WRM in Arid and Semi-arid Regions

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Course: Integrated Water Resources Management
Module: Ecology & Water Resources

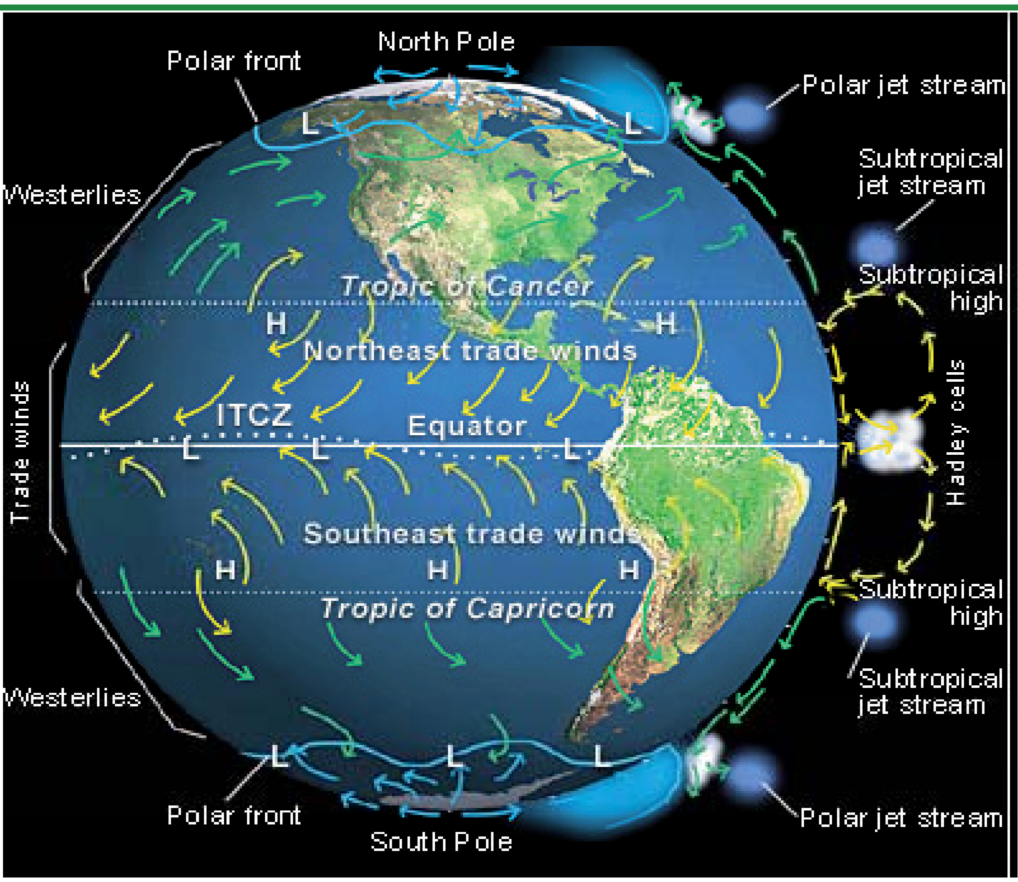
WATENV International Master Programme

Lecture: WRM in Arid and Semi-arid Regions

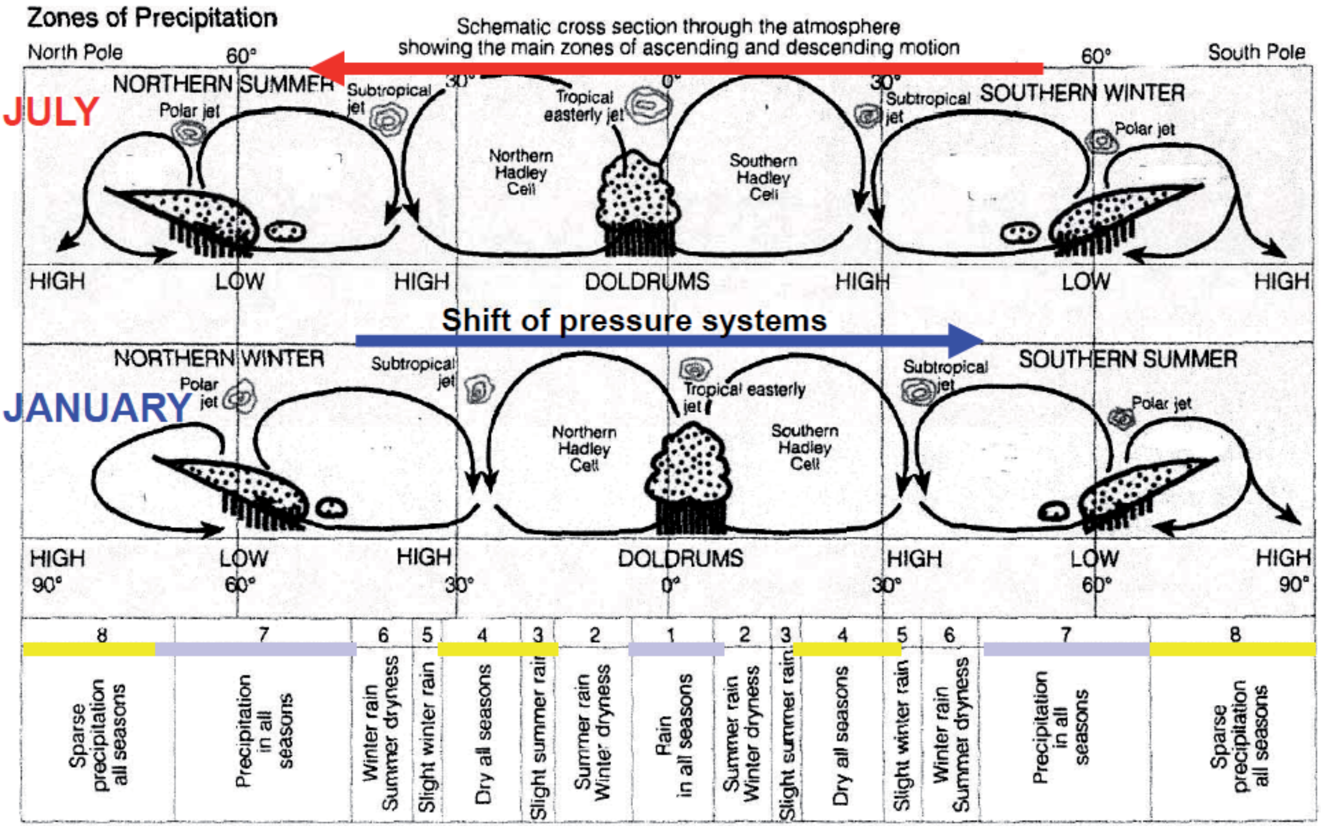
1 Global Climate and Vegetation Zones
2 The Physical Environment of Arid and Semiarid Regions
3 Soil Salinization
4 (I)WRM Approaches for Arid and Semiarid Regions

