International Conference on
Desalination, Environment and Marine Outfall Systems

Sultan Qaboos University, Muscat, Sultanate of Oman

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Desalination from an Integrated Water Resources Management Perspective

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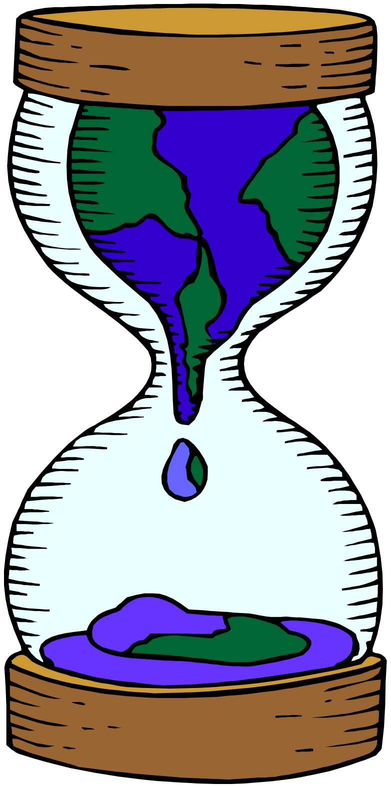
K.N.Toosi University of Technology

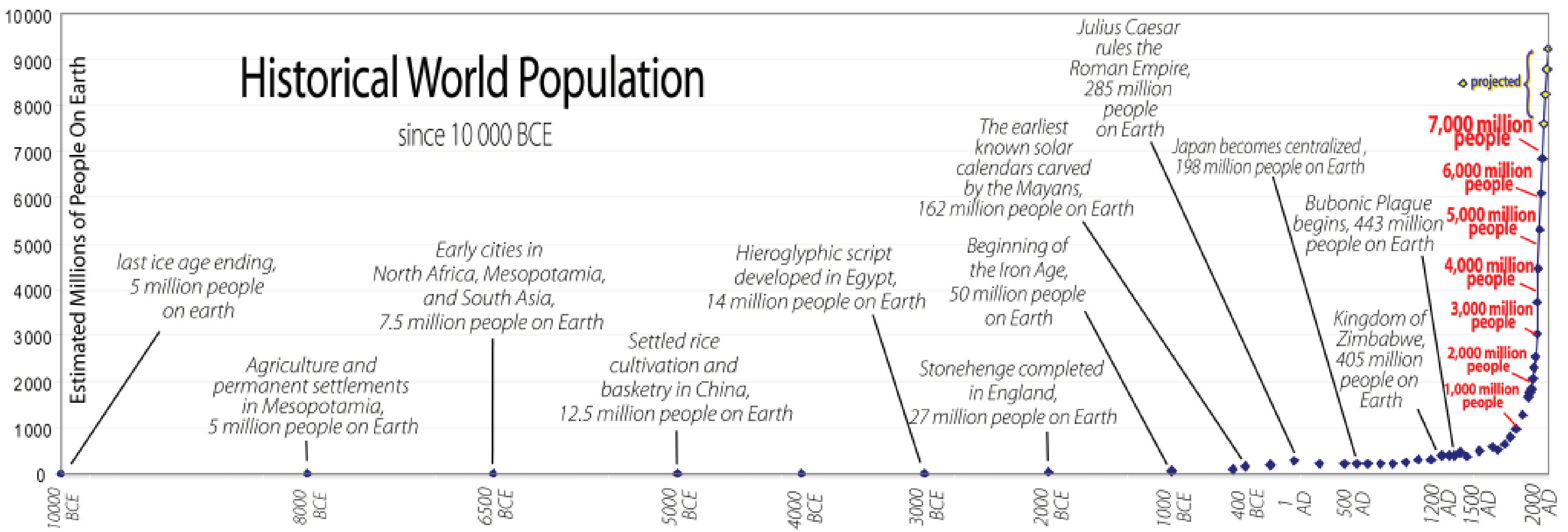
Global Water Challenges

- More than a billion people lack access to safe water supplies
- Almost three billion do not have access to adequate sanitation
- Five to ten million people die each year from water-related diseases or inadequate sanitation
- Twenty percent of the world's irrigated lands are salt-laden, affecting crop production

