

Water usage (agriculture / drinking)
parameters related to water quality/quantity,
differences, demands, standards, threats

Water: drinking

- Excluding fat, water composes approximately 70% of the human body by mass; We drink 2 to 3 L of water every day
- It was estimated (in 2006) that about 1.1 billion people lack proper drinking water; Waterborne diseases were estimated to cause 1.8 million deaths each year
- water quality is defined by chemical, biological and/or radiometric standards
- before app. 1850 water quality was checked only by its taste, smell, and appearance
- among the first parameters that were measured (in the beginning of 20th century) was the presence of coliform bacteria
- even nowadays, microbial pathogenic parameters are very important because of their immediate health risk unlike the toxic chemicals, which may or may not impose immediate health risk

Water: drinking (important parameters)

Physical	Metals and Trace Elements	Nonmetallic Constituents	Organic Chemicals	Microbiological Parameters
Conductivity	Al, Ag, As, Ca, Cd, Cr,	pH, acidity, alkalinity, dissolved oxygen,	Methane	Fecal coliforms
Salinity	Cu, Fe, Mg, Mn, Na,	carbon dioxide, bicarbonate, B, Cl, CN, F,	Oil and grease	Bacteria
Sodicity	Ni, Pb, Se, Sr, Zn	I, ammonium, nitrite, nitrate, P, Si, sulfate	Organic acids	Viruses
Dissolved solids			Volatile acids	
Temperature			Organic C	
Odors			Pesticides	
			Phenols	
			Surfactants	

Accessibility of drinking water (in some “developing” countries)

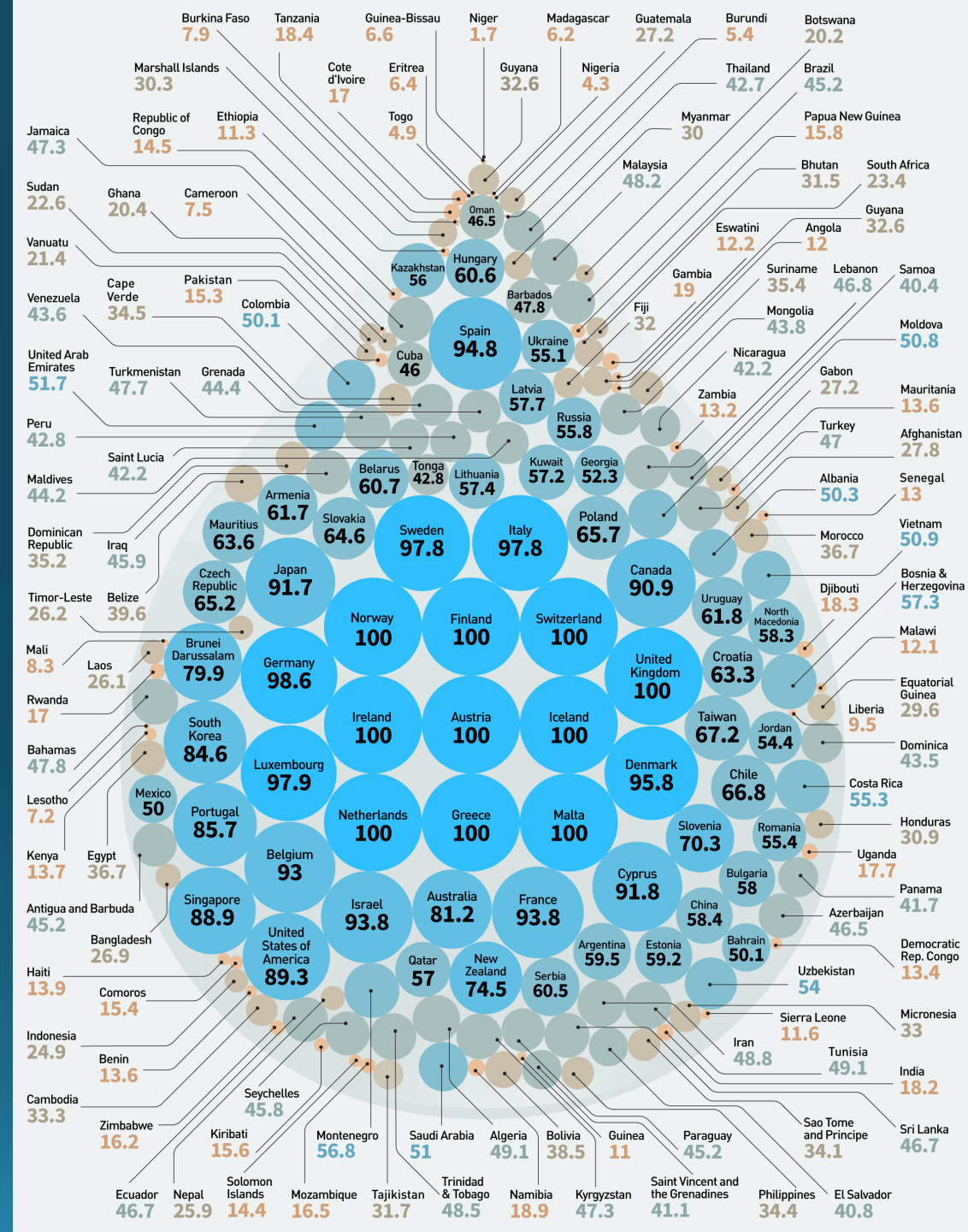
Percentage of Population with Access to Safe Drinking Water (2000)

Country	%	Country	%	Country	%
Algeria	89	Indonesia	78	South Africa	86
Azerbaijan	78	Iran	92	South Korea	92
Brazil	87	Iraq	85	Sudan	67
Chile	93	Kenya	57	Syria	80
China	75	Mexico	88	Turkey	82
Cuba	91	Morocco	80	Uganda	52
Egypt	97	Peru	80	Venezuela	83
India	84	Philippines	86	Zimbabwe	83

Source: United Nations Children’s Fund (UNICEF).^[1]

Quality of tap water in different parts of the world

- many information on quality of tap water can be found online
- example: Environmental Performance Index study carried out by Yale University <https://epi.yale.edu/epi-results/2020/component/h2o>



Water: drinking (mineralization)

Macro- and Microelements, Their Recommended Daily Intake, and the Effects of Deficiency

Element	Recommended Daily Intake (mg)	Effects of Deficiency
Ca	900–1200	Osteoporosis, rickets, neurological disorders
Fe	14–18	Anemia
P	700–900	Muscular weakness, bone aches, lack of appetite
Mg	300–370	Gastrointestinal problems, muscular cramps
Na	1000	Gastrointestinal problems, diarrhea, weakness, headache
K	2–3.5	Muscular weakness, neurological disorders
Zn	13–16	Hair loss, skin lesions, reduced resistance to infection
Cu	2–2.5	Anemia, heart arrhythmia, blood vessel rupture
F	1.5–4	Tooth decay
I	0.15–0.16	Underactive thyroid, goiter
Se	0.06–0.075	Cancer, heart diseases, reduced resistance to microbiological and viral infection, reduced antibody production

Water: drinking

- The World Health Organization (WHO) worldwide and the European Community (EC) in Europe elaborate and publish guidelines which pertain to drinking water standards
- By these guidelines, each country defines its **maximum admissible concentrations** (MACs) of contaminants in drinking water
- **inorganic** pollutants:
 - dangerous: lead, mercury, cadmium, arsenic, cyanides, asbestos
 - hazardous: aluminum, antimony, barium, boron, chromium, cobalt, copper, manganese, nickel, silver, tin, vanadium, zinc, fluorides, nitrates/nitrites
- **organic** pollutants → diverse group of chemicals (pesticides, pharmaceuticals, personal care products, endocrine disrupting chemicals, industrial additives, fire retardants, residues of chemical weapons); significant pollutants are organohalogens
- several organic and some inorganic toxins have teratogenic effects

Water: drinking

- total concentration of organic compounds in water is not high in most cases, it varies from 0 to 1 mg/L in groundwater, from 1 to 5 mg/L in most surface waters, and from 20 to 25 mg/L in some waters with the highest concentration of organic matter
- the main hazard to life, health of humans, flora and fauna comes from anthropogenic organic compounds. The number of known organic compounds is now estimated to be about 16 million, 2 million of which are produced by synthesis alone
- every year, approximately 250,000 new compounds are synthesized, about 1000 of which are manufactured on an industrial scale. App. 70,000 organic compounds are commercially available with an annual global production of 100–200 million tons.
- approximately one-third of all organic compounds produced end up in the environment, including water
- particularly important are **organohalogen compounds** and **pesticides** as a result of their common use (in the past), persistence in the environment and toxicity