1 Global Climate and Vegetation Zones

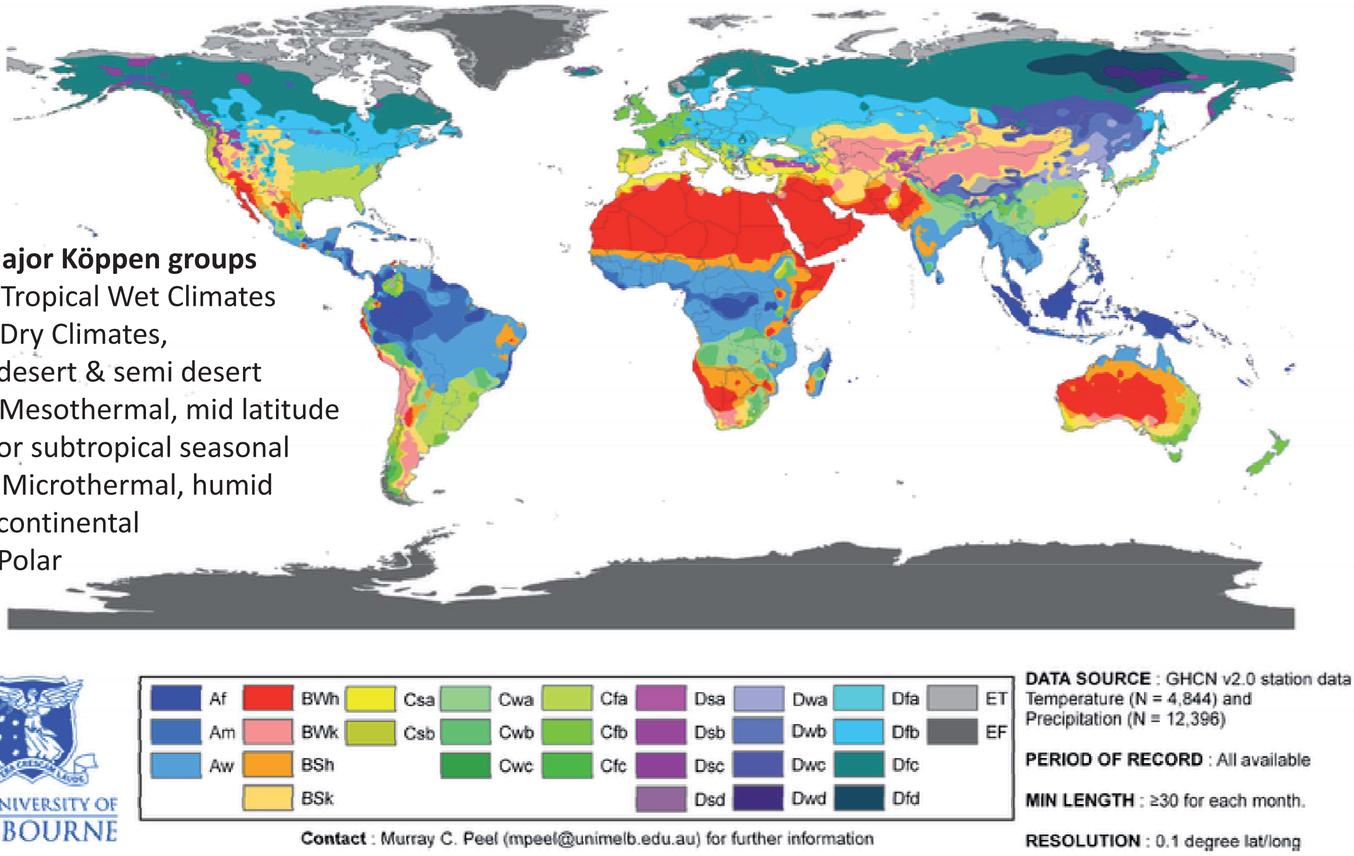
Global Atmospheric Circulation – Map View



Global Zones of Precipitation and Dryness



Köppen-Geiger Global Climate Classification

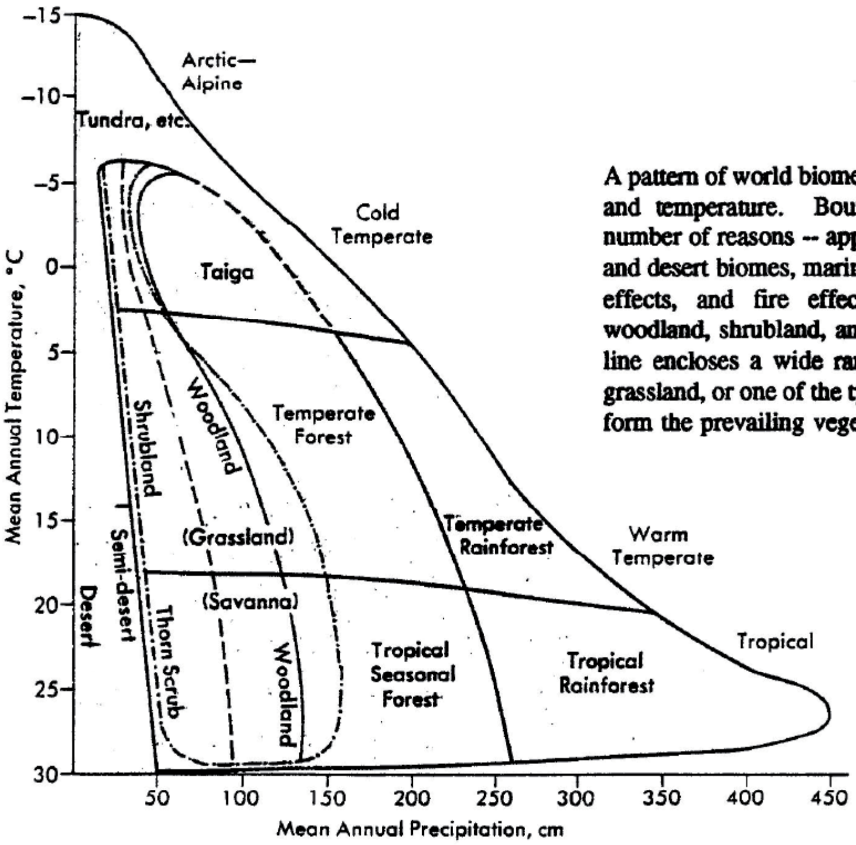


Major Köppen groups

A Tropical Wet Climates
B Dry Climates, desert & semi desert
C Mesothermal, mid latitude or subtropical seasonal
D Microthermal, humid continental
E Polar

