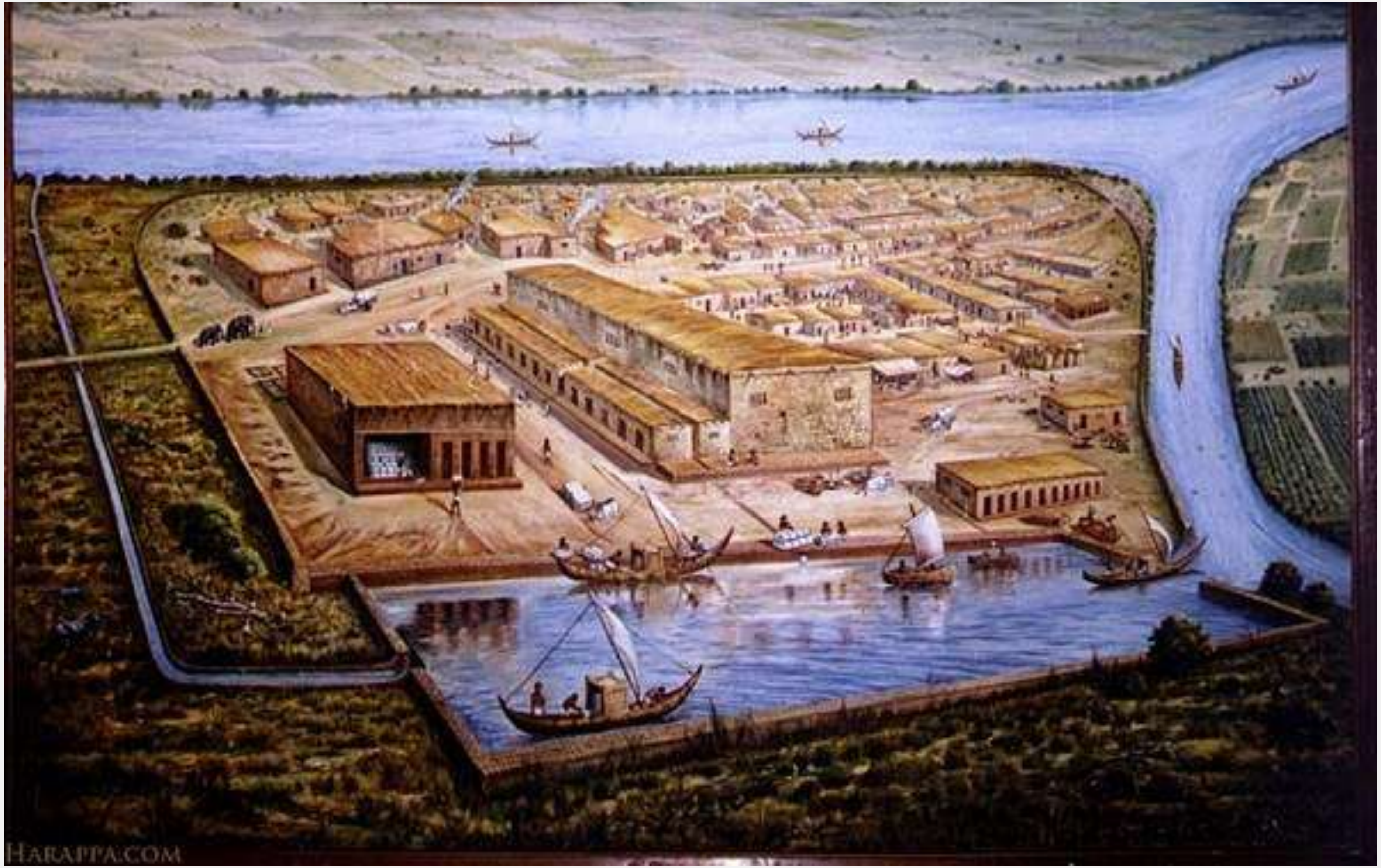
Source: https://www.youtube.com/watch?v=yNVN4W2CcWA

Dholavira - Harappan Site

- The main drains were ***high enough for a tall man to walk*** through easily.
- The rainwater collected through these drains was stored in yet another reservoir that was carved out in the western half of the citadel.
- Altogether the reservoirs have an area of about 10 hectares, or 10 percent of the area within the walls.
- This fabulous system made it possible for the Dholavirans to thrive in their desert home.

