NPTEL ONLINE CERTIFICATION COURSES

Introduction to Environmental Engineering and Science – Fundamentals and Sustainability Concepts

Dr. Brajesh Kumar Dubey
Department of Civil engineering
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Weekly Topic

Environmental Biological concepts

Lecture 21: Oxygen Demand in Environmental Systems

CONCEPTS COVERED

Environmental Biological Aspects

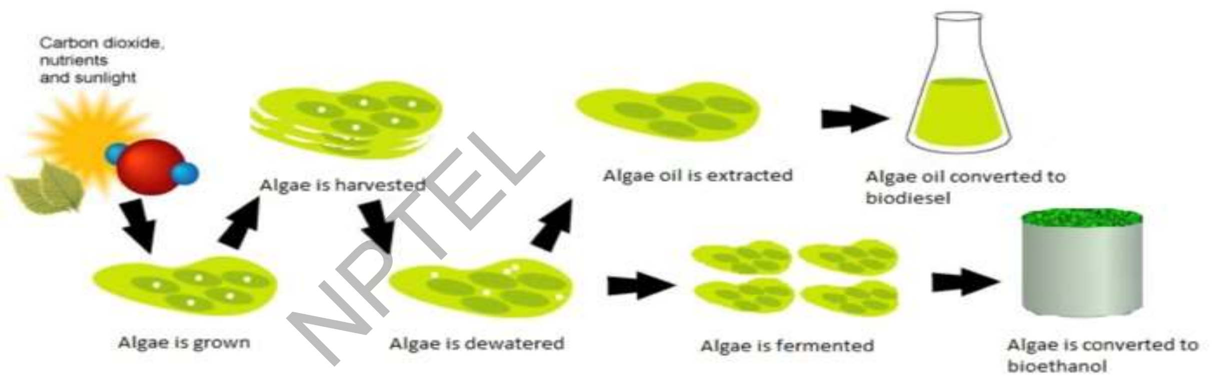
- Oxygen Demands, BOD, COD, TOC etc.
- Oxygen in natural systems
- Associated SDGs
- Carbon, Nitrogen, Phosphorus, Sulphur Cycles

Major Organism Groups with Representative Members

Viruses
Bacteria
Fungi Algae
Protozoa
Macrophytes Fish
Rotifers
Micro crustaceans
Macro invertebrates

Some organism groups are important in environmental engineering

Producing Biodiesel from algae



https://energyeducation.ca/encyclopedia/Algae_biofuel

Oxygen Demand

Biochemical oxygen demand or **BOD** is a chemical procedure for determining the amount of dissolved **oxygen** needed by aerobic **biological** organisms in a body of water to break down organic material present in a given water sample at certain temperature over a specific time period.

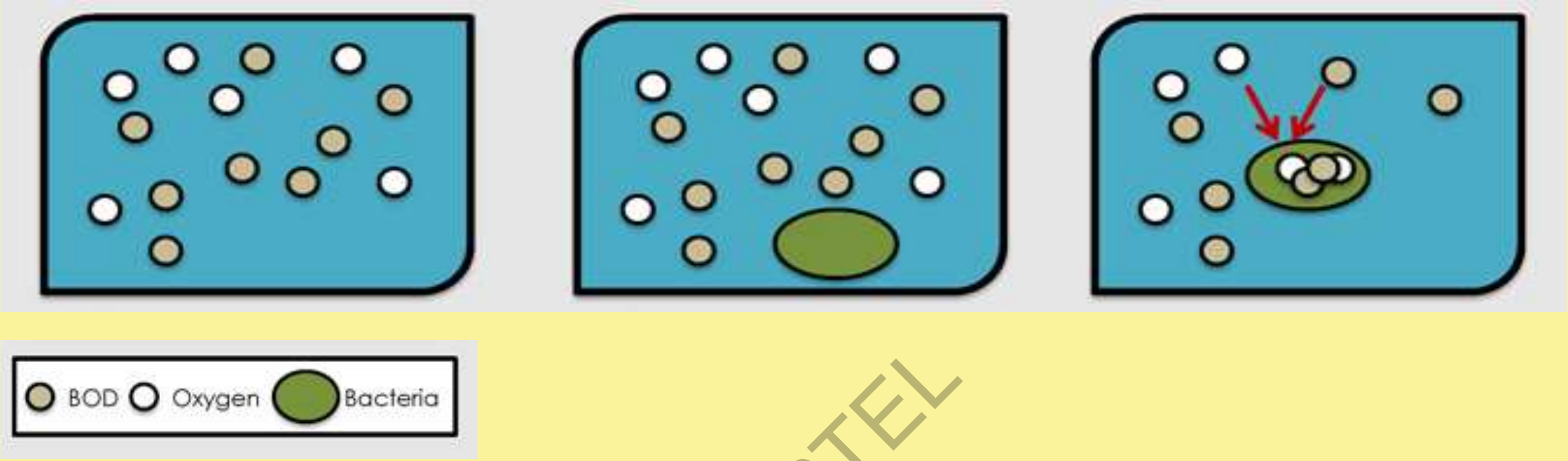
Aerobic decomposition

Organic matter +O2 $\xrightarrow{\text{Microbes}}$ **CO_2+H_20 +New cells + Stable products(NO_3,PO_4,SO_4)**

Aerobic decomposition

Organic matter $\xrightarrow{\text{Microbes}}$ **CO_2+H_20 +New cells + Unstable products(H_2S, NH_3,CH_4)**

Simple BOD concept



In receiving stream, high BOD level can cause depleted oxygen, making it difficult for aquatic animal to survive.

Oxygen Demand: Definition and Notation

BOD	Biochemical oxygen demand – the amount of oxygen utilized by microorganisms in oxidizing carbonaceous and nitrogenous organic matter.
CBOD	Carbonaceous biochemical oxygen demand – BOD where the electron donor is carbonaceous organic matter.
NBOD	Nitrogenous biochemical oxygen demand – BOD where the electron donor is nitrogenous organic matter.
ThOD	Theoretical oxygen demand – the amount of oxygen utilized by microorganisms in oxidizing carbonaceous and / or nitrogenous organic matter, assuming that all of the organic matter is subject to microbial breakdown, that is, it is biodegradable.
BOD_5	5-day biochemical oxygen demand – the amount of oxygen consumed (BOD exerted) over an incubation period of 5 days; the standard laboratory estimate of BOD. The BOD_5 utilizes the notation y_5 , referring to the BOD exerted (y) over 5 days of incubation.
BOD_U	Ultimate biochemical oxygen demand – the amount of oxygen consumed (BOD exerted) when all of the biodegradable organic matter has been oxidized. The BOD_U utilizes the notation L_o, referring to its potential for oxygen consumption when proceeding to complete oxidation.
COD	Chemical oxygen demand – the amount of chemical oxidant, expressed in oxygen equivalent, required to completely oxidize a source of organic matter; COD and ThOD should be near equal.

BOD of Selected Waste Streams

Origin	BOD_5(mg O_2/L)
River	2
Domestic Waste Water	200
Pulp and Paper mill	400
Commercial laundry	2,000
Sugar beet factory	10,000
Tannery	15,000
Brewery	25,000
Cherry – canning factory	55,000

Steps to Calculate the carbonaceous ThOD		
Step	Description of Step	Example
Step 1	Write the equation describing the reaction for oxidation of the carbon – based chemical of interest to carbon dioxide and water (for example, for benzene, (C_6H_6)	$C_6H_6 + O_2 \rightarrow CO_2 + H_2O$
Step 2	Balance the equation in the following sequence: (a) balance the number of carbon atoms; (b) balance the number of hydrogen atoms; (c) balance the number of oxygen atoms.	For benzene, (a) place a 6 in front of CO_2 to balance the carbon; (b) place a 3 in front of H_2O to balance the hydrogen; (c) place a 7.5 in front of the oxygen to balance the oxygen; $C_6H_6 + 7.50_2 \rightarrow 6CO_2 + 3H_2O$
Step 3	Use the Stoichiometry of the balanced chemical reaction, applying unit conversions, to determine the carbonaceous ThOD.	Assume the initial concentration of benzene = 156 mg/L: (156 mg benzene)/L × (1 mole benzene)/ 78 g benzene × (7.5 mole O_2) / mole benzene × (32 g O_2)/mole O_2 = 480 mg O_2/L

Determination of carbonaceous, nitrogenous and total ThOD

A waste contains 300 mg/L of $C(H_20)$ and 50 mg/L of NH_3-N. Calculate the carbonaceous ThOD, and the total ThOD of the waste.

Write the balanced equation $C(H_2O) + O_2 \dashrightarrow CO_2 + H_2O$

- The reaction shows that 1 mole of oxygen is required to oxidize each mole of $C(H_2O)$. The carbonaceous ThOD is determined from the Stoichiometry:

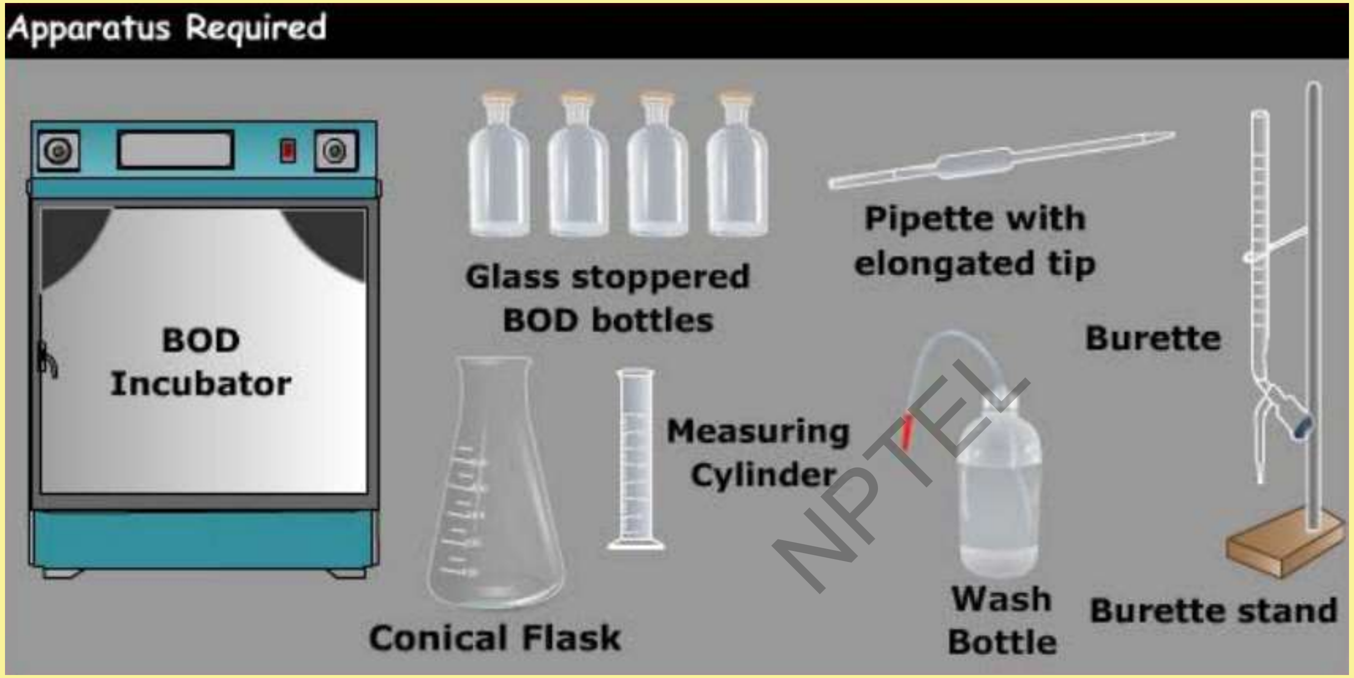
- 300 mg $C(H_2O)$ × (g/1,000 mg)× (1 mole $C(H_2O)$)/30 g $C(H_2O)$) × (1 mole O_2/mole $C(H_2O)$) × (32 g O_2/mole O_2) × 1,000 mg/g = 320 mg/L.

- Next, write the balanced equation describing oxidation of ammonia – nitrogen to nitrate:
- $NH_3 + 2O_2 \rightarrow NO_3^- + H^+ + H_2O$

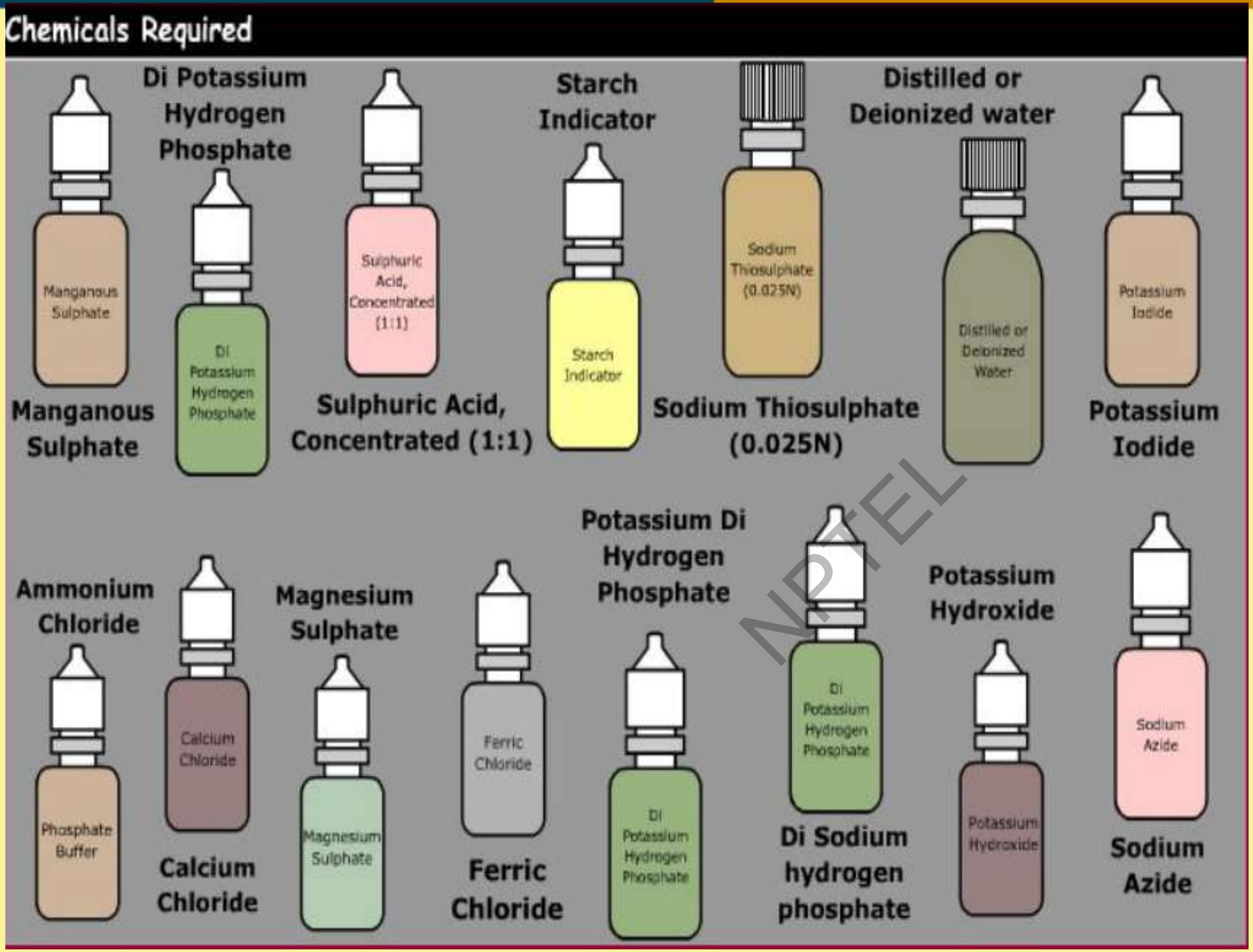
- This reaction shows that 2 moles of oxygen are required to oxidize each mole of NH_3. Be aware that the ammonia concentration is reported as mg N/L, not mg NH_3/L. The nitrogenous ThOD is determined from the Stoichiometry:

- 50 mg NH_3 – N/L × g/1,000 mg × 1 mole NH_3 – N/14 g NH_3 – N × 2 mole O_2/ mole NH_3 – N × 32 g O_2/ mole O_2 × 1,000 mg/g = 229 mg/L.
- The total ThOD of the waste equals 320 + 229 = 549 mg/L.

Procedure



http://mitpolytechnic.ac.in/downlaods/09_knowledge-bank/05_civil/SEM-5/PHE/exp13f.pdf



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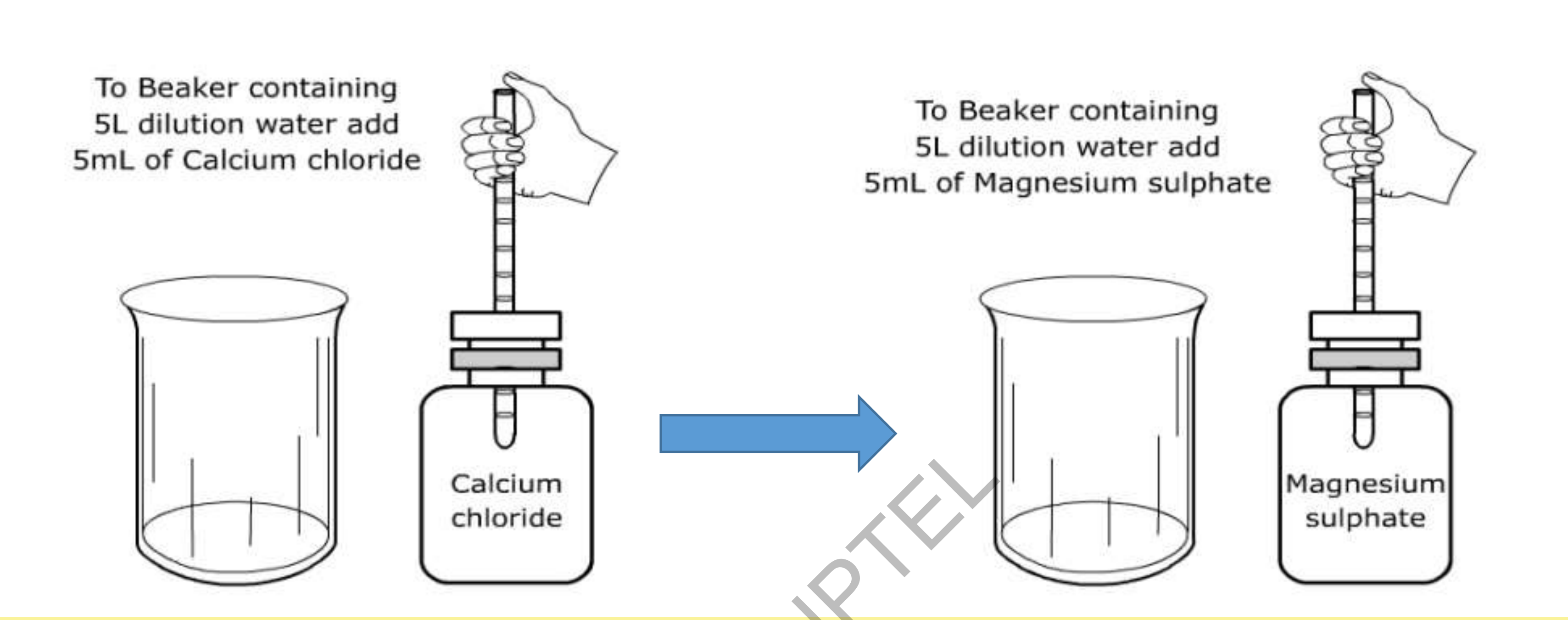
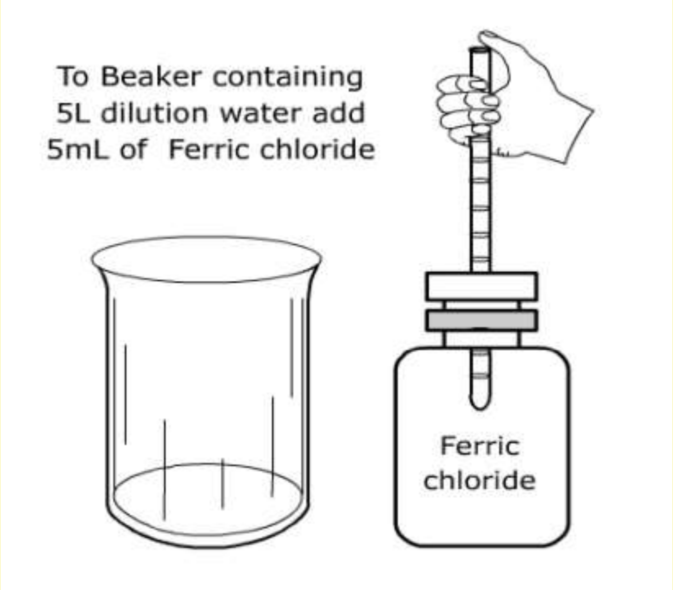
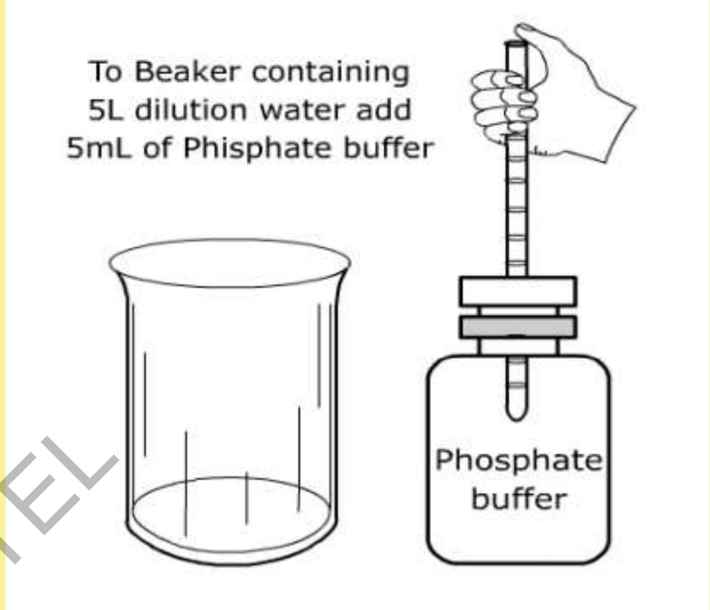
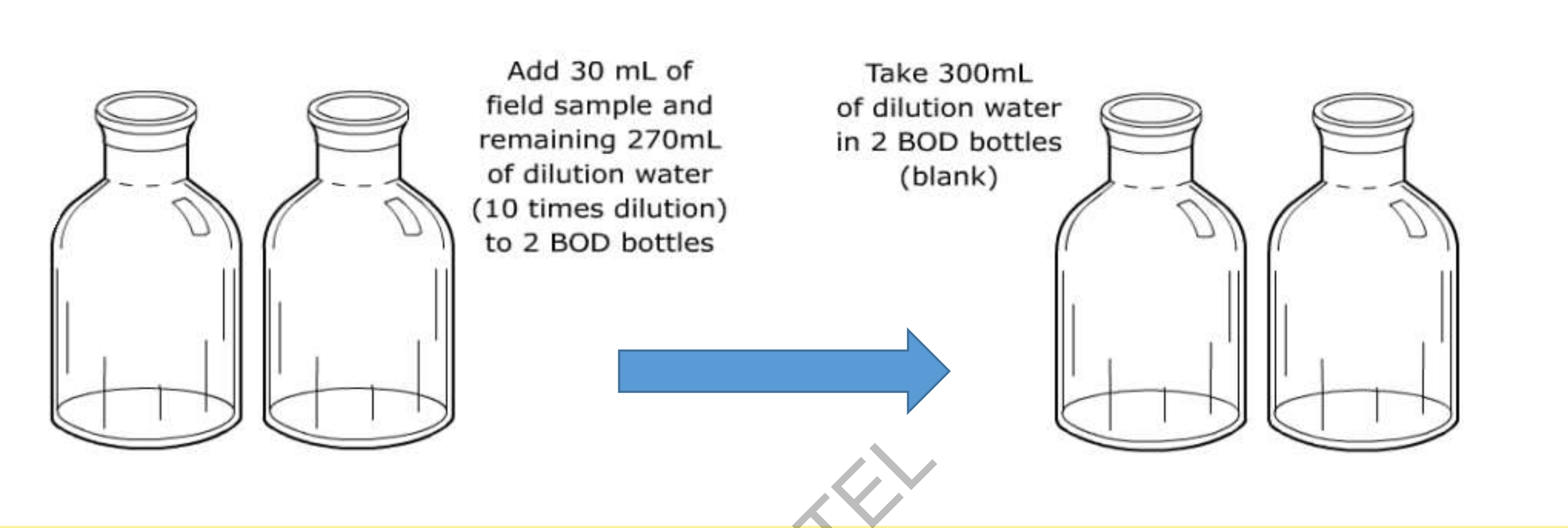

To Beaker containing
5L dilution water add
5mL of Calcium chloride
Calcium
chloride
To Beaker containing
5L dilution water add
5mL of Magnesium sulphate
Magnesium
sulphate

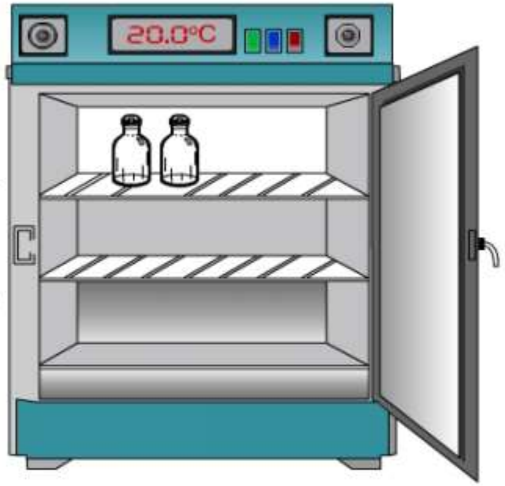

To Beaker containing
5L dilution water add
5mL of Ferric chloride
Ferric
chloride


To Beaker containing
5L dilution water add
5mL of Phisphate buffer
Phosphate
buffer


Add 30 mL of
field sample and
remaining 270mL
of dilution water
(10 times dilution)
to 2 BOD bottles
Take 300mL
of dilution water
in 2 BOD bottles
(blank)

Each one of the blank and the sample needs to be titrated immediately as per the procedure given in DO chart.