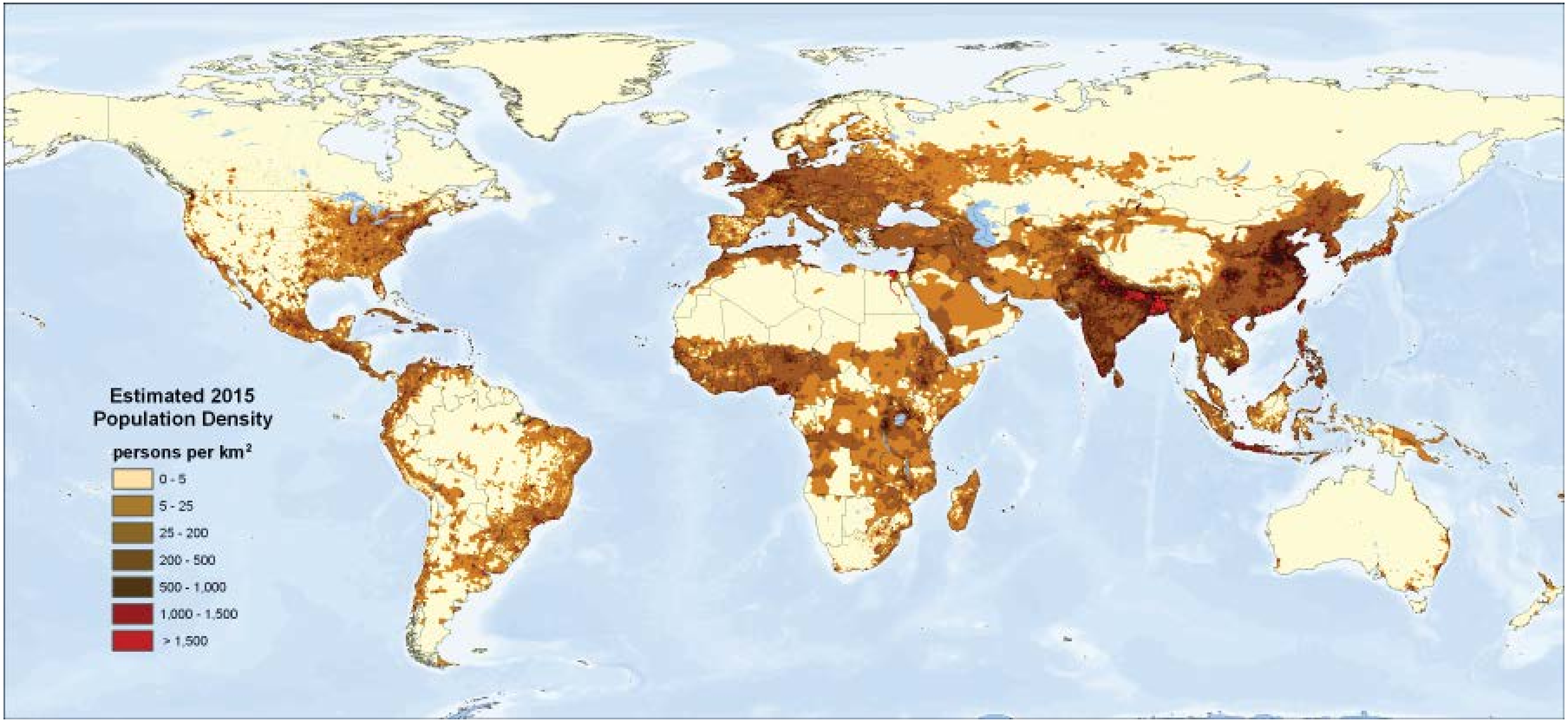


World Population

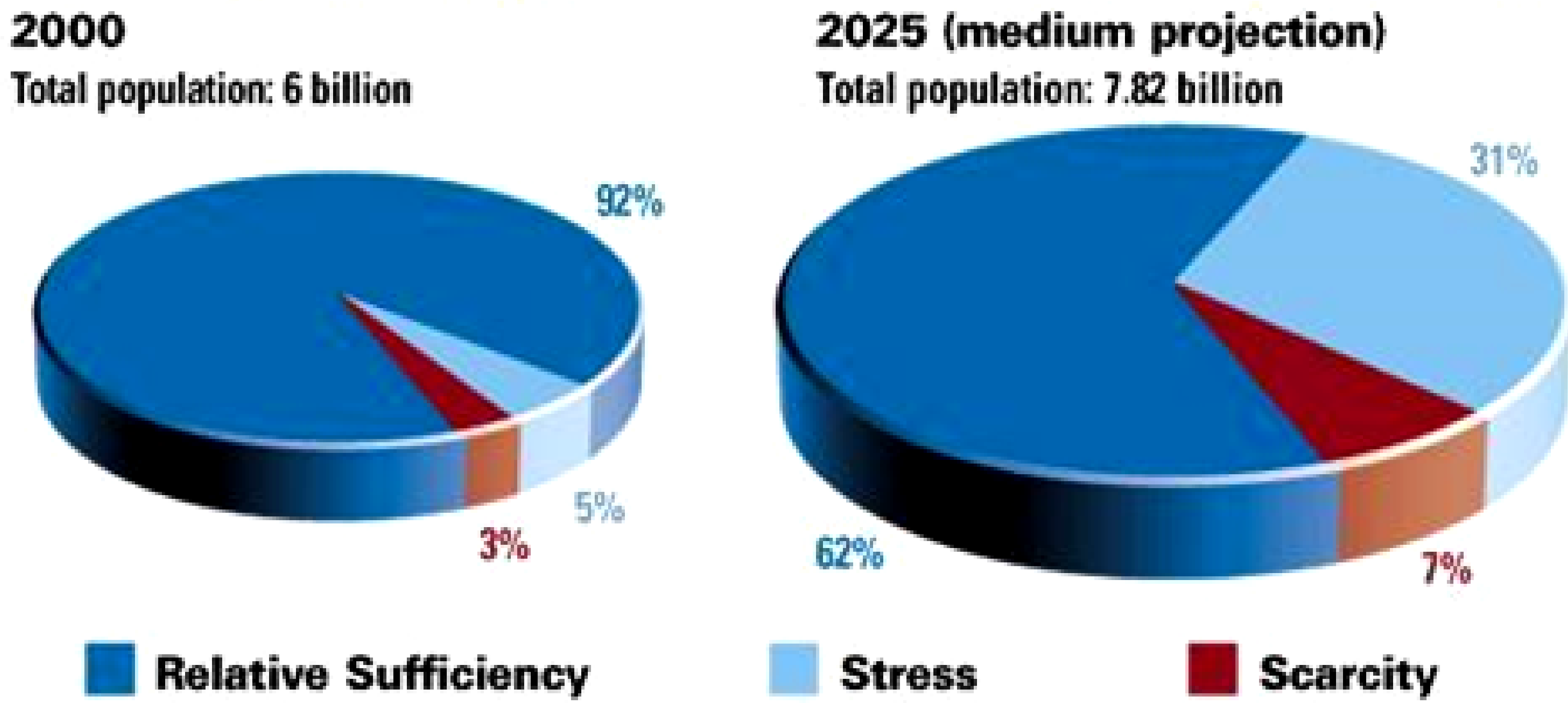
World Population



World Population Distribution

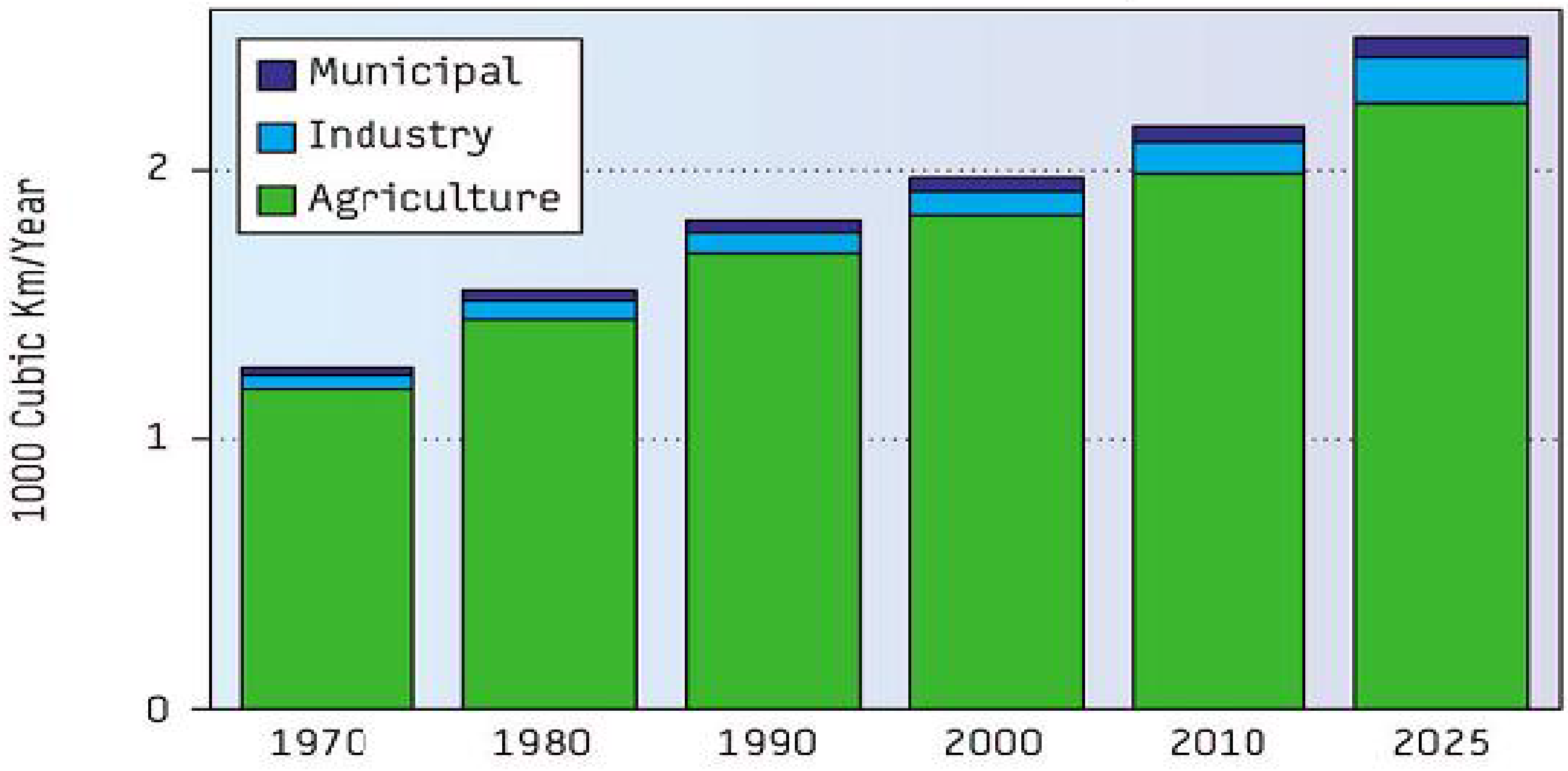


Fresh Water Availability

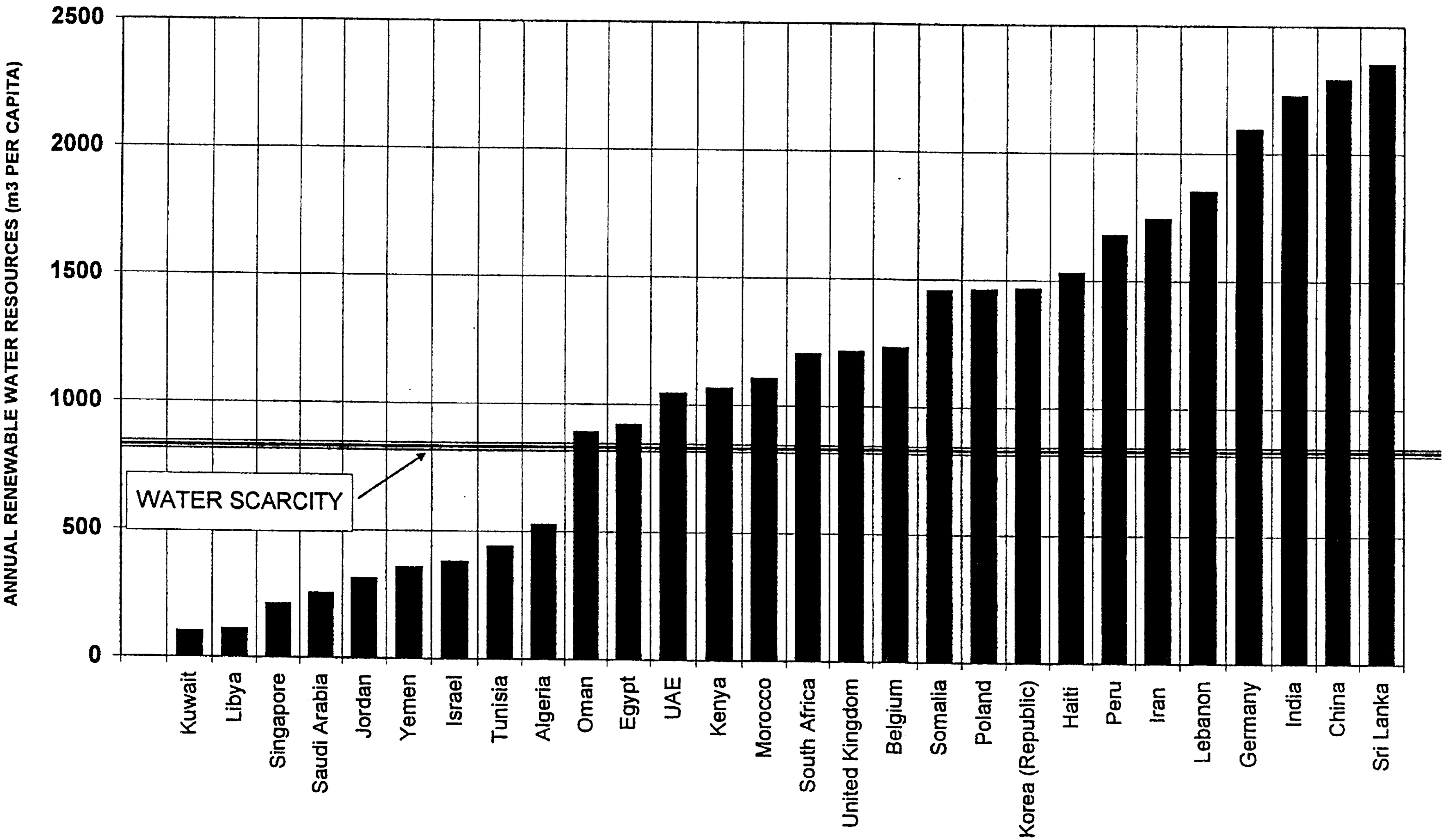


1710 m3/person/year 1000 m3/person/year

Global Water Consumption



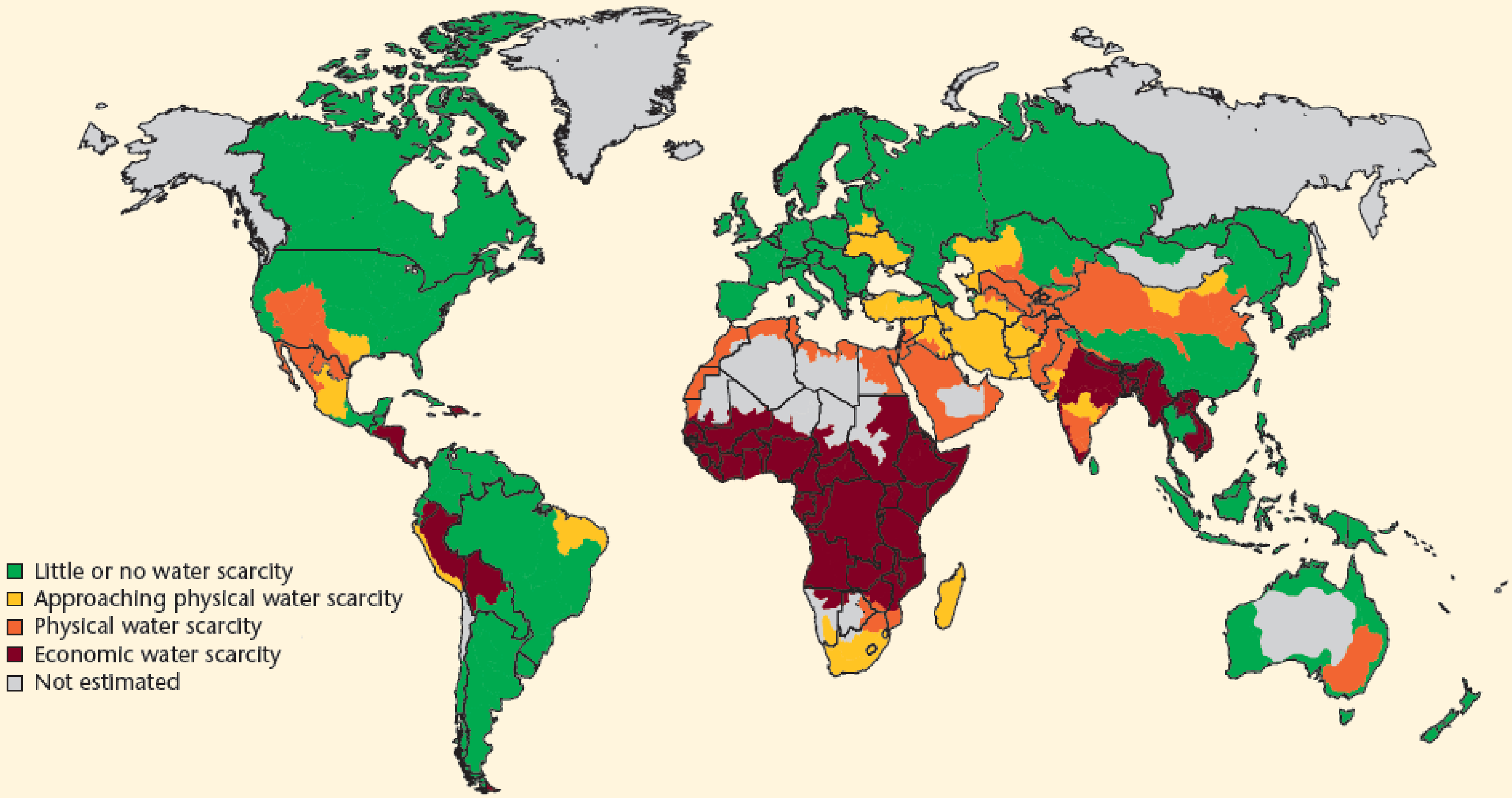
Annual Available Water Resources



Source: Wangnick 2004

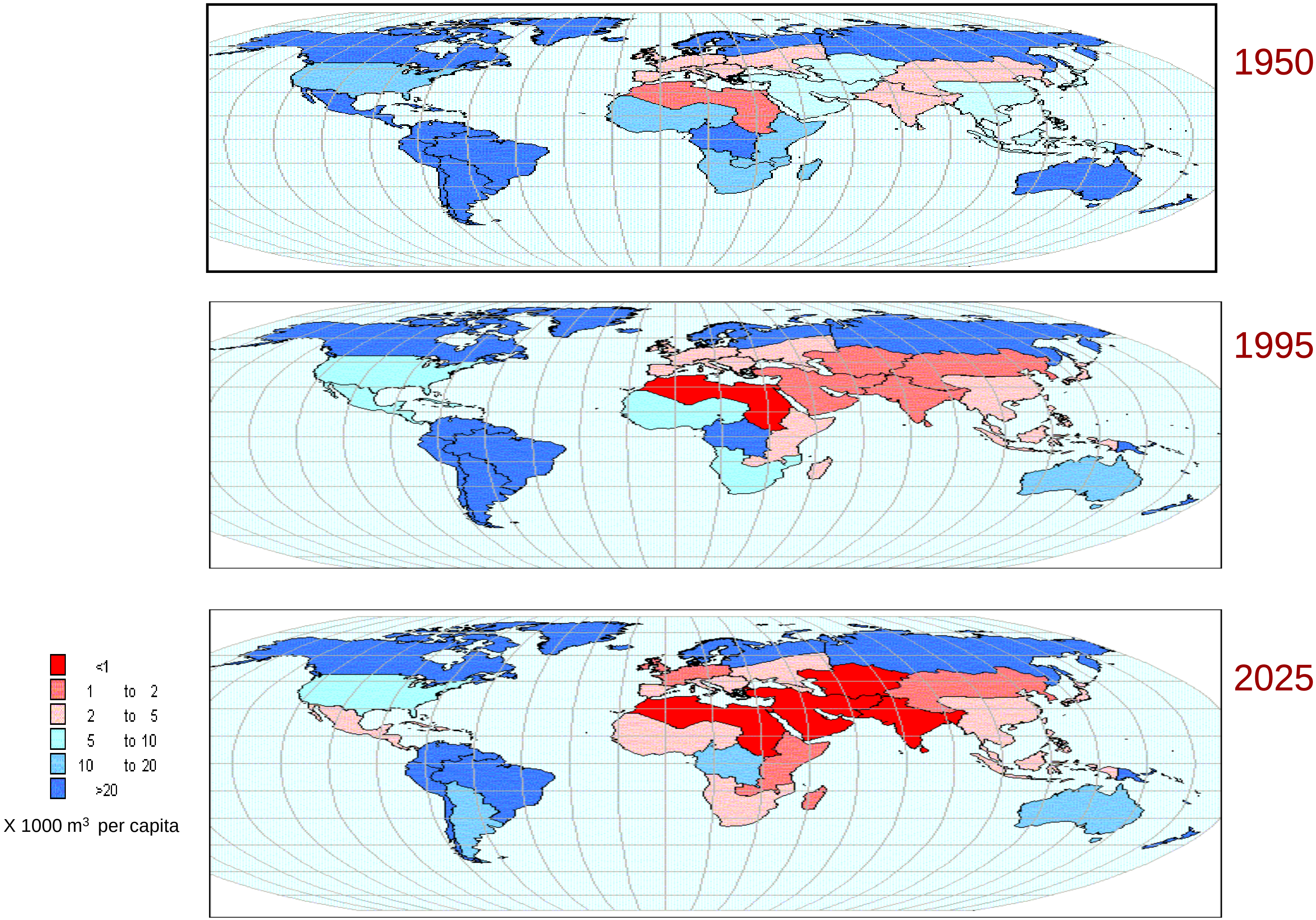
Water Scarcity

Increasing water scarcity

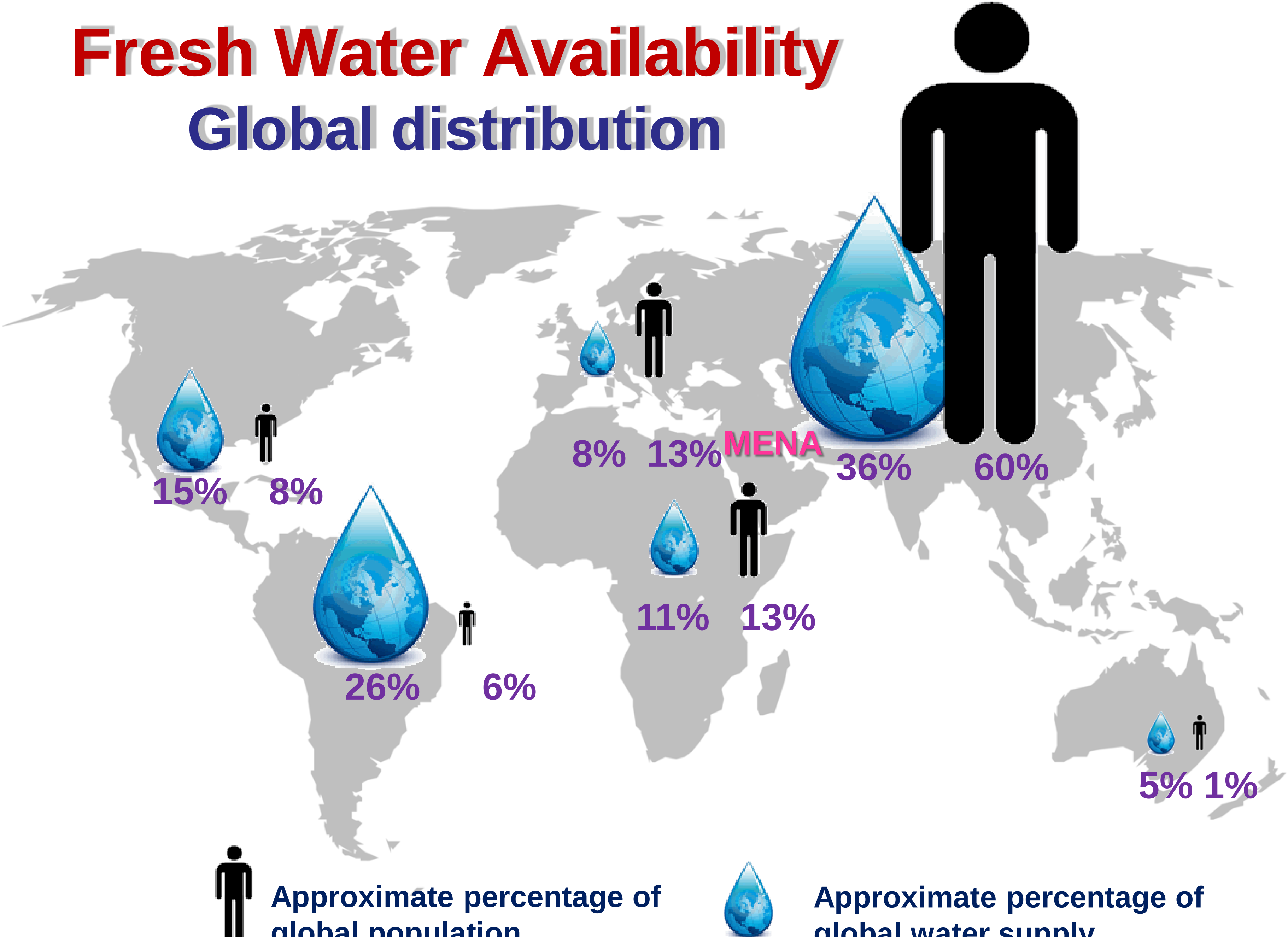


Source: Based on Comprehensive Assessment of Water Management in Agriculture 2007.

Fresh Water Availability



Fresh Water Availability
Global distribution