THE UNIVERSITY OF MELBOURNE

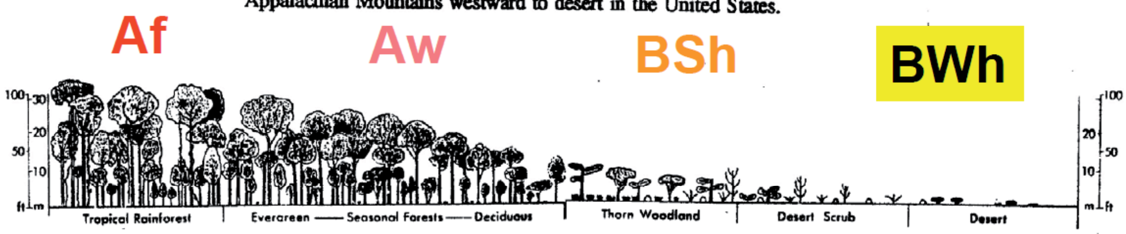
World Biomes



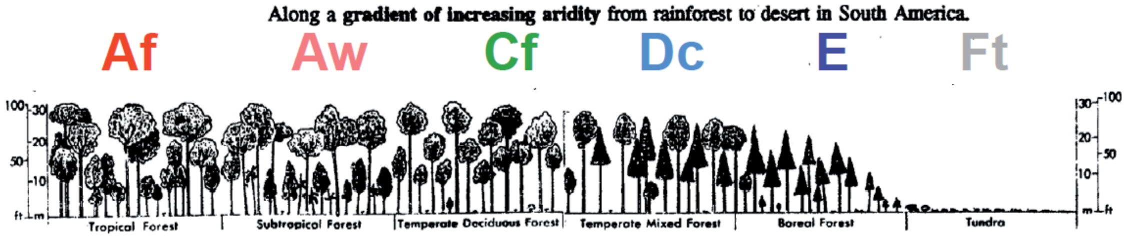
A pattern of world biome-types in relation to climatic humidity and temperature. Boundaries between types are -- for a number of reasons -- approximate. In climates between forest and desert biomes, marine vs. continental climatic effects, soil effects, and fire effects can shift the balance between woodland, shrubland, and grassland types. The dot-and-dash line encloses a wide range of environments in which either grassland, or one of the types dominated by woody plants, may form the prevailing vegetation in different areas.

Global Vegetation Gradient

EAST ==> WEST GRADIENT IN TEMPERATE LATITUDES
Along a **gradient of increasing aridity** from mesophytic (moist) forest in the Appalachian Mountains westward to desert in the United States.

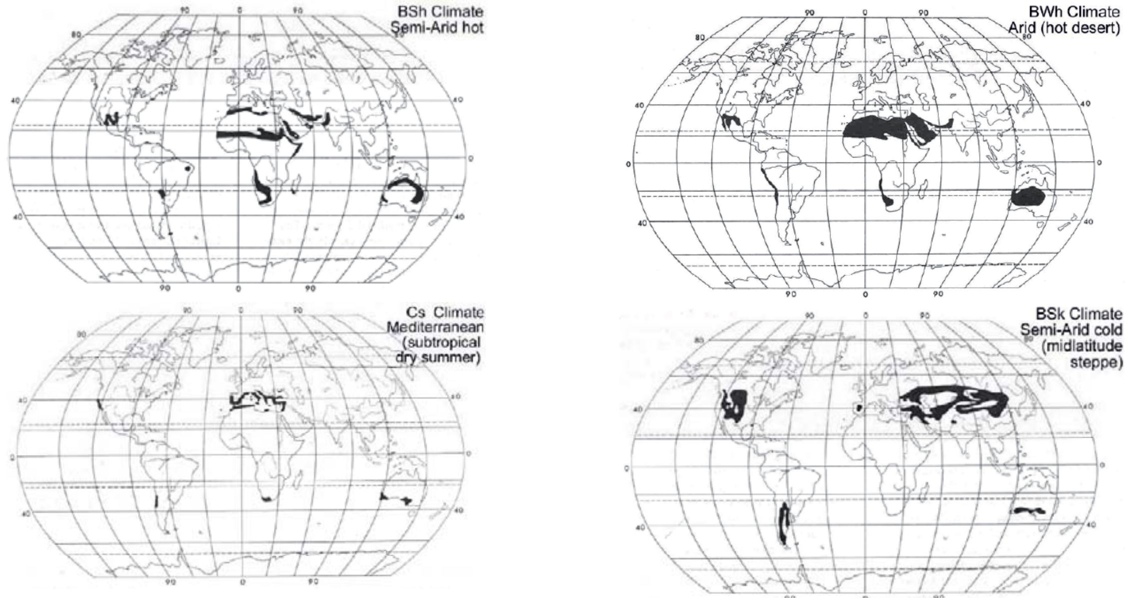


GRADIENT FROM TROPICAL ==> SUBTROPICAL LATITUDES
Along a **gradient of increasing aridity** from rainforest to desert in South America.

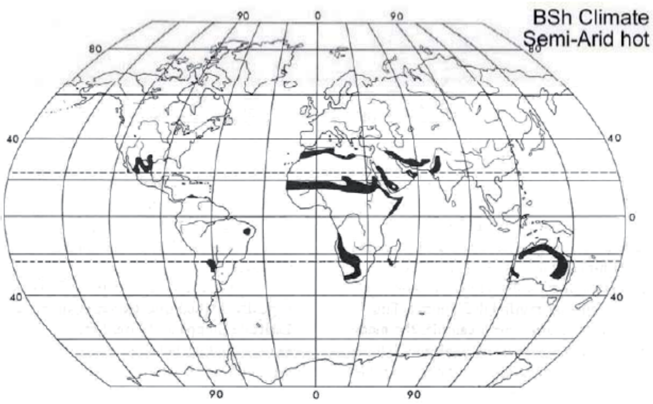


GRADIENT FROM TROPICAL ==> POLAR LATITUDES
Along a gradient of decreasing temperature from tropical seasonal forest northward (in forest biomes) to the arctic tundra.

2 The Physical Environment of Arid and Semiarid Regions



Climate: Semi-arid hot



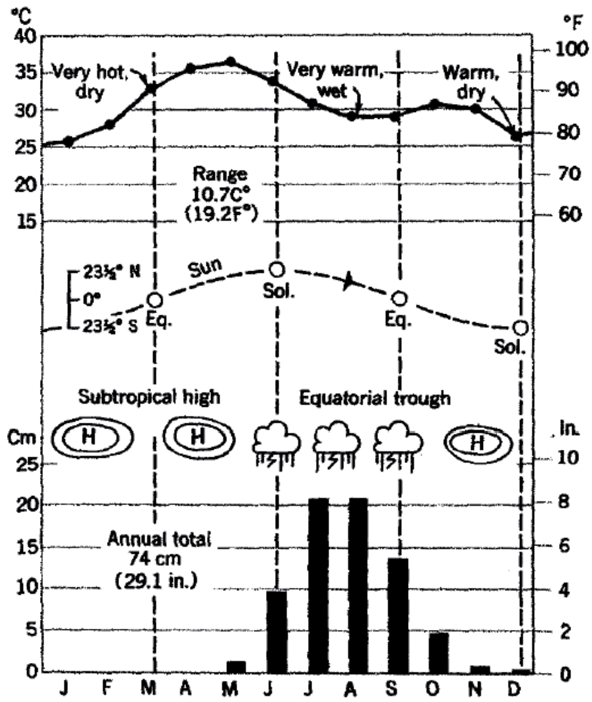
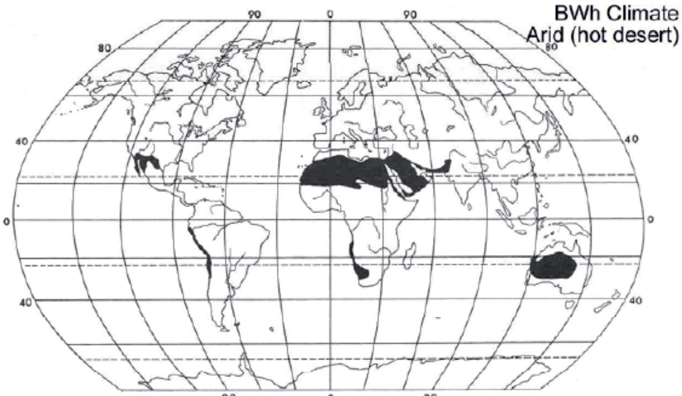


FIGURE 8.15 Dry tropical climate, semiarid subtype (4s). Kayes, Mali, at lat. 14½° N, lies in the Sahel of West Africa. In normal years there is a short wet season. The dry season is long, with a succession of rainless months.