Remaining 2 BOD bottles of the blank and the sample needs to be kept in BOD incubator at 20°C for 5 days. After which the blank and the sample needs to be titrated as per the procedure given in DO chart.



http://mitpolytechnic.ac.in/downlaods/09_knowledge-bank/05_civil/SEM-5/PHE/exp13f.pdf

- BOD5 = Do_i – Do_f / P

Do_i = Initial dissolved oxygen

Do_f = Final dissolved oxygen (after days)

P= Dilution factor = Volume of wastewater / volume of wastewater + dilution water

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Lecture 22: BOD Examples, Oxygen Levels in Surface waters, COD

Example: 10.0 mL sample of sewage mixed with enough water to fill a 300 mL bottle has an initial DO of 9.0 mg/L.To help assure an accurate test, it is desirable to have at least a 2.0 mg/ L drop in DO during the five-day run, and the final DO should be at least 2.0 mg/L. For what range of BOD_5 would this dilution produce the desired results?

The dilution fraction is P = 10 / 300. To get at least a 2.0 mg/L drop in DO, the minimum BOD needs to be

$$BOD_5 > \frac{DO_i - DO_f}{P} = \frac{2.0\ mg/L}{(10/300)} = 60\ mg/L$$

To assure at least 2.0 mg/L of DO remains after five days requires that

$$BOD_5 > \frac{(9.0-2.0)\,mg/L}{10/300} = 210 \text{ mg/L}$$

This dilution will be satisfactory for BOD_5 values between 60 and 210 mg/L.

Example :

Find the BOD of raw Sewage id 2.5 mL of raw sewage has been diluted to 250 mL and the DO concentration of the diluted sample at the beginning of BOD test was 8 mg/L and 5mg/L after 5-day incubation at 20˚C.

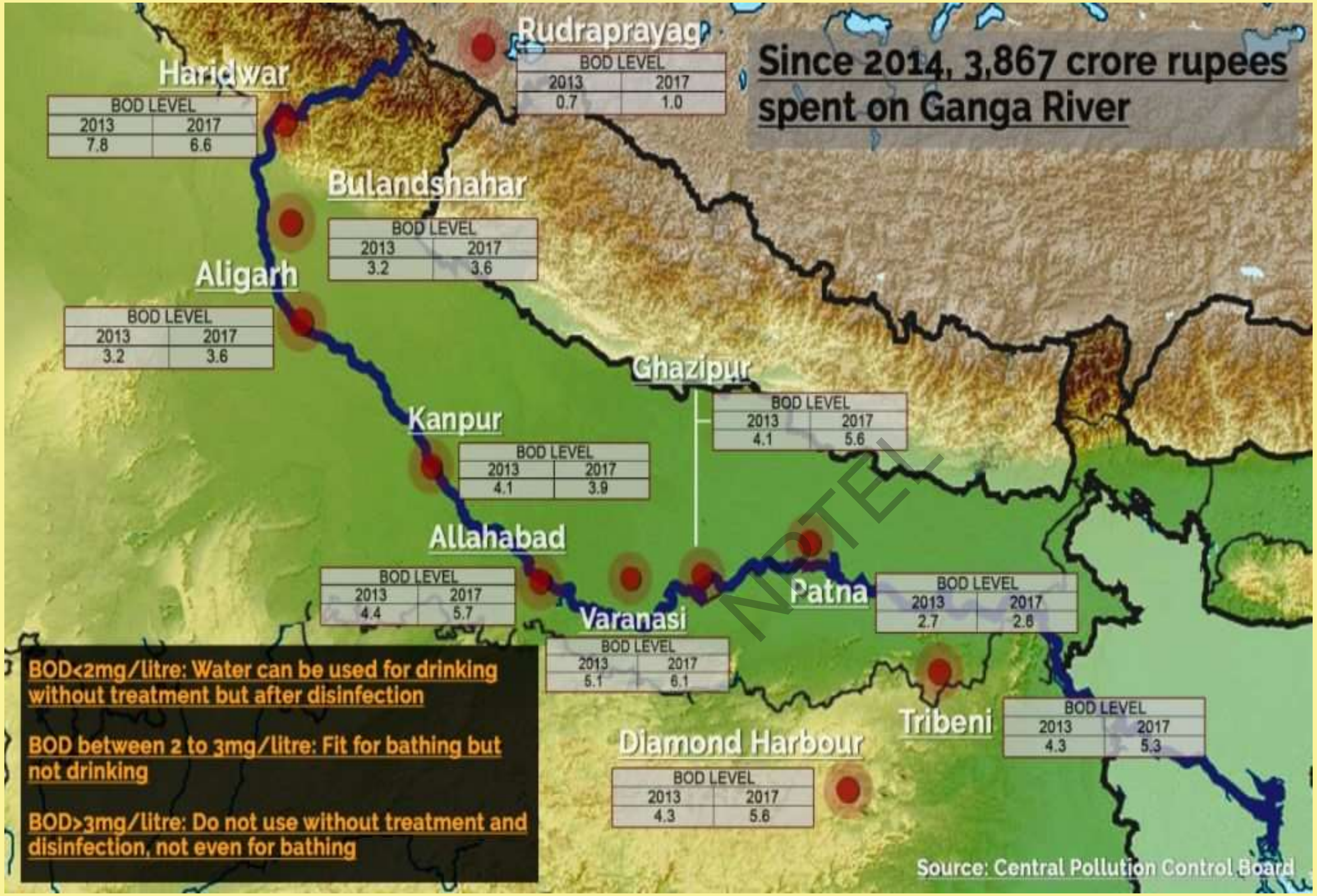
- Volume of sample of sewage is 2.5mL
- Volume of diluted sample is 250mL
- Dilution ratio = 250/2.5 = 100.
- Loss of DO during test = DO before - DO after testing= 8-5 = 3 mg/L.
- BOD of sewage = loss of oxygen * Dilution Factor

= 3 mg/L * 100 = 300 mg/L.

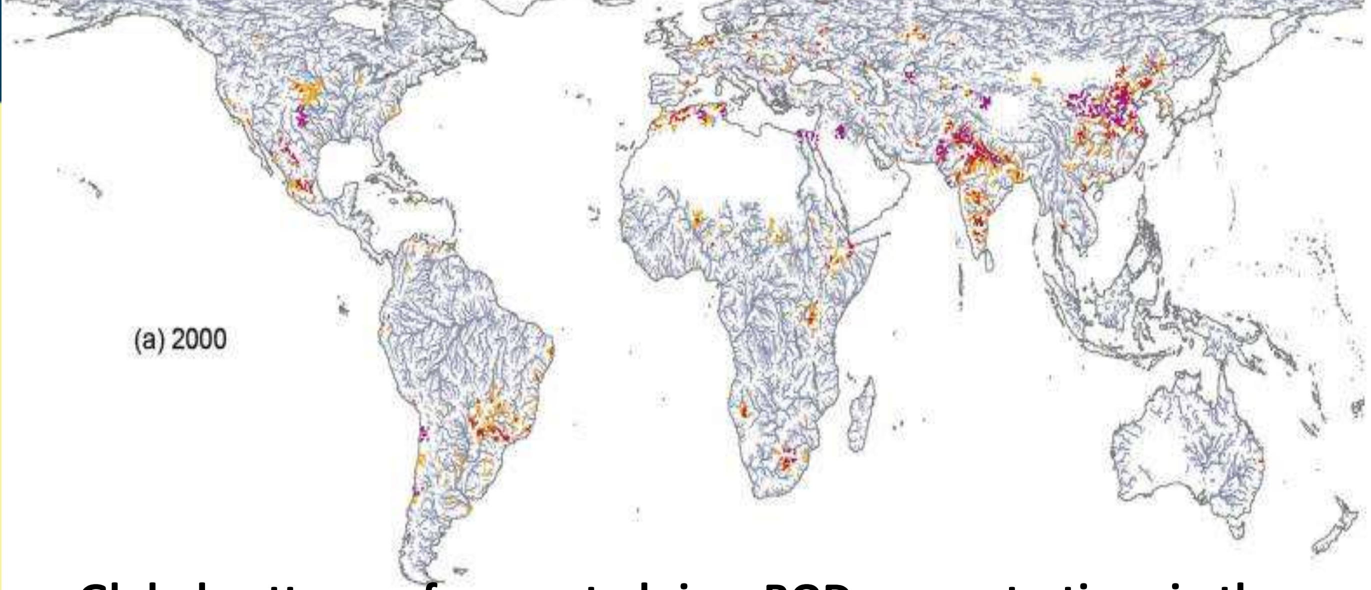
Home work

Determine the BOD of the sewage when 2% solution of it is incubated for 5 days at 20˚C. The depletion of oxygen was found to be 4 ppm.

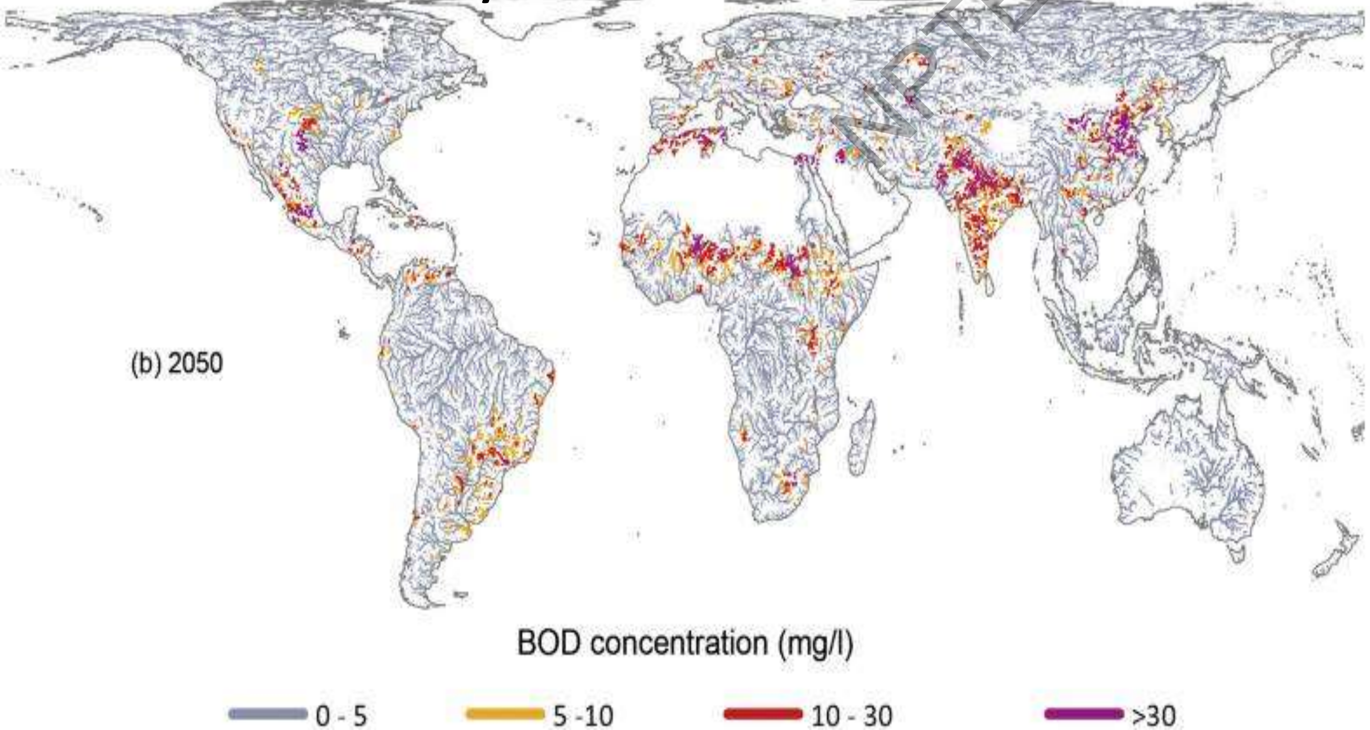
BOD kinetic will de done at the later week (week 7)

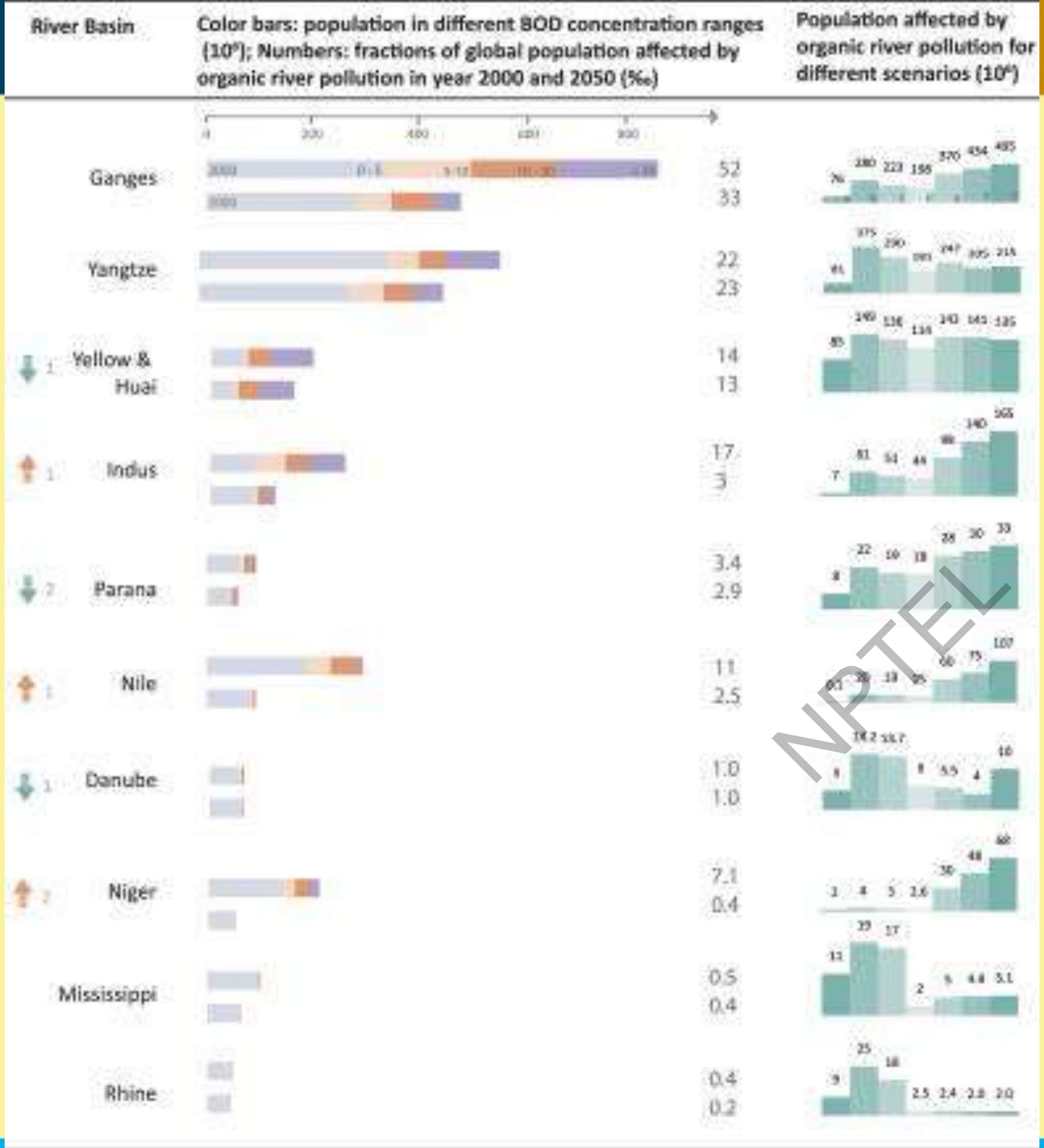


Since 2014, 3,867 crore rupees spent on Ganga River
Rudraprayag
BOD LEVEL 2013 0.7 2017 1.0
Haridwar
BOD LEVEL 2013 7.8 2017 6.6
Bulandshahar
BOD LEVEL 2013 3.2 2017 3.6
Aligarh
BOD LEVEL 2013 3.2 2017 3.6
Ghazipur
BOD LEVEL 2013 4.1 2017 5.6
Kanpur
BOD LEVEL 2013 4.1 2017 3.9
Allahabad
BOD LEVEL 2013 4.4 2017 5.7
Varanasi
BOD LEVEL 2013 5.1 2017 6.1
Patna
BOD LEVEL 2013 2.7 2017 2.8
Tribeni
BOD LEVEL 2013 4.3 2017 5.3
Diamond Harbour
BOD LEVEL 2013 4.3 2017 5.6
BOD<2mg/litre: Water can be used for drinking without treatment but after disinfection
BOD between 2 to 3mg/litre: Fit for bathing but not drinking
BOD>3mg/litre: Do not use without treatment and disinfection, not even for bathing
Source: Central Pollution Control Board



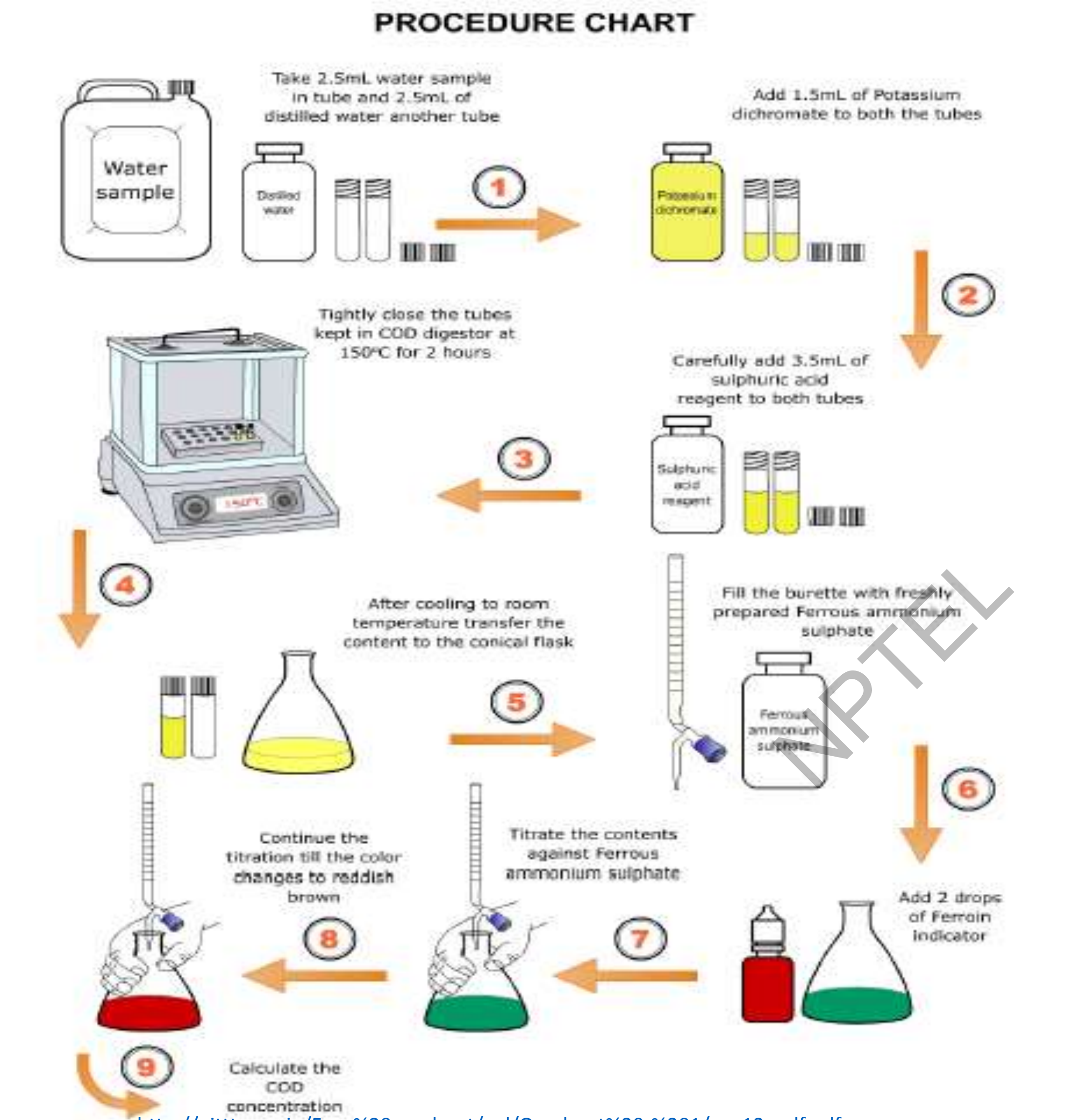
Global patterns of computed river BOD concentrations in the years 2000 and 2050 https://www.nature.com/articles/srep43289





a-d : scenarios in year 2000, e-g: scenarios in year 2050;
a: Only urban population BOD loading and natural dilution;
b: Urban population and livestock BOD loadings and natural dilution;
c: Urban population and livestock BOD loadings, natural dilution and degradation;
d: Urban population and livestock BOD loadings, natural dilution and degradation and wastewater treatment plants;
e: Only urban population change;
f: Urban population and intensive livestock production change;
g: Urban population, livestock production and river discharge.

Number of people (in millions) living along polluted rivers in 10 major river basins. https://www.nature.com/articles/srep43289



http://nitttrc.ac.in/Four%20quadrant/eel/Quadrant%20-%201/exp12_pdf.pdf

Discharge limit of BOD and COD in surface water is 30 mg/L and 250 mg/L respectively.

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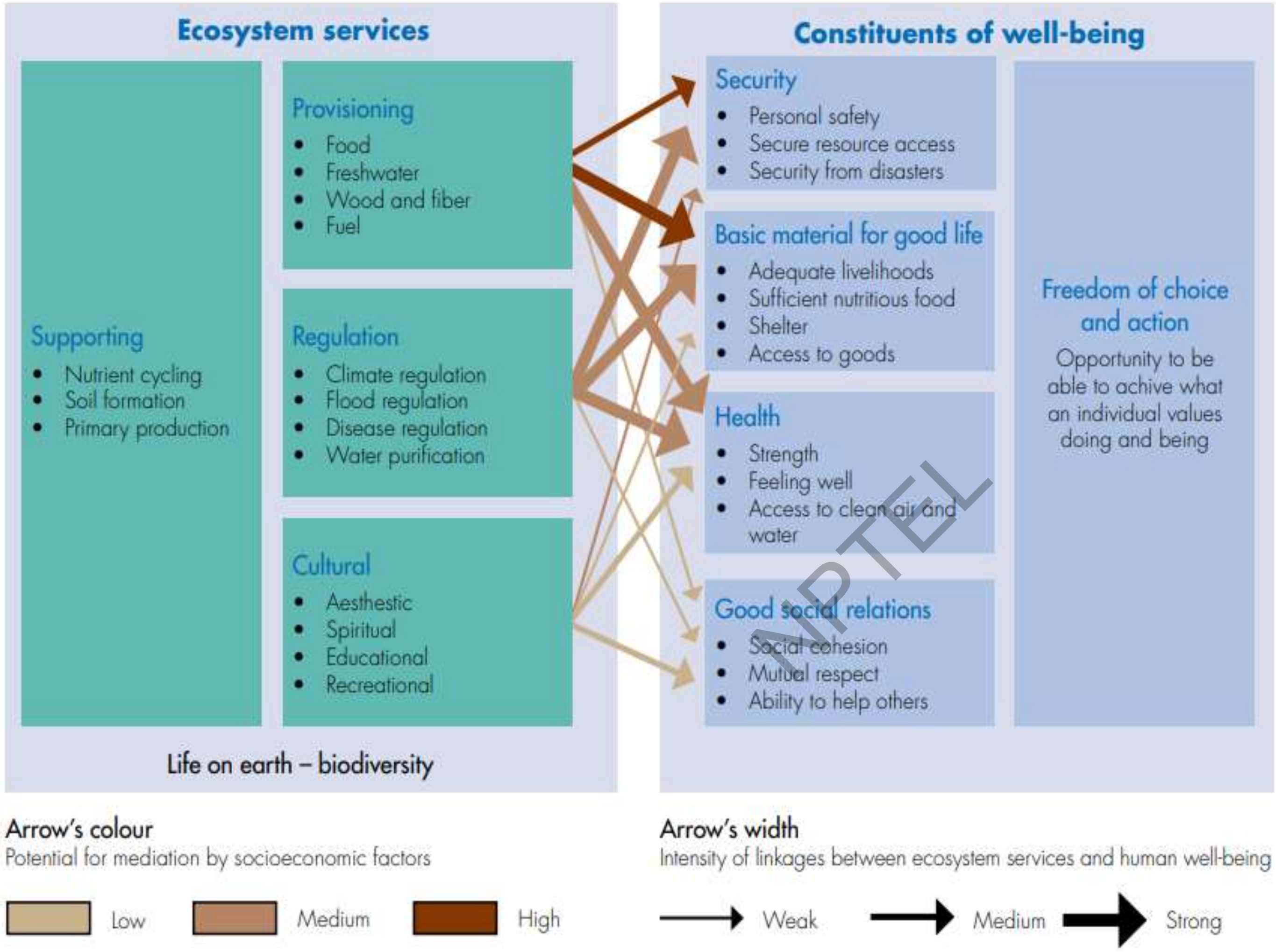
Lecture 23: Environmental Health Basics and SDGs

Environmental Health Science

- The study of those factors in the environment that affect human health the environment
  - Pollutants in air, water and soil which are transferred to humans by inhalation, ingestion, or absorption.
  - Which results in adverse health effects.