Water Crises in the MENA Region
(Middle East and North Africa)

Population of the MENA region =

5% of the world population

Freshwater availability in the MENA region=

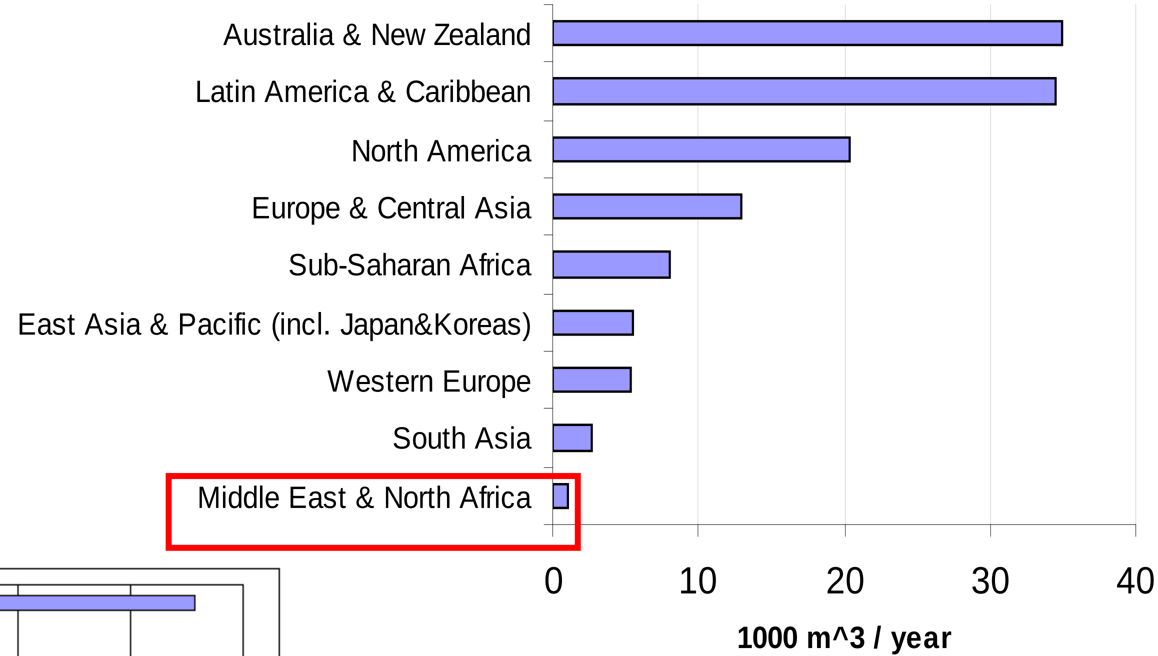
1% of the global freshwater

it is expected that water availability per capita will decrease to ½ of the present situation during the next 30 years

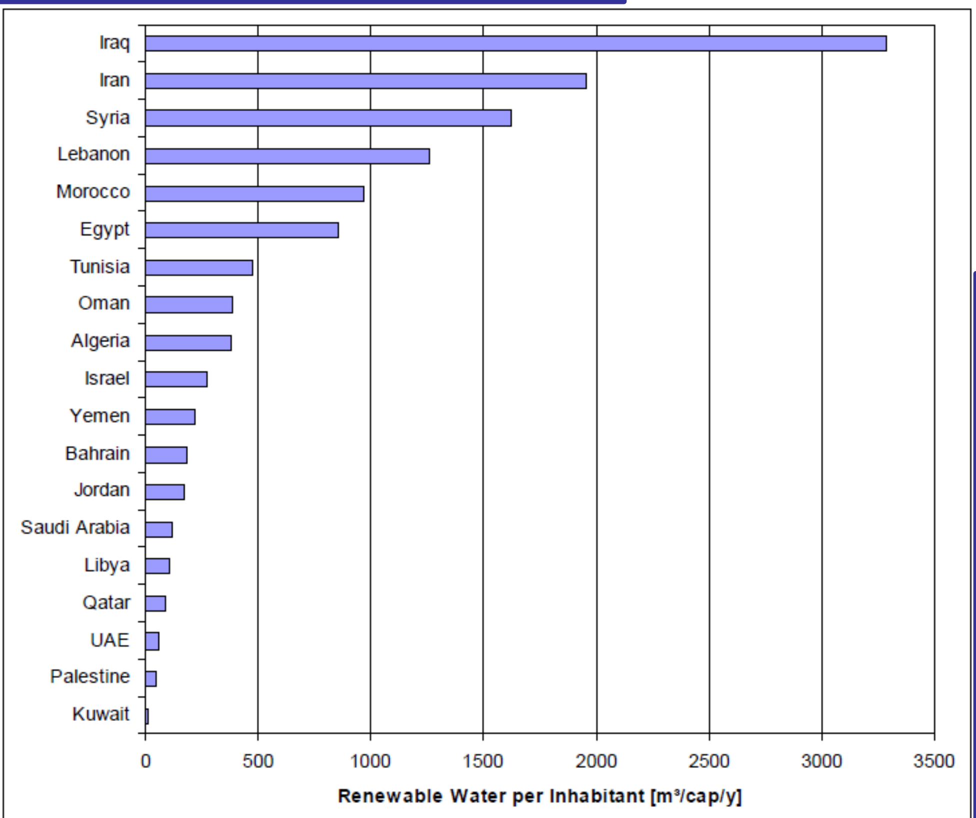
Water Crises in the MENA Region

- Irrigation with the proportion of 87% is the biggest consumer with low efficiency;
- Up to 50% of the municipal water is wasted in the distribution systems; (World Bank, 1995)
- Groundwater is the most important resource;
- 60% of the desalinisation plants of the world are installed in this region.