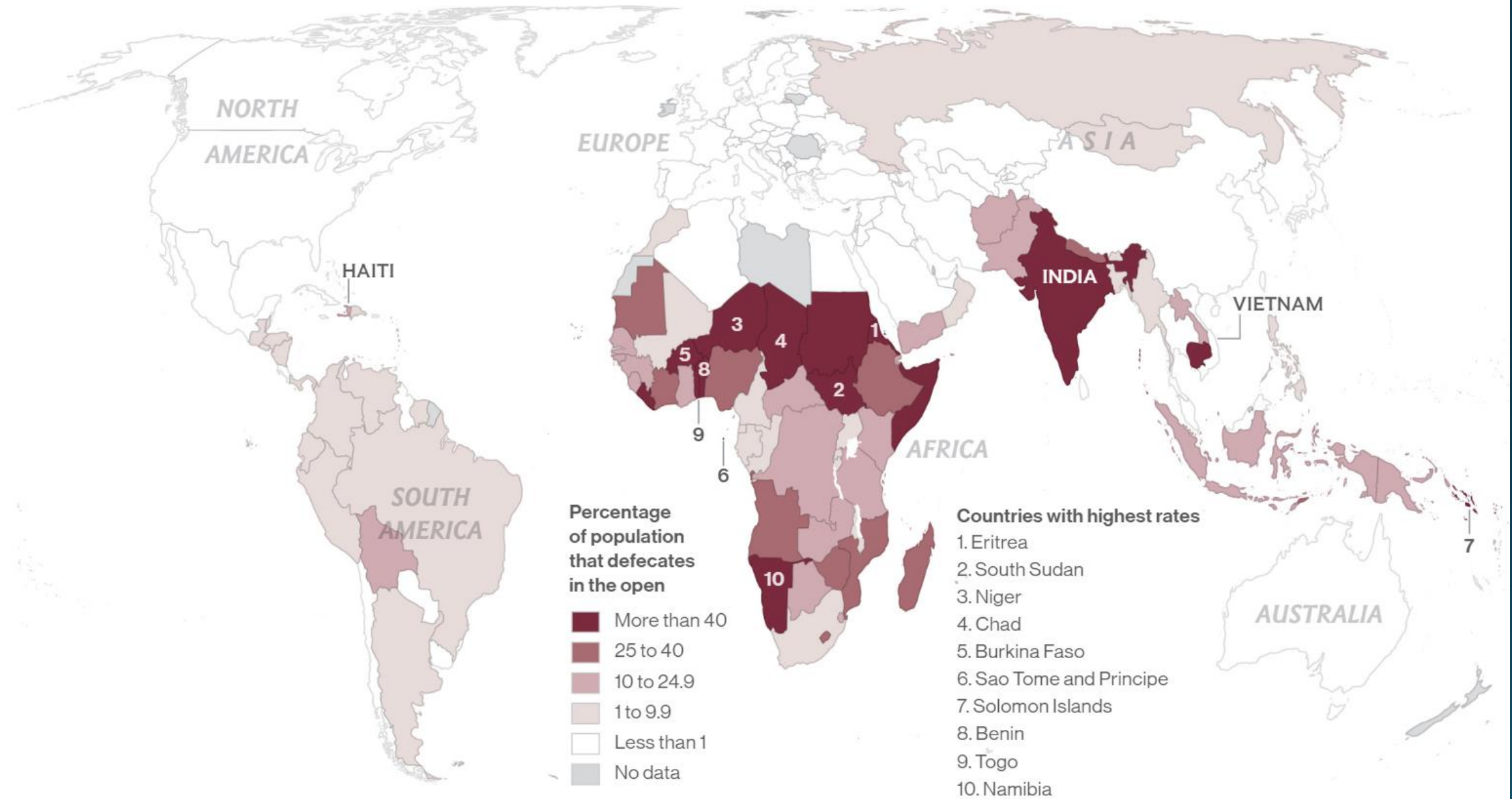
Water: drinking

- Pathogens transmitted through drinking-water

Guidelines for drinking-water quality, WHO, 2011.

	Pathogen	Health significance ^b	Persistence in water ^c	Resistance to chlorine ^d	Relative infectivity ^e	Important animal source
Bacteria	<i>Burkholderia pseudomallei</i>	High	May multiply	Low	Low	No
	<i>Campylobacter jejuni</i> , <i>C. coli</i>	High	Moderate	Low	Moderate	Yes
	<i>Escherichia coli</i> – Pathogenic ^f	High	Moderate	Low	Low	Yes
	<i>E. coli</i> – Enterohaemorrhagic	High	Moderate	Low	High	Yes
	<i>Francisella tularensis</i>	High	Long	Moderate	High	Yes
	<i>Legionella</i> spp.	High	May multiply	Low	Moderate	No
	<i>Leptospira</i>	High	Long	Low	High	Yes
	Mycobacteria (nontuberculous)	Low	May multiply	High	Low	No
	<i>Salmonella</i> Typhi	High	Moderate	Low	Low	No
	Other salmonellae	High	May multiply	Low	Low	Yes
	<i>Shigella</i> spp.	High	Short	Low	High	No
	<i>Vibrio cholerae</i>	High	Short to long ^g	Low	Low	No
Viruses	Adenoviruses	Moderate	Long	Moderate	High	No
	Astroviruses	Moderate	Long	Moderate	High	No
	Enteroviruses	High	Long	Moderate	High	No
	Hepatitis A virus	High	Long	Moderate	High	No
	Hepatitis E virus	High	Long	Moderate	High	Potentially
	Noroviruses	High	Long	Moderate	High	Potentially
	Rotaviruses	High	Long	Moderate	High	No
	Sapoviruses	High	Long	Moderate	High	Potentially
Protozoa	<i>Acanthamoeba</i> spp.	High	May multiply	High	High	No
	<i>Cryptosporidium hominis</i> / <i>parvum</i>	High	Long	High	High	Yes
	<i>Cyclospora cayetanensis</i>	High	Long	High	High	No
	<i>Entamoeba histolytica</i>	High	Moderate	High	High	No
	<i>Giardia intestinalis</i>	High	Moderate	High	High	Yes
	<i>Naegleria fowleri</i>	High	May multiply ^h	Low	Moderate	No
Helminths	<i>Dracunculus medinensis</i>	High	Moderate	Moderate	High	No
	<i>Schistosoma</i> spp.	High	Short	Moderate	High	Yes

Lack of water treatment/sanitation



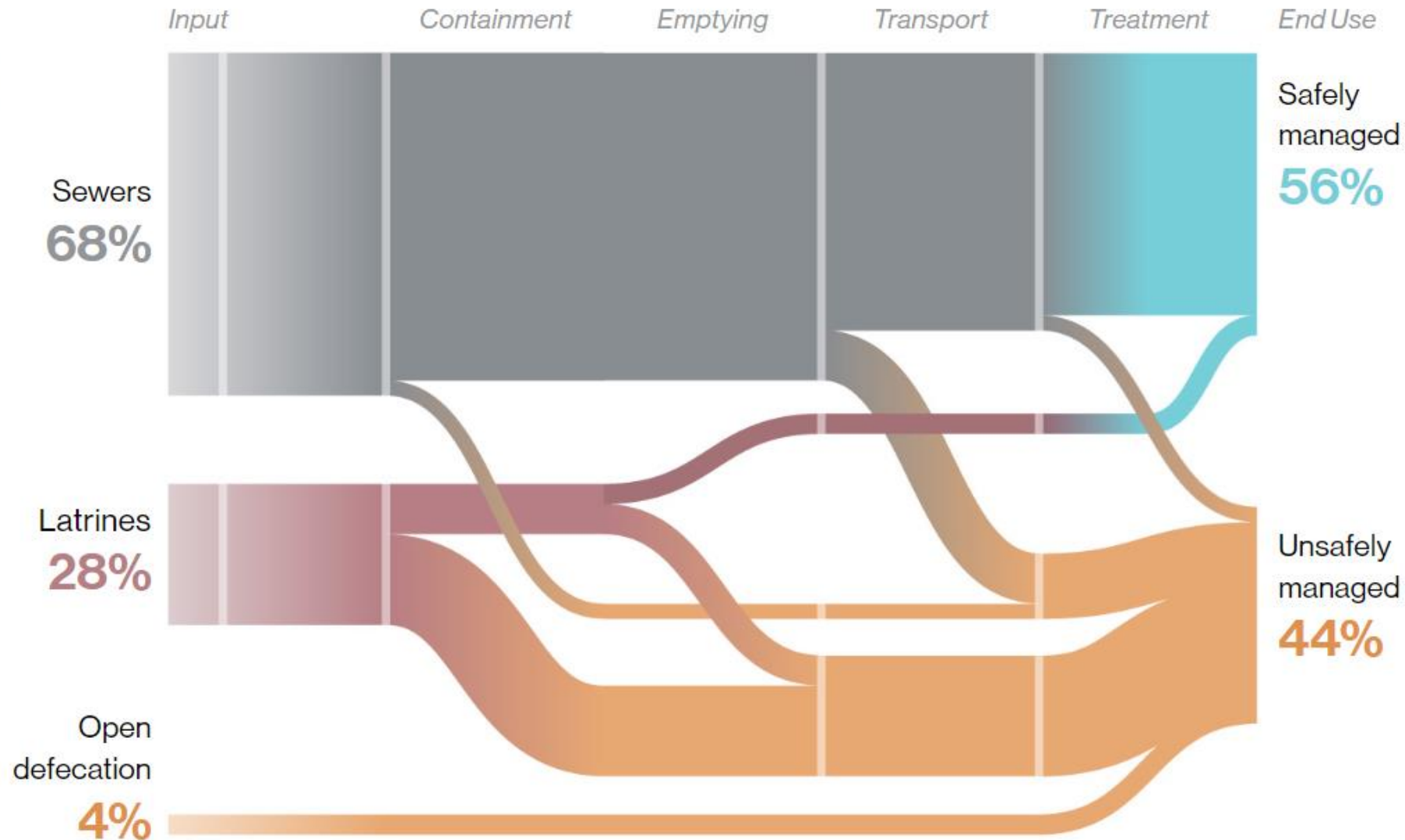
source: <https://www.nationalgeographic.com/magazine/article/toilet-defecate-outdoors-stunting-sanitation>