What are the Basic requirements for a healthy environment?

- Clean air, water and soil
- Safe and adequate food
- Stable global peaceful environment



Links between ecosystem services and various constituents of human well-being. Adapted from Millennium Ecosystem Assessment, 2005.

Target area

- Water supplies
- Waste water treatment
- Waste management
- Prevention and control of land pollution and Vector control
- Food hygiene and safety
- Air quality management
- Environmental radiation hazards
- Occupational health and safety
- Environmental noise management

A 2017 CPCB report has shown that Ganga water is unsafe for even domestic purposes at several sites. Representative image. Credit: PTI

Types of pathogens present in wastewater

Bacteria

The faeces of a healthy person contains large numbers of bacteria (> 10^{10}/g), most of which are not pathogenic. Pathogenic or potentially pathogenic bacteria are normally absent from a healthy intestine unless infection occurs. When infection occurs, large numbers of pathogenic bacteria will be passed in the faeces thus allowing the spread of infection to others. Diarrhoea is the most prevalent type of infection, with cholera the worst form.

Viruses.

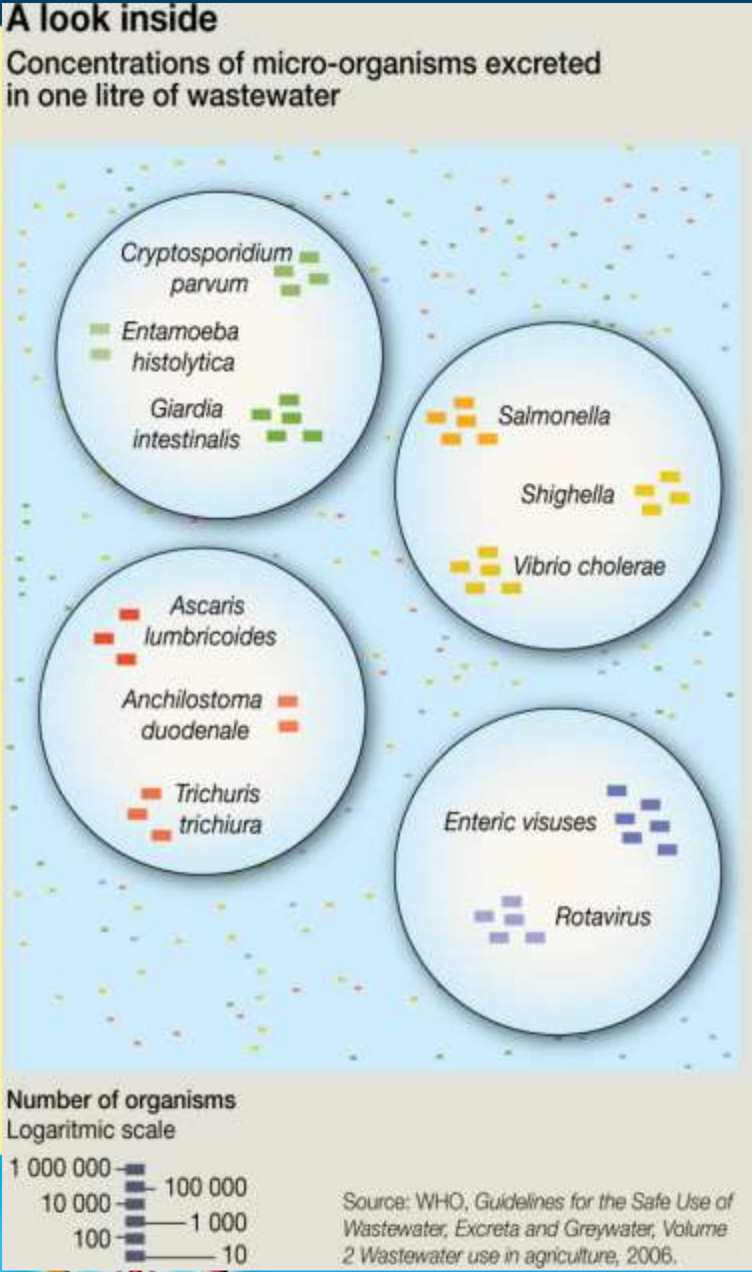
Numerous viruses may infect humans and are passed in the faeces (> 10^9/g). Five groups of pathogenic excreted viruses are particularly important: adenoviruses, enteroviruses (including polioviruses), hepatitis A virus, reoviruses and diarrhoea-causing viruses (especially rotavirus).

Protozoa. Many species of protozoa can infect humans and cause diarrhoea and dysentery. Infective forms of these protozoa are often passed as cysts in the faeces and humans are infected when they ingest them. Only three species are considered to be pathogenic: *Giardia lamblia, Balantidium coli* and *Entamoeba histolytica*.

- **Helminths.** There are many species of parasitic worms or helminths that have human hosts. Some can cause serious illnesses and the ones that pass eggs or larval forms in the excreta are of importance in considering wastewater use.

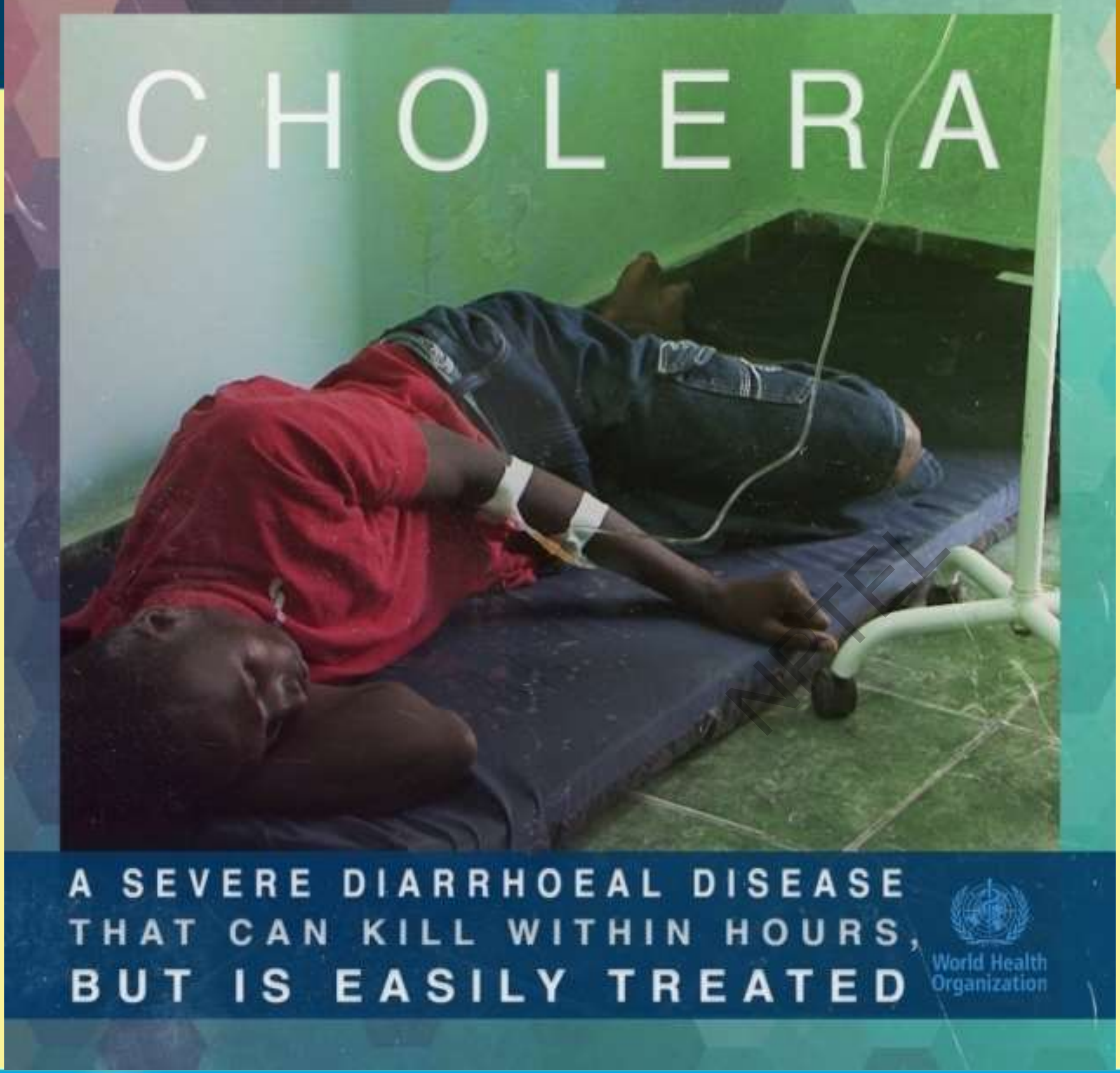
WATER BORNE DISEASE

- Viral: Viral Hepatitis A, Hepatitis E, Rotavirus diarrhoea etc.
- Bacterial: Typhoid & Paratyphoid fever, Bacillary dysentery, Cholera, Esch.Coli Diarrhoea etc.
- Protozoal: amoebiasis,giardiasis.
- Helminthic: round worm, thread worm, hydiatid disease.


A look inside
Concentrations of micro-organisms excreted in one litre of wastewater
Cryptosporidium parvum
Entamoeba histolytica
Giardia intestinalis
Salmonella
Shighella
Vibrio cholerae
Ascaris lumbricoides
Anchilostoma duodenale
Trichuris trichiura
Enteric visuses
Rotavirus
Number of organisms
Logaritmic scale
1 000 000
100 000
10 000
1 000
100
10
Source: WHO, Guidelines for the Safe Use of Wastewater, Excreta and Greywater, Volume 2 Wastewater use in agriculture, 2006.


GOAL
06
#SDGs
CLEAN WATER
AND SANITATION
Ensure availability and sustainable management
of water and sanitation for all


IMAGE CREDIT: UNICEF
1.5 BILLION PEOPLE
HAVE NO SANITATION
SERVICE AT THEIR
HEALTH FACILITY
World Health
Organization


CHOLERA
A SEVERE DIARRHOEAL DISEASE
THAT CAN KILL WITHIN HOURS,
BUT IS EASILY TREATED
World Health Organization

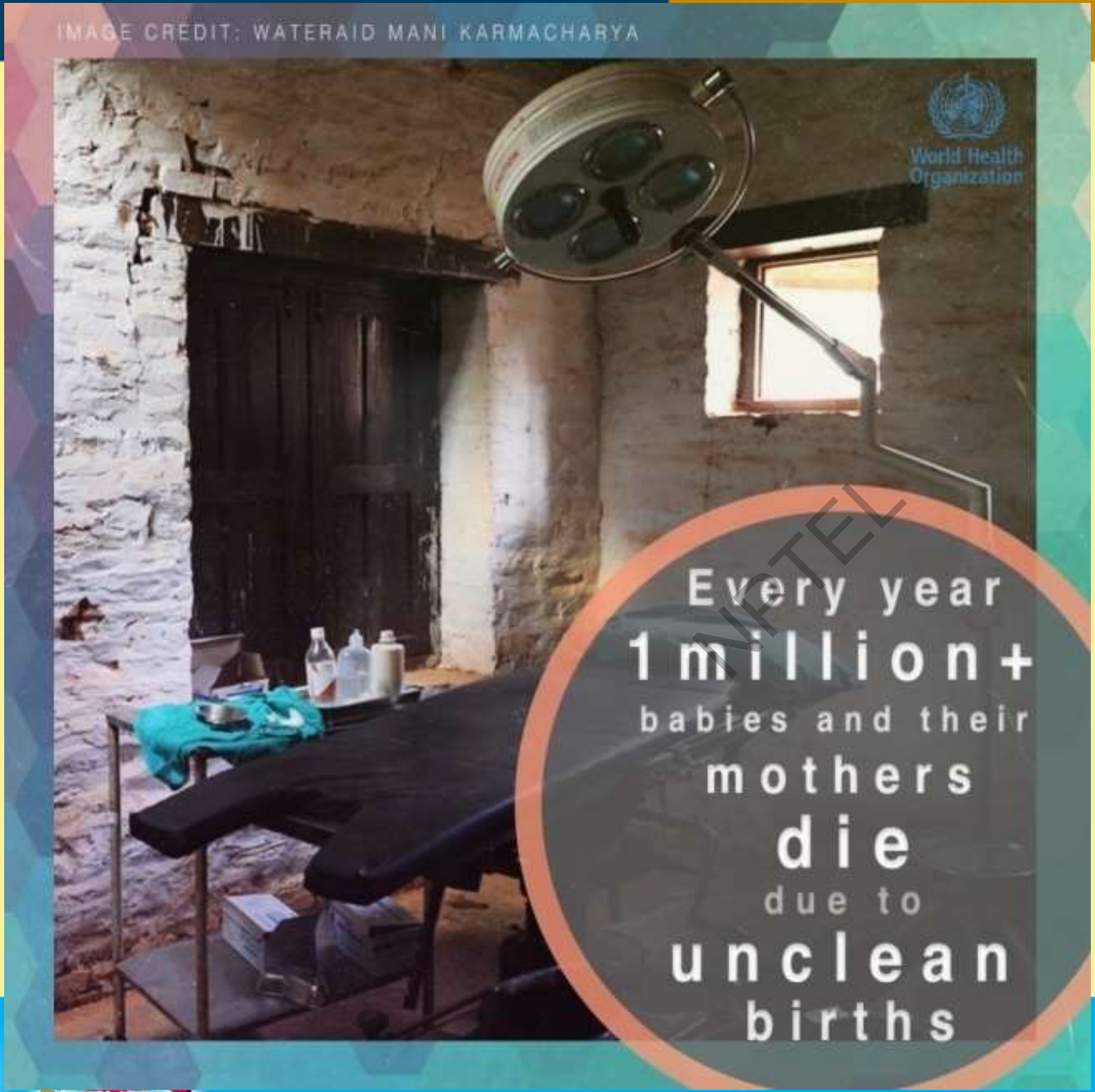
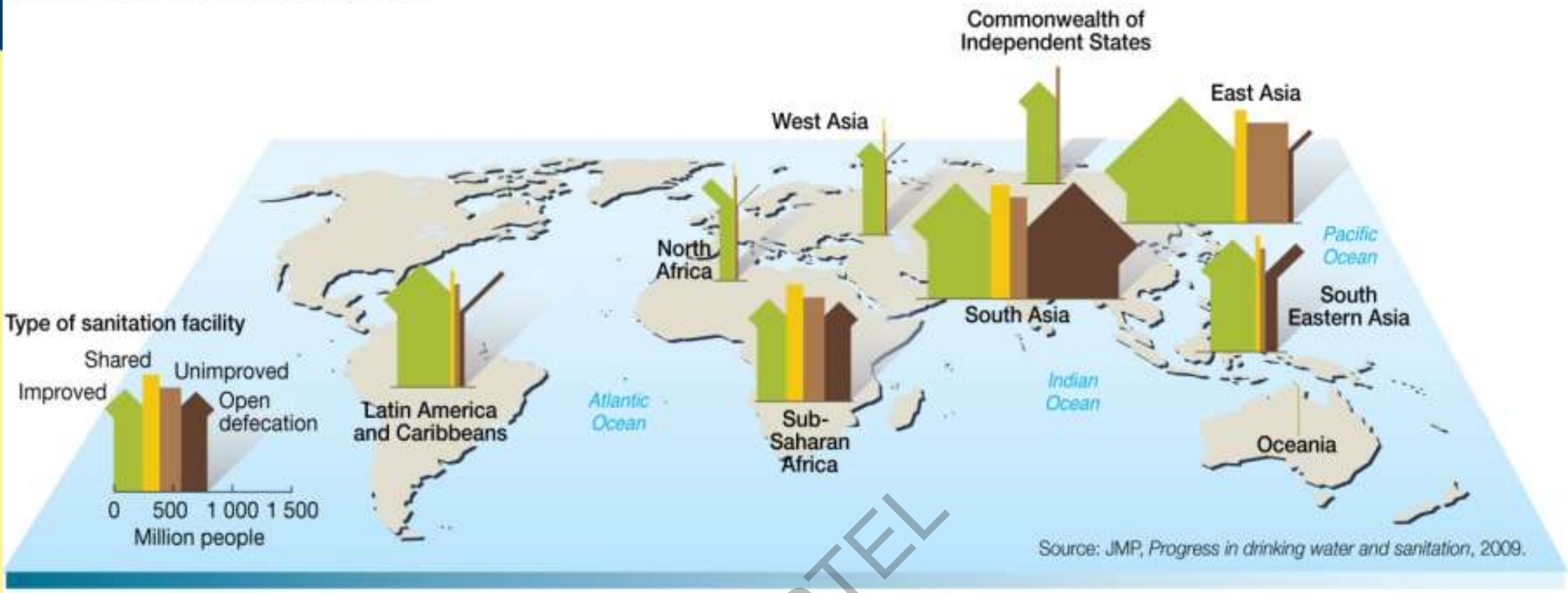


IMAGE CREDIT: WATERAID MANI KARMACHARYA
World Health Organization
Every year
1million+
babies and their
mothers
die
due to
unclean
births


1 in 4 health facilities lacks basic water services
World Health Organization
EVERYONE, EVERYWHERE HAS THE RIGHT TO QUALITY CARE


IMAGE CREDIT: UNICEF
MILLIONS OF WOMEN
give birth
in facilities without
CLEAN WATER
World Health Organization

Access to sanitation facilities



Improved: facilities that ensure hygienic separation of human excreta from human contact. Includes connection to a piped sewer system, septic tank, or pit latrines.

Shared: Sanitation facilities of an otherwise acceptable type shared between two or more households.

Unimproved: Facilities that do not ensure hygienic separation of human excreta from human contact

Open defecation: in fields, forests, bushes, bodies of water or other open spaces, or disposal of human faeces with solid waste.

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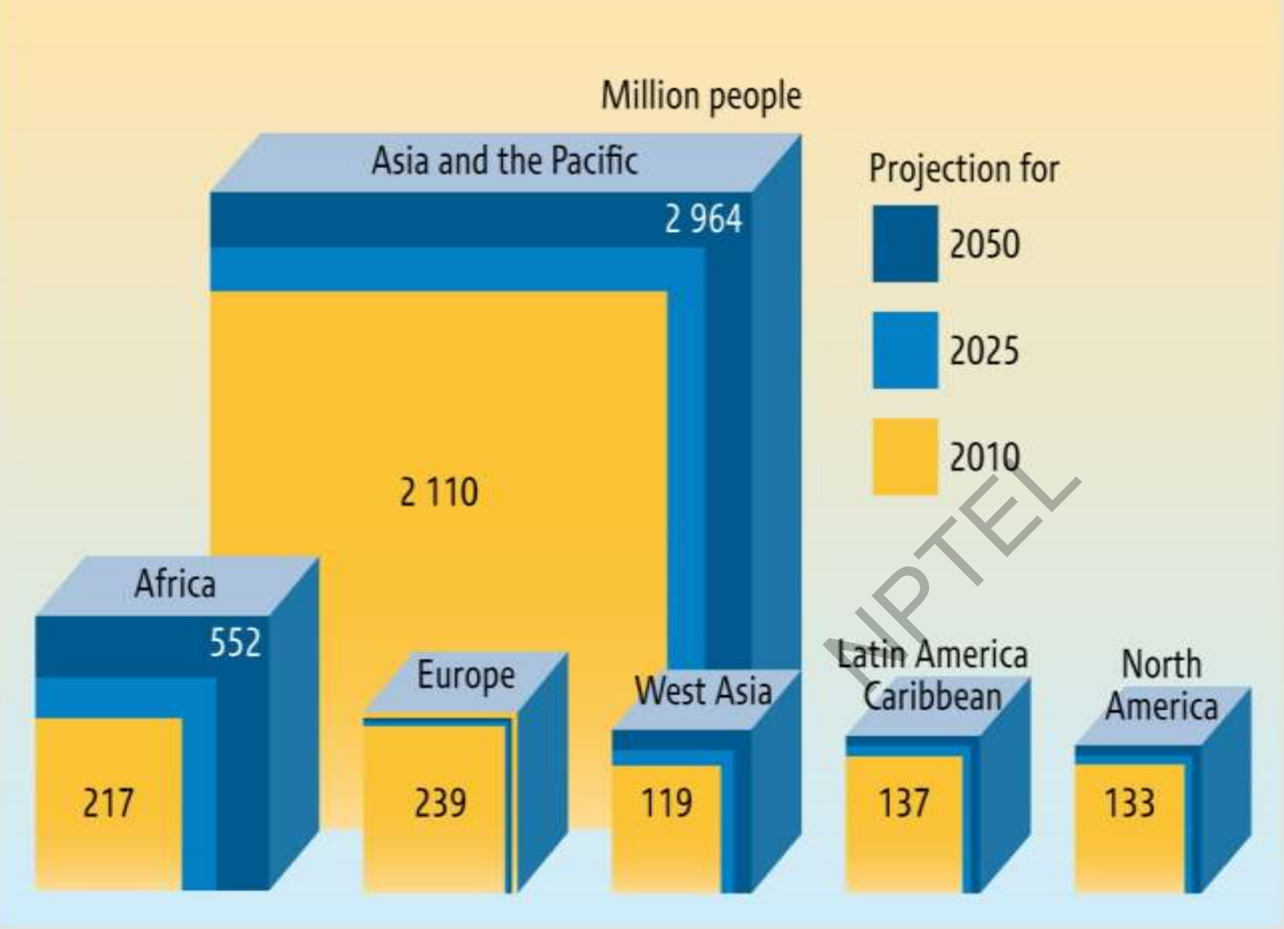
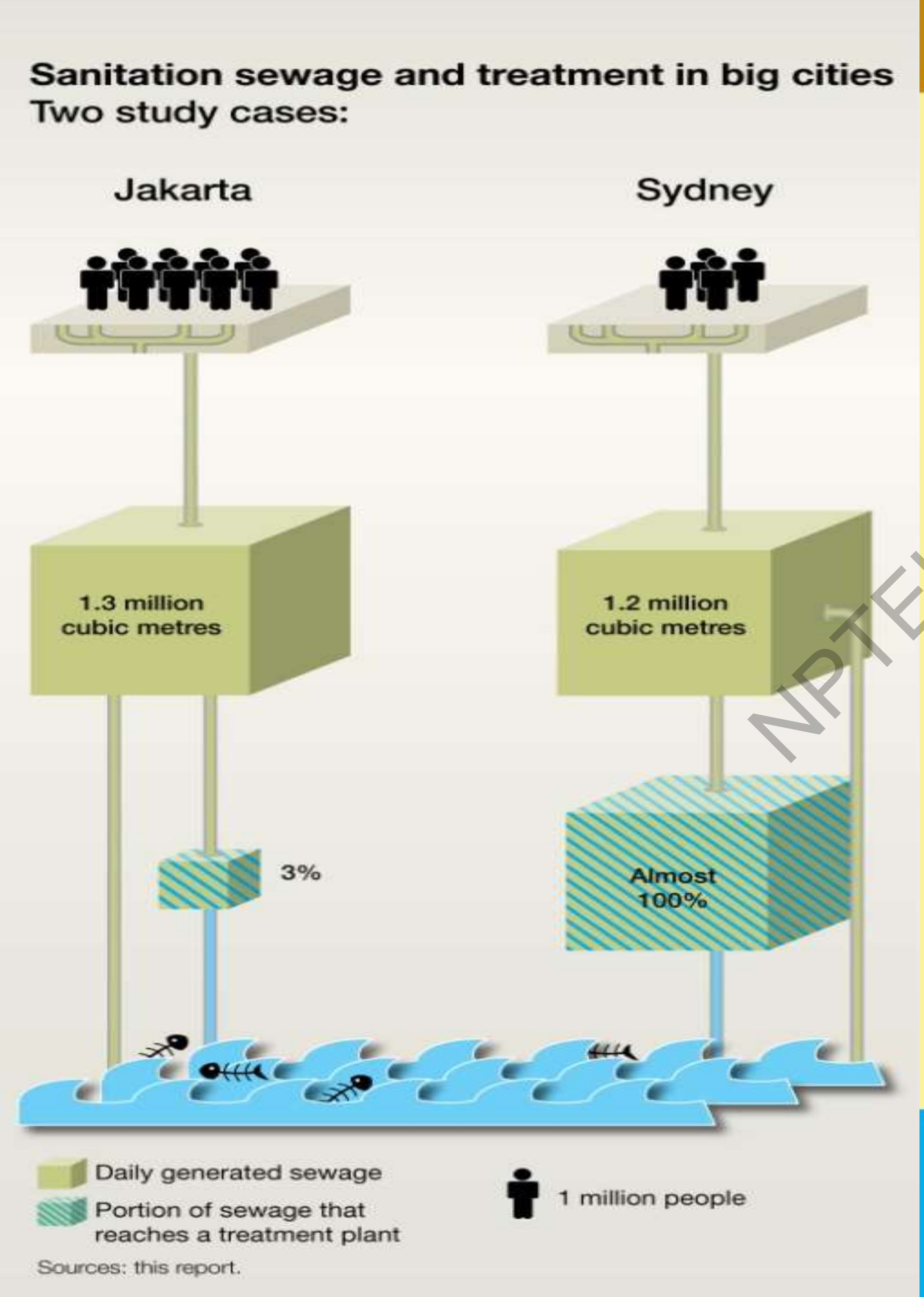
Lecture 24: Field Applications

Population living in river basins where freshwater withdrawal exceeds 40 per cent of renewable resources



Population by region was calculated averaging the results forecasted by the scenarios of the GEO-4 report using the WaterGAP modeling.