MENA has the lowest per capita water resources worldwide…it's dwindling fast!



Annual renewable water resources per capita
Source: FAO AQUASTAT (2007)

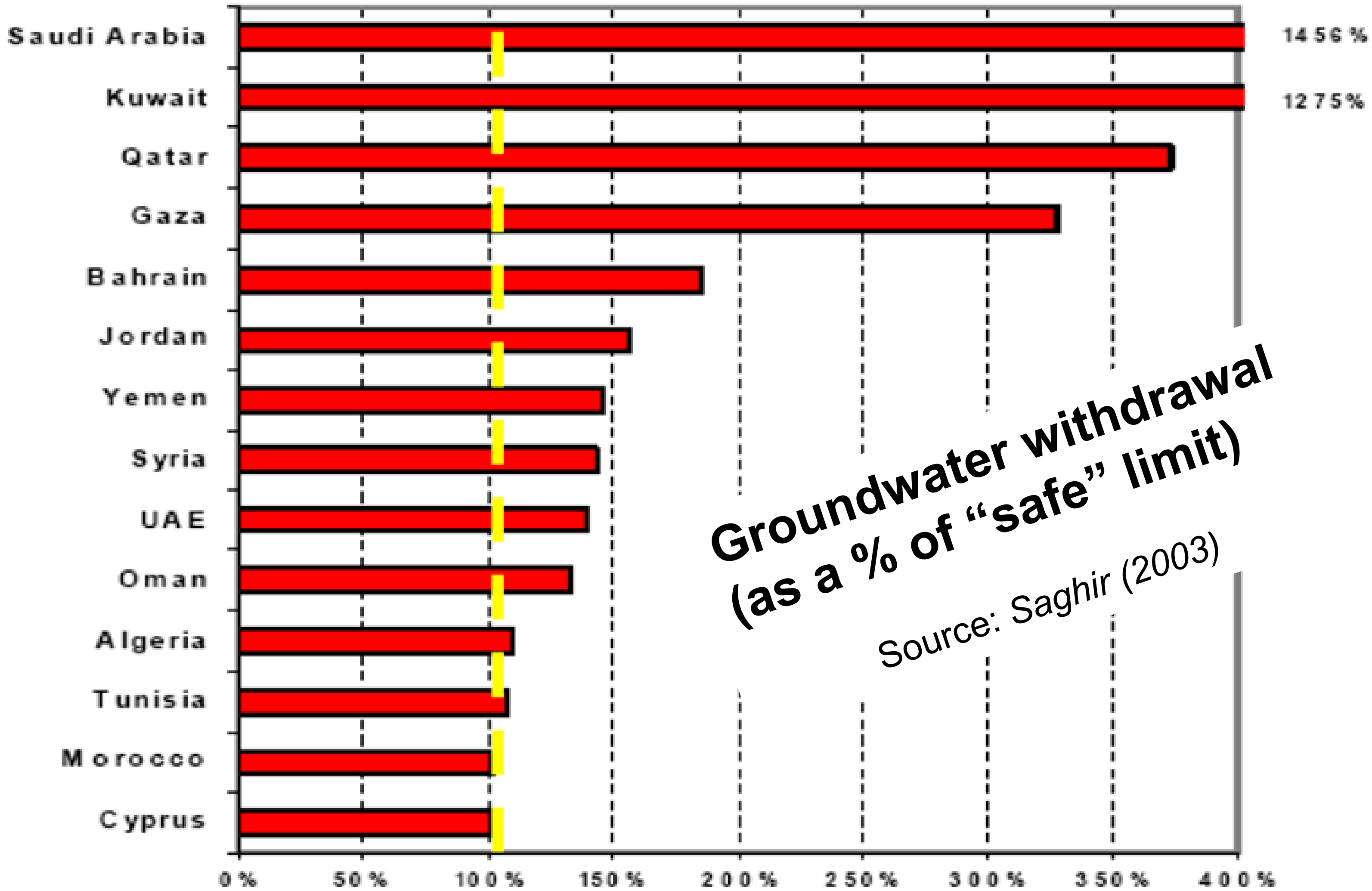


a) *Average annual renewable water resources for MENA (2007) was 1,200 m3/capita, compared to 7,000 m3/capita globally..*

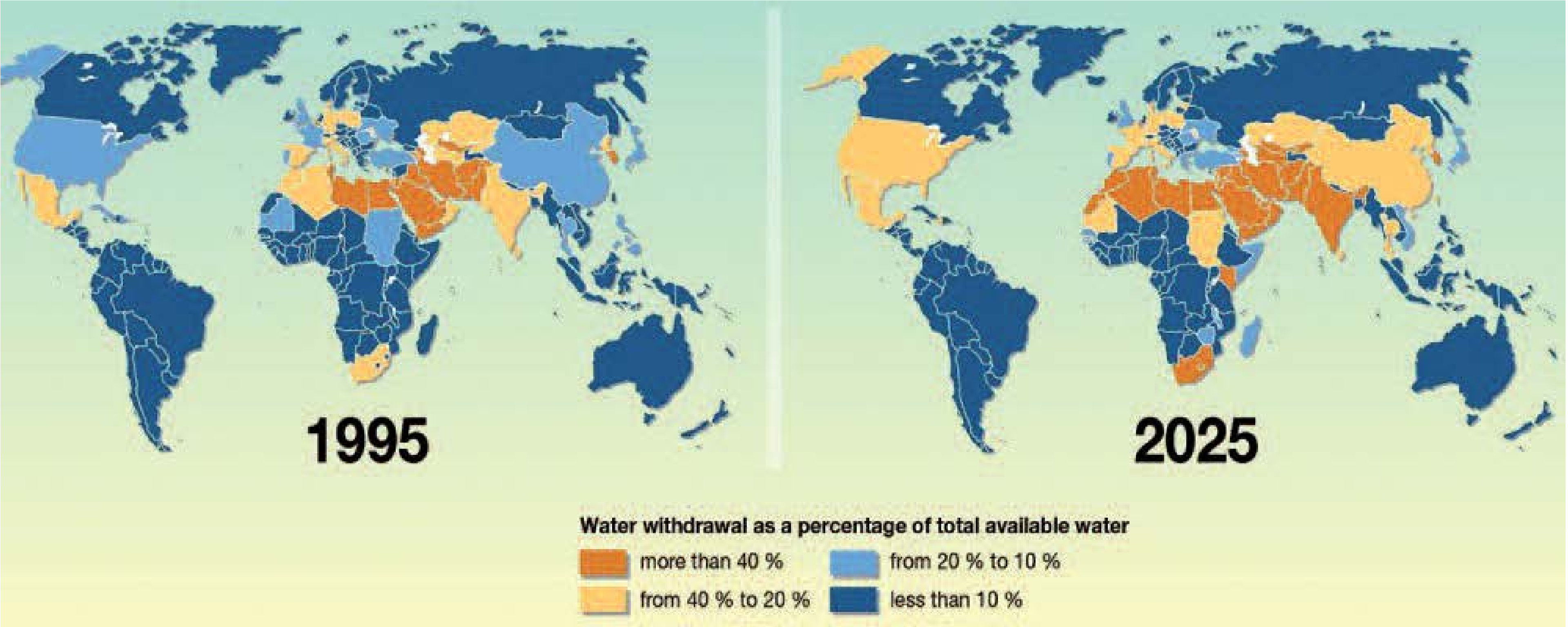
b) *14 out of the top 20 Water Scarce Countries are in MENA*

c) *Water scarcity will become a challenge to growth*

…today’s water deficit in MENA is met by overexploitation of groundwater and—to a lesser degree—by fossil-fuelled desalination, but this is not sustainable…