Climate: Arid



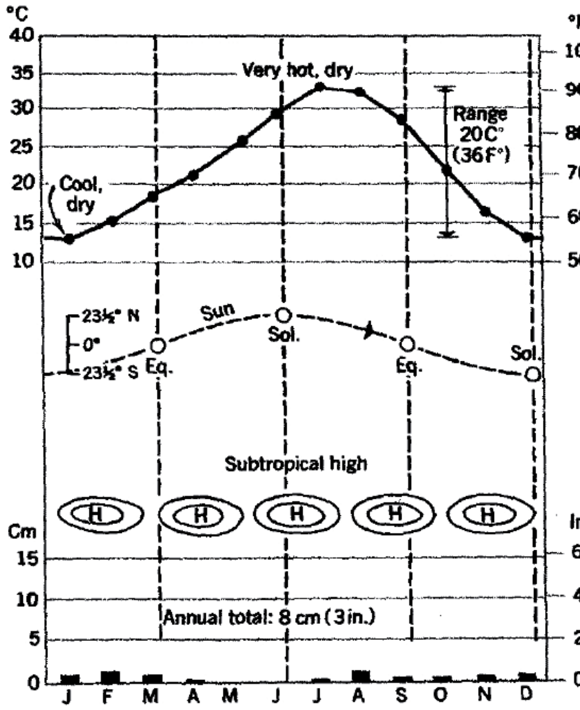
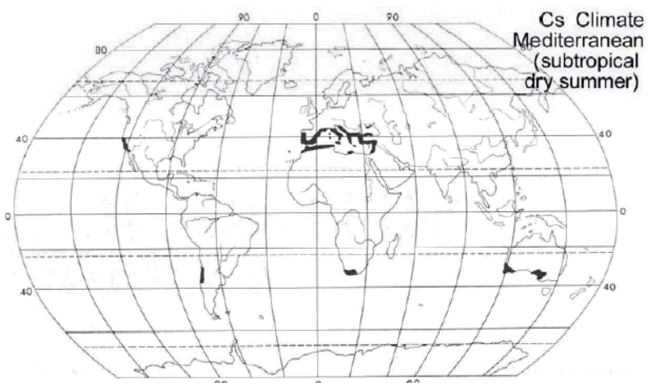


FIGURE 8.17 Dry subtropical climate, desert subtype (5d). Yuma, Arizona, lat. 33° N, has a strong seasonal temperature cycle. Compare with Wadi Halfa (Figure 8.14).

Climate: Mediterranean



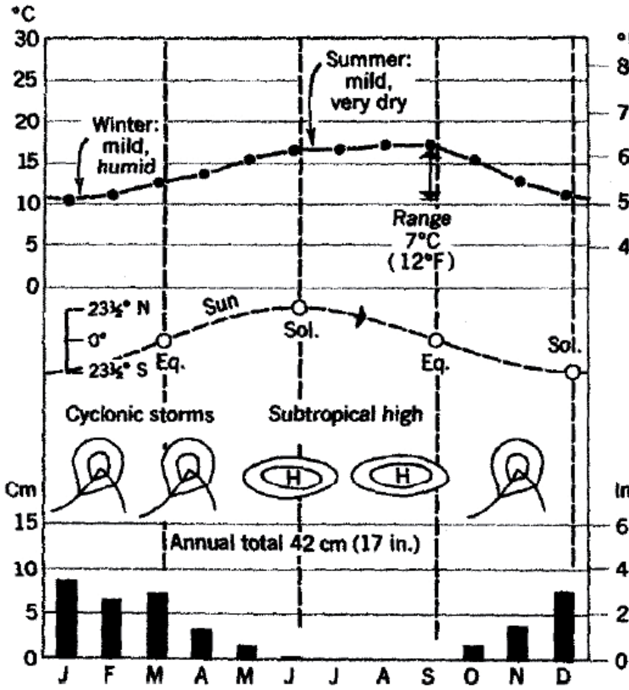
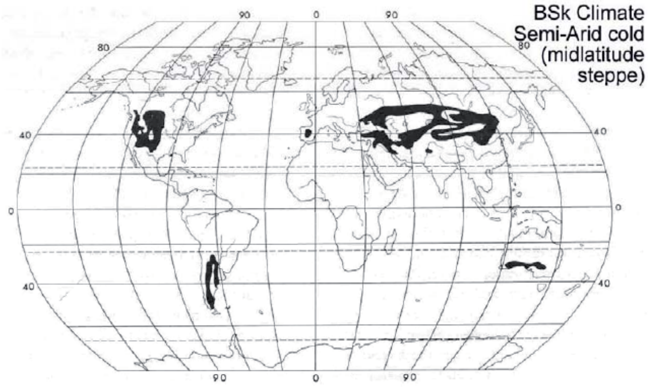


FIGURE 8.19 Mediterranean climate (7). Monterey, California, lat. 36½° N, has a very weak annual temperature cycle because of its closeness to the Pacific Ocean. The summer is very dry.

Climate: Semi-arid cold



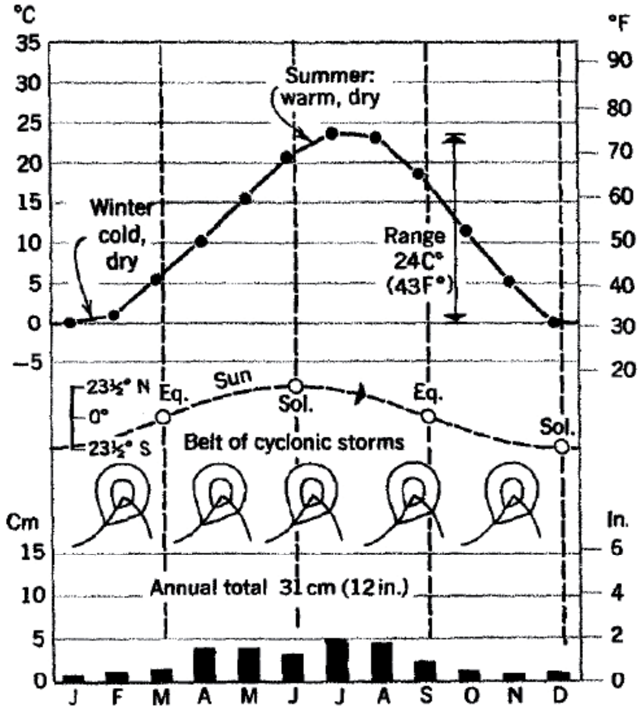


FIGURE 8.21 Dry midlatitude climate, semiarid subtype (9s). Pueblo, Colorado, lat. 38° N, shows a marked summer maximum of rainfall in the summer months.