Source: Fourth Global Environment Outlook (GEO-4 report), UNEP, 2007.


Sanitation sewage and treatment in big cities
Two study cases:
Jakarta
Sydney
1.3 million cubic metres
1.2 million cubic metres
3%
Almost 100%
Daily generated sewage
Portion of sewage that reaches a treatment plant
1 million people
Sources: this report.

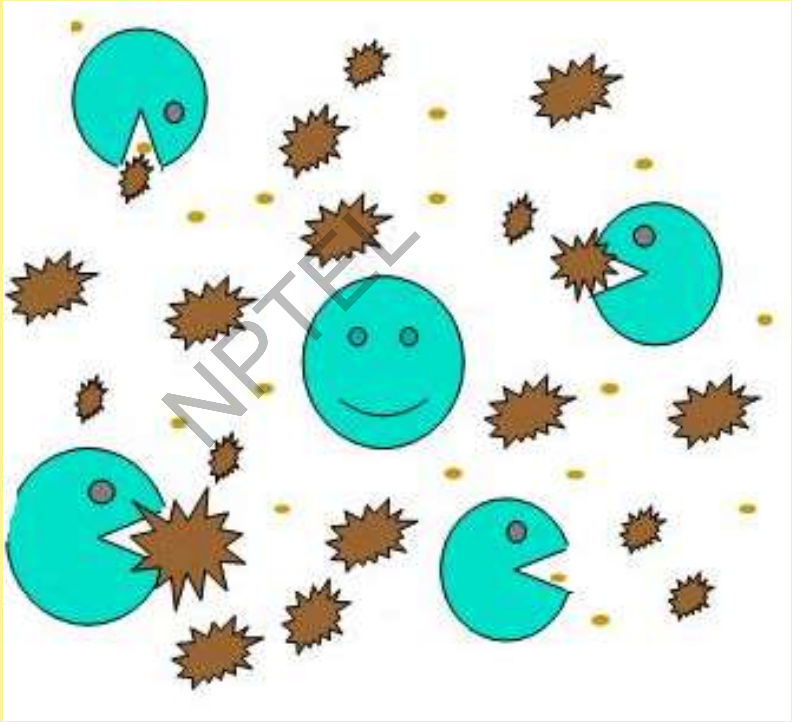
Ratio of wastewater treatment

Adapted from a map by Ahlenius, H., http://maps.grida.no/go/graphic/ratio-of-wastewater-treatment
Sources: UNEP-GPA, 2004.

Some Organism Groups Are Important In Environmental Engineering

Biological Methods of waste treatment

- Composting
- Anaerobic digestion
- Microbial fuel cell
- Bioremediation

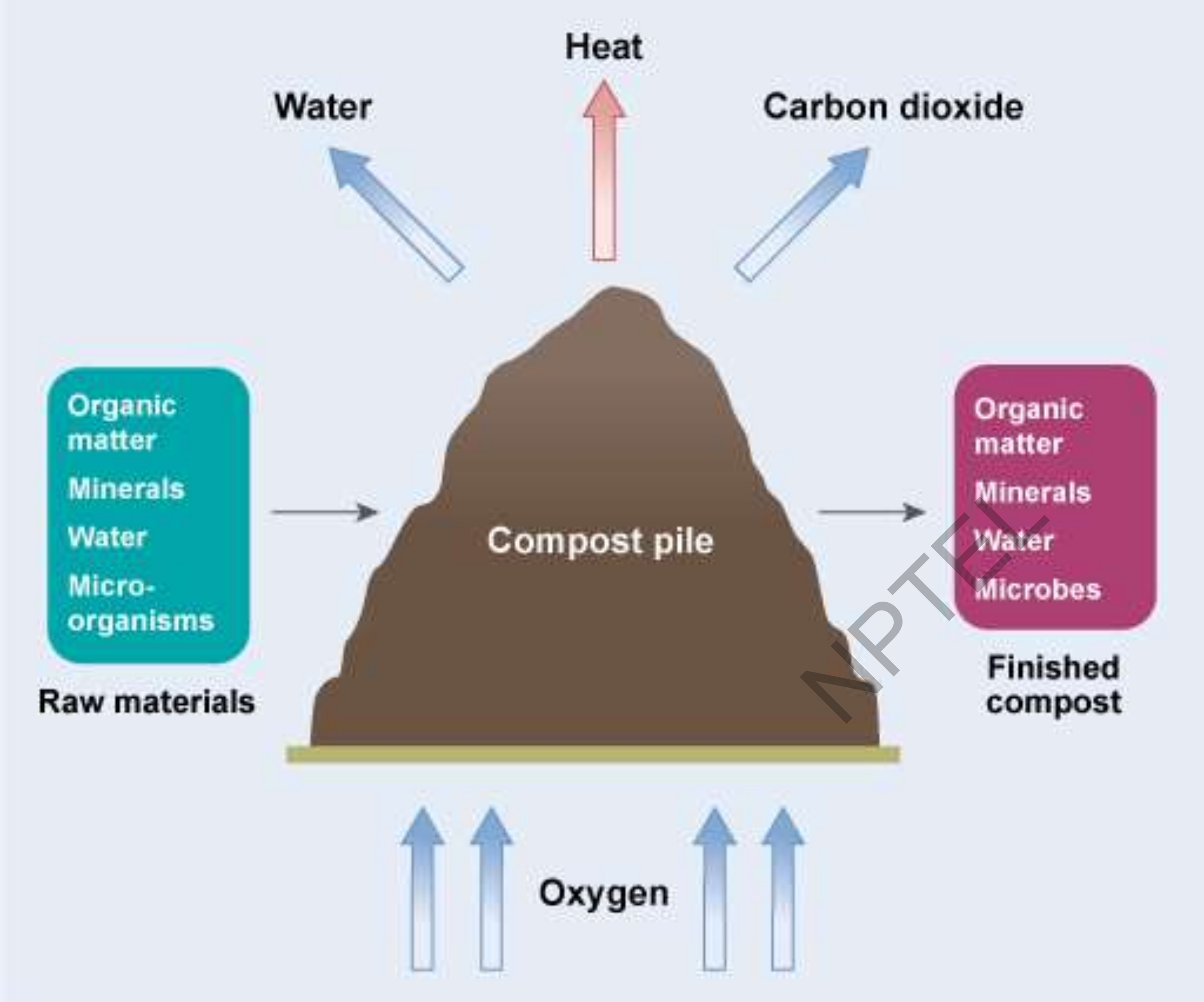


Composting (for solid waste)

https://www.fieldcompost.co.uk/store/soil

- Transformation of organic material through decomposition into a soil- like material.

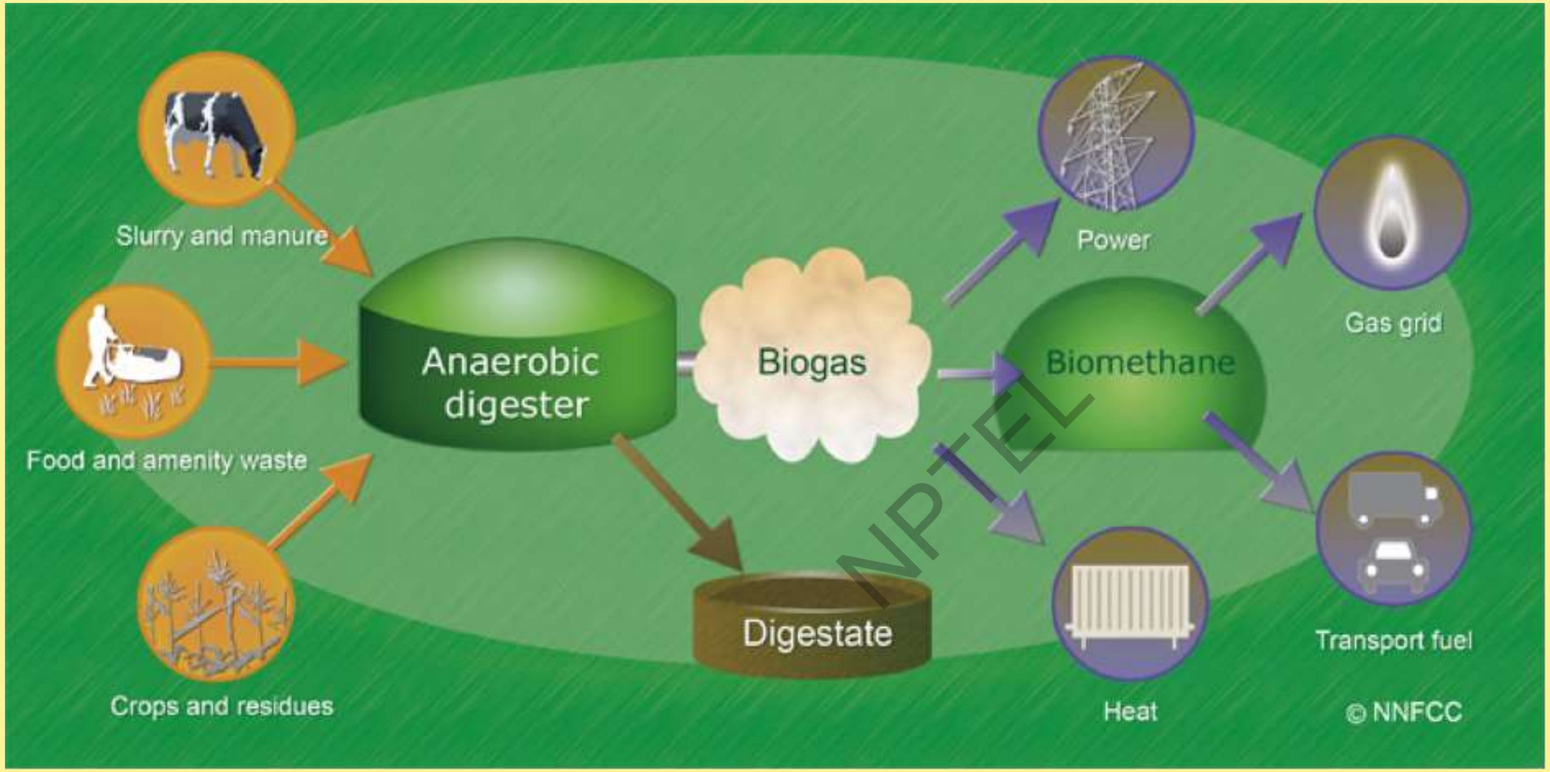
- Invertebrates (insects & earthworms) & microorganisms (bacteria & fungi) help in this transformation.



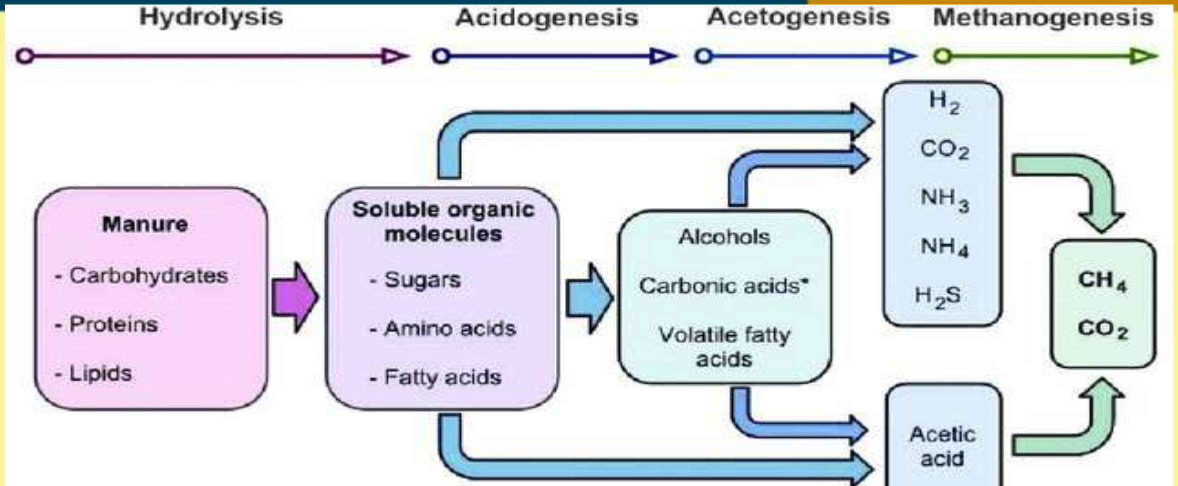
https://www.open.edu/openlearncreate/pluginfile.php/170069/mod_oucontent/oucontent/13842/90723551/2f744a9c/m4_ss8_fig8.4.jpg

- Composting can be done by individual householders and community groups or on a commercial scale.
- On the larger scale, the waste from an entire town or city could be composted if sufficient land, labor and equipment is available.
- The benefits of composting are not only the reduction of waste, but also the production of compost which is a valuable **soil improver**.
- Soils treated with compost are better able to withstand droughts and are more fertile because plant nutrients are returned to the soil, which reduces the need for chemical fertilizers.

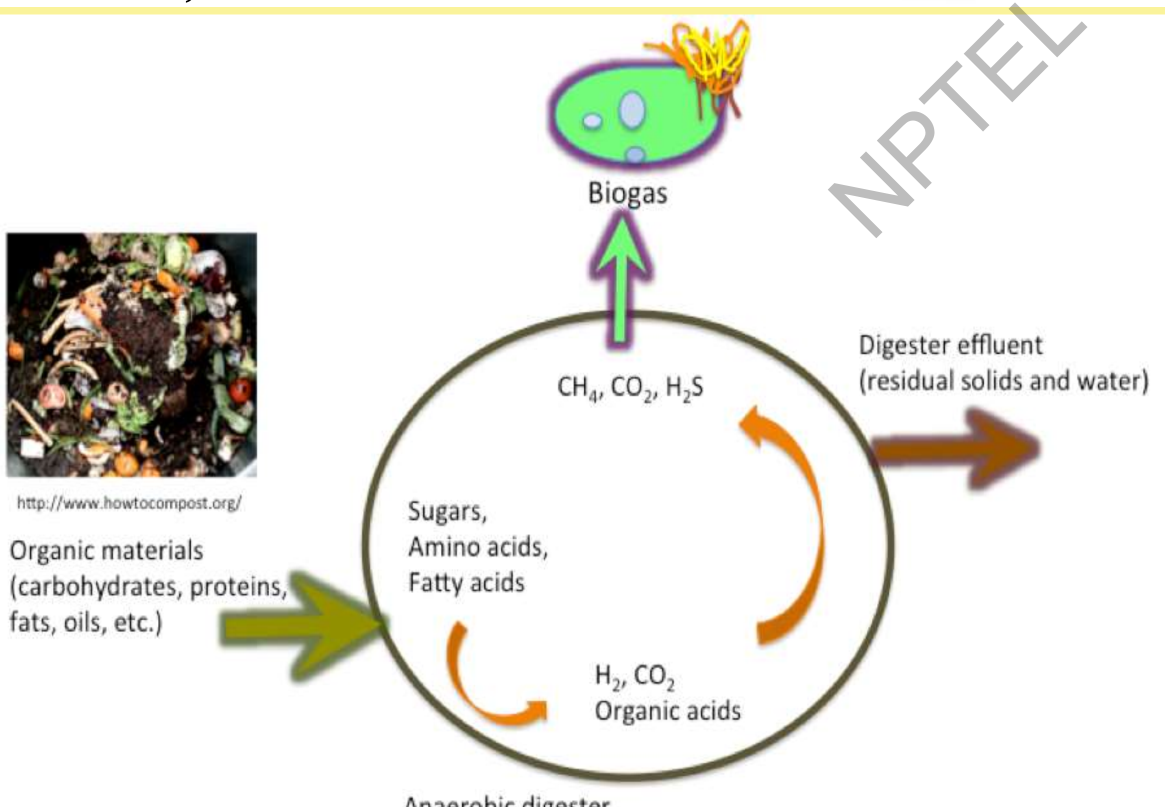
Anaerobic Digestion



http://www.biogas-info.co.uk/about/



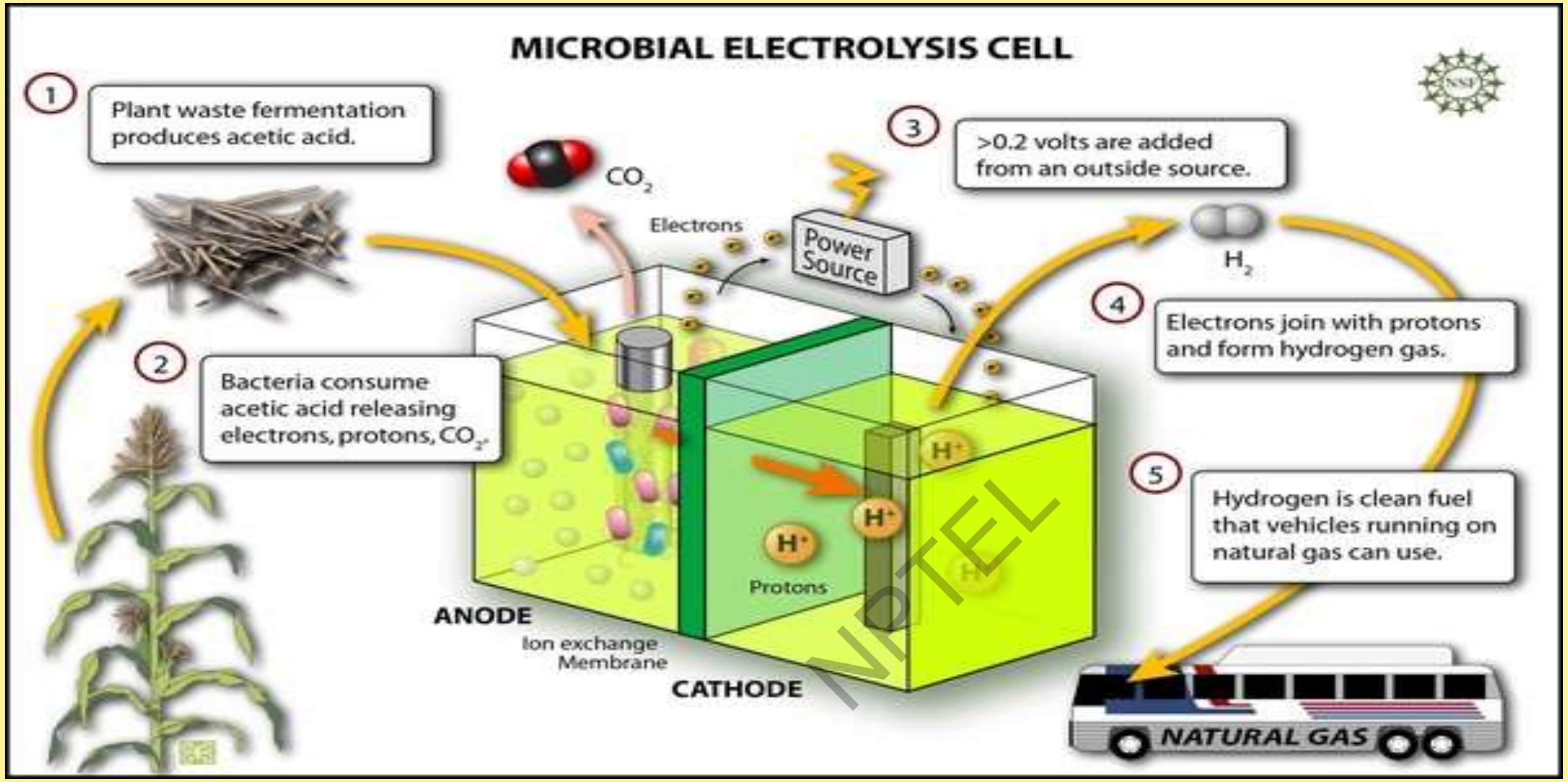
Nour et al.,2017



Credit: Dr. Caroline E. Burgess

Applications:

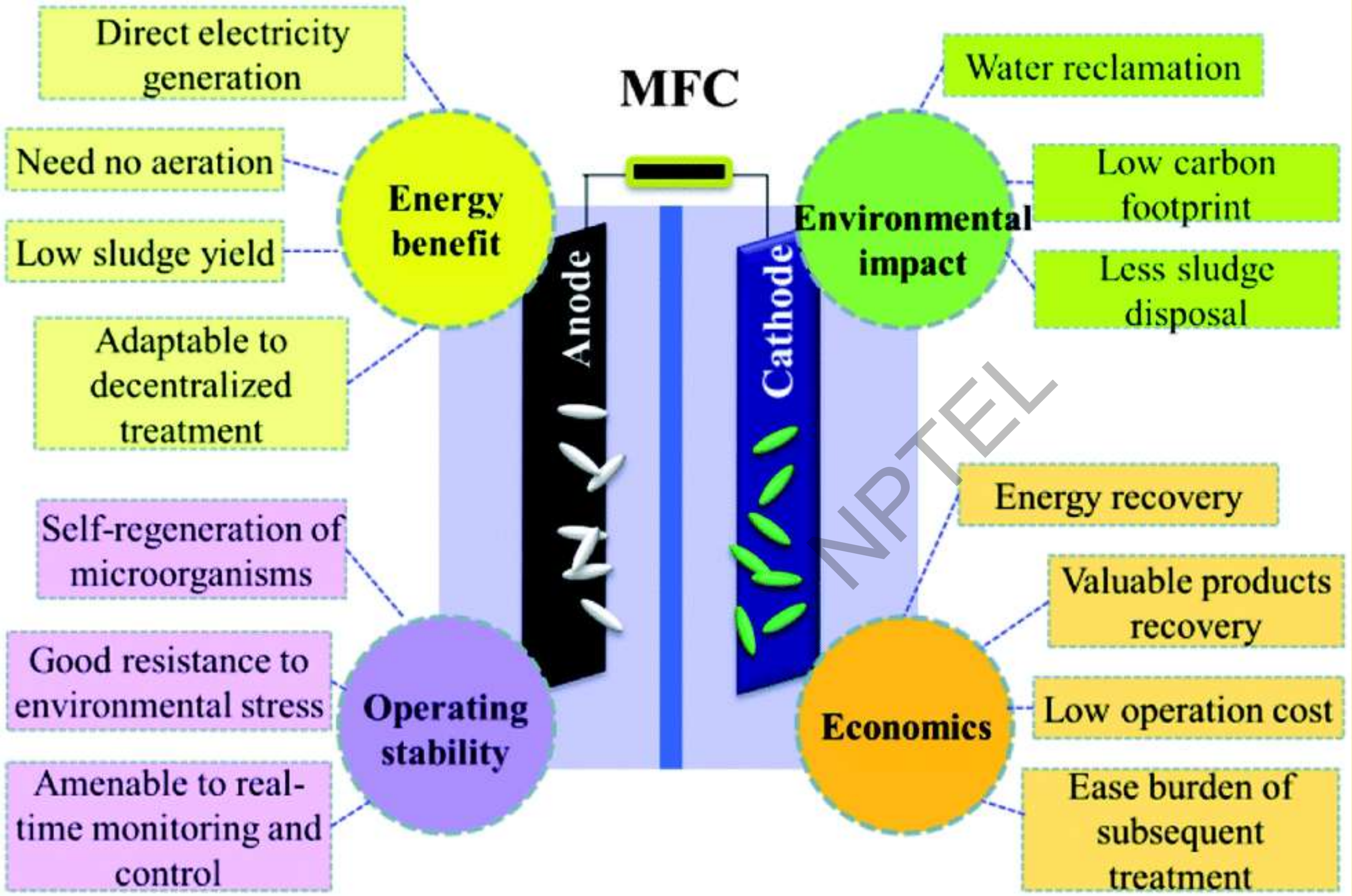
- Waste and wastewater treatment.
- Reduces the emission of landfill gas into the atmosphere.
- Power generation.
- Fertilizer and soil conditioner.
- Cooking gas.
- Vehicle fuel.



https://d2o7bfz2il9cb7.cloudfront.net/main-qimg-783bbeaf1576edca3b6f753ee76842ff

A microbial fuel cell, or biological fuel cell, is a bio-electrochemical system that drives an electric current by using bacteria and mimicking bacterial interactions found in nature.