Lack of water treatment/sanitation in highly populated areas (Delhi, India)

OVERFLOWING CITIES

Sewers aren't guarantees: In Delhi only 56 percent of waste is safely managed, because sewers leak and nearly a third of the booming city isn't connected. Many latrines empty into open drains, and 4 percent of residents — some 700,000 — defecate outdoors.

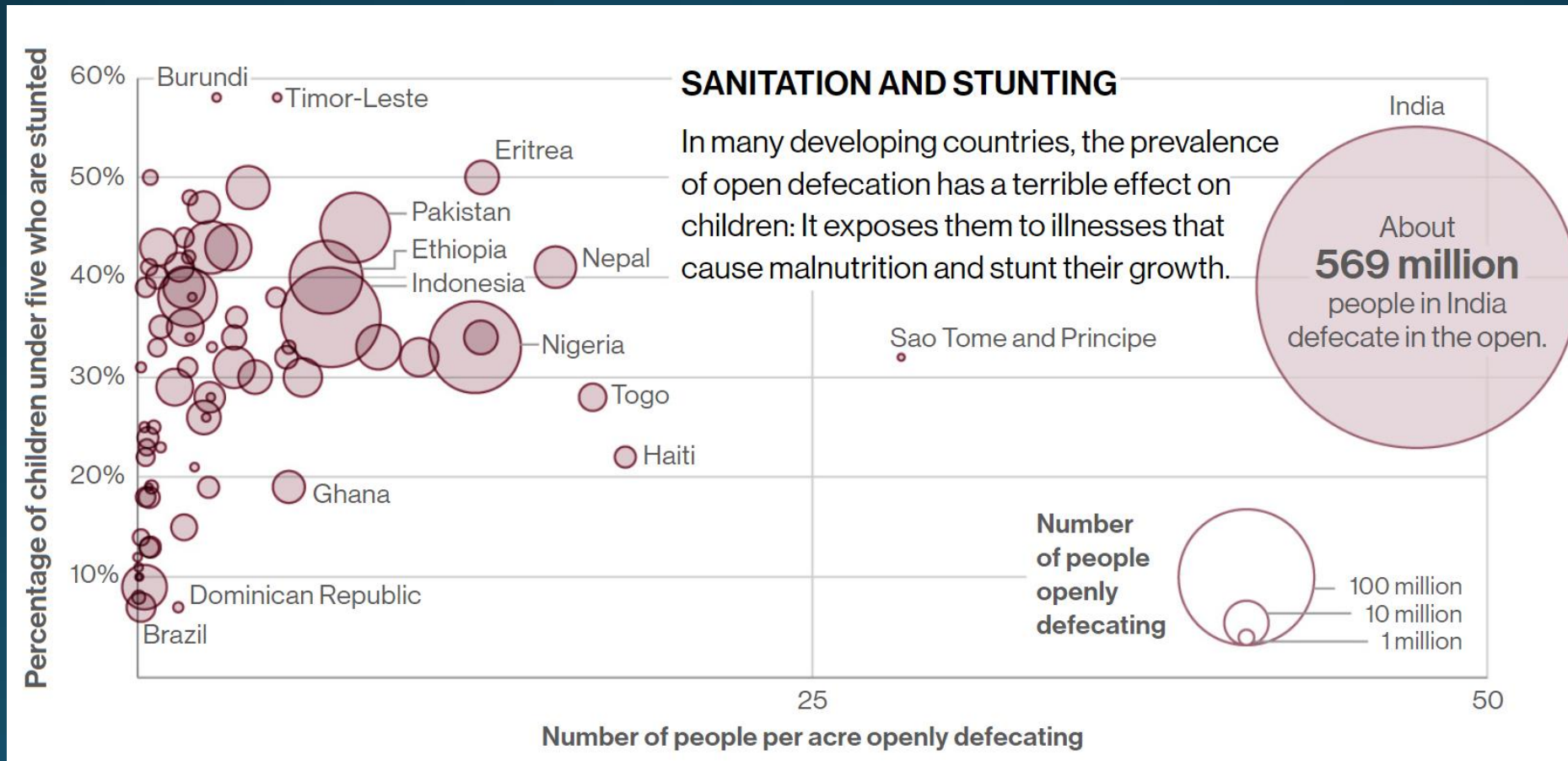
Waste treatment in Delhi, India



JASON TREAT, NGM STAFF;
KELSEY NOWAKOWSKI
SOURCES: LINDA STRANDE, SWISS FEDERAL
INSTITUTE OF AQUATIC SCIENCE AND
TECHNOLOGY (EAWAG); EMILY C. RAND,
WORLD BANK; CENTRE FOR SCIENCE AND
ENVIRONMENT, NEW DELHI

Lack of water treatment/sanitation: consequences

- diarrhea kills over 117,000 children under age five each year in India
- low water quality caused by lack of proper sanitation contributes to stunting of children



Water use in agriculture

- the standards for water quality in agriculture are (obviously) lower in comparison to drinking
- in many cases the quality parameters of water used in agriculture are not measured at all
- among the properties that are important is the salinity of irrigation water (especially in arid environments)
- whereas most of the drinking water originates from subsurface, larger part of water used in agriculture comes from rain, rivers or lakes
- water is used in agriculture mainly for irrigation purposes
- livestock production is more demanding (especially cows) when it comes to water consumption compared to growing plants only; the reason is relatively obvious, livestock animals as herbivores, must consume huge amount of plant biomass to grow their bodies

Water footprint: meat production

Table 3 *Calculated blue water footprint (BWF), green water footprint (GWF) and stress-weighted water footprint (WF) of 10 beef and six sheep study farms in litres of water/kg CW output for 2 years, 2014 and 2015*

Parameters	Beef				Sheep			
	Average	Minimum	Maximum	SD	Average	Minimum	Maximum	SD
On-farm BWF	64	19	173	48	37	22	64	11
Concentrates GWF	816	183	1843	426	936	127	1765	515
Concentrates BWF	105	23	236	55	0	0	0	0
Grass GWF	7406	4174	10 875	2068	6699	4762	8932	1398
Total BWF	169	73	409	88	37	22	65	11
Total GWF	8222	4871	11 058	1895	7635	4983	9891	1467
Total volumetric WF	8391	4993	11 130	1860	7672	5017	9933	1471
Stress-weighted ^a on-farm BWF	2.3	0.7	6.3	1.8	1.3	0.8	2.4	0.4
Stress-weighted concentrate BWF	89	20	201	46	0.7	0.1	1.3	0.4
Total stress-weighted BWF	91	22	207	47	2.0	1.3	3.5	0.7

^aStress-weighted = stress-weighted WF, weighted using the water stress index.