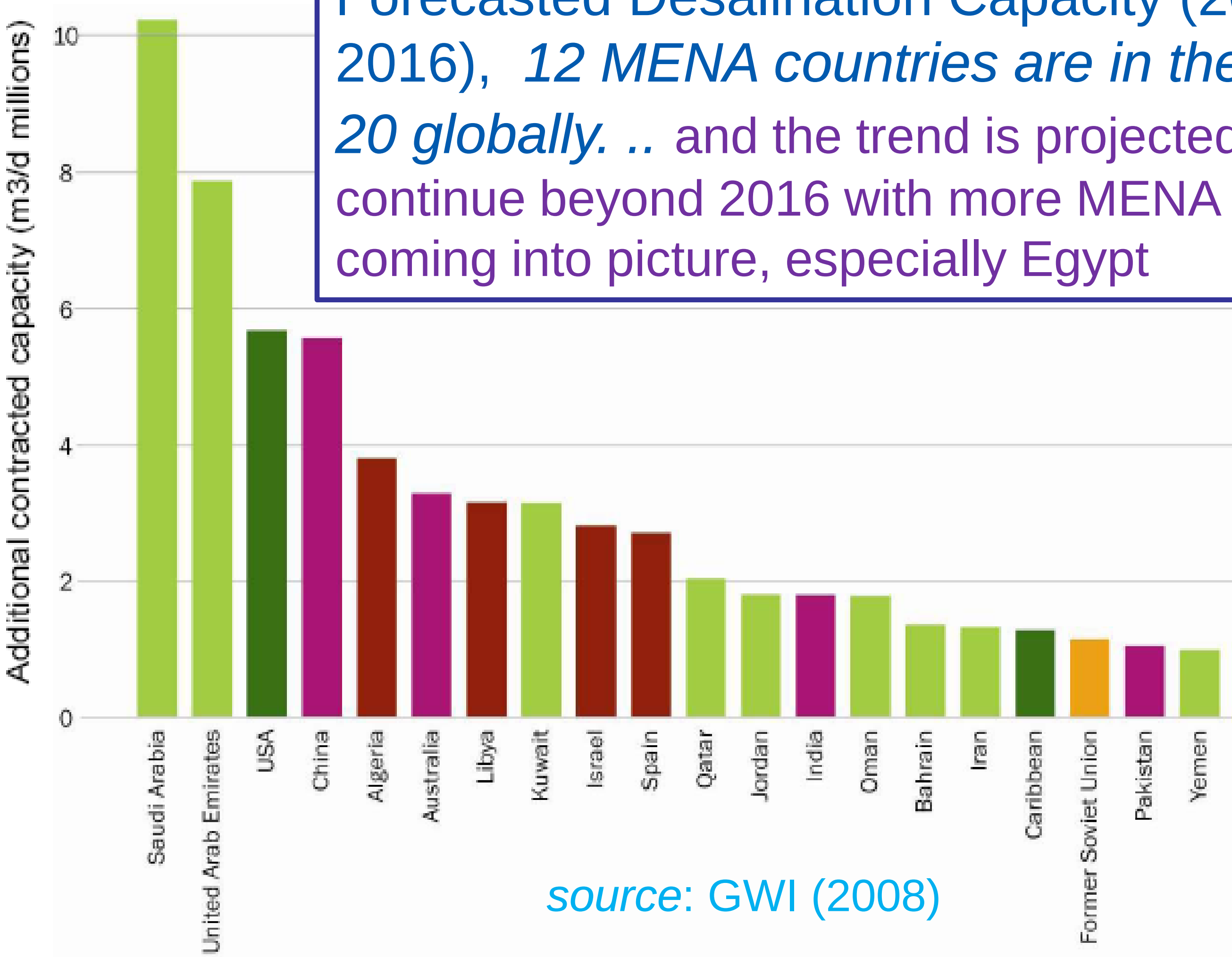


Groundwater



Desalination potential is on the rise in MENA

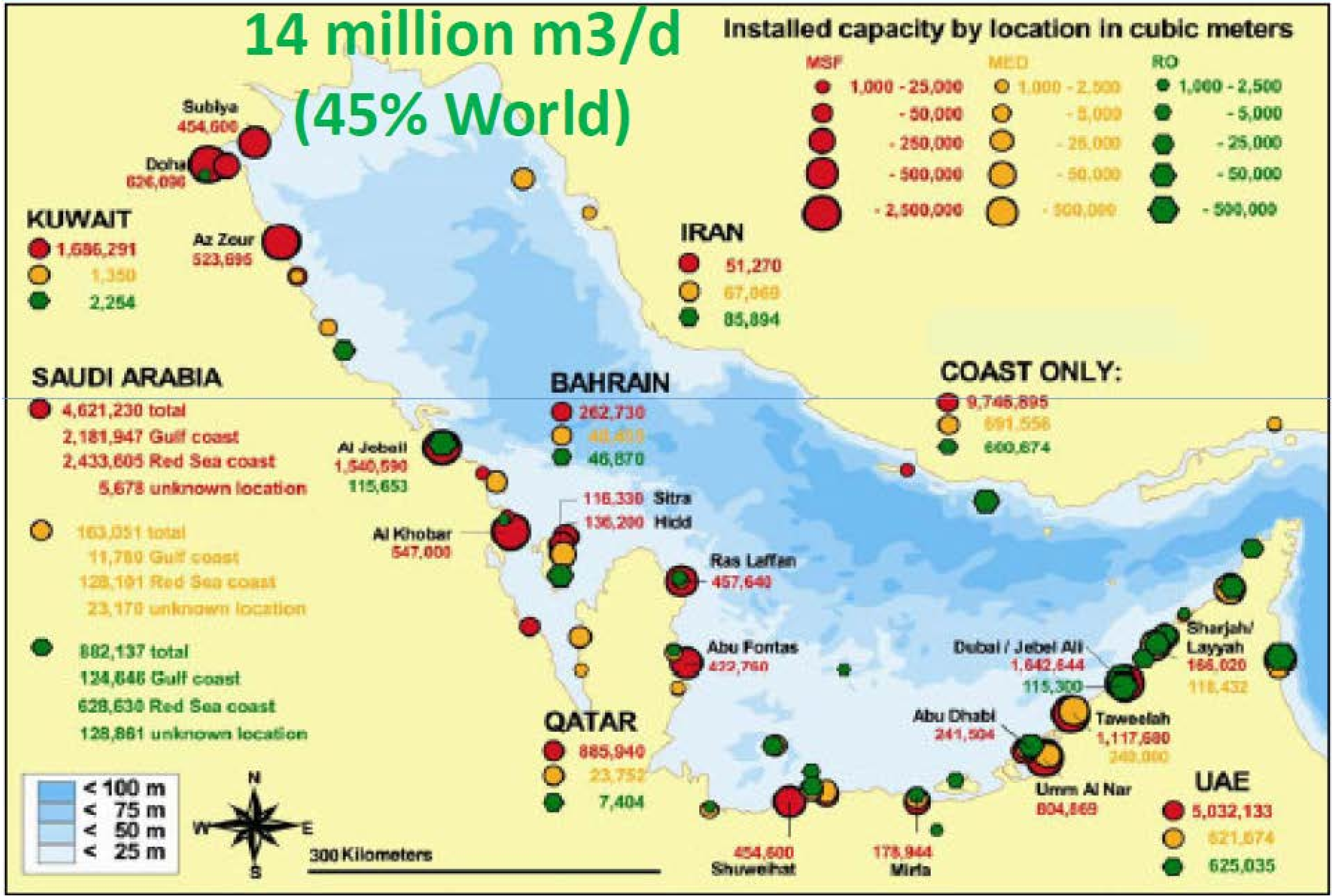
Forecasted Desalination Capacity (2008-2016), *12 MENA countries are in the TOP 20 globally. ..* and the trend is projected to continue beyond 2016 with more MENA countries coming into picture, especially Egypt



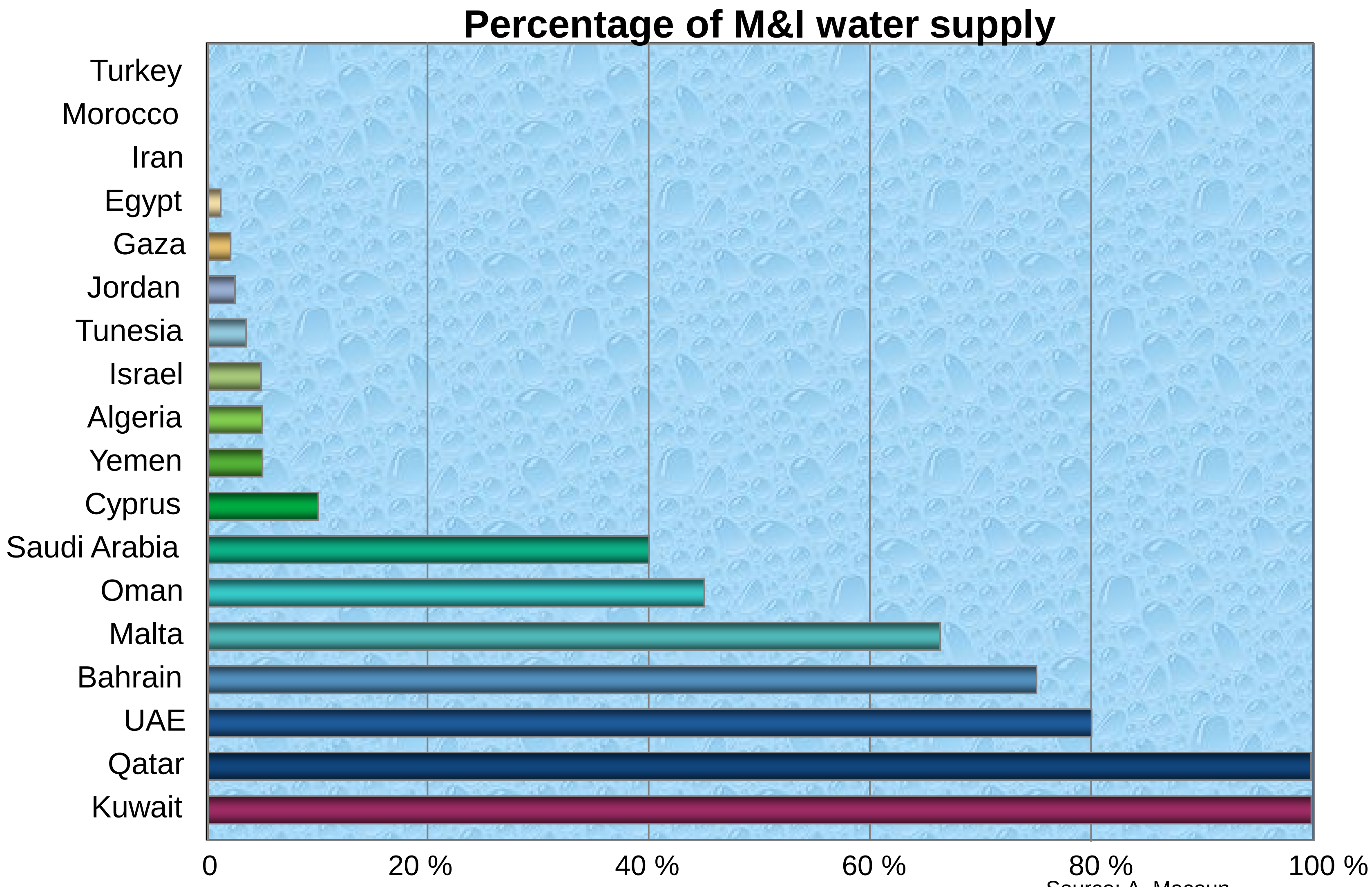
source: GWI (2008)

GCC Desalination Plants

14 million m3/d (45% World)