Potential Benefits of MFCs for Energy, Environmental, Operational and Economic Sustainability



Li et al.,2014

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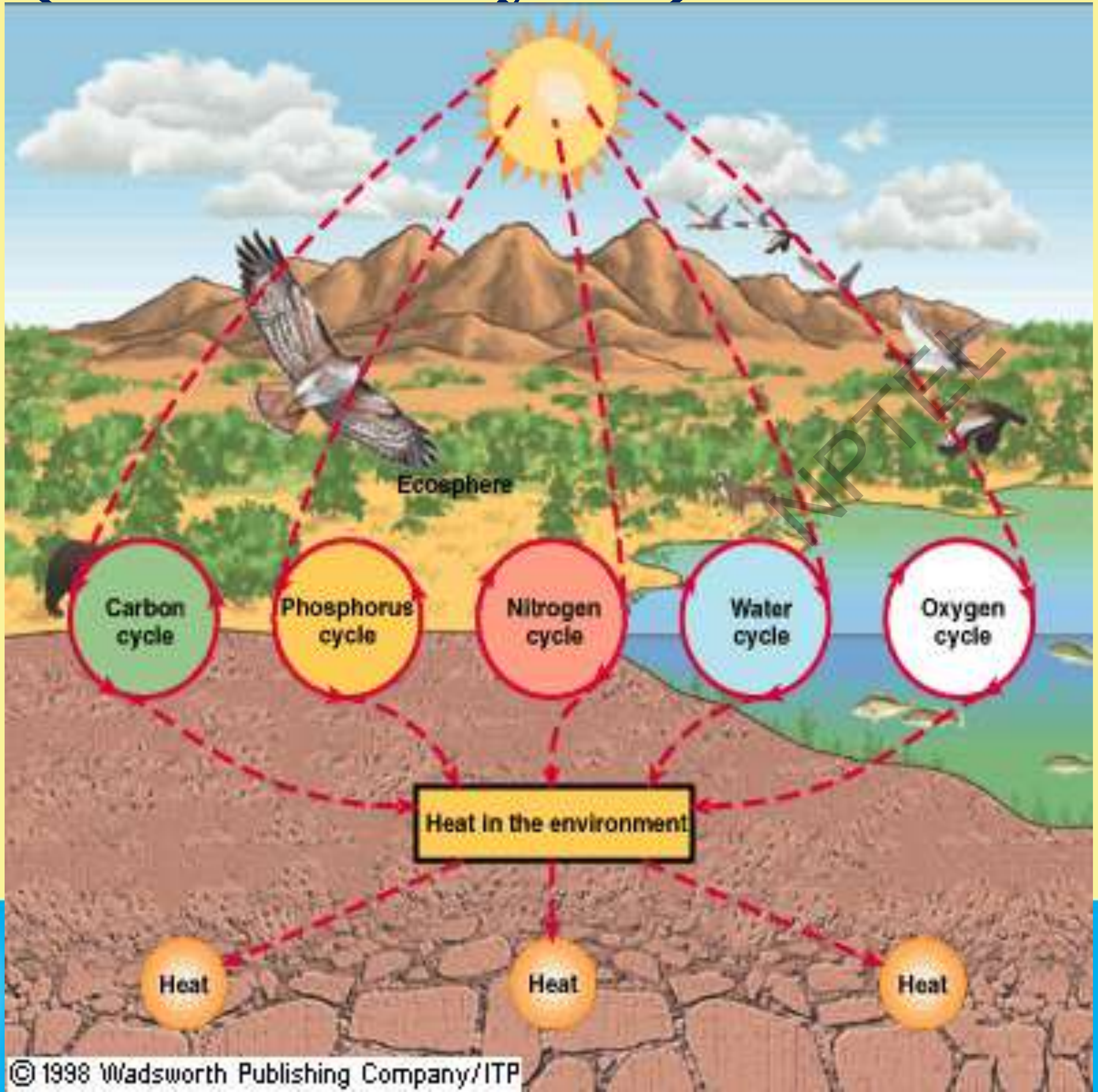
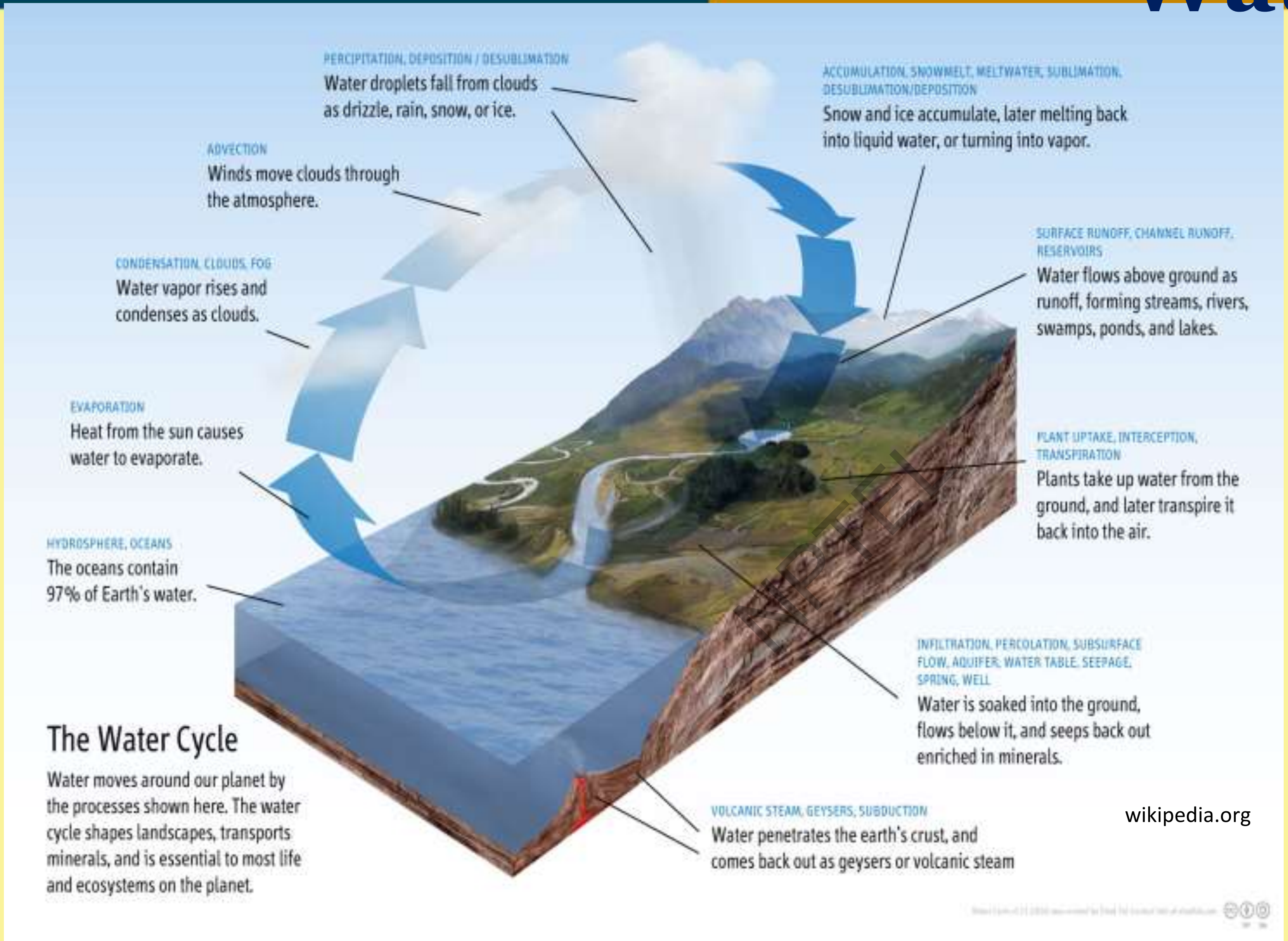
Lecture 25: Nutrient Cycle

Ecosystem function (Nutrient cycle)



Nutrients are recycled within an ecosystem

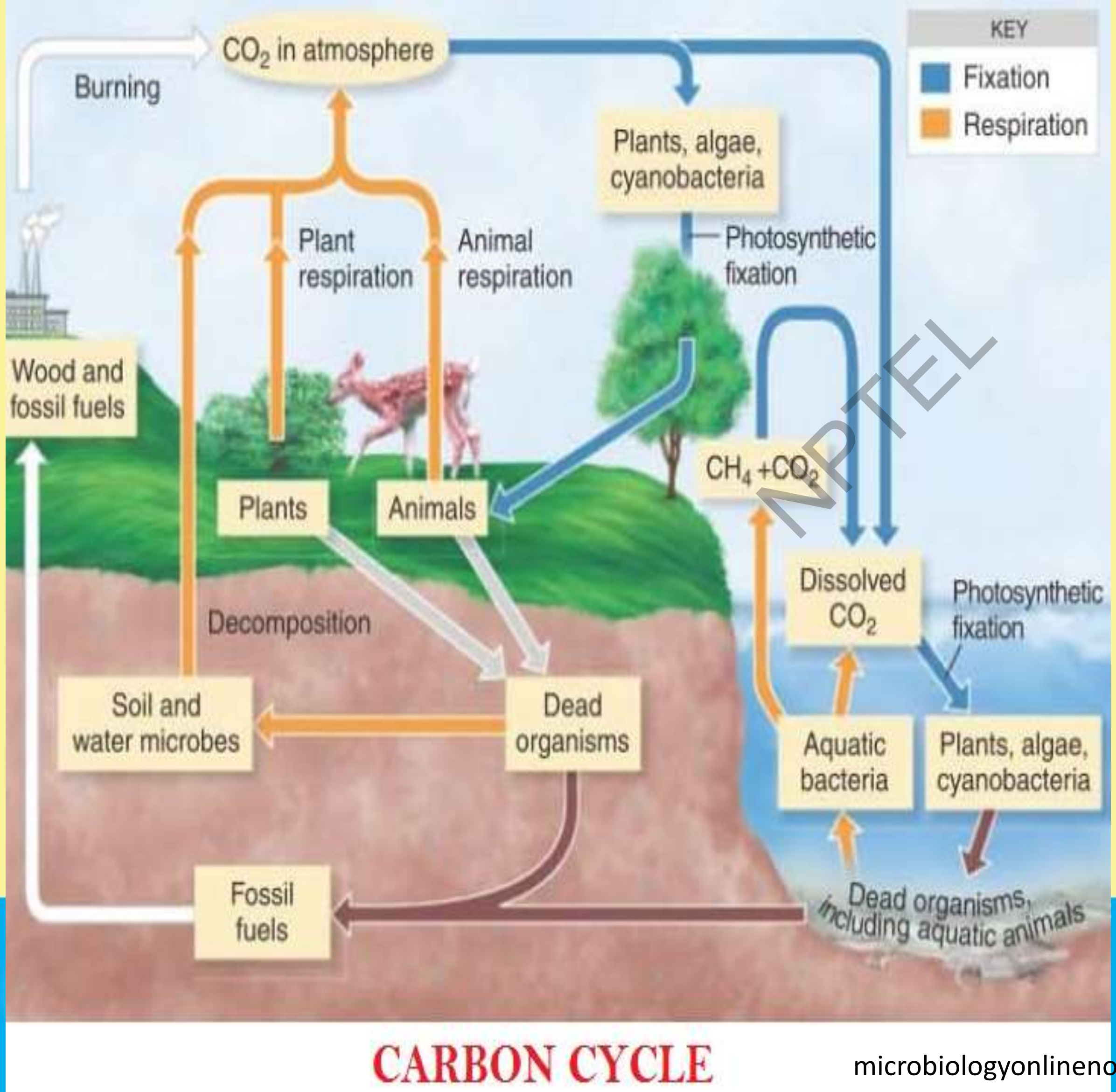
Water Cycle



wikipedia.org

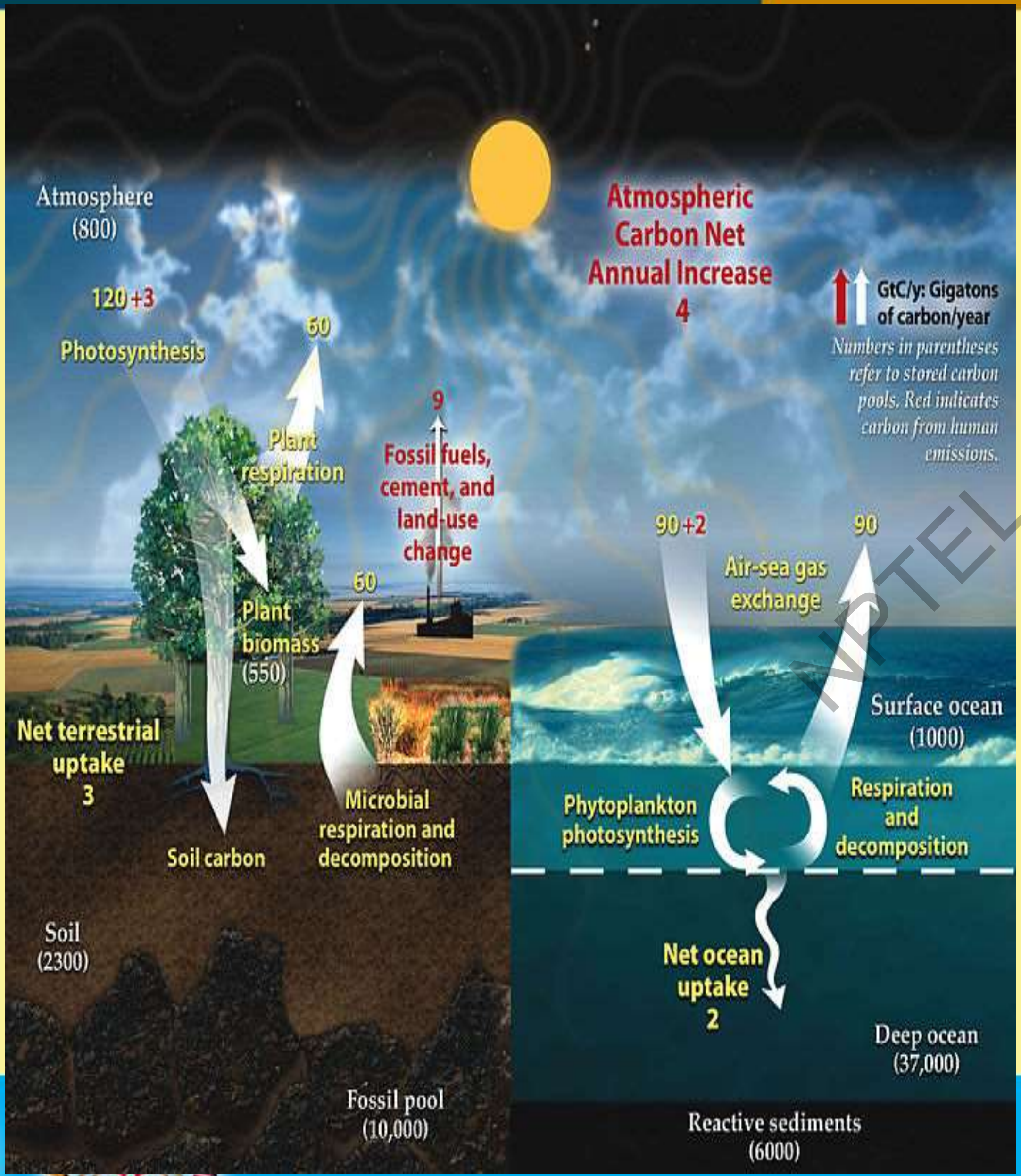
- •Evaporation
- •Condensation
- •Infiltration
- •Surface runoff

Carbon Cycle



microbiologyonlinenotes.com

The carbon cycle is the biogeochemical cycle by which carbon is exchanged among the biosphere, pedosphere, geosphere, hydrosphere,and atmosphere of the Earth.



Movement of carbon between land, atmosphere, and ocean in billions of tons per year. Yellow numbers are natural fluxes, red are human contributions, white are stored carbon. The effects of volcanic and tectonic activity are not included.

wikipedia.org

Carbon Sinks:

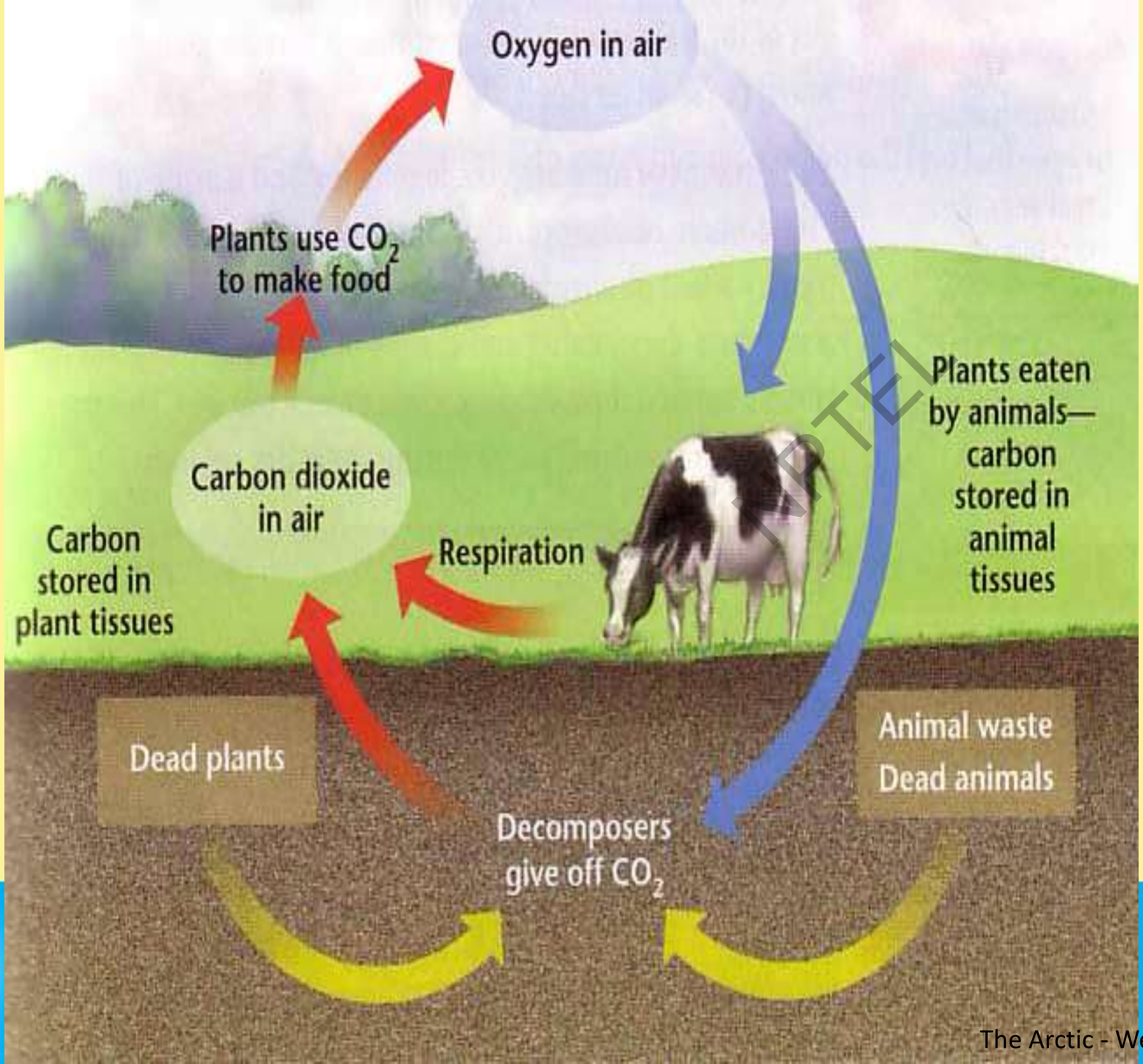
- Lithosphere – limestone (largest reservoir)
- hydrosphere – ocean (2nd largest)
- Atmosphere – in form of CO_2
- biosphere – wood, plants, dead animals

The Oxygen Cycle

The oxygen cycle is the biogeochemical transitions of oxygen atoms between different oxidation states in ions, oxides, and molecules through redox reactions within and between the spheres/reservoirs of the planet Earth

Essential for animals during respiration, released by plants
Cycles much like the carbon cycle
What is threatening this cycle? Forest deforestation, ocean pollution, etc

The Oxygen Cycle



The Arctic - Weebly

Nitrogen cycle

- The nitrogen cycle is the biogeochemical cycle by which nitrogen is converted into multiple chemical forms as it circulates among atmosphere, terrestrial, and marine ecosystems. The conversion of nitrogen can be carried out through both biological and physical processes. Important processes in the nitrogen cycle include fixation, ammonification, nitrification, and denitrification.

Forms of Nitrogen

Urea → $CO(NH2)_2$

Ammonia → NH_3 (gaseous)

Ammonium → NH_4

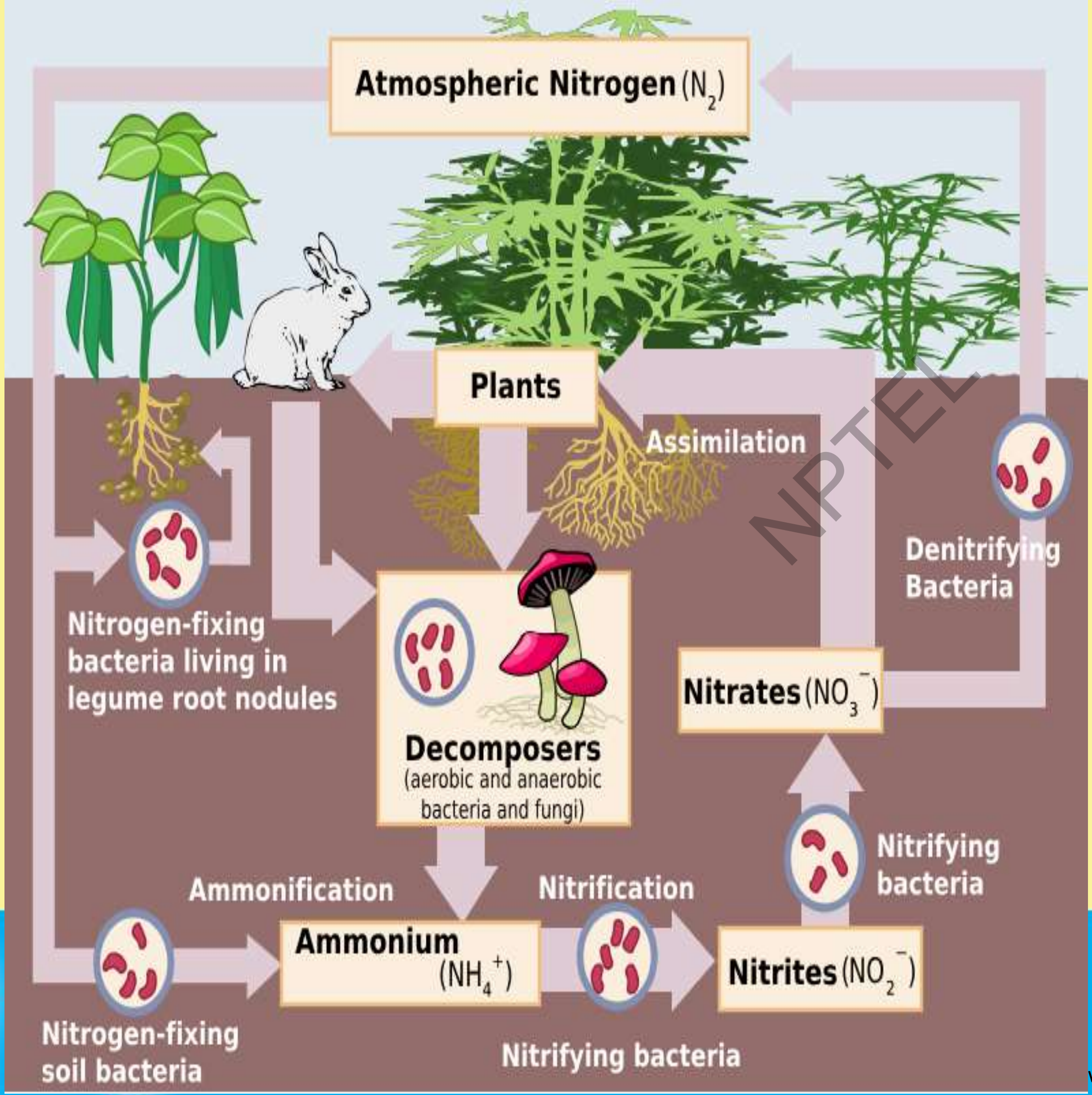
Nitrate → NO_3

Nitrite → NO_2

Atmospheric Dinitrogen →N_2

Organic N

Nitrogen cycle



wikipedia.org

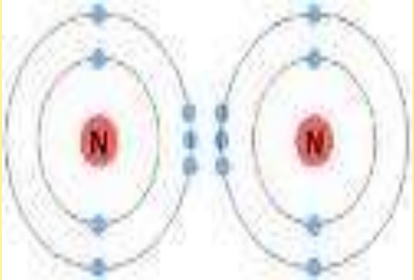
- 78% of the volume of trophosphere
- Most complex cycle
- N_2 gas can't be used 'as is' – it must be 'fixed' so that organisms can use it
- N_2 gas is modified by "nitrogen-fixing" bacteria in legumes into ammonia (NH_3) – NITROGEN FIXATION – aids in production of sugars/starches
- Bacteria turn wastes and detritus into ammonia – AMMONIFICATION – released into atm
- NH_3 is converted into nitrite (NO_2^-) which is then used to produce nitrate (NO_3^-) - NITRIFICATION

•Steps to the cycle: b/c of complexity, no certain order

N Fixation – occurs in plant, by bacteria
Ammonification
Nitrification
Assimilation
Denitrification

- Nitrogen (N) is an essential component of DNA, RNA, and proteins, the building blocks of life.