Water footprint: meat and other animal goods

Authors	Method	Product	Water Footprint	
			Irrigated Farms	Rainfed Farms
Mekonen and Hoekstra (2012)	WFN	1kg Milk	1000 L H ₂ O	
		1 kg Beef	15400 L H ₂ O	
		1 kg Eggs	3300 L H ₂ O	
Chapagain and Hoekstra (2004)	WFN	1 kg Chicken meat	4300 L H ₂ O	

source: Alberto Stanislao Atzori et al. / Agriculture and Agricultural Science Procedia 8 (2016) 50 – 57

Water footprint: various food products

source: Chapagain AK, Hoekstra AY (2004) Water Footprints of Nations. Value of Water Research Report Series No. 16, UNESCO-IHE. The Netherlands: Delft. www.waterfootprint.org

Average virtual water content	
Product	Virtual water content (l)
1 cup of tea (250 ml)	35
1 cup of coffee (125 ml)	140
1 glass of beer (250 ml)	75
1 glass of wine (125 ml)	120
1 tomato (70 g)	13
1 potato (100 g)	25
1 apple (100 g)	57
1 slice of bread (30 g)	40
1 plate of rice (100 g)	340
1 egg (40 g)	135
1 glass of milk (200 ml)	200
1 slice of cheese (100 g)	500
1 chicken breast fillet (200 g)	780
1 pork steak (200 g)	960
1 beef steak (200 g)	3,000

Water use in agriculture: plant growth and the role of photosynthesis

- Transpiration ratio = moles of transpired water / moles of assimilated carbon
expresses water efficiency of photosynthesis
- C₃ plants ≈ 500
- C₄ plants ≈ 200
- CAM plants ≈ 50
- Many agricultural plants are C₃, including wheat, barley, rapeseed, rice, or soybean
C₄ plants: corn, sorghum, sugarcane, millet, and switchgrass
CAM plants: Pineapple, Agave

Water use in agriculture: plant growth and the role of photosynthesis

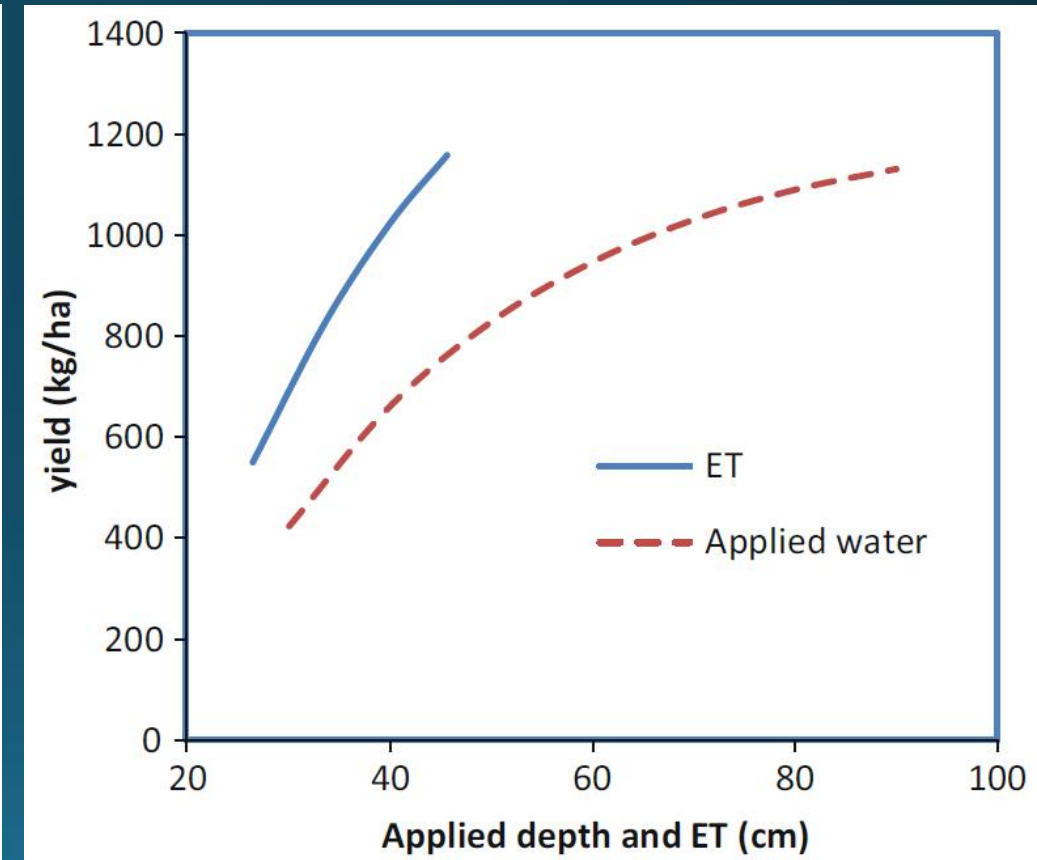
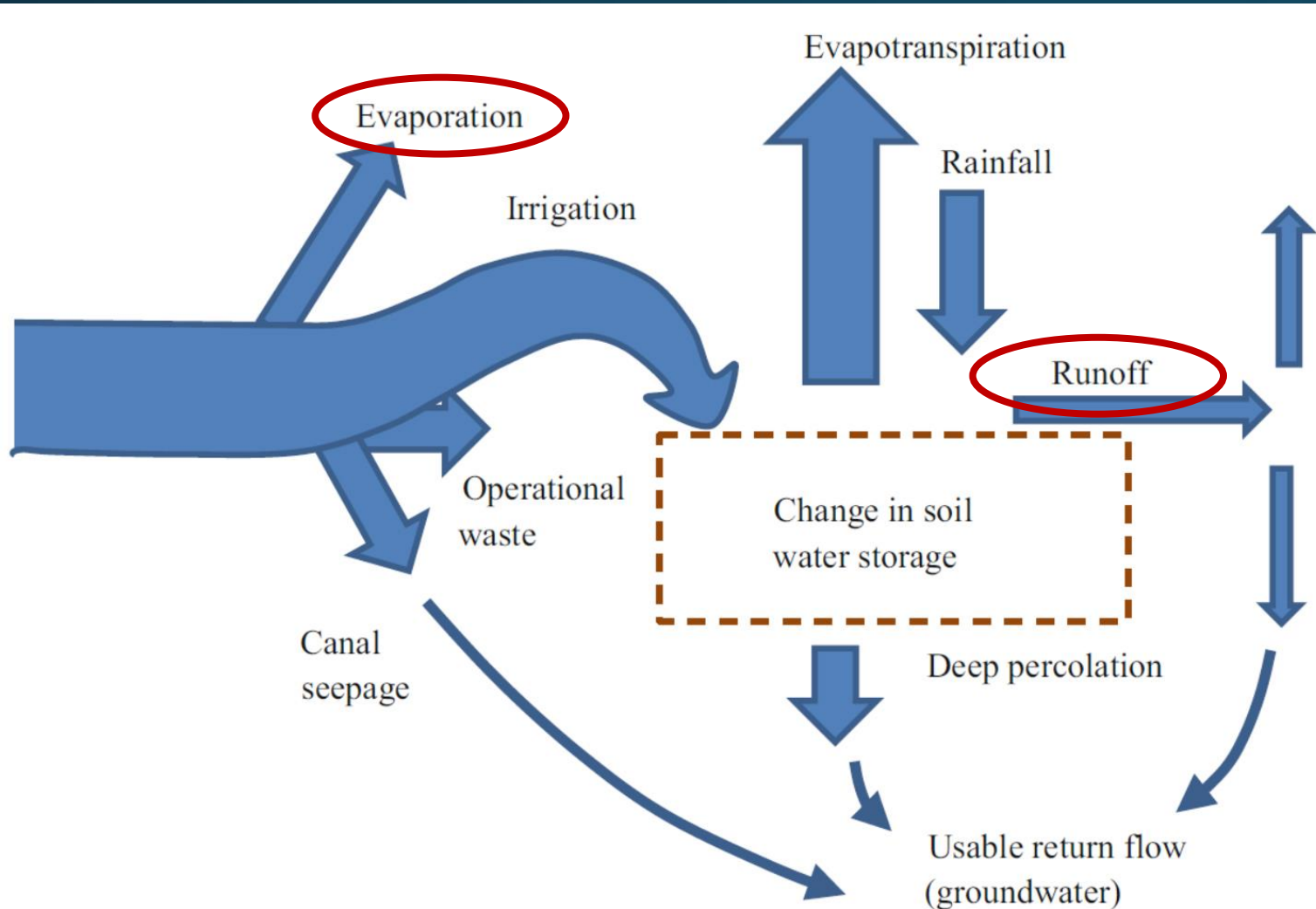
- C_3 , C_4 , and CAM plants have different mechanisms of C fixation. In the C fixation CO_2 is reduced in set of biochemical reactions called Calvin cycle.
- In case of C_3 plants first stable product in Calvin cycle is 3-phosphoglycerate, which consists of three carbon atoms (therefore C_3 plants). The enzyme Rubisco is involved these reactions in C_3 plants.
- In C_4 plants the mechanism of photosynthetic reduction of CO_2 is different. Instead of Rubisco enzyme, phosphoenolpyruvate carboxylase enzyme is used, and the product is oxaloacetate, which has 4 carbon atoms → C_4 plants.
- CAM plants (crassulacean acid metabolism) have their stomata closed during day. During night, when their stomata are opened, they fix CO_2 by the enzyme phosphoenolpyruvate carboxylase (similarly as C_4 plants) while malate is formed. This malate is stored in the vacuole and during daylight is released from the vacuole, decarboxylated and formed CO_2 is fixed through Calvin cycle

Water use in agriculture – irrigation

- 70 % of the world's food is now produced by irrigated agriculture.
- Many of the rivers in the arid and semiarid parts of the world were dammed partially because of irrigation need.
- Prior irrigation expansion (in the early 1970s) large-scale famines had followed droughts in India.
- The introduction of dams and irrigation made double-cropping possible.
- International Committee on Irrigation and Drainage found that there are almost 300 million ha of land is being irrigated in the world (which roughly equals to 1/3 of China).
- One of the most important concepts in water resources management is sustainability. With respect to groundwater resources, it means that the rate of extraction from an aquifer should not exceed the rate of aquifer recharge.