Source: https://www.youtube.com/watch?v=yNVN4W2CcWA

Architects view of Lothal city



- This view shows pipes carrying effluent out of the city into the forest.
- This view also shows influent water into the city for fresh water use.

Source: *https://www.wonderslist.com/10-fascinating-facts-indus-valley-civilization/*

Sanitation in Lothal

- Lothal's sophisticated sanitary and drainage system was a hallmark of ancient Indus cities.
- All of ***Lothal's drainage channels met at right angles,*** engineered with ***several steps to separate solid and liquid wastes***, which the river Sabarmati carried into the sea.

Source: *https://www.mdpi.com/2073-4395/10/6/821/htm*

Lothal: Sanitary drainage at the acropolis

- The most unique aspect of planning during the Indus valley civilization was the system of ***underground drainage***.
- The main sewer, 1.5 meters deep and 91 cm across, connected to many north-south and east-west sewers.
- It was made from bricks smoothened and joined together seamlessly.
- ***The expert masonry kept the sewer watertight.***
- Drops at regular intervals acted like an automatic cleaning device.
- A wooden screen at the end of the drains held back solid wastes.
- Liquids entered a cess poll made of radial bricks.
- Tunnels carried the waste liquids to the main channel connecting the dockyard with the river estuary.
- ***Commoner houses had baths and drains that emptied into underground soakage jars.***

Source: https://www.harappa.com/lothal/14.html

Traditional agricultural waste management technique

- The Waste Management Techniques used in Ancient India were successful enough to recycle the household wastage.
- Burning of wood or coal was used for cooking purpose and the *carbon was decomposed underground.*
- Villagers followed easy techniques and ***dug a small hole in the backyard to collect daily household waste and covered it with mud/sand till the pit got leveled.***
- After a few months, this land was used in the farms as ***compost.***
- In another method big holes were made near big tree and the waste was collected in it.
- The waste contents were mixed with the mud during watering of the tree and were slowly converted into compost.
- ***Returning of food waste to soil was a common practice since Vedic times***, sustainably recycling nutrients and micronutrients and in present day we are experimenting this technique as compost.

Source: https://sbm.gov.in/gbdw20/images/Fund/Different_models_of_CBGBiogasPlants.pdf

Other ancient sewer systems

Figures: Ancient Terrakota ring wells

- In various sites, wastewater was canalized into ***cesspools***, which could have been ring-wells, as in ***Jorwe (1375 to 1050 BC) or in Ujjain (ca. 500 BC).***
- This supposition can help us to understand why S. H. Dhirajlal and D. S. Bhalchandra wondered about some constructions dated at 150 BC in ***Nasik,*** if they were '***ring-wells or soak-pits'.***
- In the ***3rd century BC at Taxila***, domestic wastewater was canalized out from the houses through ***earthenware drain-pipes into soak-pits.***
- In ***Pushkalavati***, the ancient capital of Gandhara, the same wastewater management of ***drain, soakpit and/or cesspoo***l were commonly used.
- In the ***antique Delhi,*** during the 3rd century BC, the same kind of system was used: drains, which are still visible in todays Purana Qila, canalized wastewater into ***'wells, which may have functioned as soak-pits'.***

Source: https://www.tandfonline.com/doi/pdf/10.1080/00438243.1989.9980100?needAccess=true
https://www.thehindu.com/news/national/tamil-nadu/terracotta-ring-well-unearthed-at-agaram/article32286658.ece

Other ancient sewer systems

Figure: Arikamedu archeological site

- During the *Sangam Period (ca. 300 BC to 300 AD),* in the southeastern part of the subcontinent, ***industrial wastewater management*** was developed in Arikamedu, an Indo-Roman trading station.
- The wastewater management has been improved around 150 AD with ***corbelled drains***, which seems quite unique for the area.
- This system drained water from basins, supposed to be a part of a ***textile and dye industry.***
- So, whereas in the rest of Ancient India, drains and other wastewater disposal were implemented for domestic effluents, in ***Arikamedu*** the wastewater management concerned the industry.
- During the second phase, the diffusion of wastewater management techniques seems to follow the main trade route of the region, which joined Ujjain to Taxila.
- Indeed, wastewater management in south-east South Asia is probably linked with the presence of Mediterranean populations, and the very same populations could even have had an influence on water engineering techniques in the northern part of the region.