- All organisms require nitrogen to live and grow.



Nitrogen's triple bond

- Although the majority of the air we breathe is N_2, most of the nitrogen in the atmosphere is unavailable for use by organisms.
- This is because the strong triple bond between the N atoms in N_2 molecules makes it relatively inert (like a noble gas).

How can we use N_2?

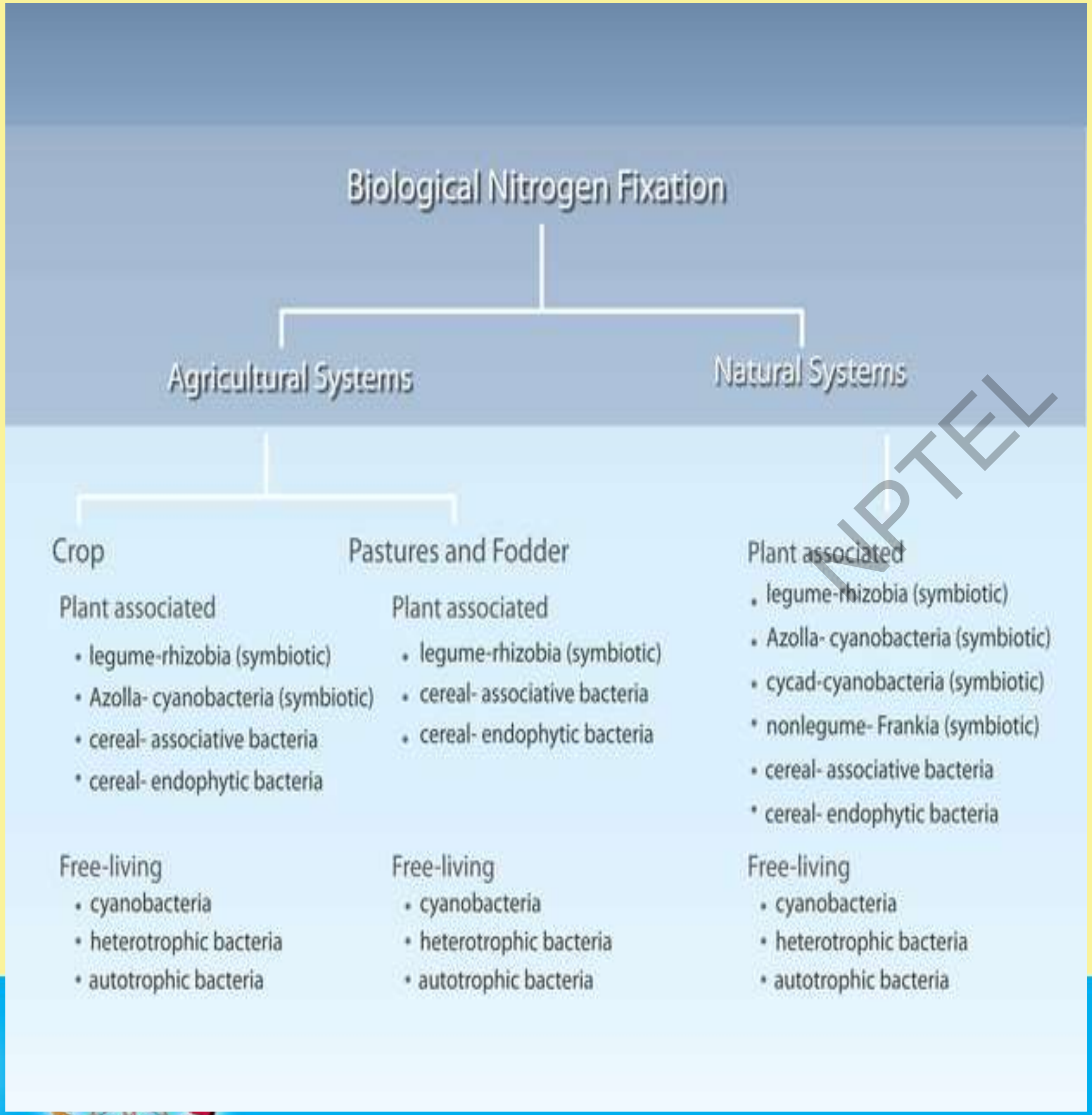
- In order for plants and animals to be able to use nitrogen, N_2 gas must first be converted to more a chemically available form such as ammonium (NH_4^+) or nitrate (NO_3^-)

Nitrogen Fixation

Nitrogen fixation is a process by which nitrogen in the air is converted into ammonia (NH_3) or related nitrogenous compounds. Atmospheric nitrogen, is molecular dinitrogen (N_2), a relatively nonreactive molecule that is metabolically useless to all but a few microorganisms. Biological nitrogen fixation converts N_2 into ammonia, which is metabolized by most organisms.

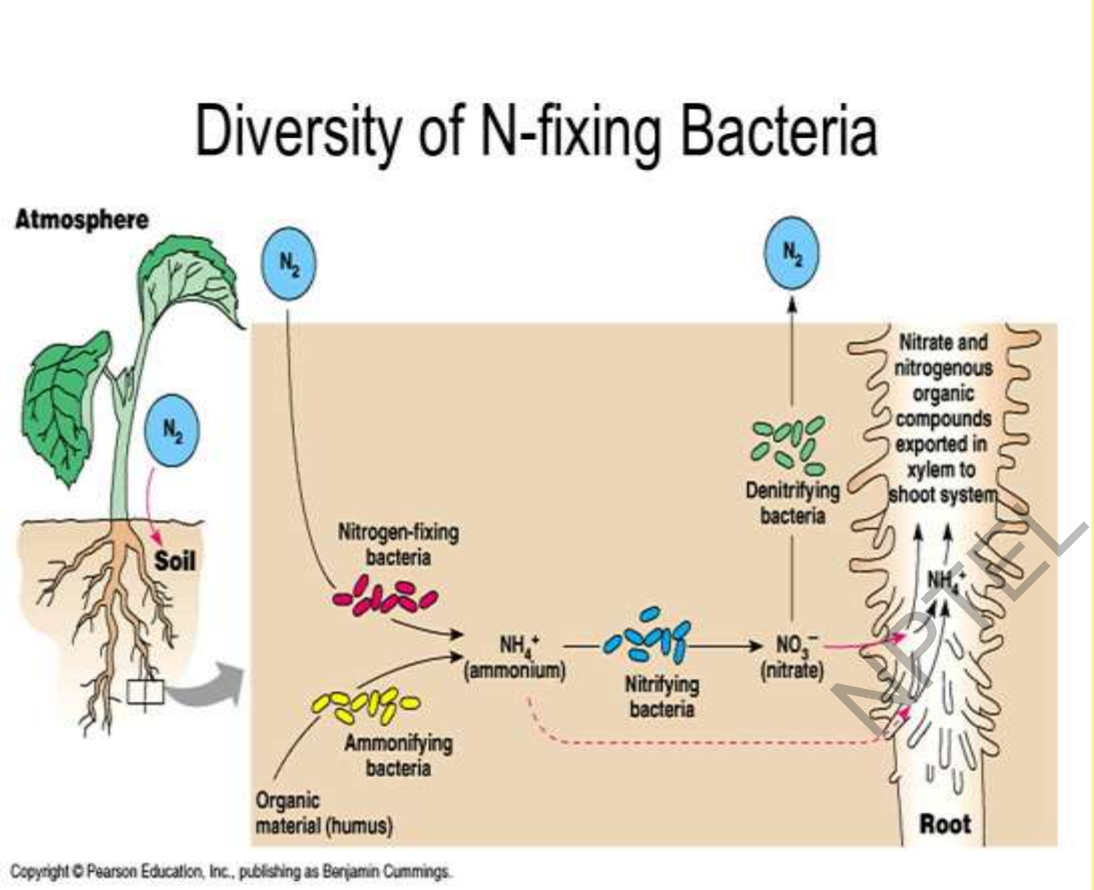
(N_2 --> NH_3 or NH_4^+)

Nitrogen Fixation (BIOLOGICAL)



Bacteria (called Nitrogen-fixing bacteria)
These bacteria form relationships with host plants.
The bacteria live in nodules found in the roots of the legume family of plants
(e.g. beans, peas, and clover)

Wagner, S. C.. (2011)



Nodules full of nitrogen-fixing bacteria on the roots of a soya plant

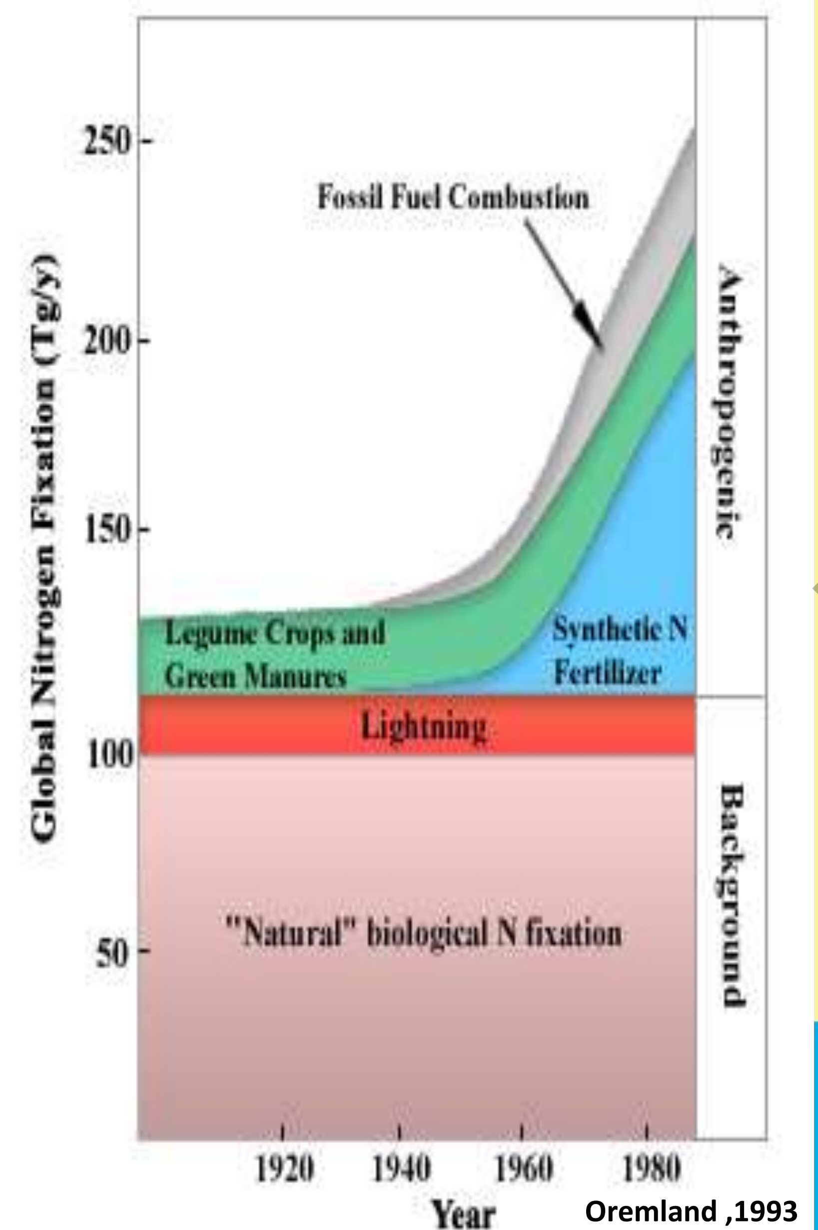
Nitrogen Fixation (ENVIRONMENTAL)

High-energy natural events which break the bond N_2

Examples:

- lightning
- forest fires
- hot lava flows

Nitrogen Fixation (Anthropogenic)

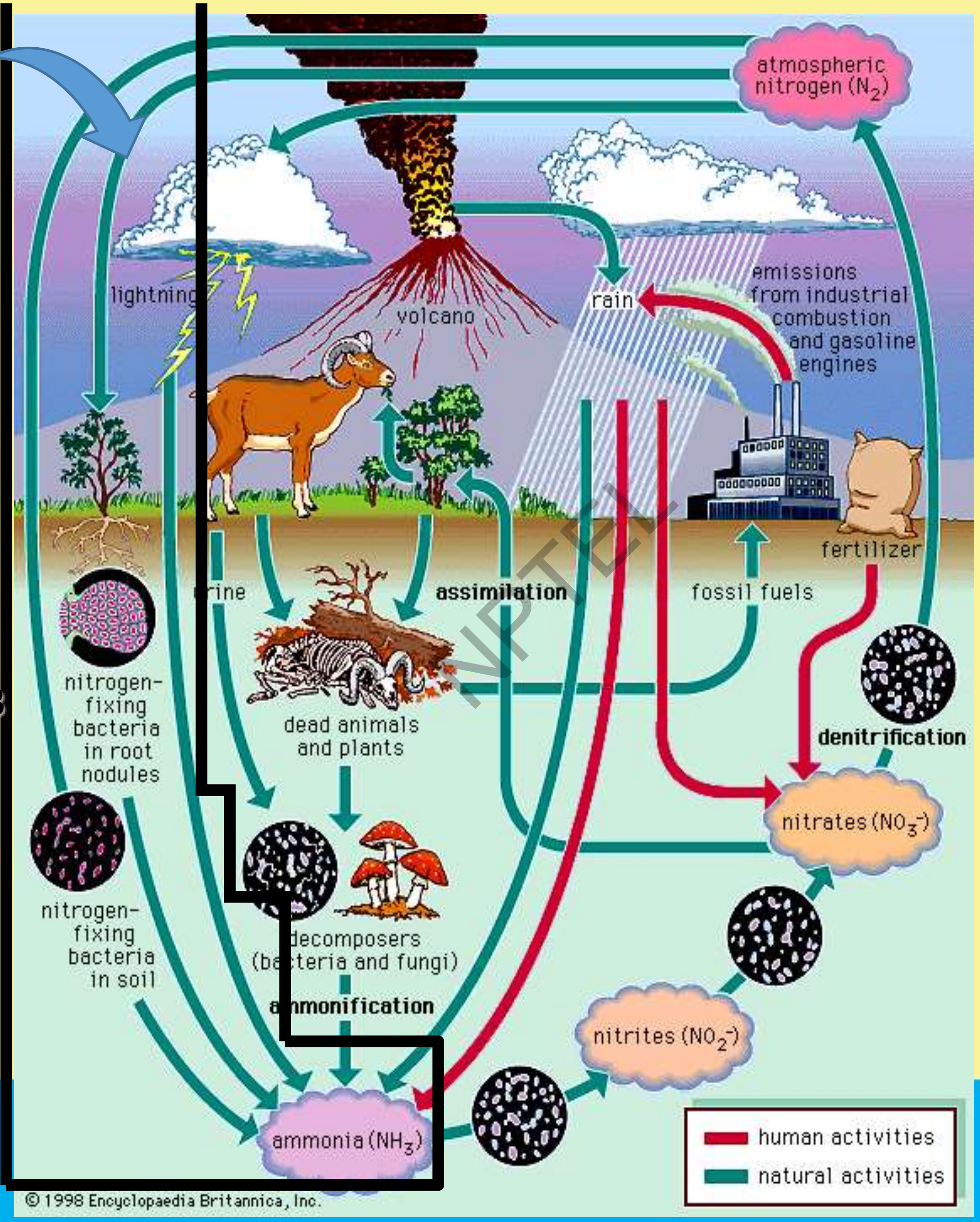


Oremland ,1993

Burning fossil fuels, using synthetic nitrogen fertilizers, and cultivation of legumes all fix nitrogen

Nitrogen Fixation

Atmospheric Nitrogen is broken into useable nitrogen (NH_3 or NH_4^+)



Nitrogen Mineralization also called Ammonification

Nitrogen mineralization is a cascade of microbial and enzymatic activities which converts organic N to inorganic form through aminization (from macromolecules of organic N compounds to simple organic N compounds such as amino acids, amino sugars, and nucleic acids) and ammonification (from simple organic N compounds to ammonium (NH4+)) (Zaman et al., 1999a, 1999b).

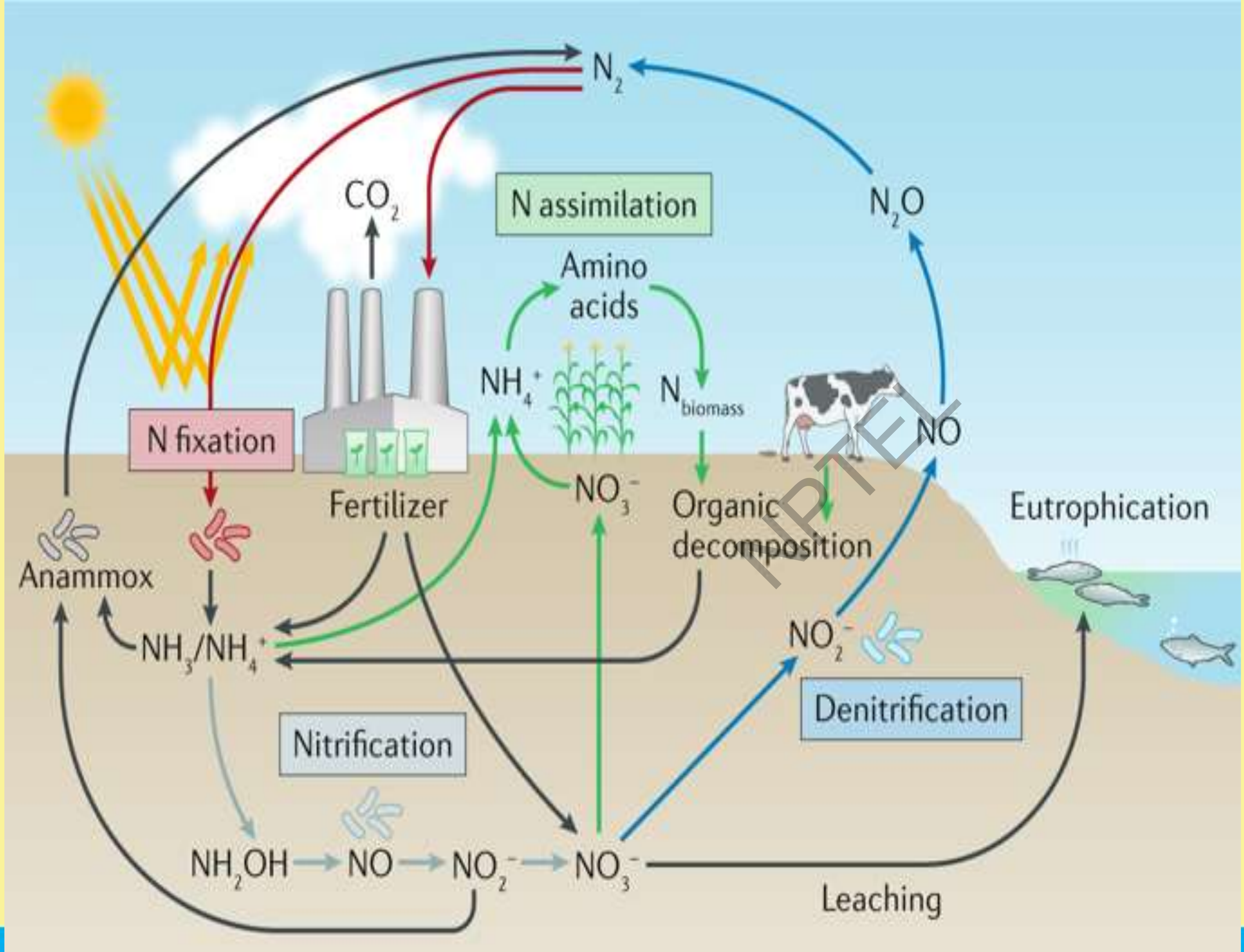
•Decay of dead things, manure, etc.

•Done by decomposers (bacteria, fungi, etc.)

•During this process, a significant amount of the nitrogen contained within the dead organism is converted to ammonium (NH_4^+).

Opposite of Mineralization is immobilization

Nitrification and Denitrification



Lehnert - 2018

Human Impact

FERTILIZERS

- Extra nitrogen fertilizer can runoff, where it contaminates surface water or infiltrates into ground water.
- In drinking water, excess nitrogen can lead to cancer in humans and respiratory distress in infants.

www.earth.columbia.edu

Human Impact

e360.yale.edu

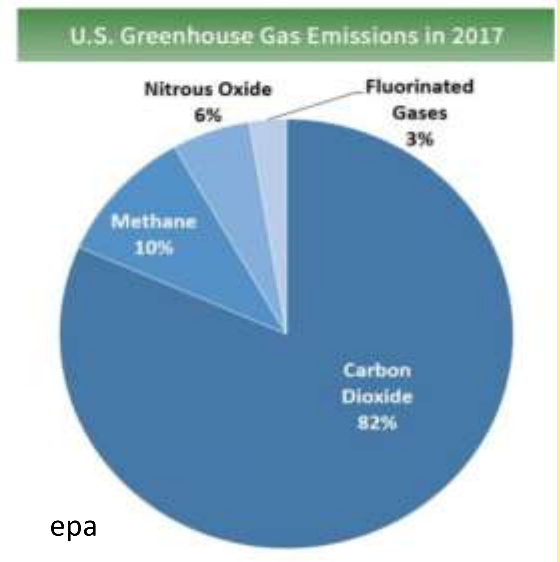
In surface waters, extra nitrogen can lead to nutrient over-enrichment.

This leads to

- fish-kills,
- harmful algal blooms,
- and species shifts in aquatic and land ecosystems

Some forms of nitrogen (like NO_3^- and NH_4^+) can also enter the atmosphere to become:

1. smog- nitric oxide (NO)
2. Greenhouse gas- nitrous oxide (N_2O)
3. Acid Rain- (nitrogen oxides



epa

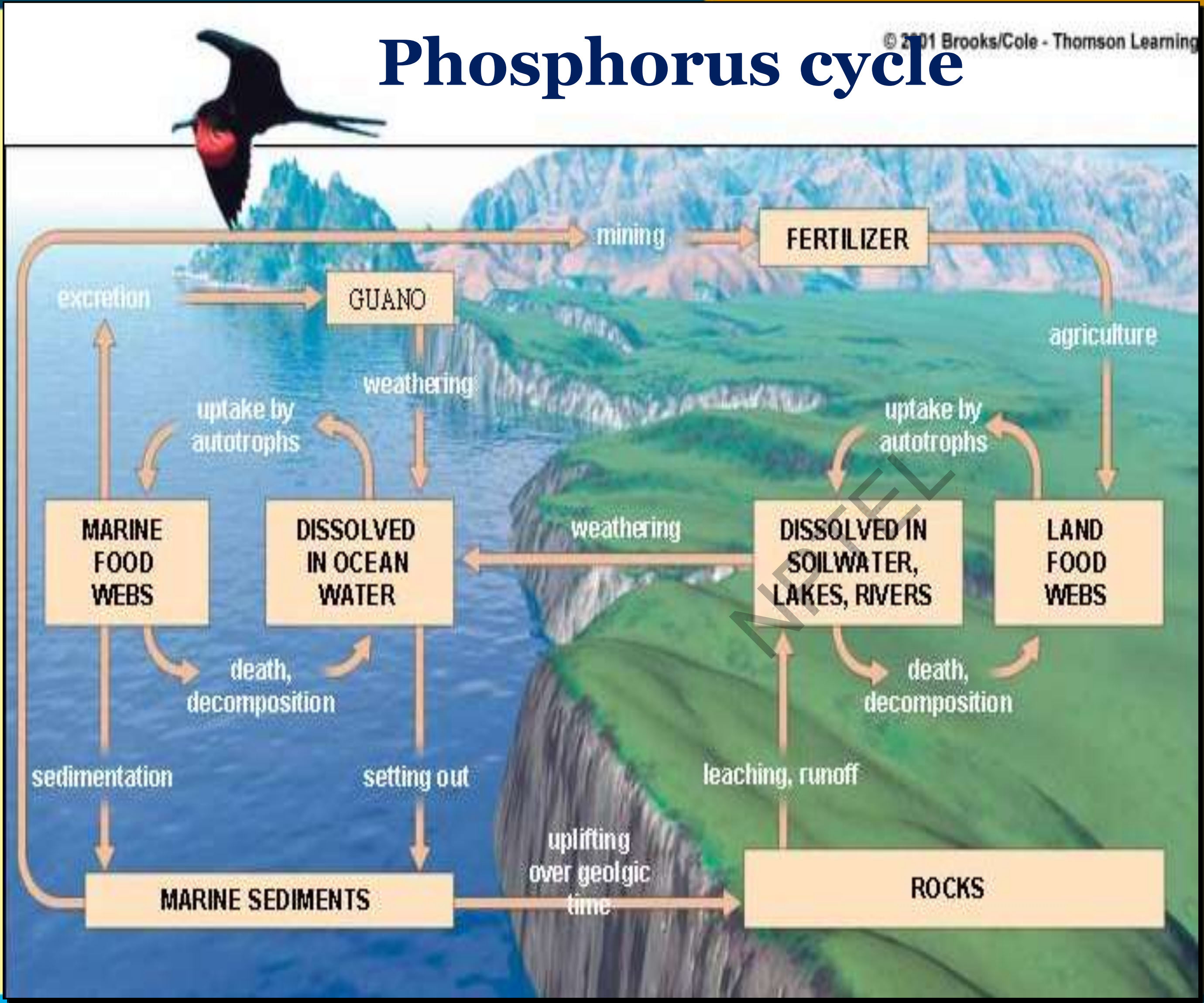
Nitrous oxide has an atmospheric lifetime of 110 years. The process that removes nitrous oxide from the atmosphere also depletes ozone. So nitrous oxide is not only a greenhouse gas, but also an ozone destroyer.