Water use in agriculture – irrigation

Farm scale water balance → the goal is to reduce/limit evaporation and runoff



Agriculture – irrigation methods

- older – traditional with no external force (pressure) → relying solely on gravity
- newer (more recent) piped systems → water is transported by applied pressure (usually 2 – 3 bars) , which is provided by pumping unit(s) or supply tank elevated at certain point above reference level
- in practice the two approaches are often combined to effectively (economically) deliver water in given circumstances and environmental settings

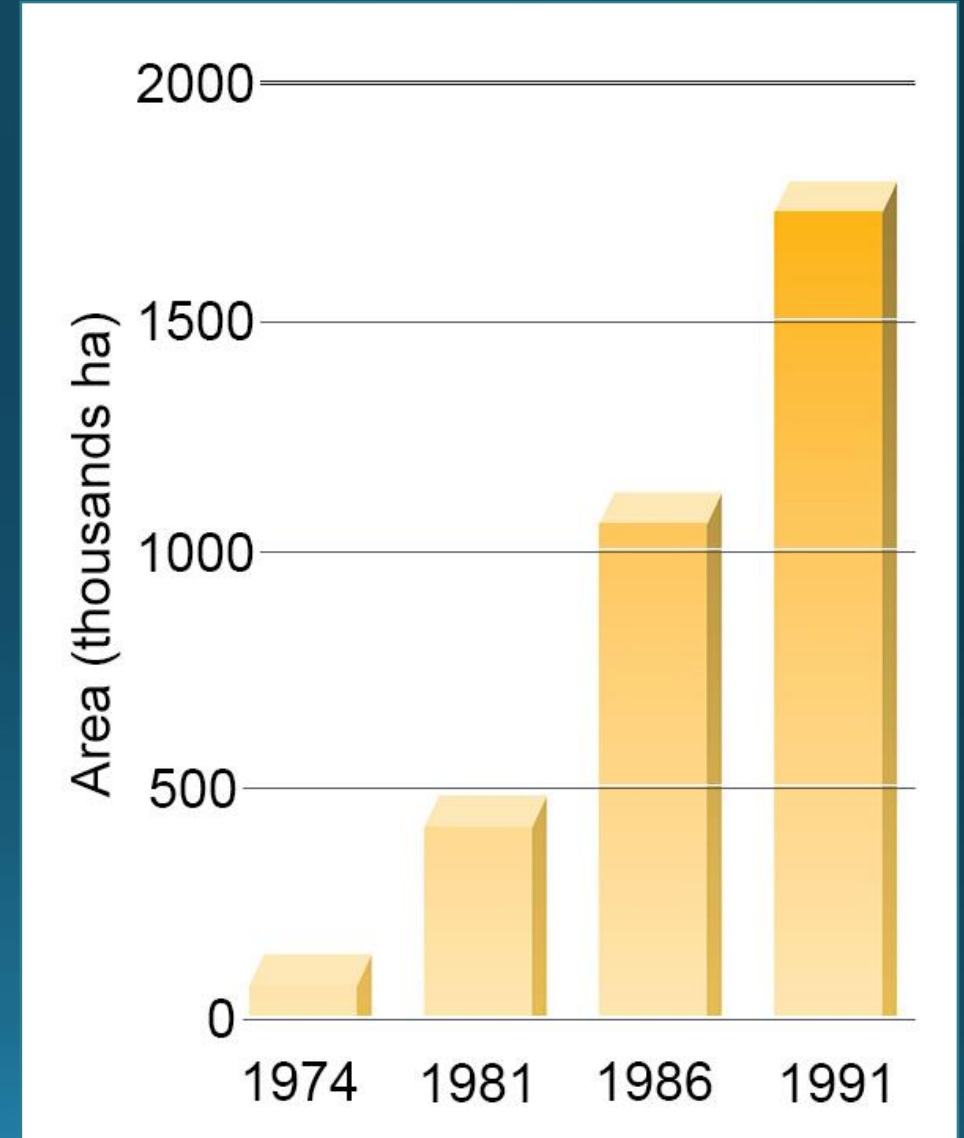
Agriculture – irrigation methods

- 1. Surface: water is applied by gravity across the soil surface by flooding or small channels (i.e., basins, borders, paddies, furrows, rills, corrugations)
- 2. Sprinkler: water is applied at the point of use by a system of nozzles (impact and gear driven sprinkler or spray heads) with water delivered to the sprinkler heads by surface and buried pipelines, or by both.
- 3. “Micro” irrigation: water is applied to the point of use through low pressure, low volume discharge devices (i.e., drip emitters, line source emitters, micro spray and sprinkler heads, gravity and low-pressure bubblers) supplied by small diameter surface or buried pipelines.
- 4. Subirrigation: water is made available to the crop root system by upward capillary flow through the soil profile from a controlled water table.

Each irrigation method and irrigation system has specific site applicability, capability, and limitations.

Agriculture – irrigation (more localized water delivery)

- in the past: use of sprinkler irrigation and/or flooding → disadvantage: loss of water via evaporation – water not entering plant roots (and partially also due to surface runoff or percolation to deeper soil layers)
- general trend: recent increase of localized irrigation →



Agriculture – irrigation methods

- no external force (pressure) involved in water transport → relying solely on gravity

figures: Waller and Yitayew, 2016. Irrigation and Drainage Engineering. Springer



Furrow irrigation system in Arizona



Square and trapezoidal irrigation ditches (Credit NRCS)



Imperial diversion dam (Courtesy of United States Bureau of Reclamation)

Agriculture – irrigation methods

- piped systems → water is transported by applied pressure (usually 2 – 3 bars)
- linear (bellow) or center pivot (right) architecture



Hand-line and wheel-line (Credit NRCS)



Center pivot irrigation systems (Credit NRCS)

Center pivot irrigation systems in the Sahara desert (Credit NASA)

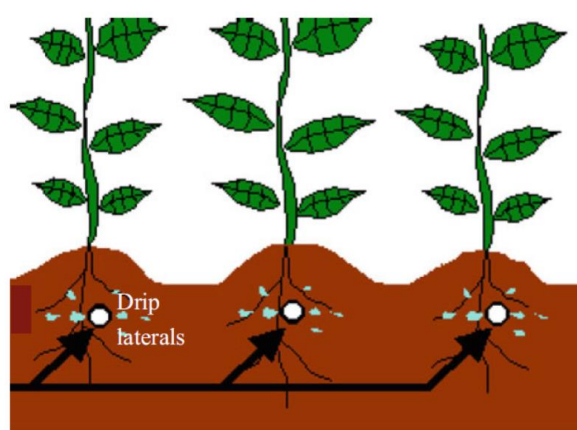


Agriculture – irrigation methods

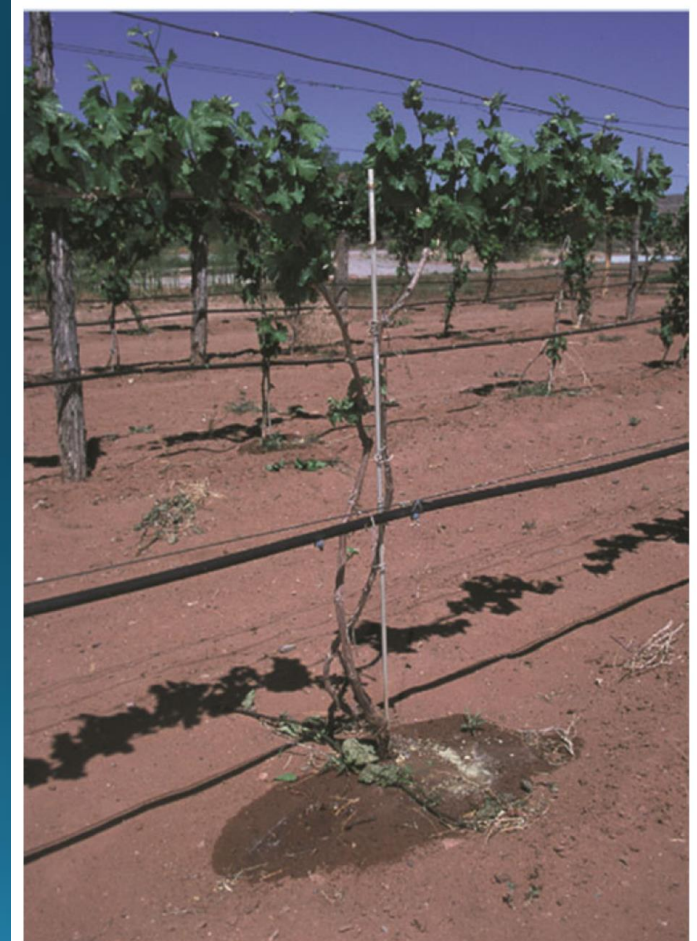
- drip irrigation → in arid climates (reduces evaporation/runoff as much as possible), water is applied either on the surface or from below