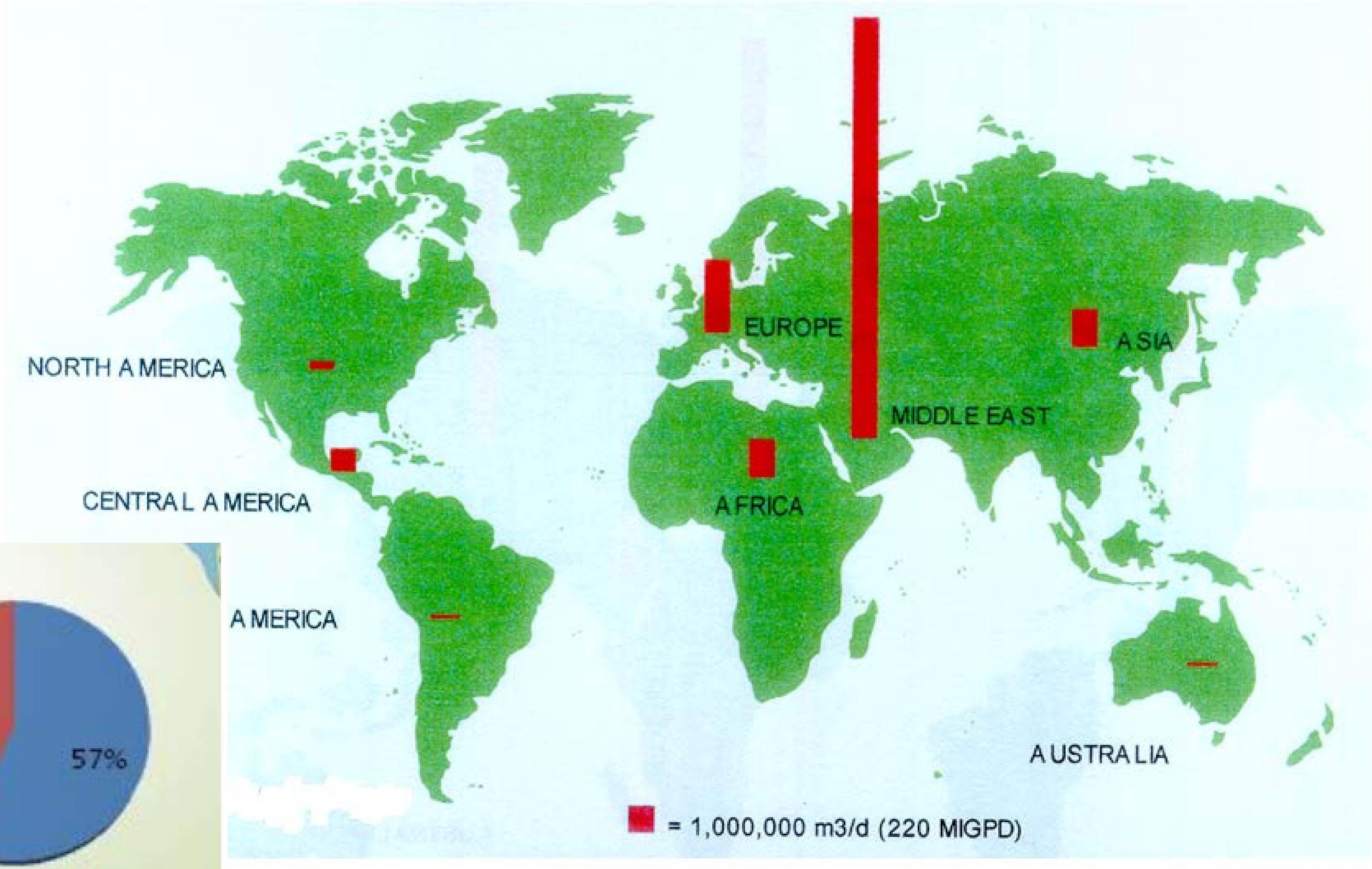


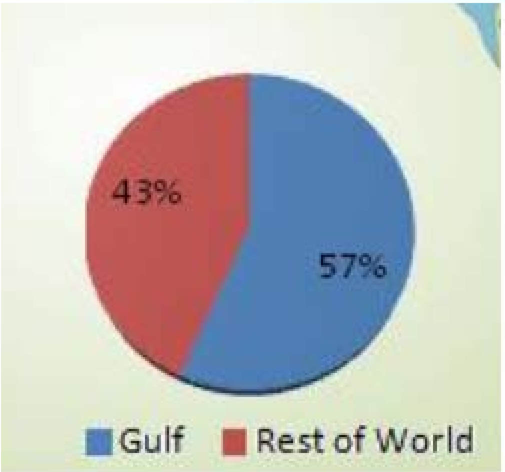
Desalinated Water as share of municipal and industrial water supply