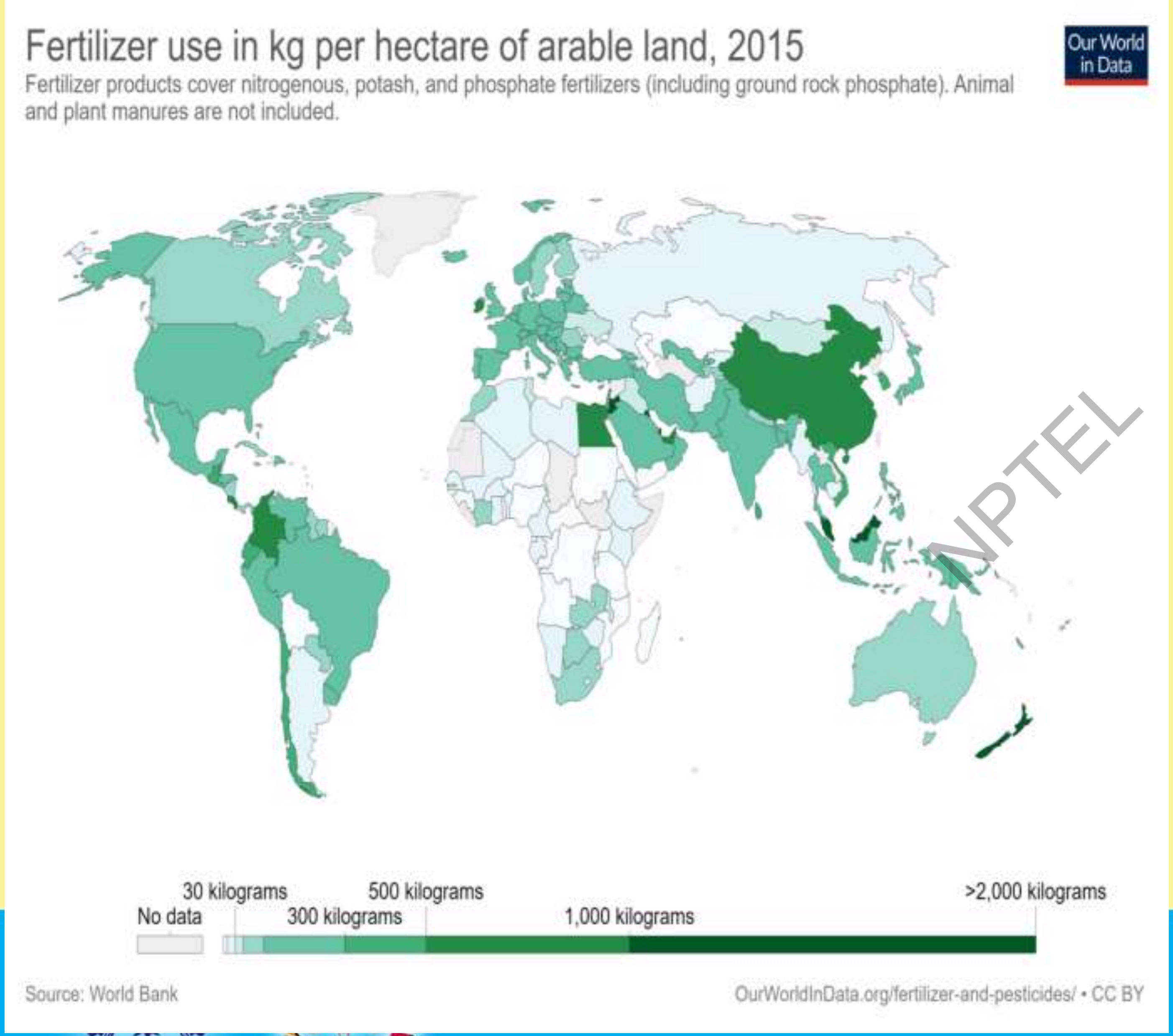
- **Nitrous Oxide (N_2O) has a GWP 265–298 times that of CO_2 for a 100-year timescale.**

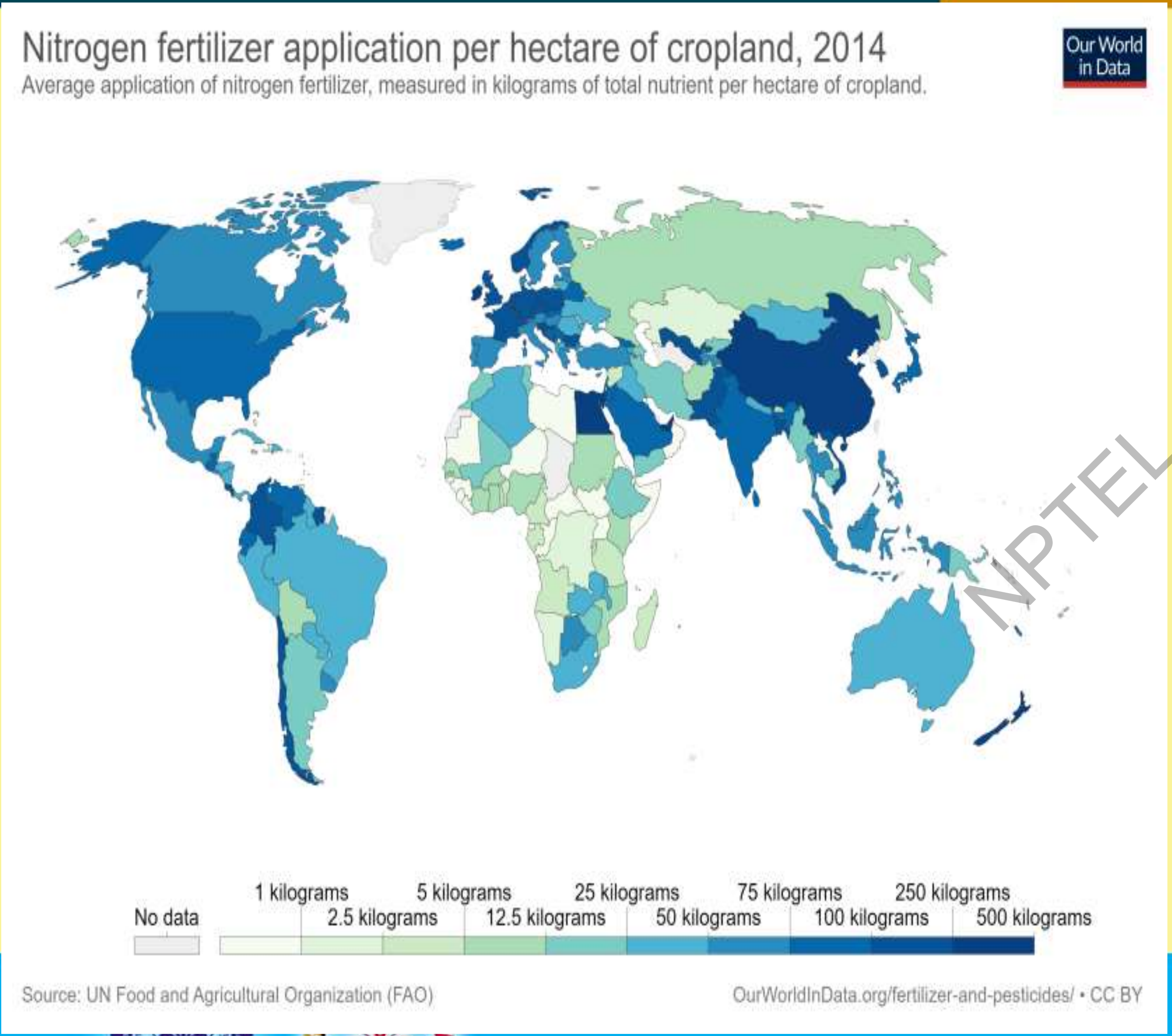
Phosphorus cycle

The phosphorus cycle is the biogeochemical cycle that describes the movement of phosphorus through the lithosphere, hydrosphere, and biosphere. Unlike many other biogeochemical cycles, the atmosphere does not play a significant role in the movement of phosphorus, because phosphorus and phosphorus-based compounds are usually solids at the typical ranges of temperature and pressure found on Earth.

Phosphorus cycle




Fertilizer use in kg per hectare of arable land, 2015
Fertilizer products cover nitrogenous, potash, and phosphate fertilizers (including ground rock phosphate). Animal and plant manures are not included.
Our World in Data
30 kilograms
500 kilograms
>2,000 kilograms
No data
300 kilograms
1,000 kilograms
Source: World Bank
OurWorldInData.org/fertilizer-and-pesticides/ • CC BY


Nitrogen fertilizer application per hectare of cropland, 2014
Average application of nitrogen fertilizer, measured in kilograms of total nutrient per hectare of cropland.
Our World in Data
No data
1 kilograms
2.5 kilograms
5 kilograms
12.5 kilograms
25 kilograms
50 kilograms
75 kilograms
100 kilograms
250 kilograms
500 kilograms
Source: UN Food and Agricultural Organization (FAO)
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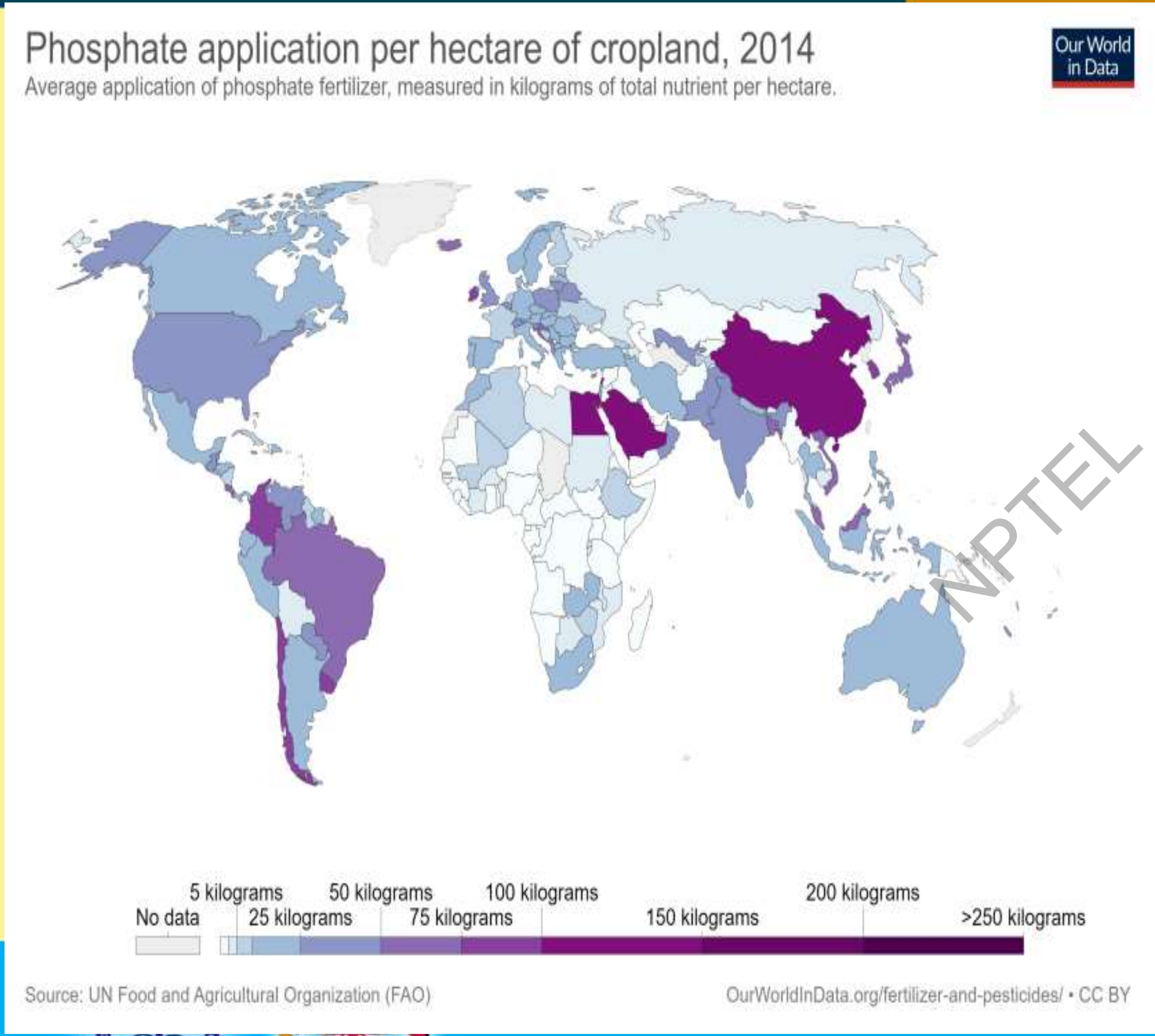

Phosphate application per hectare of cropland, 2014
Average application of phosphate fertilizer, measured in kilograms of total nutrient per hectare.
Our World in Data
No data
5 kilograms
25 kilograms
50 kilograms
75 kilograms
100 kilograms
150 kilograms
200 kilograms
>250 kilograms
Source: UN Food and Agricultural Organization (FAO)
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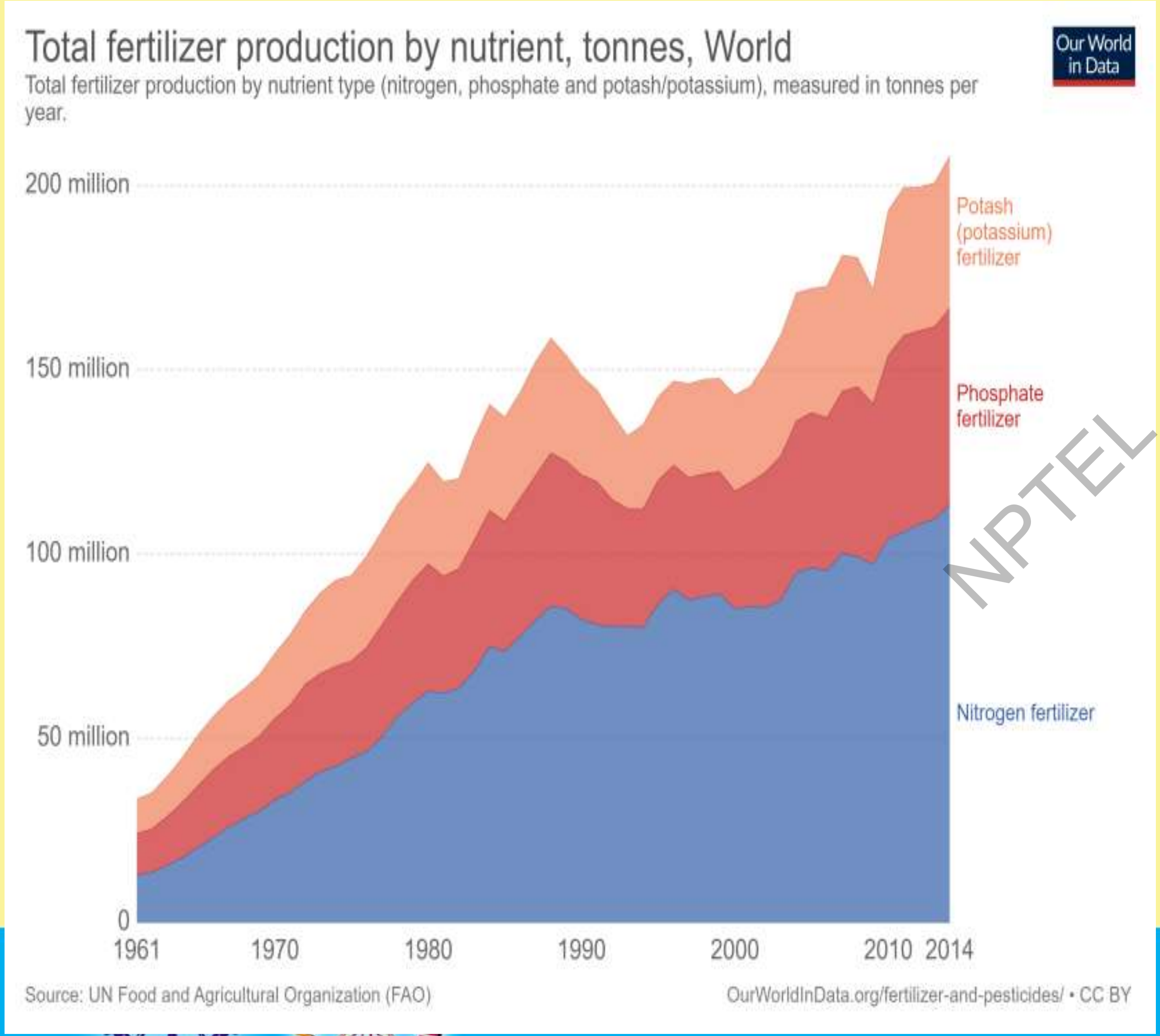
Total fertilizer production by nutrient, tonnes, World
Total fertilizer production by nutrient type (nitrogen, phosphate and potash/potassium), measured in tonnes per year.
Our World in Data
200 million
150 million
100 million
50 million
0
1961
1970
1980
1990
2000
2010
2014
Potash (potassium) fertilizer
Phosphate fertilizer
Nitrogen fertilizer
Source: UN Food and Agricultural Organization (FAO)
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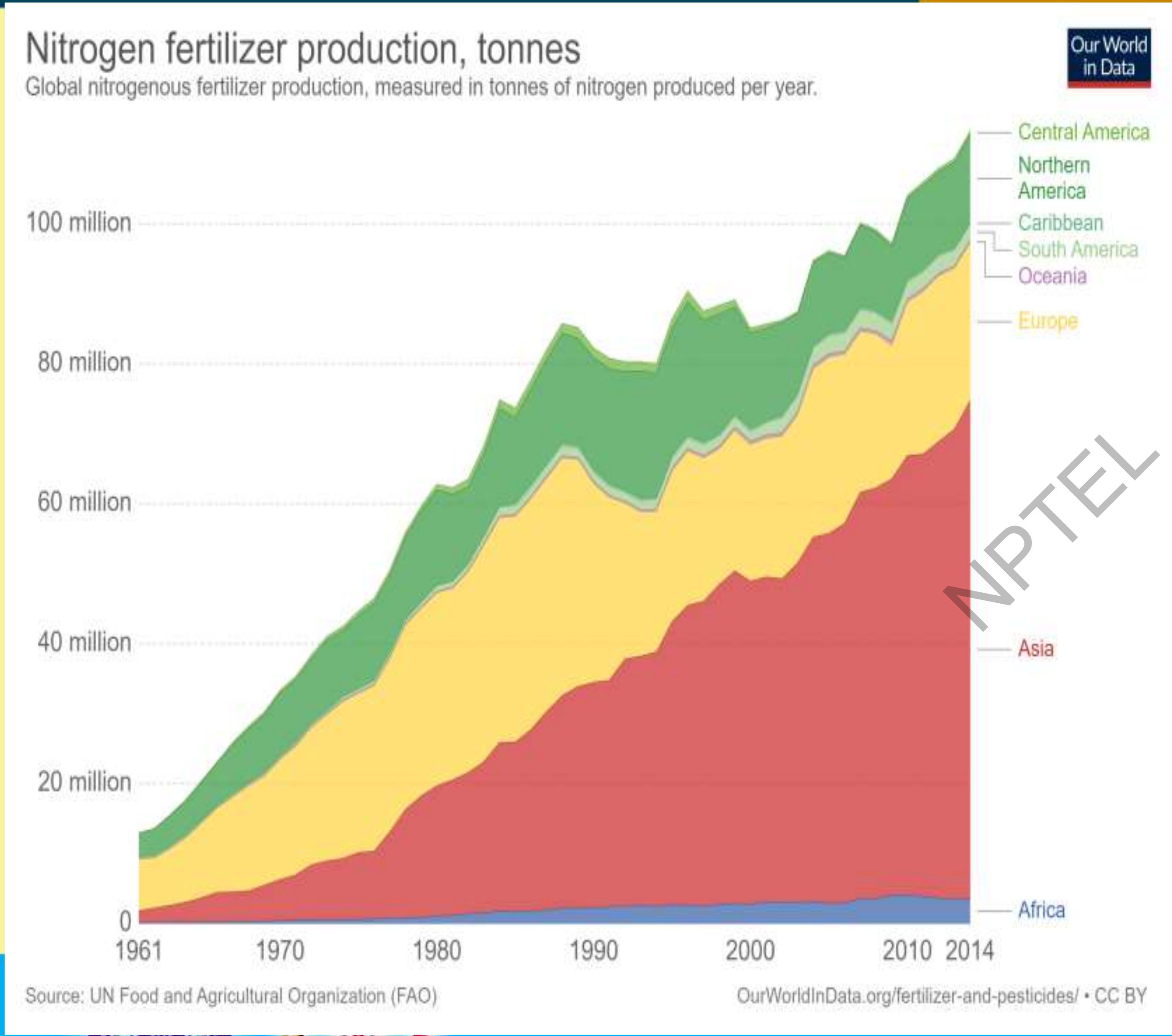
NPTEL


Nitrogen fertilizer production, tonnes
Global nitrogenous fertilizer production, measured in tonnes of nitrogen produced per year.
Our World in Data
100 million
80 million
60 million
40 million
20 million
0
1961
1970
1980
1990
2000
2010
2014
Central America
Northern America
Caribbean
South America
Oceania
Europe
Asia
Africa
Source: UN Food and Agricultural Organization (FAO)
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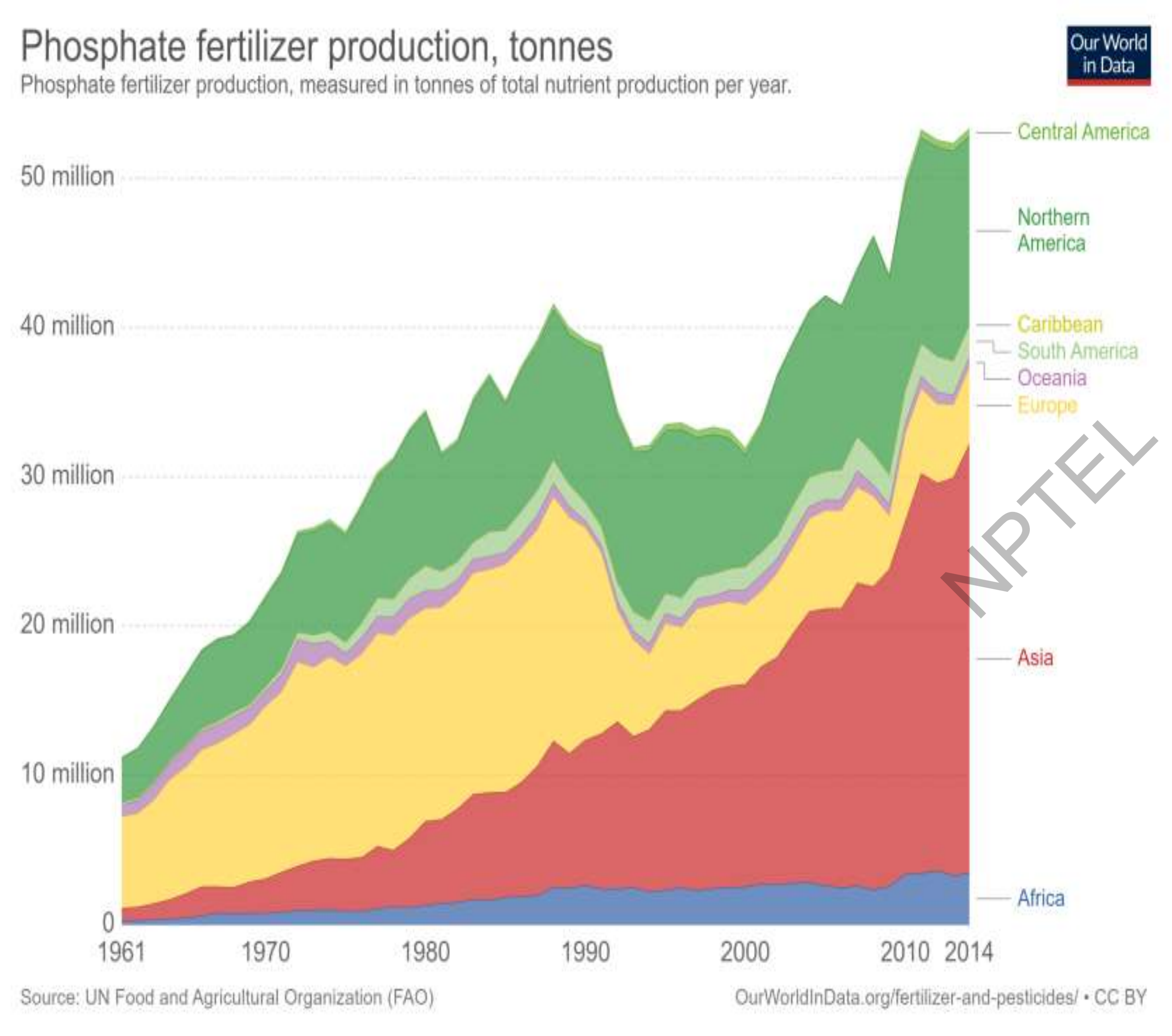
Phosphate fertilizer production, tonnes
Phosphate fertilizer production, measured in tonnes of total nutrient production per year.
Our World in Data
50 million
40 million
30 million
20 million
10 million
0
1961
1970
1980
1990
2000
2010
2014
Central America
Northern America
Caribbean
South America
Oceania
Europe
Asia
Africa
NPTEL
Source: UN Food and Agricultural Organization (FAO)
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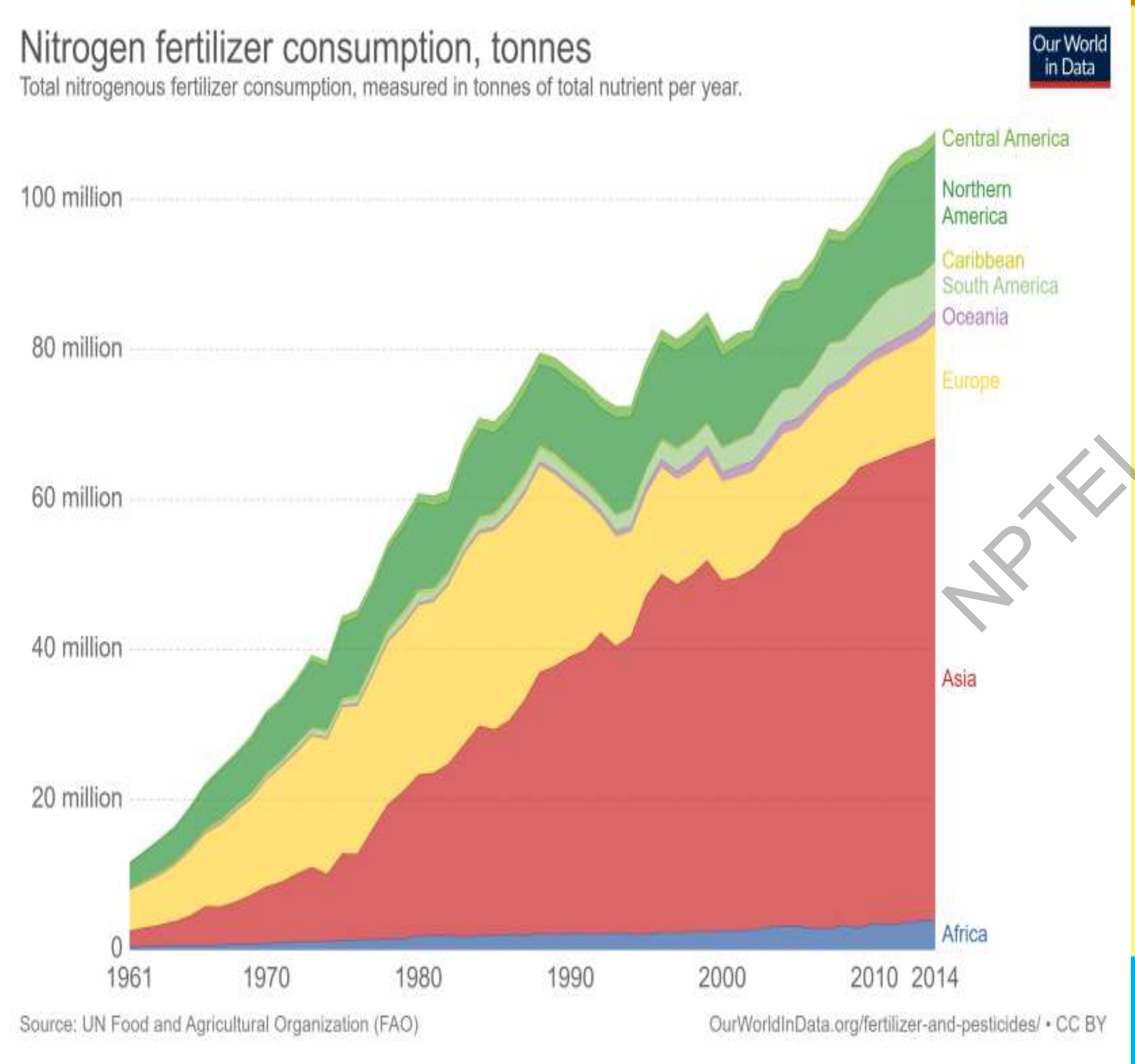