Source: https://www.tandfonline.com/doi/pdf/10.1080/00438243.1989.9980100?needAccess=true

Wastewater management techniques in South Asia

Historical Periods	3200 BC	1900 BC	500 BC	200 BC	150 BC	150 BC – 150 AD
	Harappan periods		Northern Black Polished ware (NBP)			Sangam
Sites	Greater Indus Valley: Mohenjo-daro, Harappa, Dholavira etc.	Gulf of Cambay/ Gujarat: Lothal	Central India: Ujjain	Northern South Asia: Taxila, Pushkalavati and Delhi	Central India: Nasik	South India: Arikamedu
Wastewater Management Techniques	– Latrines – Drainage and Sewage disposal: • Soak-pits • Pipe network • Drains with sedimentation cesspits	– Drainage and Sewage disposal: • Soak-pits • Pipe network • Drains with sedimentation cesspits	– Drainage and Sewage disposal: • Soak-pits • Pierced pots (latrines?) • Ring-wells = soak-pits?	– Drainage and Sewage disposal: • Drain-pipes • soak-pits • cesspools • Ring-wells = soak-pits?	– Drainage and Sewage disposal: • Ring-wells = soak-pits?	– Covered drains for industrial effluent disposal

Source: https://www.academia.edu/8795221/Sanitation_and_water_management_in_ancient_South_Asia

Application of Traditional Systems in Modern world

- Comparison of Ancient Achievement to the Modern Ones, although to some extent, there are ***differences in the apparatus used today and the scale of applications***, still there are ***no differences in the fundamental principles used.***
- The advent of the use of ***concrete*** helped the Roman engineers to substantially ***increase the scale*** of aqueduct projects as compared to their preliminary structures.
- The famous Trevi-fountain in Rome is still fed by aqueduct water from the same sources of the ancient Aqua Virgo; however, the Acqua Vergine Nuova is now a pressurized aqueduct.
- ***The long-term sustainability*** of Minoan cisterns is evidenced by the fact that this technique is ***still practiced today in the rural areas of Crete, Hellas.***

Figure: Roman civilization aqueducts

Source: https://www.unrv.com/images/400width/architecture.png

- ***Flushing toilets*** equipped with seats resembling present-day toilets and drained by sewers has existed during ***Minoan and Indus valley civilizations.***
- Also, the ***community toilets*** continue to act as an important part of sanitation provision in the developing world and are especially ***suited to high-density population in urban areas.***
- For instance in ***South Africa, eThekwini municipality***, centred upon Durban, has made ***community ablution blocks (CABs)*** a cornerstone of its efforts to supply water and ***sanitation facilities to the un-served in high-density informal settlements.***

Figure: Community toilets in South Africa

Source: https://commons.wikimedia.org/wiki/File:Community_ablution_block_(8152068784).jpg

Application of Traditional Systems in Modern world

- Of course there are similarities between Roman tenements and modem African informal settlements – high population density, lack of space, limited access to sewers - which make ***community toilets a practical sanitation solution in both.***
- ***Public latrines were often heated***, while seats framed by sculptured dolphins have also been found in ancient civilization.
- This correlates with contemporary experience as ***users of CABs in Durban reported low satisfaction with certain blocks, linked to them being poorly maintained, unclean and malodorous.***
- Community toilets built with the ***cooperation of and maintained by local users are found in the slums of Mumbai and Pune in India***, where blocks incorporate features such as ***ventilation, accommodation for caretakers and their families and special design features for children***.