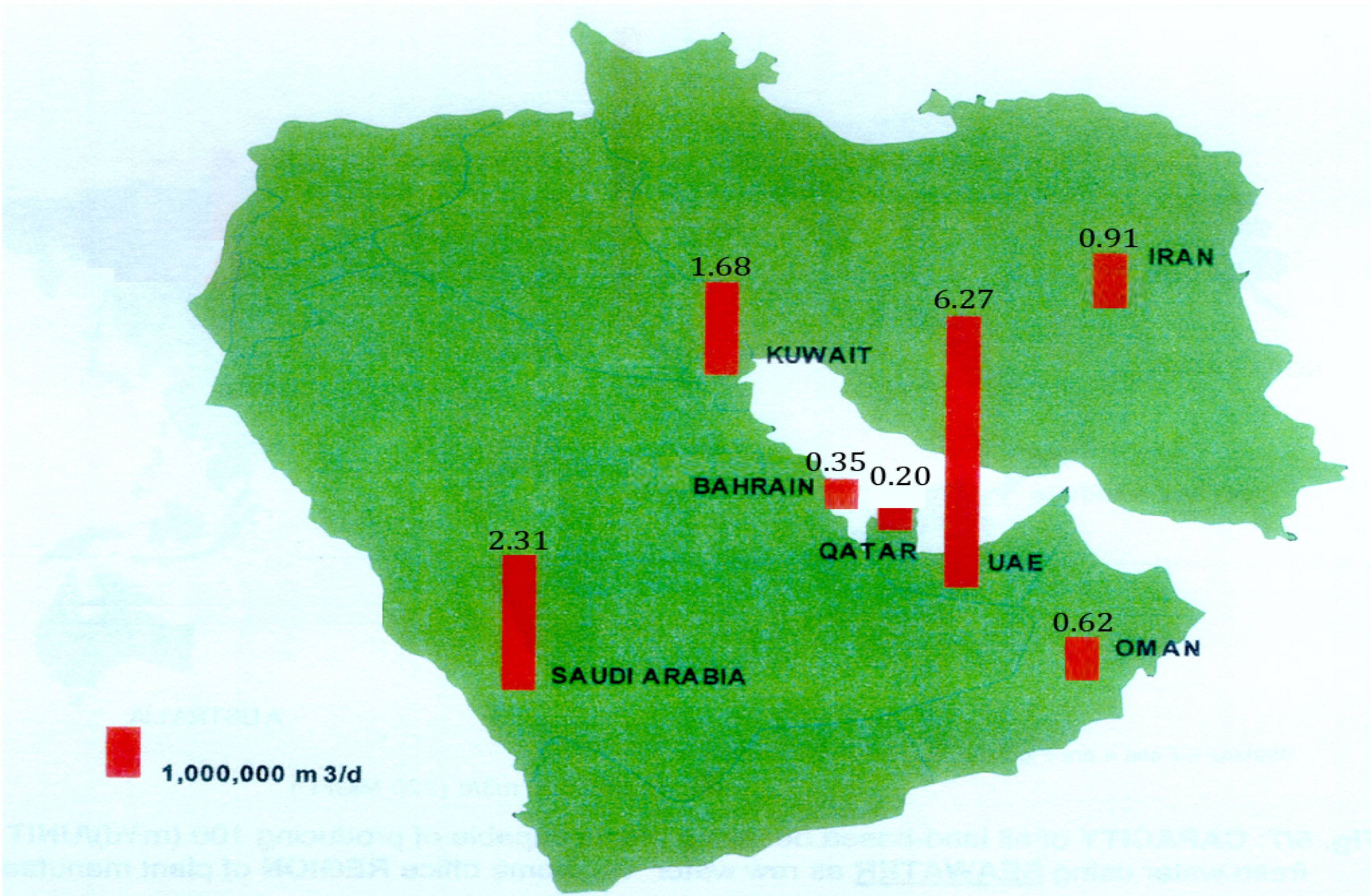
Source: A. Macoun

Sea water desalination capacity in the world

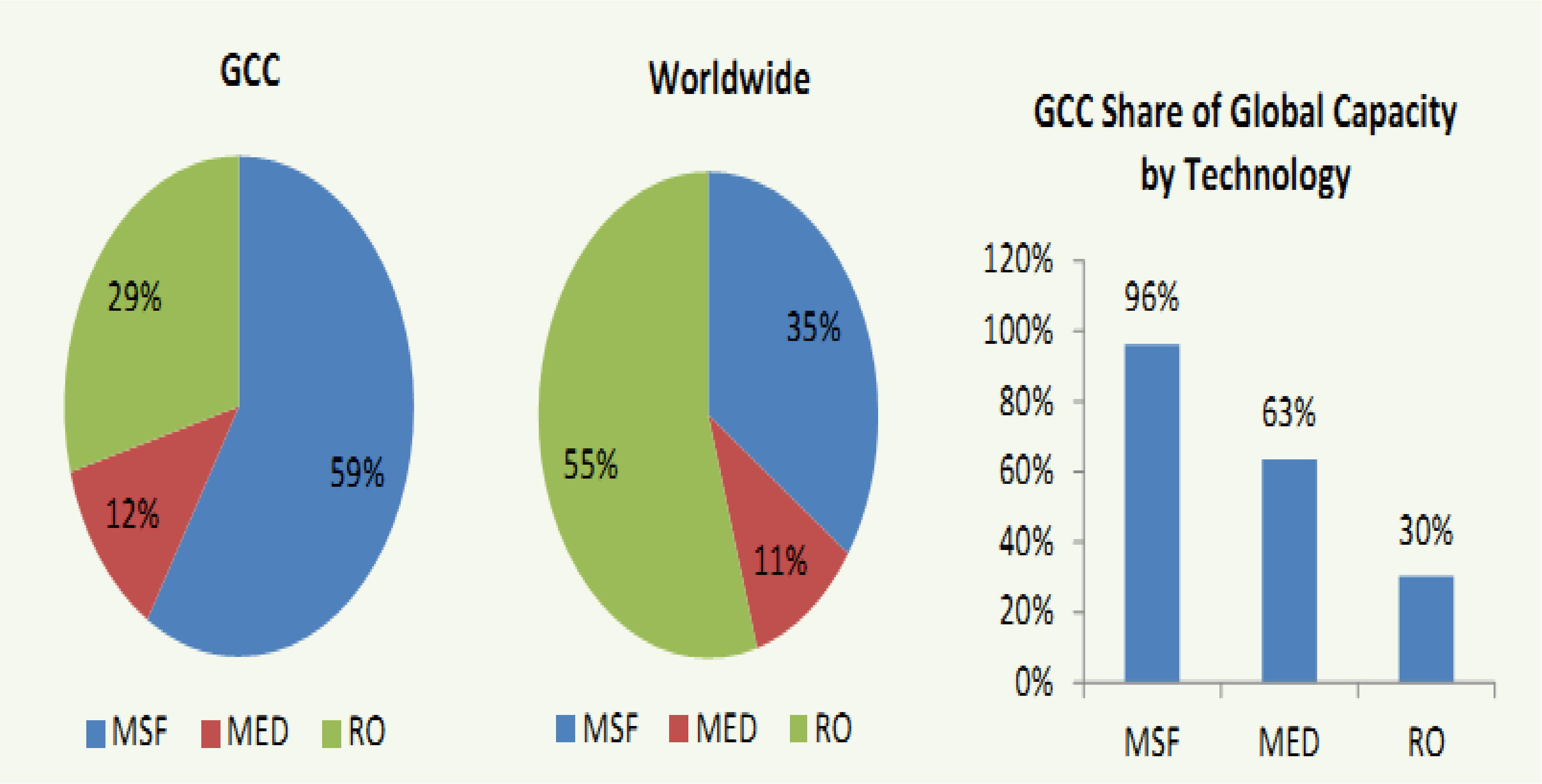




Seawater desalination capacity in the Middle East

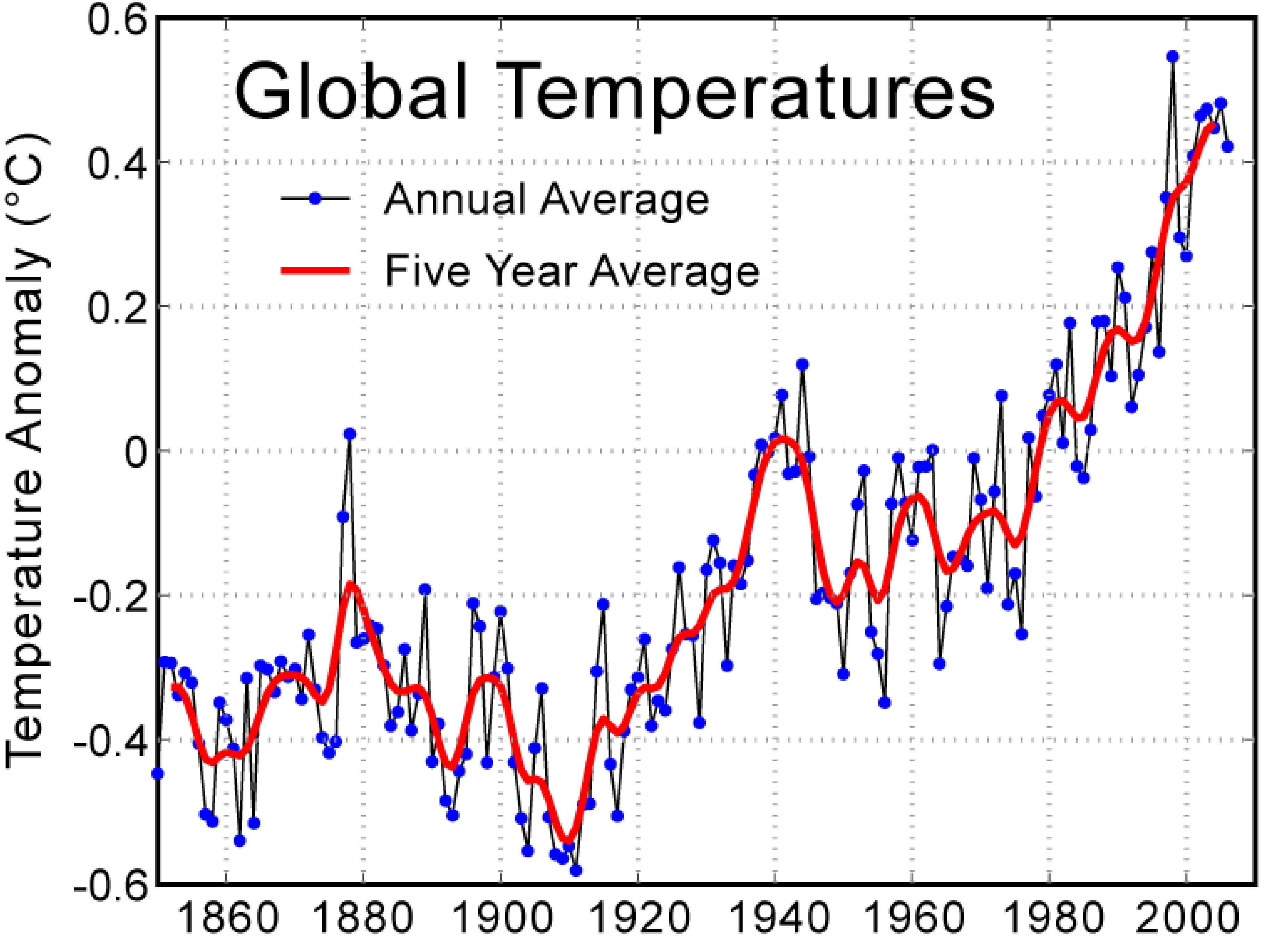


Online desalination technology capacity in the Gulf Cooperation Council (GCC) and worldwide 2012



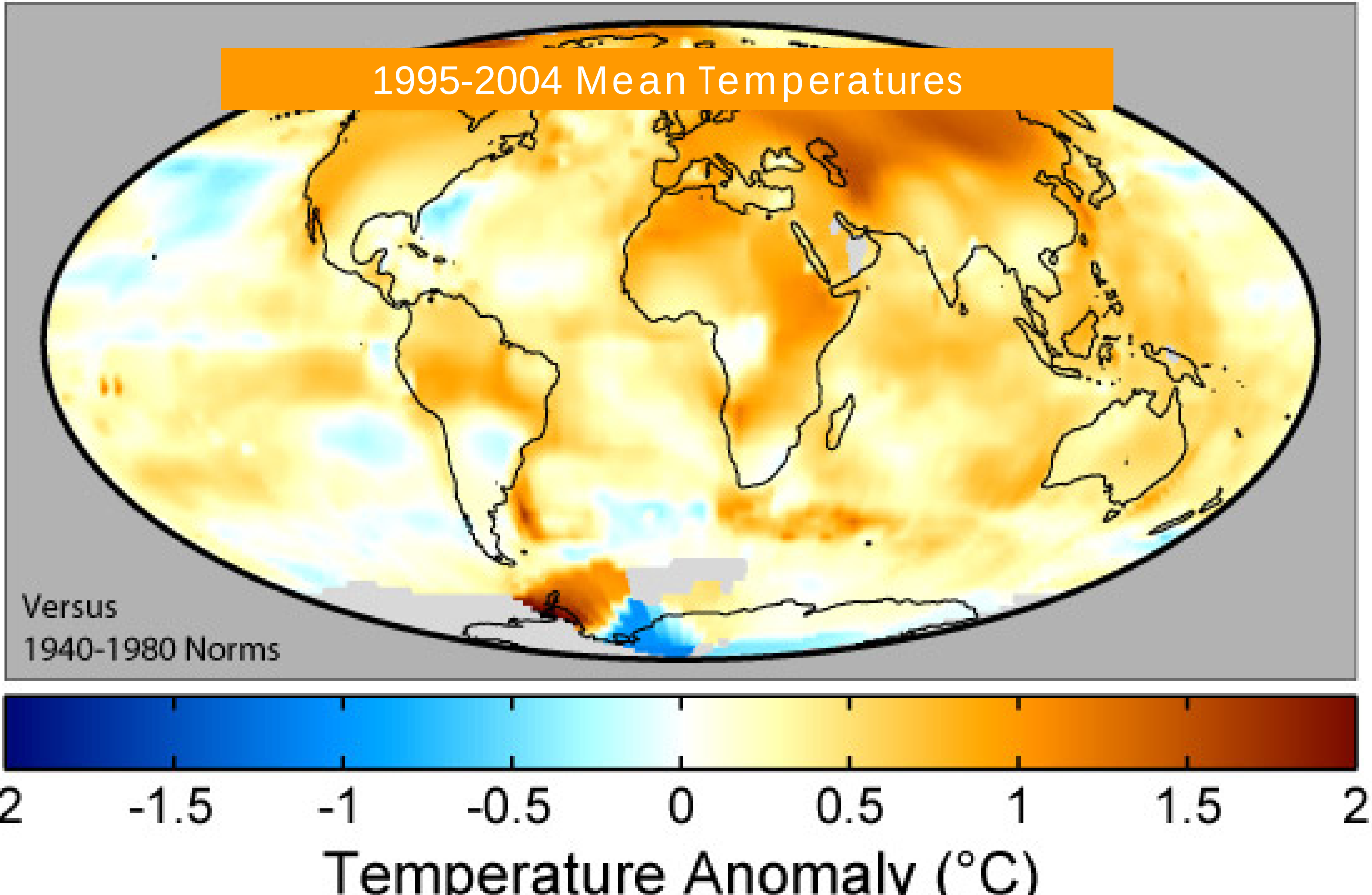
Source: Saif, 2012

Global Warming



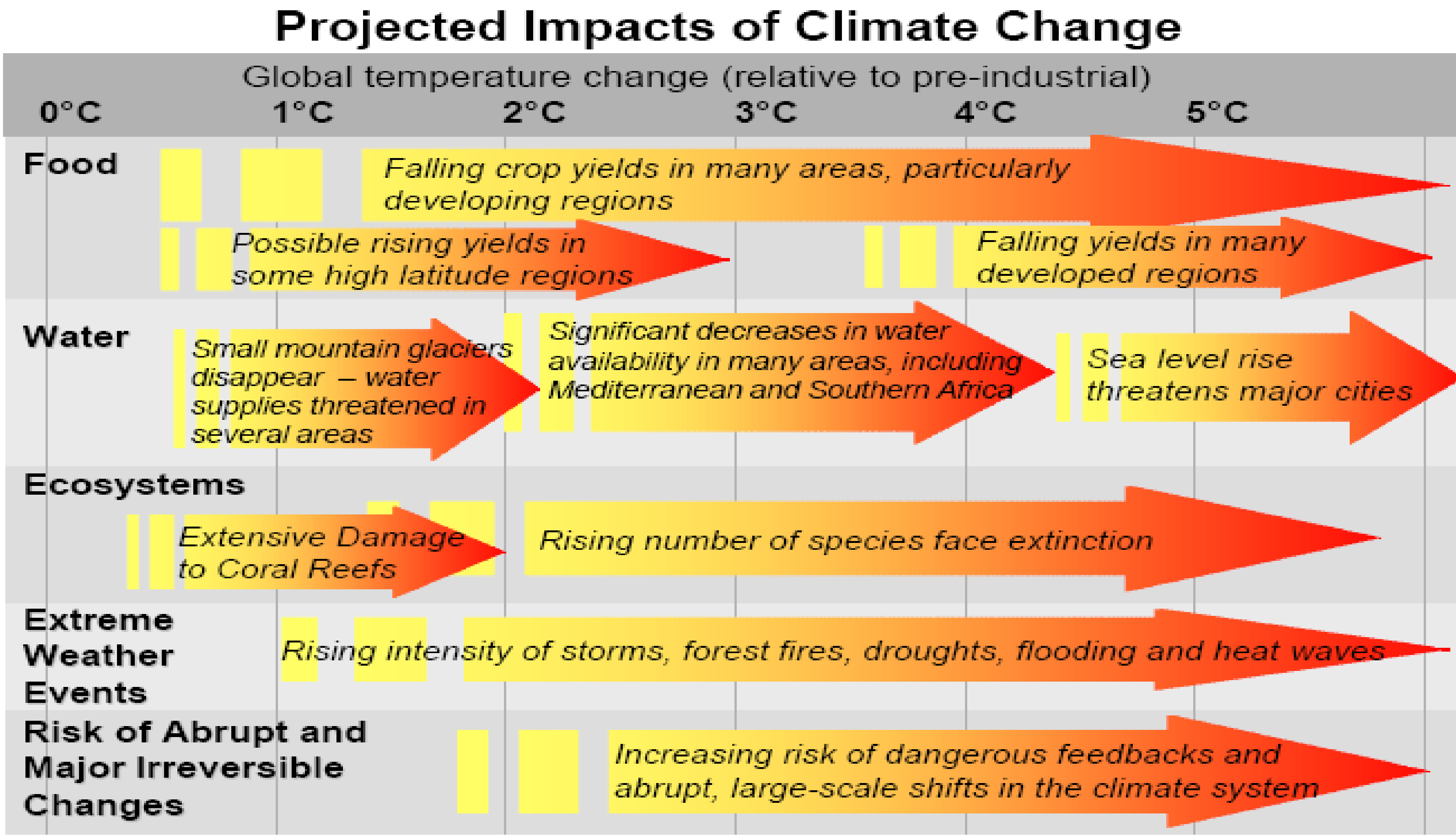
Global Temperatures
Annual Average
Five Year Average
Temperature Anomaly (°C)
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
1860
1880
1900
1920
1940
1960
1980
2000

1995-2004 Mean Temperatures



Climate Change

is effecting our environment, our societies and our cultures



What does the future hold…..?

WATER:

- Water deficit is projected to increase from 50 BCM per year today to 150- to 235 BCM per year by 2050, based on the level of water use efficiency and wastewater reuse adopted, 2/3 times the physical volume of the Nile River flow…***scary!***

ENERGY:

- Correspondingly, about 31 billion barrels of fuel is needed to desalinate about 150 BCM of water per year by 2050 (e.g., KSA today uses > 1.5 million bbls/day for desal)…***not sustainable***