Drip emitter and polyethylene tubing hanging from trellis wire (Credit NRCS)



Subsurface drip irrigation (Courtesy of Paul Colaizzi, USDA-ARS)



Vineyard drip irrigation system on trellis (Credit NRCS)

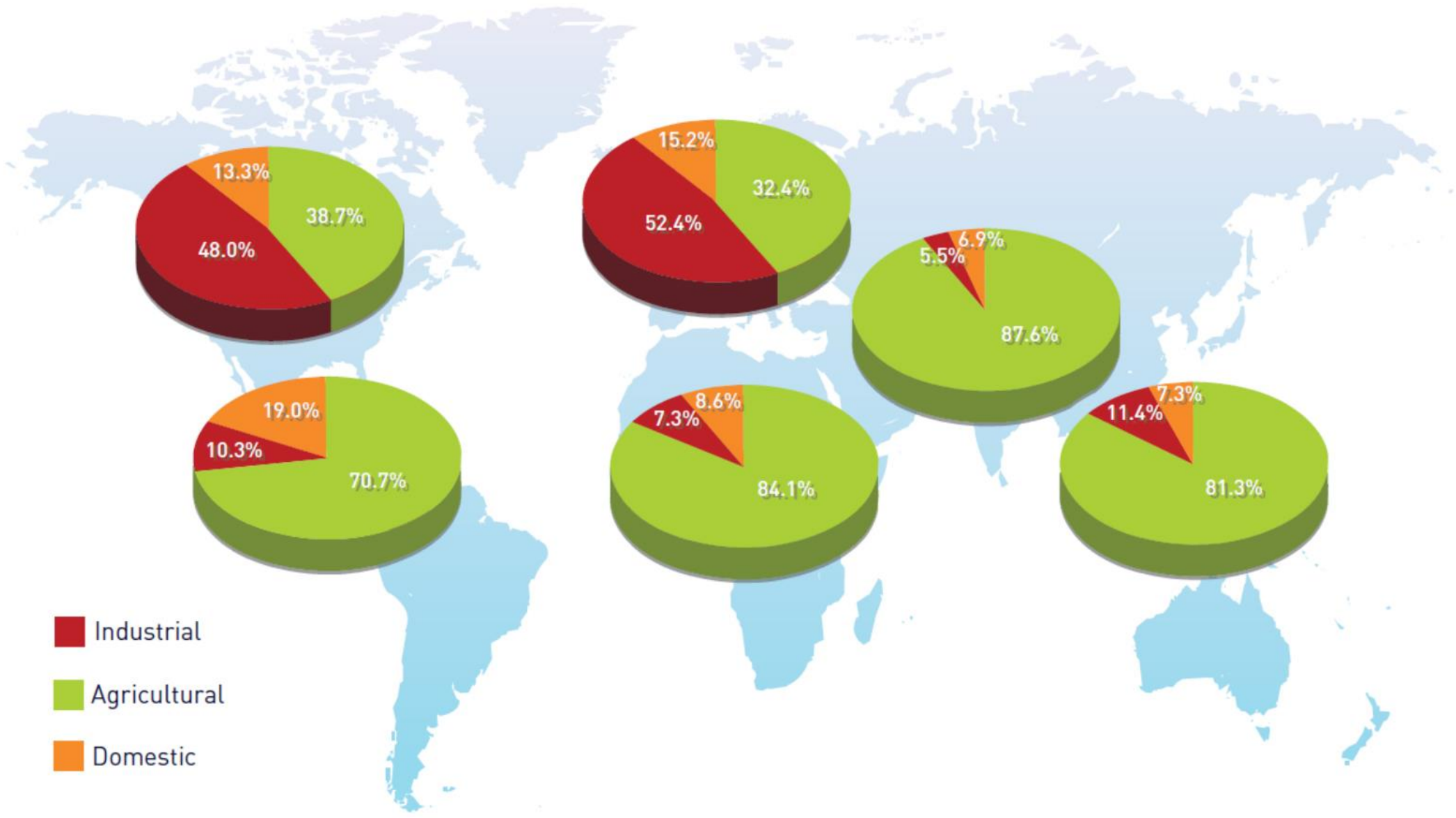
figures: Waller and Yitayew, 2016. Irrigation and Drainage Engineering. Springer

Water use in agriculture – irrigation

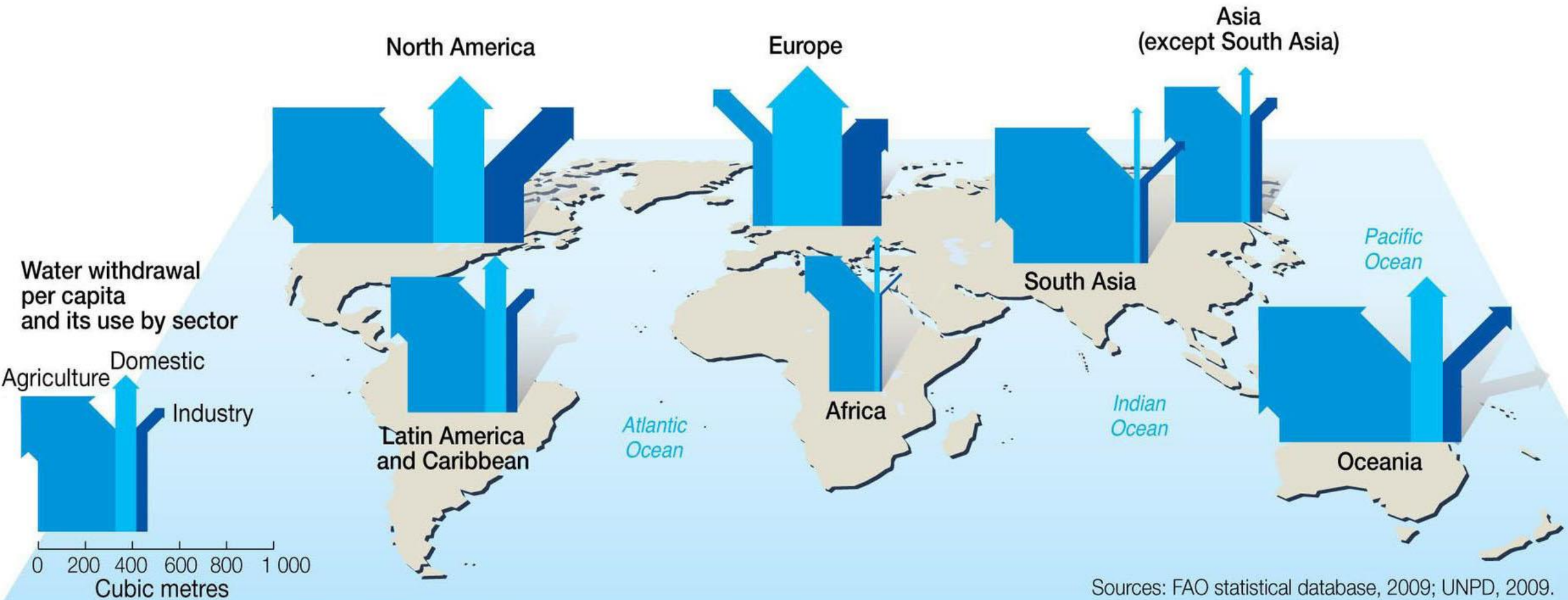
- Although quantitative aspect of water is often stressed, its quality is important as well
- Chemical composition: low concentration of sodium salts and potentially toxic elements
- Biological aspects: irrigation water can be source of plant pathogens
- Plant pathogens detected in irrigation water resources include species of *Phytophthora*, *Pythium*, bacteria, viruses, plant parasitic nematodes, and various genera of fungi

How fresh water is being used

Breakdown of use in developed and developing countries



Water withdrawal and use



Sources: FAO statistical database, 2009; UNPD, 2009.

Crops for human food / feed for livestock, biofuel

45 %

FEED (36 %) Diesel (9 %)*

55 %

Food for humans

Feed for livestock/fuel for industry

Food for humans

100 % calories

50 %

100 %

82% feed and fuel

USA (middle east)

In the year 2000, app. 7% of total corn production was used for making ethanol, today it app. 40%

61%

Europe

EU decided that up to 2020 10% of fuels must be made from renewable sources

58% food

China

China is second biggest grower of corn and 77% of crops is used as a feed for livestock. Humans consume 82% of rice crops

73%

USA

United states are biggest grower (and exporter) of corn, which is globally the most important feed for livestock. US are also important grower of soy, but in near future Brazil will probably take No.1 spot.