Figure: Public toilets in Mumbai

Source: https://w.ndtvimg.com/sites/3/2018/06/01201842/public-toilets-india.jpg

Application of Traditional Systems in Modern world

- The *public baths* of Indus valley civilization and Roman civilization were a ***focal point for socialising and community activities.***
- So, community toilets also have the potential to fulfil an equivalent role. For instance, it has been suggested that involving users in project design could promote the ***transformation of CABs into sites of social activity in the communities.***
- ***Examples*** of modem toilets representing a focal point for community activities can be found in ***Indonesia***, where toilets linked to decentralised wastewater treatment systems ***attract community members for meetings and prayers and cooking through use of biogas.***
- So, with respect to community systems, the *main features of learning* are not related to technical design specifics, but rather what we can learn from ancient civilisations about their *social function.*
- The *modern sanitation technologies* require additional features to *contain pathogens, ensure hygiene and safe handling of excreta and an appropriate degree of wastewater treatment*, which were not prioritised in ancient systems.

Source: https://sci-hub.mksa.top/10.2166/wst.2013.628

Application of Traditional Systems in Modern world

- Although *ancient water and wastewater technologies* could be classified as sustainable and decentralised systems in the contemporary developing world, many have *limited applicability and involve discharge directly into the environment.*
- With the limitations of no pathogen removal, nutrient removal and energy recovery, many technical improvements are needed to make ancient systems suitable for the modern world.
- Toilets based on the ancient *Amazonian production of Terra Prêta soil* are an *intriguing proposition and further research* is warranted into their application, particularly in situations where the end product can be used as a *soil-enhancer in rural or urban agriculture.*

Figure: Terra preta Soil

Source: https://sci-hub.mksa.top/10.2166/wst.2013.628

Terra Preta Toilets

- Urine diversion terra preta toilets are a low cost, *dry terra preta sanitation (TPS) systems based on urine diversion and the addition of charcoal producing lasting and highly fertile soils* with properties similar to the recently discovered pre-Columbian man-made terra preta soils.
- The terra preta toilets are based on a three-step process of collection (including urine diversion), lactic acid fermentation (lacto-fermentation) and vermicomposting.
- Any urine diversion or composting toilet can thus been adapted for TPS. The main advantage of lacto-fermentation is that ***no gas (e.g. methane) and no odour is produced what makes it particularly interesting for in-house systems even in urban areas.***
- *Vermicomposting* transforms the carbon and nutrients into the deep black, fertile and stable soil, which also has the potential as a long-term carbon sink

Figure: Terra preta Toilet

Source: https://sswm.info/water-nutrient-cycle/wastewater-treatment/hardwares/site-storage-and-treatments/terra-preta-toilets

Terra Preta Composting

- Terra Prêta soils did not leave archaeological or written record, but a legacy in the form of islands of enhanced soil, which still contain around ***three times more soil organic matter than surrounding infertile soils.***
- Terra Prêta sanitation is an intriguing prospect and has been recreated in buckets with ***air-tight lids and addition of a charcoal-based mix.***
- The technology warrants further investigation, such as into ***optimising the composition of the additive mix and its cost,*** with obvious applications for the end product in both urban and rural agriculture.