Vegetation

Biome	Climate	Maximization of Phytosynthesis	Minimization of Water Loss
Desert, Semi-desert	Arid (BW) Semi-arid (BS)	Not a problem; availability of water main controlling factor	Deep roots, waxy leafs; deciduous habit; water storage in stems; ephemeral habit
Temperate Forests	Mediterranean (Cs)	Broadleaf and evergreen habits	Smaller/waxy leaves, need summer protection

Characteristics of Semi-arid Regions

- In semi-arid regions rainfall has a high variability in space and time: years without any precipitation, but local heavy rainfall events possible
- Rain fed agriculture is depending on rainfall amount and distribution during the vegetation season – high uncertainty!
- The knowledge of beginning and duration of rainy season is essential (-> forecast techniques)
- Probability of rainfall data -> risk analysis, improve the planning of the agricultural activities.

Source:

3 Soil Salinization

Salinization is

when the amount of salt in soil increases to contain more salt than normal.

Usually, plants and soil organisms are killed or their productivity is severely limited on affected lands.

Types of Soil Salinization

Dry land salinization
(natural)

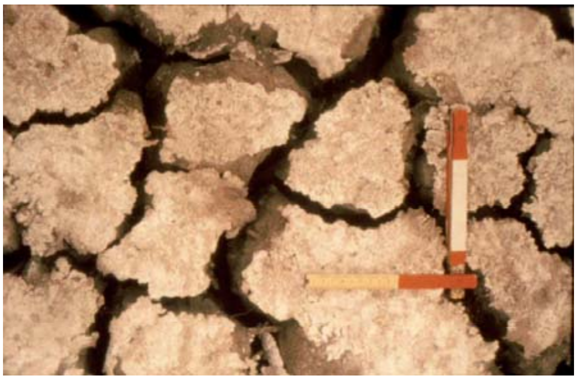
Irrigation salinization
(human activity)

Soil Salinization Worldwide

The Salinity Problem

- Soil salinization has been identified as a major process of land degradation,
- and the main cause of desertification, particularly in arid and semi-arid areas.

- **The world is losing at least *3 ha of productive land <u>per minute</u>* because of soil salinity!**



The Salinity Problem

Main Causes of Salinization

The main factors leading to a progressive accumulation of salts at/or near to the soil surface are:

- High content of salt in the soil profile
- Salinity of the soil solution
- Mineralized groundwater
- High level of the water table
- Intrusion of sea-water in the aquifer
- Irrigation with saline waters
- Absence of adequate drainage systems

Main Causes of Salinization

Human-induced factors may lead to salinization of irrigated land:

- Irrigation of waters rich in salts;
- Rising water table due to human activities (filtration from unlined canals and reservoirs; uneven distribution of irrigation water; poor irrigation practice, improper drainage);
- Use of fertilizers and amendments, especially in situations of intensive agriculture with low permeability and limited possibilities of leaching;
- Wastewater disposals and wastewater irrigation;
- Contamination of soils with salt-rich waters and industrial by-products.

4 (I)WRM Approaches

Drought management: mitigating negative effects of drought

Make use of marginal water resources

Sustainable use of fossil resources?

Working in Arid and Semi-arid Regions

- Limited science base
- Scarce data
- Experience from humid regions inappropriate
- Regions of potential conflicts over water scarcity

- More research
- Data sharing
- Monitoring networks
- Strategies to support peace and security

UNESCO IHP, 2011

World Wide Services for Hydro-meteorological Data

- UNESCO United Nations Education, Scientific and Cultural Program
- WMO World Meteorological Organization
- UNDP UN Development Programme
- UNEP UN Environmental Programme
- World Weather Records
- World Survey of Climatology
- National Climatic Data Center (NCDC), US weather service
- World Data Center at the US National Climatic Center in Asheville/USA
- Global Runoff Data Centre at BfG, Koblenz, Germany
- Global Rainfall Data Centre at DWD, Offenbach, Germany

Water Resources Management Solutions

- Water Harvesting Techniques
  - Surface (rain/flood) water harvesting
  - Groundwater harvesting
  - Atmospheric water (fog/dew) harvesting
- Fossil Groundwater Resources
- Use of Saline Waters

Rainwater Harvesting

WH Type	Roof and Courtyard	Micro-Catchment	Macro-Catchment
Techniques	Treated surfaces e.g. sealed, paved, compacted, smoothened	Collecting surface runoff and storing in the root zone of an infiltration basin: contour bunds, interrow-WH, semicircular bunds, contour bench terraces, ...	Runoff from hillslopes is conveyed to the target area: hillside conduit systems, semi-circular hoops, cultivated reservoirs/tanks, stone dams, ...
Kind of Storage	cisterns, ponds, jars, tanks	soil profile (ponds)	soil profile, cisterns, ponds, reservoirs
Aquifer Recharge	none	very limited	limited

Prinz (2002), changed

Floodwater Harvesting

WH Type	Flood water harvesting within the stream bed	Flood water diversion
Techniques	Dam, inundation, infiltration: terraces, percolation dams	wild flooding water dispersion water distribution
Kind of Storage	soil profile reservoirs	soil profile ponds
Aquifer Recharge	strong	very strong

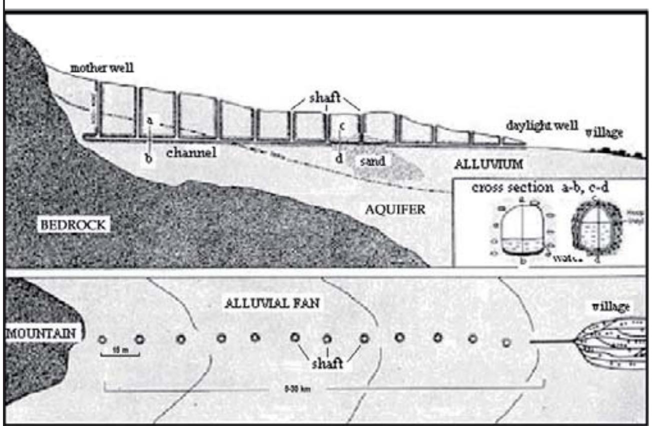
Prinz (2002), changed

Groundwater Harvesting

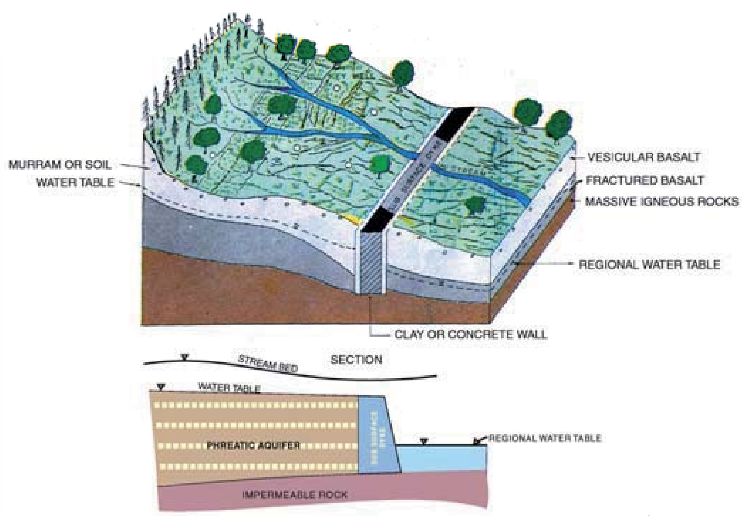
WH Type	Qanat system	Groundwater dams	Special wells
Techniques	short qanats medium sized qanats long distance qanats	sand storage dams subsurface dams	horizontal wells artesian wells
Kind of Storage	ponds	substrate profile	soil profile, ponds
Aquifer Recharge	limited	medium	medium