54%

Brazil

more than a half of soy beans is used for feeding the livestock. Brazil is world's leading producent of ethanol from sugar cane

72%

Africa

Small farmers grow crops mainly for direct consumption. Cassava, Yams, Sorghum are used for feeding the livestock

89%

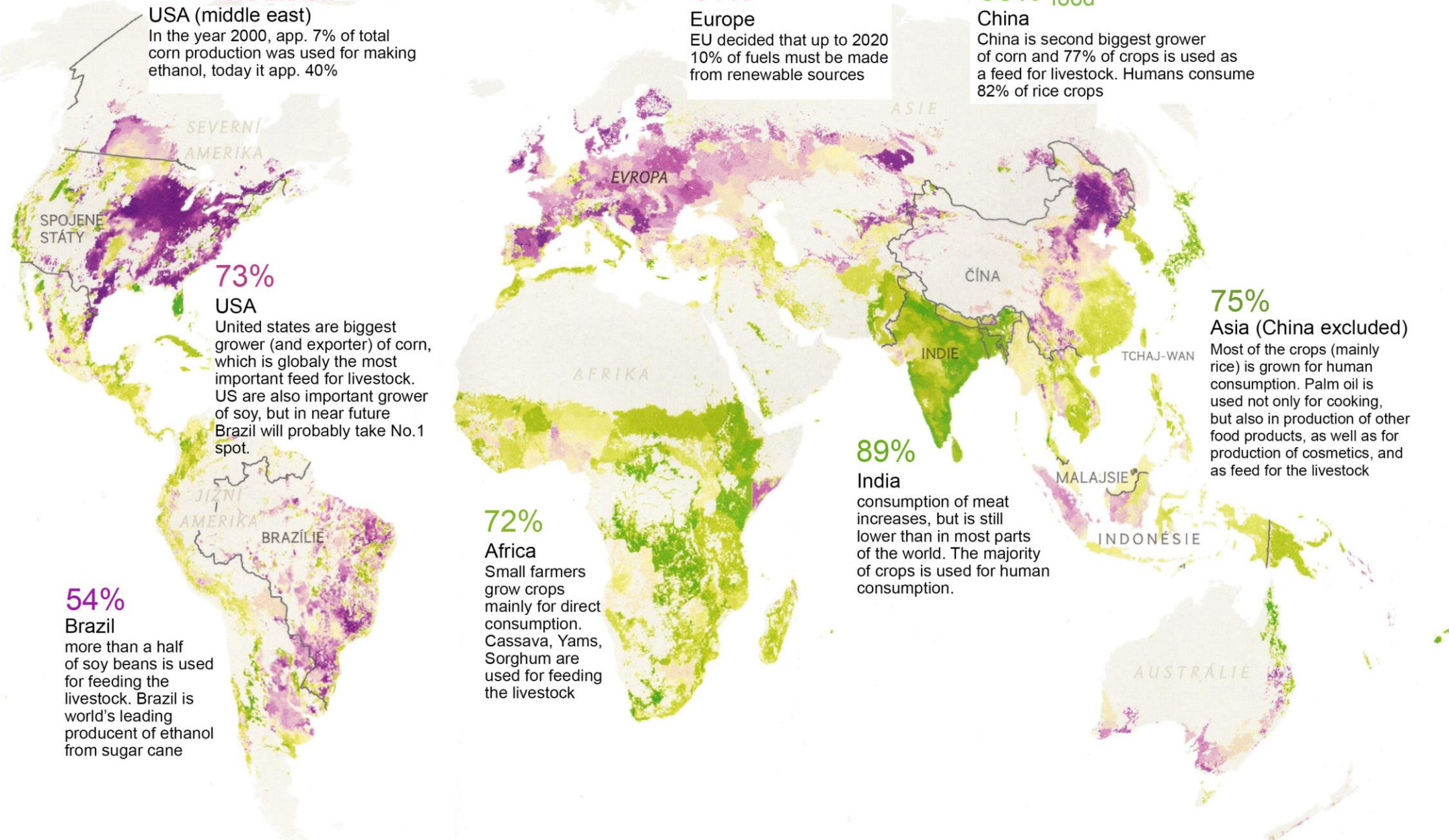
India

consumption of meat increases, but is still lower than in most parts of the world. The majority of crops is used for human consumption.

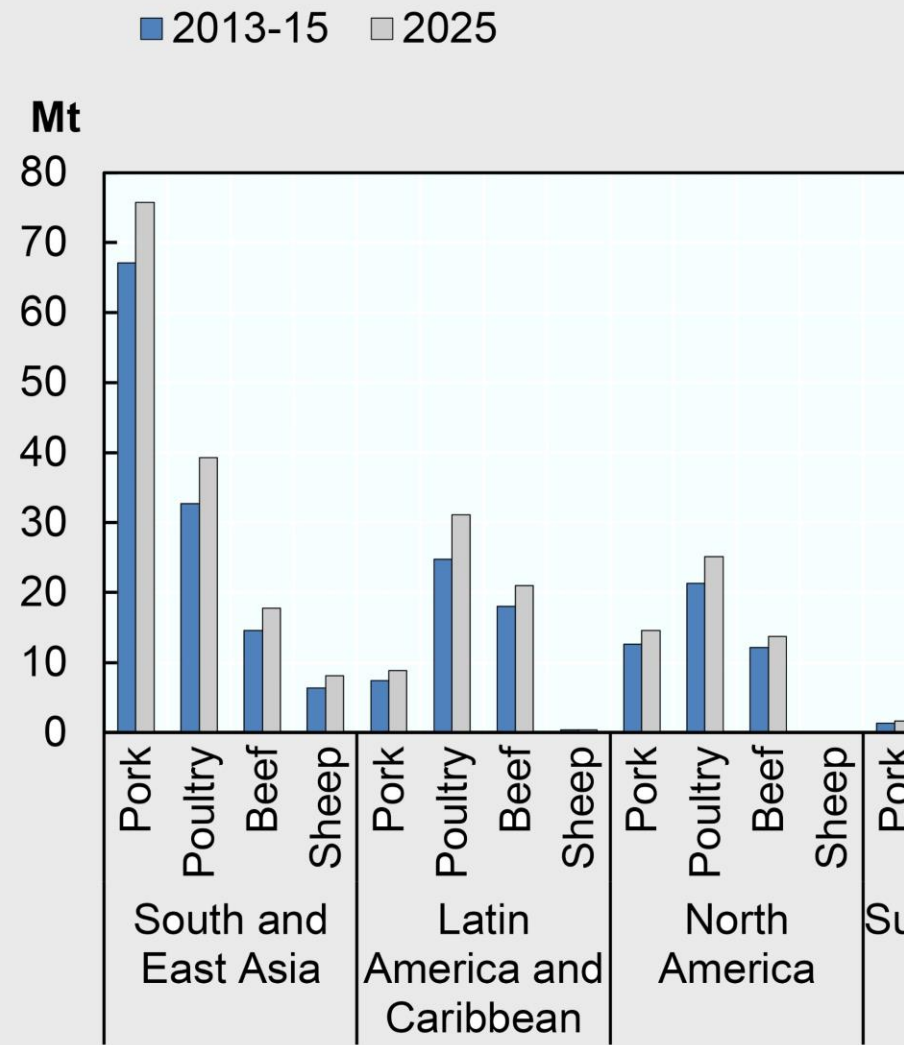
75%

Asia (China excluded)

Most of the crops (mainly rice) is grown for human consumption. Palm oil is used not only for cooking, but also in production of other food products, as well as for production of cosmetics, and as feed for the livestock