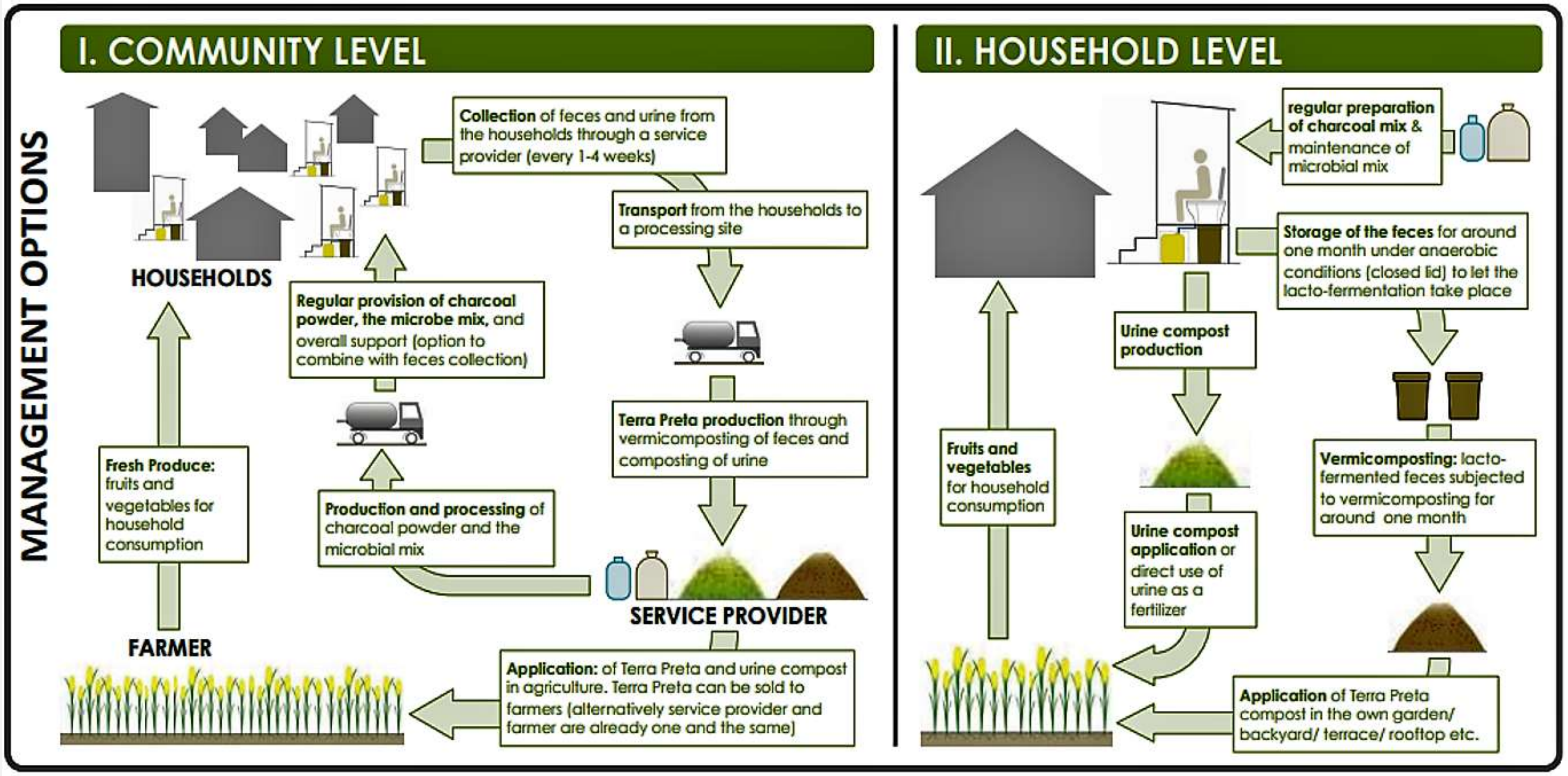
Figure: Terra preta Composting technique

Source: https://sswm.info/water-nutrient-cycle/wastewater-treatment/hardwares/site-storage-and-treatments/terra-preta-toilets

Application of Traditional Systems in Modern world

- The ***reuse of urine in the laundries of ancient Rome*** is also relevant to today, bearing in mind the interest in recovering the nutrients within urine by struvite precipitation which can then be used as a fertiliser.
- In *Nepal* it was recently considered that large volumes of urine are required for ***struvite reuse as fertiliser to be financially sustainable***, whereas in ancient ***Rome urine was evidently sufficiently lucrative to be taxed and sold.***
- *Rainwater collection* was also widespread in the ancient world and is certainly something that could be disseminated more widely in many developing and developed countries to augment existing water resources.
- In the case of *e-Tbekwini municipality, South Africa* the strategic response has also encompassed ***75,000 urine diversion (dry) toilets*** supplied to those in ***sparsely populated areas beyond existing sewerage coverage.***

Large-scale and small-scale application of TPS systems



Source: https://sswm.info/water-nutrient-cycle/wastewater-treatment/hardwares/site-storage-and-treatments/terra-preta-toilets

hank ou

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