Prinz (2002), changed

Groundwater Harvesting: Qanat, GW Dam



Technical features of qanat (profile and plan)
Sala & Deom: The 261 Karez of the Sauran Region (Middle Syrdarya). Transoxiana 13, Agosto 2008



www.indg.in

Atmospheric Water Harvesting: Fog and Dew

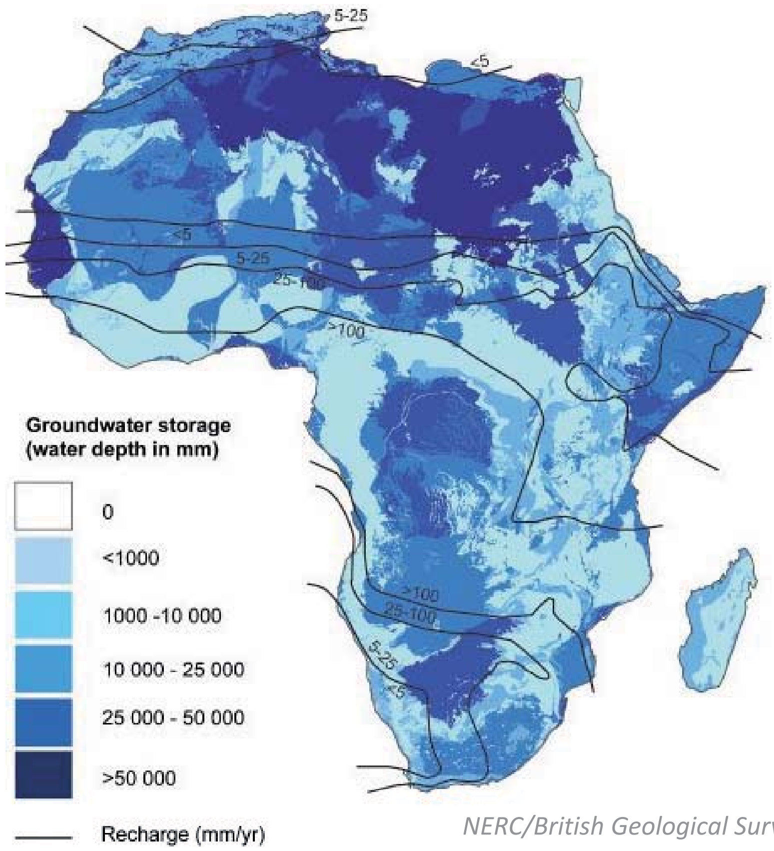
- Fog: suspension of very small, usually microscopic water droplets in the air
- Best conditions for utilization in coastal, low precipitation areas with nearby cold ocean currents (e.g. Namibia, Atacama)
- Plants and artificial surfaces (e.g. netting-surfaced traps or polyethylene sheets) can be exposed to collect moisture

Fog Harvesting in Bellavista, Peru (Source: National Geographic)

Fossil Groundwater Resources

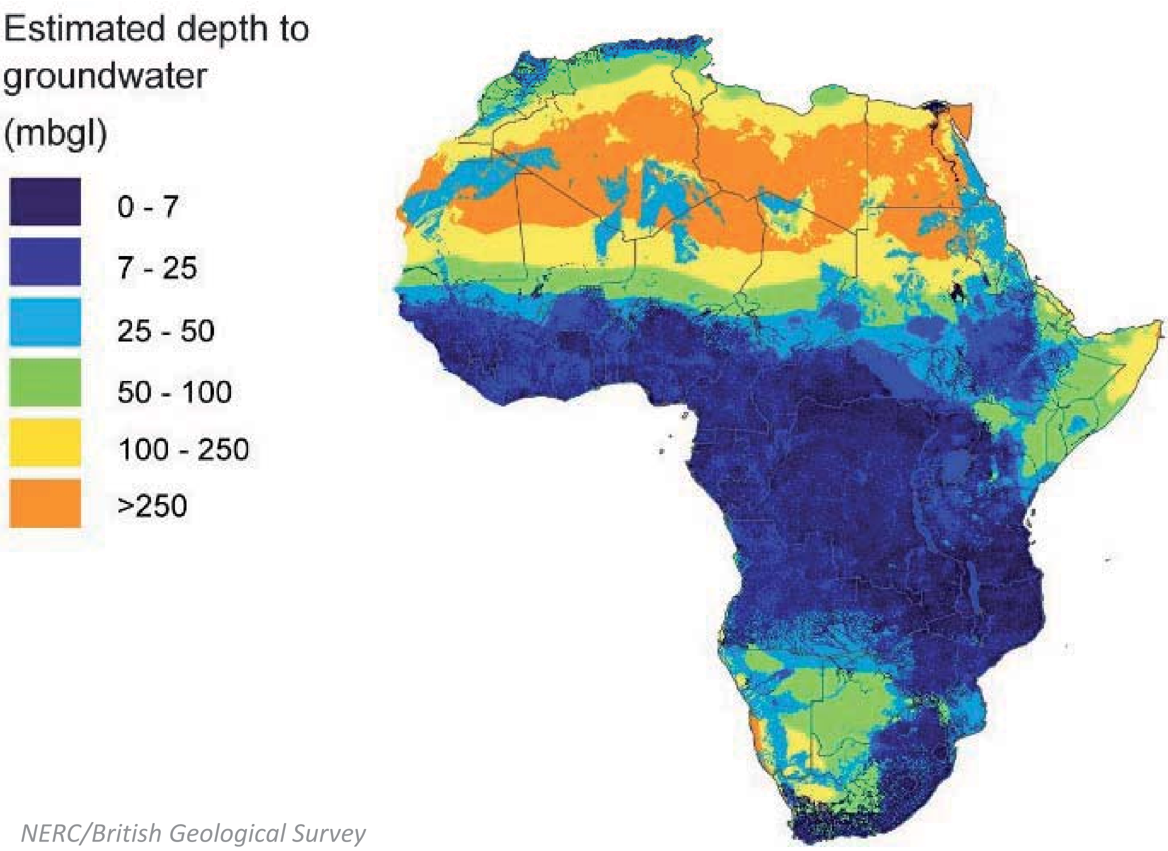
- First time discovered while drilling for oil
- BGR Atlas for Africa: 100 times more water in subsurface reservoirs than on the surface
- Many aquifers are 100s of meters deep -> water extraction expensive
- Fossil: thousands of years old, not a renewable resource!
- Future generations might not be able to continue the exploration of this water -> not sustainable?