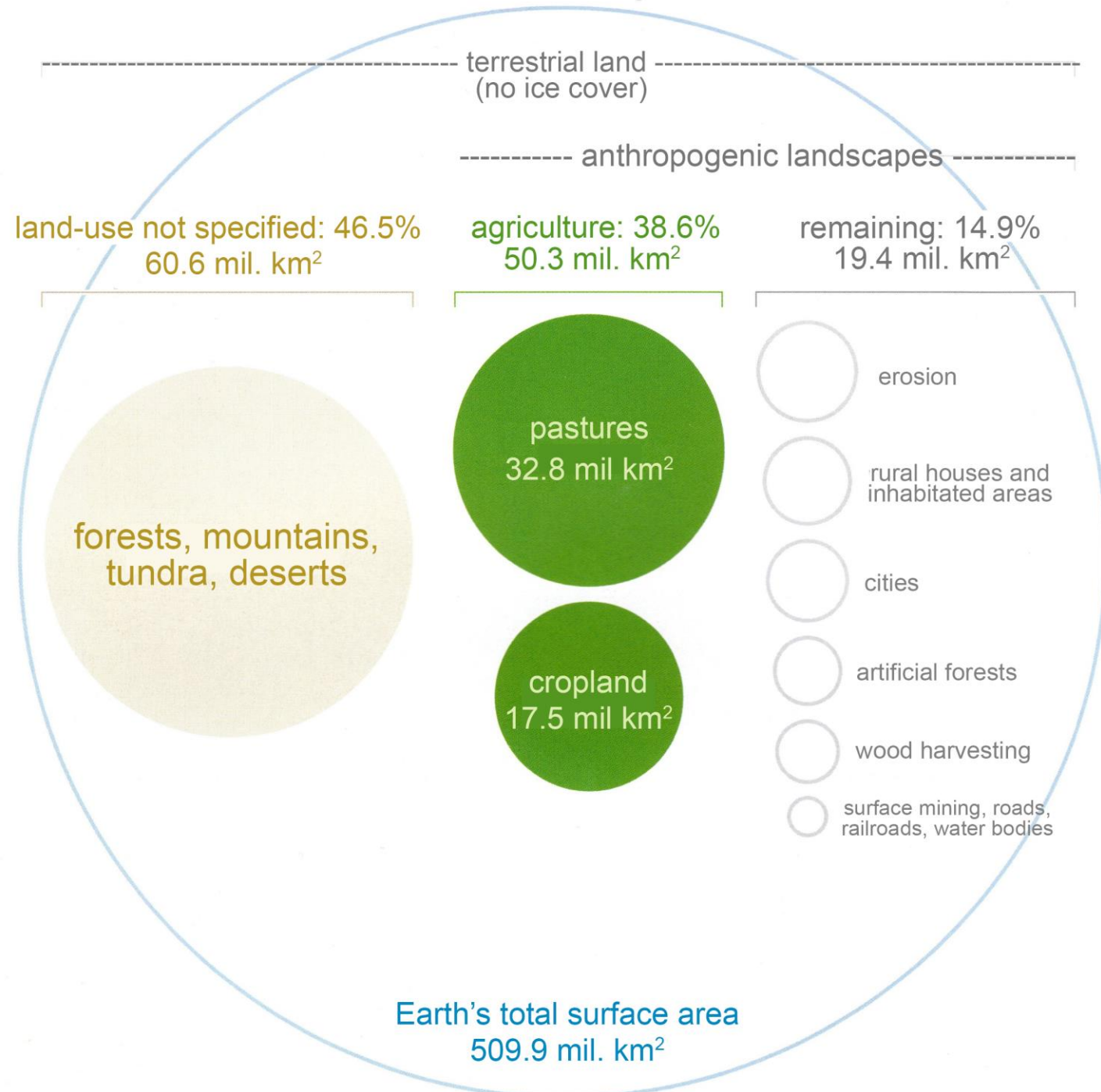
Global meat production:



GLOBAL MEAT CONSUMPTION

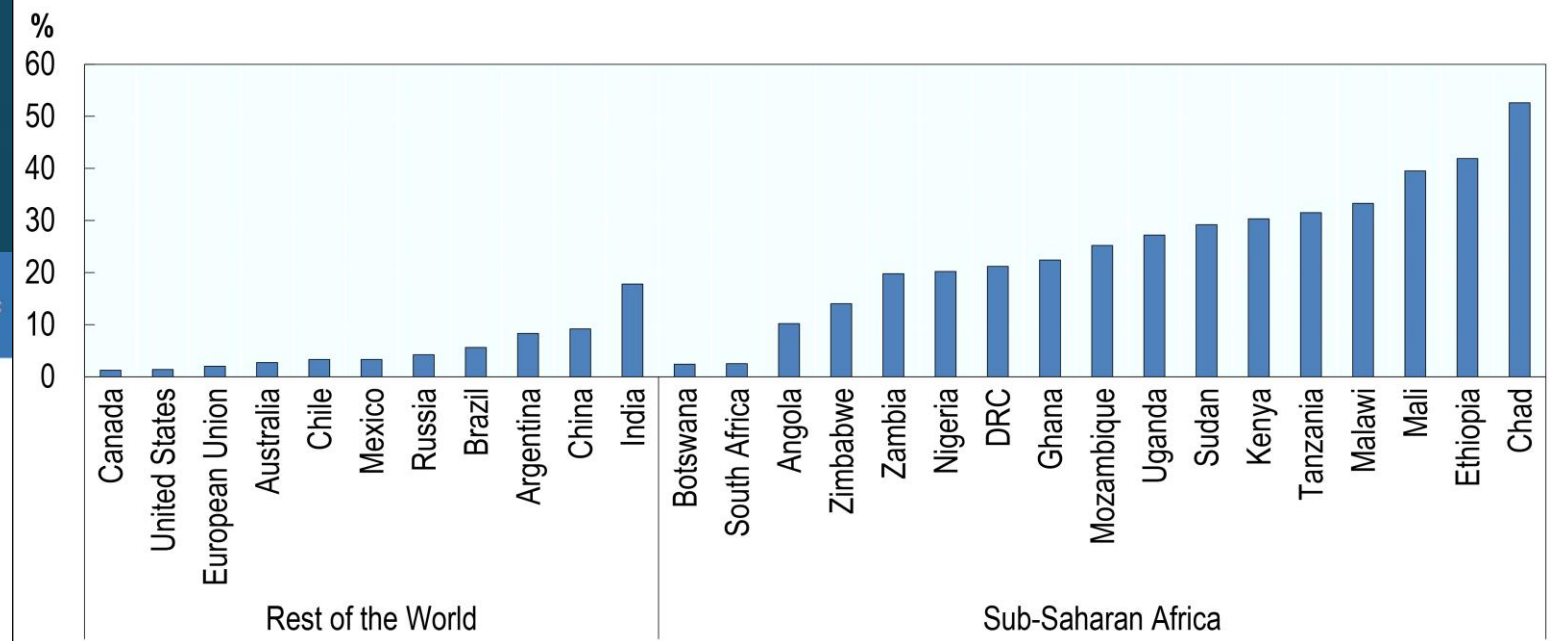
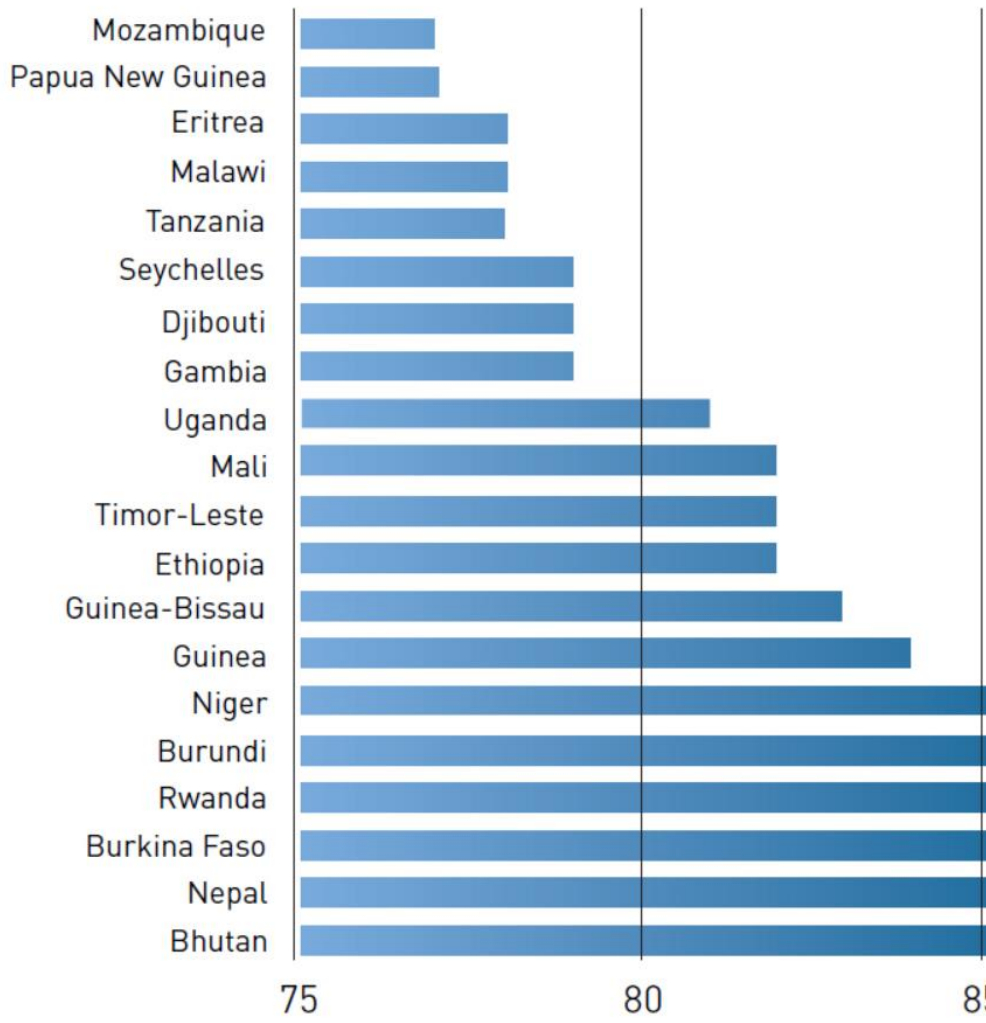
The FAO predicts a doubling in global meat consumption by 2050.
70 per cent of agricultural land worldwide is currently used for livestock, more than half of it for growing livestock feed.





agriculture as a share of total GDP → (2014)

The 20 Countries that Rely Most on Agriculture*



Growth of the area used for agriculture and the increase in crop yield from 2013/2015 to 2025 (left)
Share of agricultural area in 2025 (right)