Nitrogen fertilizer consumption, tonnes
Total nitrogenous fertilizer consumption, measured in tonnes of total nutrient per year.
Our World in Data
100 million
80 million
60 million
40 million
20 million
0
1961
1970
1980
1990
2000
2010
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Central America
Northern America
Caribbean
South America
Oceania
Europe
Asia
Africa
Source: UN Food and Agricultural Organization (FAO)
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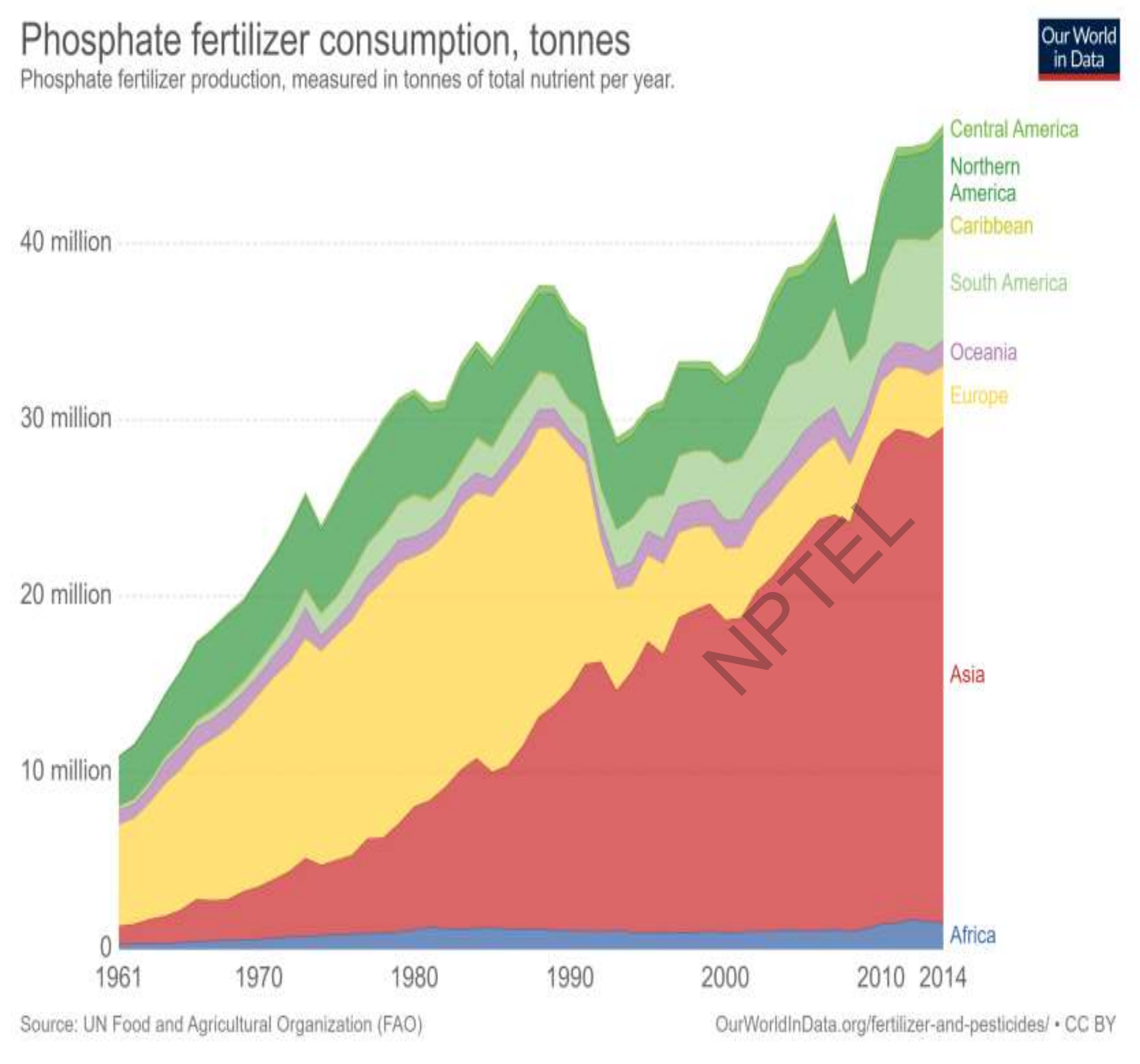

Phosphate fertilizer consumption, tonnes
Phosphate fertilizer production, measured in tonnes of total nutrient per year.
Our World in Data
40 million
30 million
20 million
10 million
0
1961
1970
1980
1990
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2010
2014
Central America
Northern America
Caribbean
South America
Oceania
Europe
Asia
Africa
NPTEL
Source: UN Food and Agricultural Organization (FAO)
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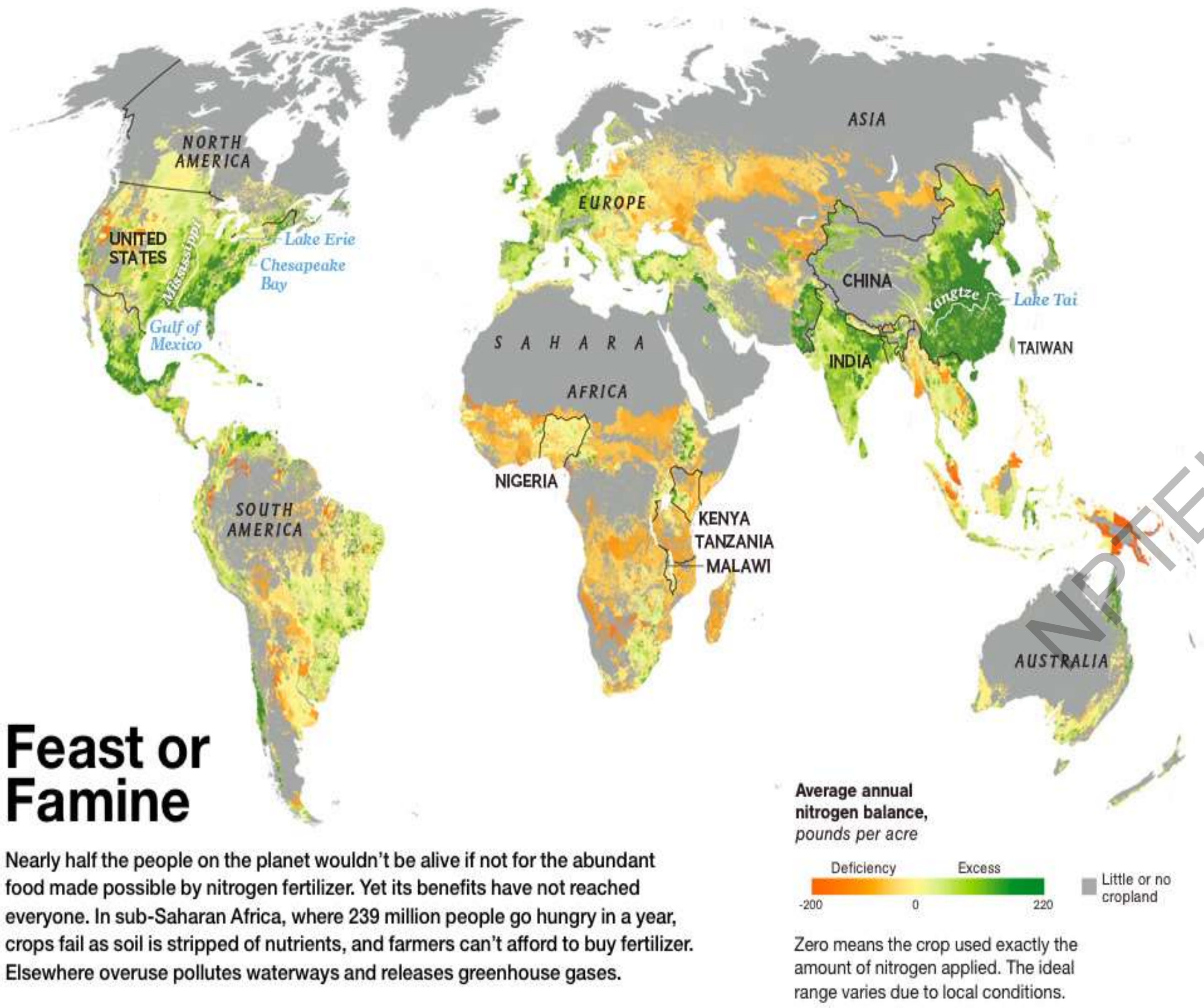
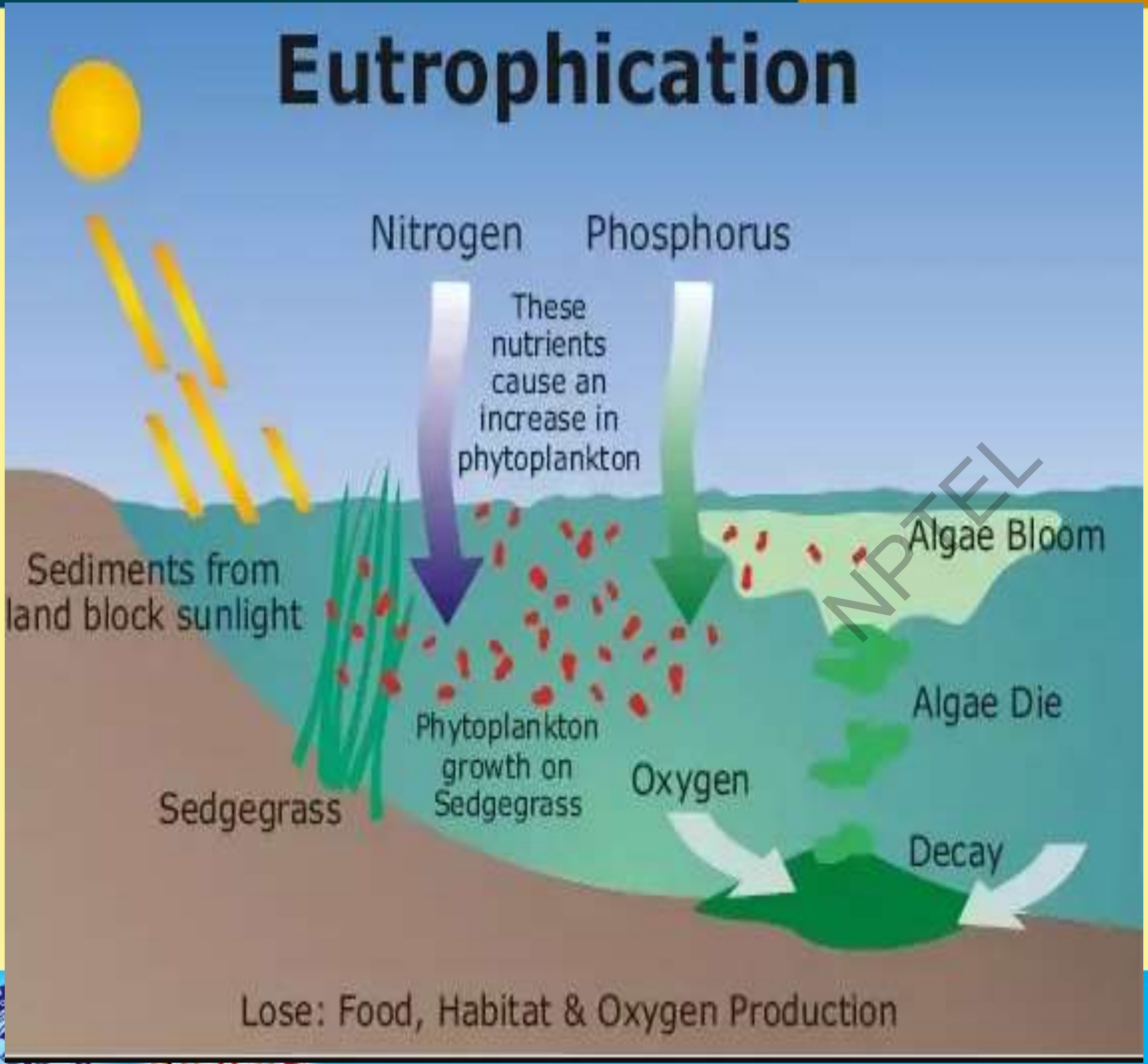


Feast or Famine

Nearly half the people on the planet wouldn't be alive if not for the abundant food made possible by nitrogen fertilizer. Yet its benefits have not reached everyone. In sub-Saharan Africa, where 239 million people go hungry in a year, crops fail as soil is stripped of nutrients, and farmers can't afford to buy fertilizer. Elsewhere overuse pollutes waterways and releases greenhouse gases.

JEROME N. COOKSON AND LAWSON PARKER, NGM STAFF
SOURCE: PAUL C. WEST, INSTITUTE ON THE ENVIRONMENT, UNIVERSITY OF MINNESOTA

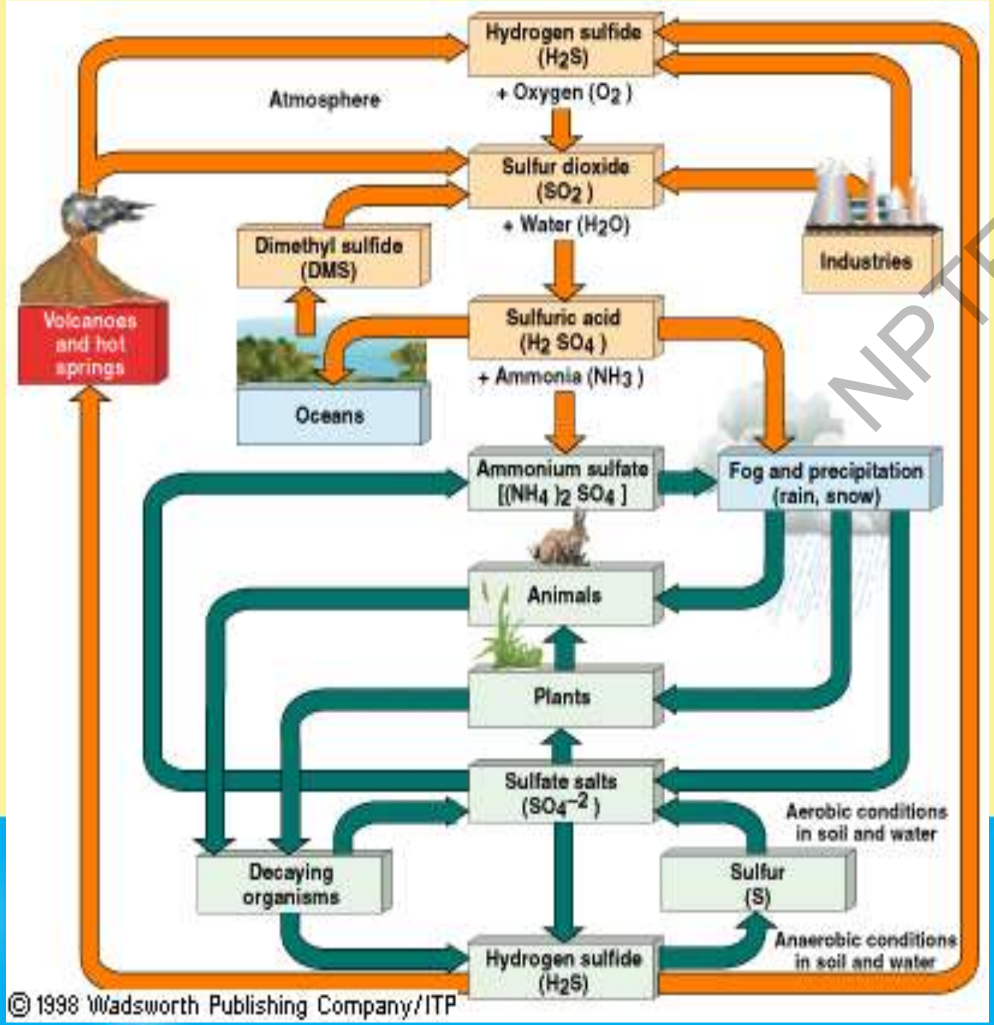

Eutrophication
Nitrogen
Phosphorus
These nutrients cause an increase in phytoplankton
Algae Bloom
Sediments from land block sunlight
Algae Die
Phytoplankton growth on Sedgegrass
Oxygen
Sedgegrass
Decay
Lose: Food, Habitat & Oxygen Production
NPTEL

Measures to reduce artificial eutrophication

1. Reducing the use of phosphates as builders in detergents
2. Reducing the use of nitrate containing fertilizers
3. Using tertiary sewage treatment methods to remove phosphate and nitrate before discharging the effluent into rivers and lakes
4. Directing waste water away from lakes to safe treatment & disposal sites
5. Aerating lakes and reservoirs to prevent oxygen depletion particularly during algal blooms
6. Removing phosphate- rich plant material from affected lakes
7. Removing phosphate rich sediments by dredging

Sulfur cycle

- The sulfur cycle is the collection of processes by which sulfur moves between rocks, waterways and living systems. Such biogeochemical cycles are important in geology because they affect many minerals



- Sulfur is released as rocks erode and plants assimilate this
- Mostly found under ground like phosphorus
- H_2S is released by decomposers and during volcanic eruptions; some H_2S in soil is converted into sulfur by aerobic bacteria and plants assimilate this
- 99% of all sulfur in the atmosphere is due to man
- SO_2 gas is released by industries; SO_2 then reacts with water to form H_2SO_4 which falls to the earth as acid rain

Phytoremediation – Constructed wetland

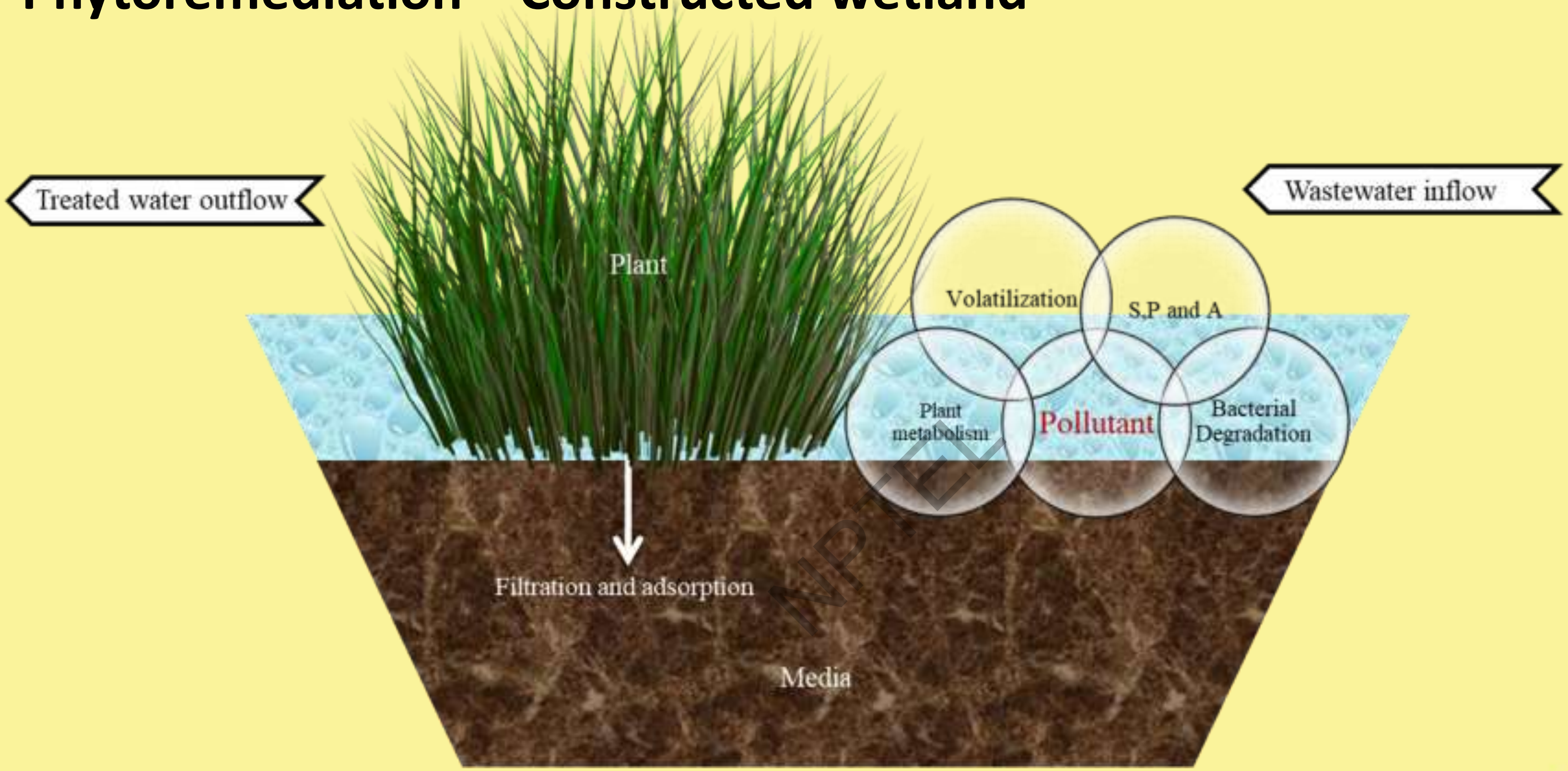


Fig. Fate of pollutant in the constructed wetland(S, P&A (=Sedimentation; P= precipitation and A= Adsorption).

Sharma et al., 2019

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Thank you