Fossil Groundwater Resources



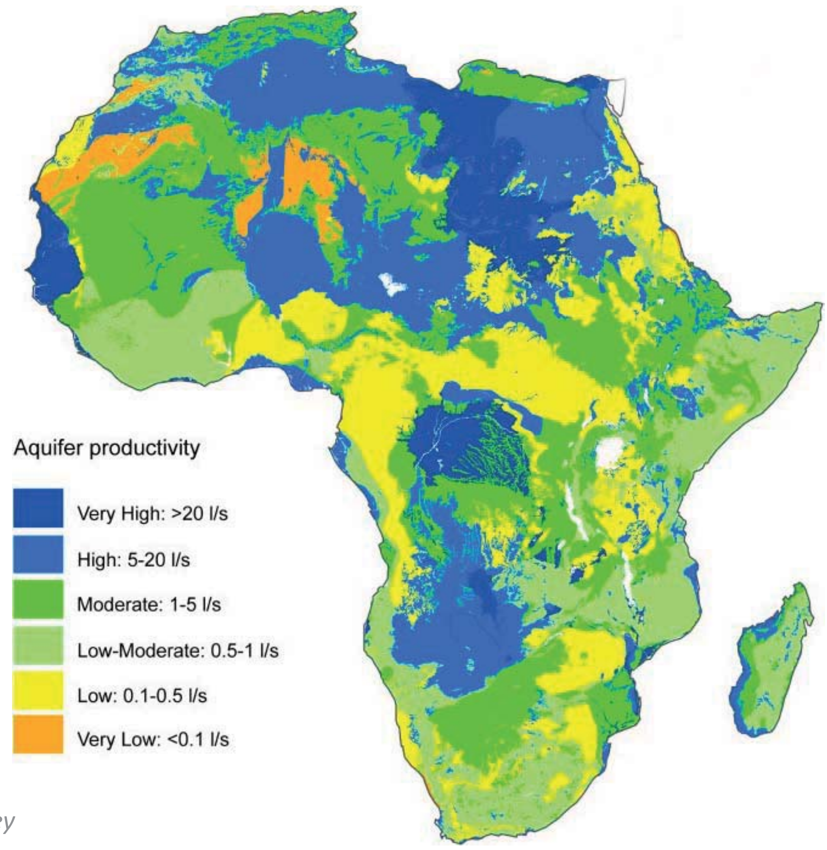
NERC/British Geological Survey

Fossil Groundwater Resources



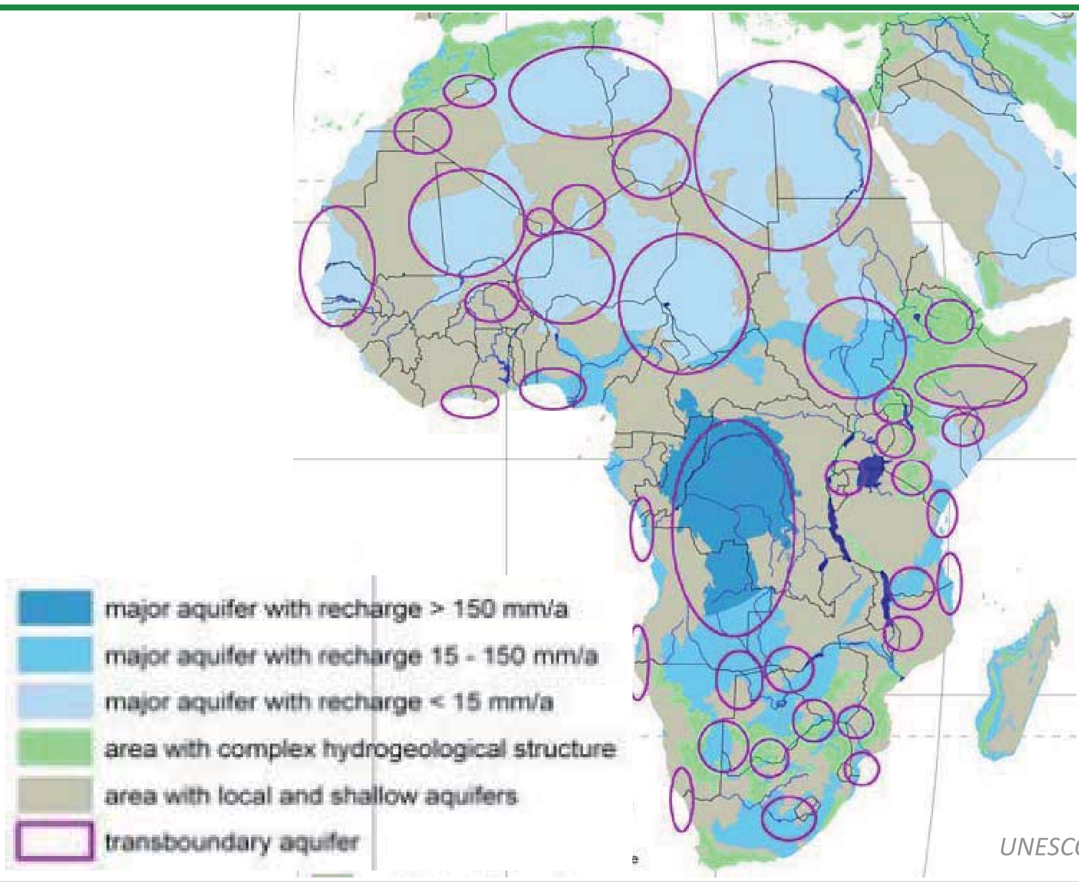
NERC/British Geological Survey

Fossil Groundwater Resources



NERC/British Geological Survey

Transboundary Aquifers



UNESCO/BGR 2004

Utilization of Fossil Groundwater Resources in Libya

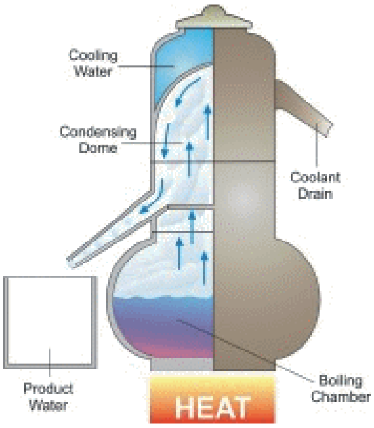
- Libya: water scarcity (low availability, increasing demand)
- Coastal aquifers became brackish due to seawater intrusion
- 40 000 yrs old ice age waters under the Sahara („fossil water“)
- Large non-renewable resource – great potential but:
- Implementation of project is approx. 25 yrs, design life is 50 yrs – then Libya‘s next generation might face a drastic change in water availability! *Cf. Situation in Yemen, which will soon run out of water!*

www.drinkingwater.org


National Geographic

Use of Saline Waters: Desalination

- Desalination is a very old technique based on distillation
- 2002: about 12,500 desalination plants around the world in 120 countries produce some 14 million m³/day of freshwater, which is less than 1% of total world consumption.
- Mainly in Saudi Arabia, Kuwait, the Emirates, Qatar, Bahrain, USA
- Needs large amounts of energy and specific infrastructure



Source: USGS


Jebel Ali Desalination Staion, Dubai
Lahmeyer International

Use of Saline Waters for Irrigation

- Water availability for irrigation could be enhanced through **proper use of saline water** and the recycling of drainage waters for irrigation
- The term salinity used herein refers to the total dissolved concentration of major inorganic ions (i.e. Na, Ca, Mg, K, HCO3, SO4 and Cl) in irrigation, drainage and ground waters, for example as a total salt concentration (mg/l).
- a practical index of salinity is the electrical conductivity (EC), expressed in units of deciSiemen per metre (dS/m)

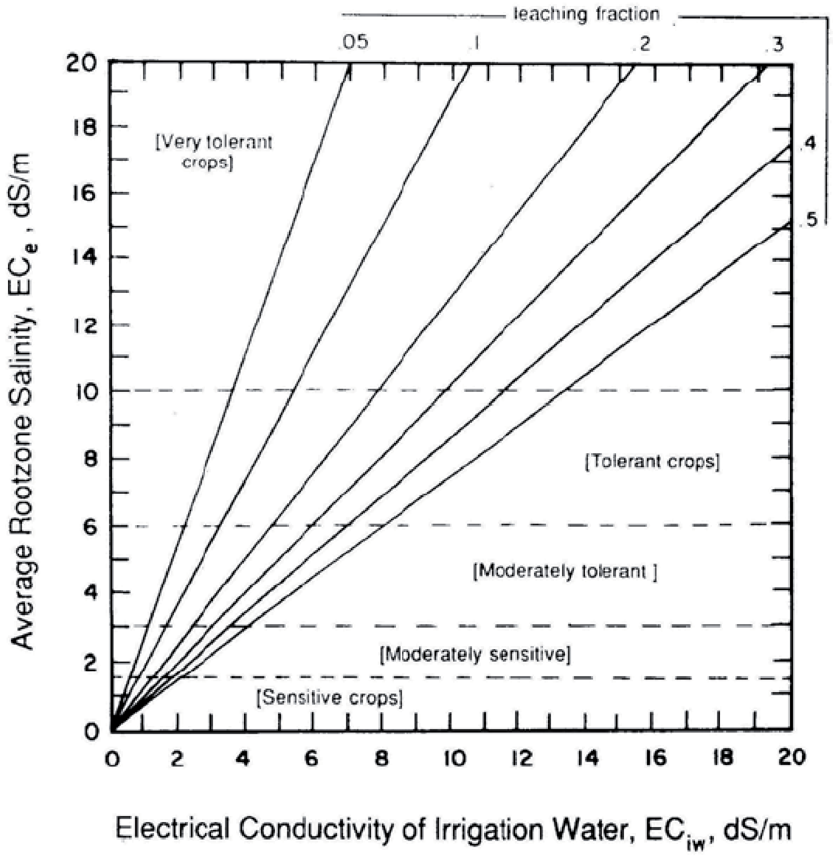
Classification of Saline Waters

TABLE 1
Classification of saline waters

Water class	Electrical conductivity dS/m	Salt concentration mg/l	Type of water
Non-saline	<0.7	<500	Drinking and irrigation water
Slightly saline	0.7 - 2	500-1500	Irrigation water
Moderately saline	2 - 10	1500-7000	Primary drainage water and groundwater
Highly saline	10 - 25	7000-15 000	Secondary drainage water and groundwater
Very highly saline	25 - 45	15 000-35 000	Very saline groundwater
Brine	>45	>35 000	Seawater

Saline Hazard Assessment

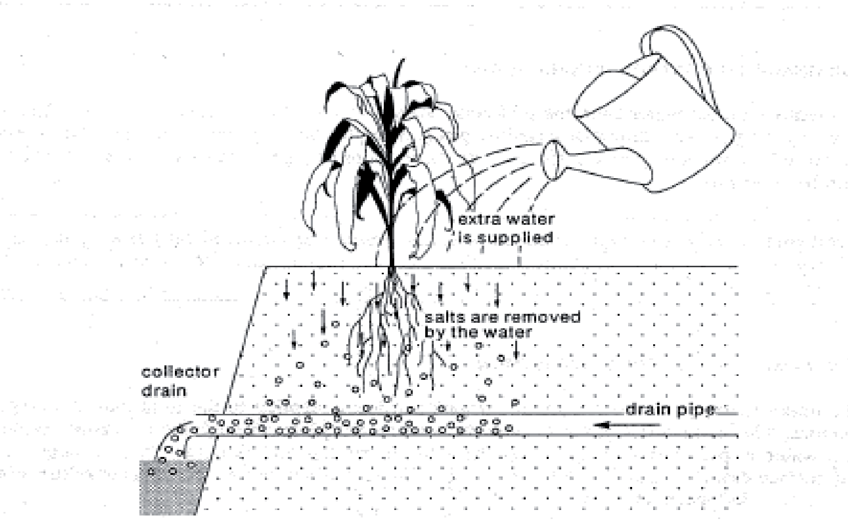
Figure:
Relationships between ECe (saturation extract basis), ECiw and leaching fraction under conventional irrigation management
(after Rhoades 1982)



Drainage to Control Salinization

With good maintenance,
the drainage system will function properly,
control water table and risk of salinisation,
and high yields can be achieved!

FIGURE 7
Extra irrigation water is applied to remove salts from the root zone



References

- Hufschmidt, M.M., Kindler, J. (1991): Approaches to Integrated Water Resources Management in Humid Tropical and Arid and Semiarid Zones in Developing Countries. Report IHP-III Projects 10.1(a) and 10.2(a), UNESCO, Paris.
- ASCE (Ed.), 1990: Agricultural Salinity Assessment and Management. ASCE Manuals and Reports on Engineering Practice No. 71. American Society of Civil Engineers, New York.
- FAO, 1992: The use of saline waters for crop production. By J.D. Rhoades, A. Kandiah & A.M. Mashali. Irrigation and Drainage Paper No. 48. Food and Agriculture Organisation of the United Nations, Rome.
- Prinz, D. (2002). The Role of Water Harvesting in Alleviating Water Scarcity in Arid Areas. Keynote Lecture, Proceedings, International Conference on Water Resources Management in Arid Regions. 23-27 March, 2002, Kuwait, Institute for Scientific Research, Kuwait, (Vol. III, 107-122).
- Umali, D.L., 1993: Irrigation-Induced –salinity – A Growing Problem for Development and the Environment. World Bank Technical Paper No. 215. The World Bank, Washington D.C..
- A M MacDonald, H C Bonsor, B´E´O Dochartaigh and R G Taylor (2012): Quantitative maps of groundwater resources in Africa. Environ. Res. Lett. 7,

Thank you for your attention!

IWRM in Arid and Semi-arid Regions

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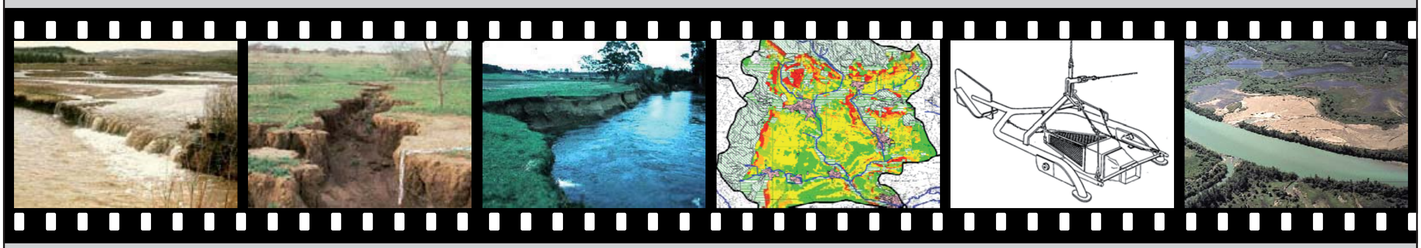

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