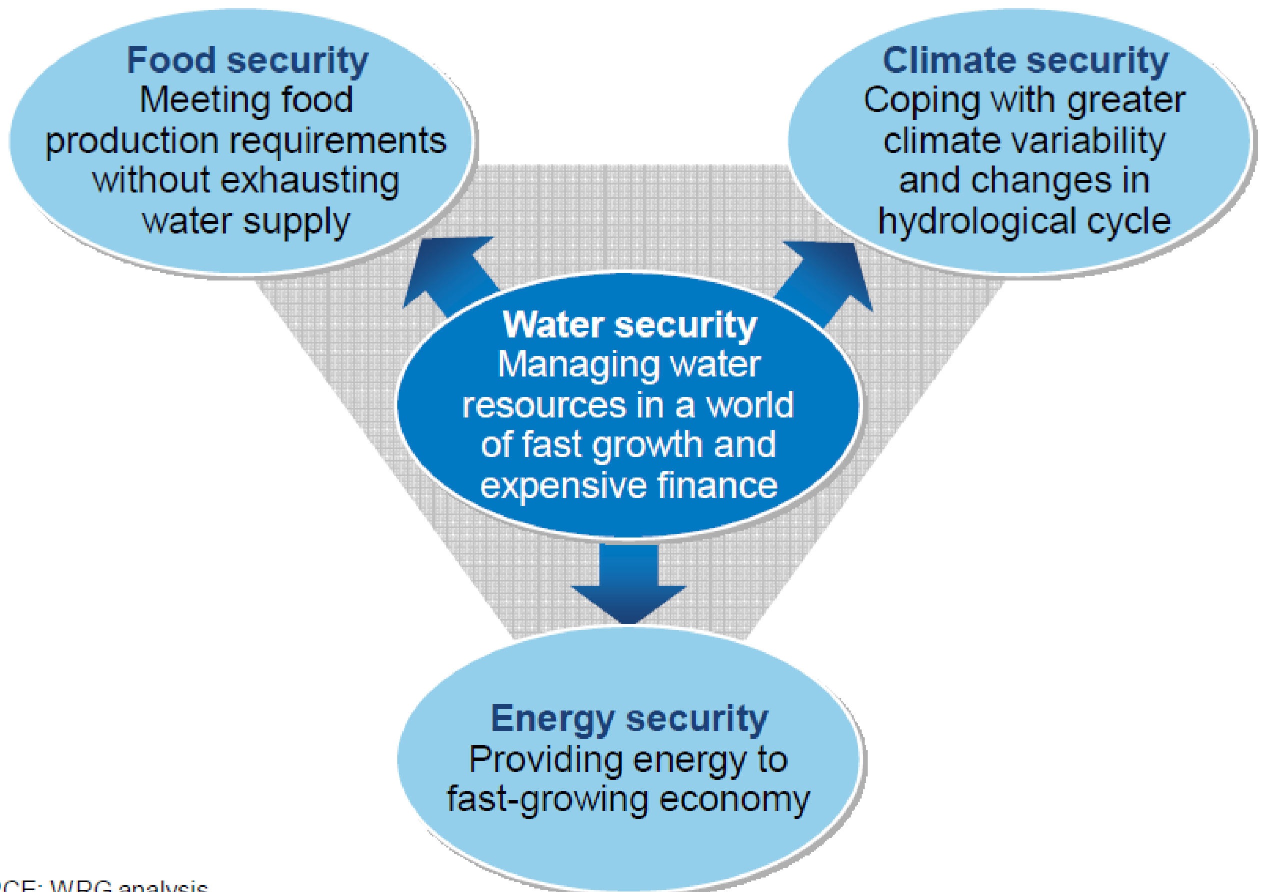
Environmental impacts/GHG Emissions:

- Which corresponds to 9.6 GtC (gigatonnes of carbon) of CO_2 emissions per year by 2050….***not sustainable (global good)***

And food security…?

- 60 % of food from irrigated agr. (21 Mha, consuming 251BCM+)
- In some areas, fossil groundwater is being exploited for irrigation…***not sustainable***…rainfed plays a good role but threatened by Climate Change.

The Nexus approach



SOURCE: WRG analysis

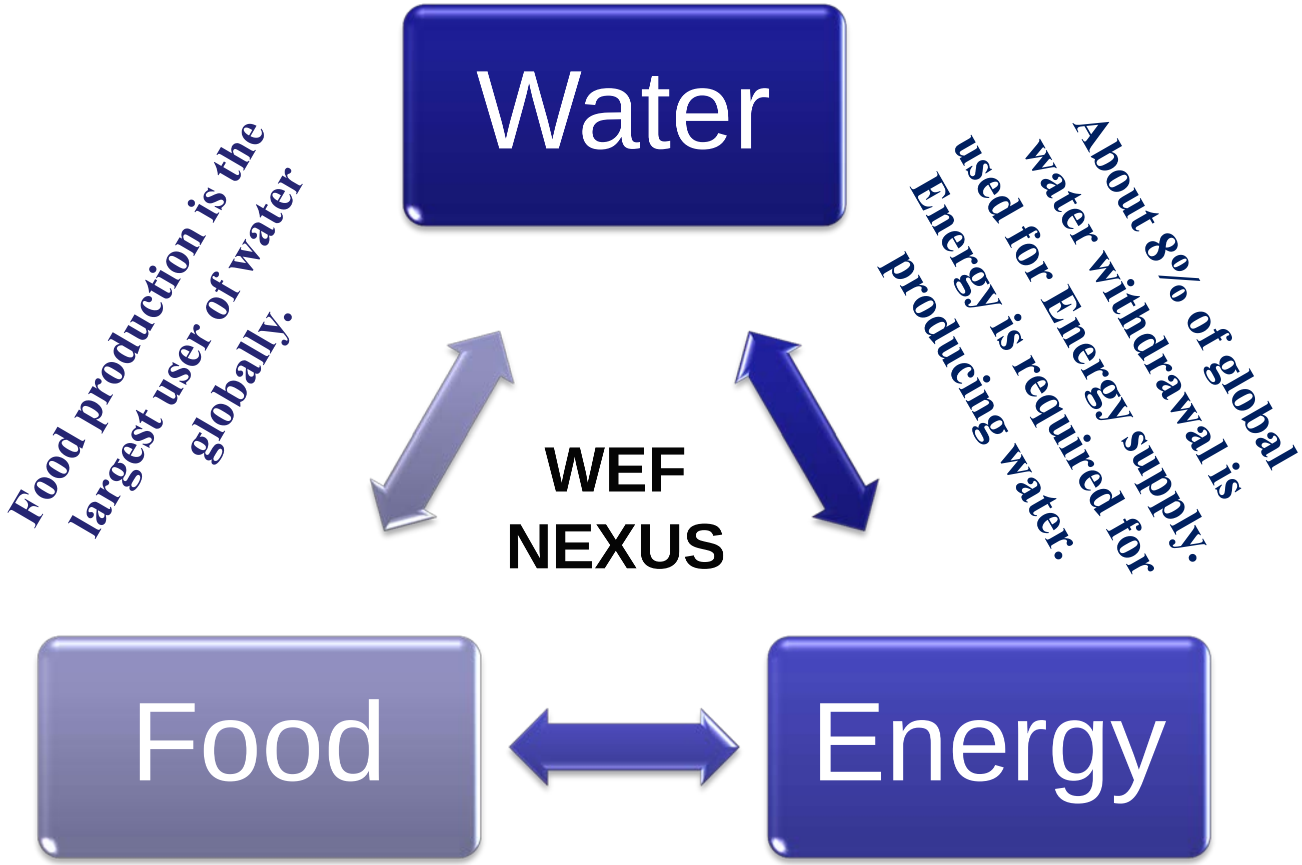
Water has moved from a marginal input towards a central enabler of food, energy and climate security – and a vital prerequisite for growth.

Sustainability

Sustainable development means meeting the needs of people along with saving the natural resources for next generations

WEF Security means that in all over the world people should have the physical and economical access to all the resources to meet their needs

water, energy and food security can be achieved through a Nexus approach – an approach that integrates management and governance across sectors and scales



Food production is responsible for around 30 % of total global energy demand.
Crops can themselves be used to produce bio-fuels.

WEF Nexus & Desalination

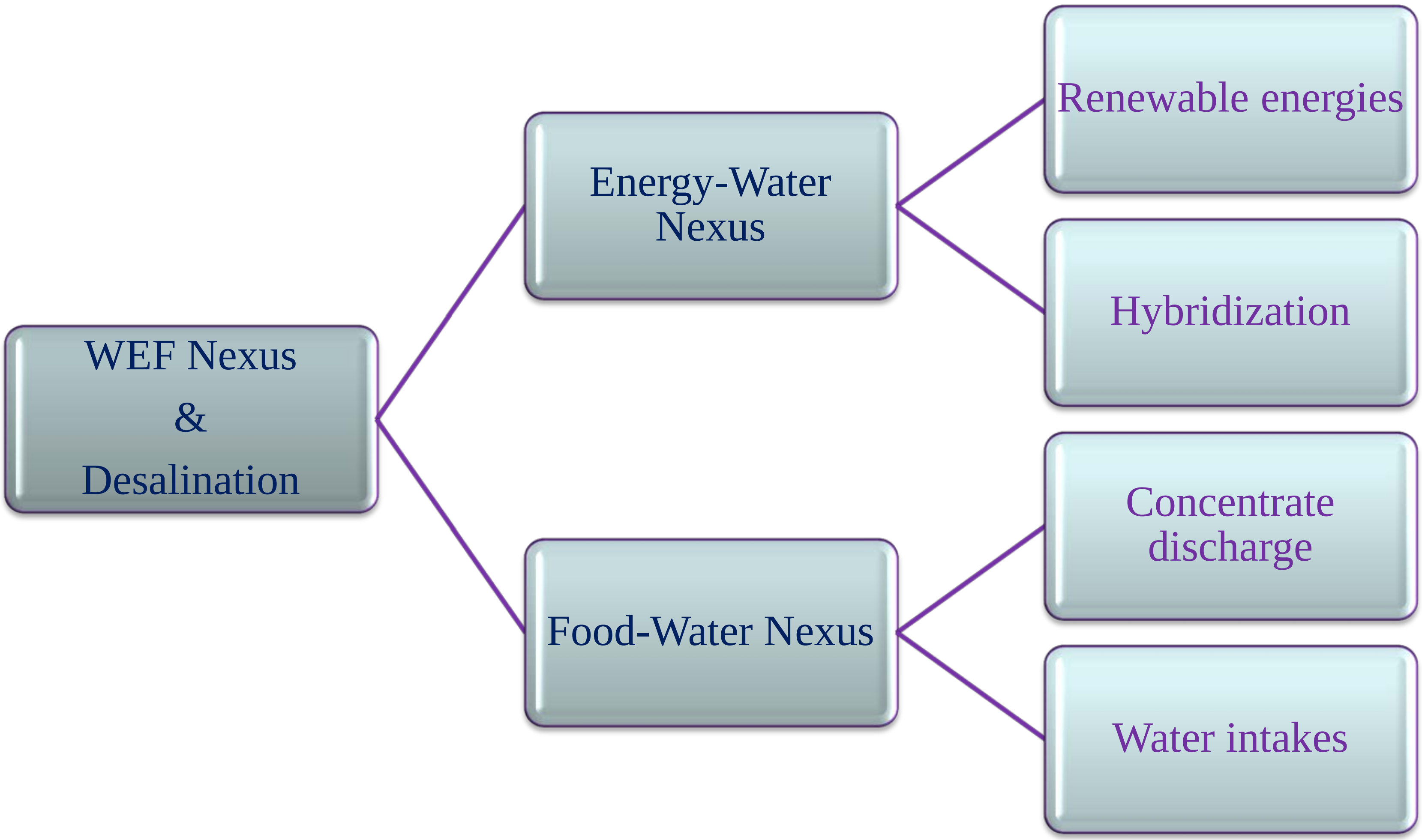
- **Desalination is one of the biggest energy users in the world (about 1 ton of oil is required for every 20 tons of freshwater produced even if all the heat can be extracted from the oil)**

- **Over the last 50 years Fossil fuels account for the most of energy which is being used in such process**

- **Depletion of fossil fuels, air pollution and greenhouse gases emission are desalination consequences**

- **These pollutants will make changes in ecosystems, destroy some kinds of animals or plants or change their normal existence as a part of the food chain.**

Steps in desalination to approach Nexus



Desalination & Renewable Energies

Renewable Energies

Solar	Wind	Wave	Geothermal

Wind

- Coastal areas , mountain stations & islands
- RO & MVC
- Cost Effective

Geothermal

Electricity generation

Mature

Distillation & RO

Hybridization

Hybridization	Explanation
MSF or MED + RO	Cool water from MSF heat rejection will feed RO sys.
MSF + Power Generation	MSF will use heat from Power generation
Nuclear heat reactors + MSF or RO	Electricity from nuclear reactor will drive pumps in OP or heat water in MSF
MD + MSF or ME or RO	Hybridization with ME and MSF is under research
NF membrane + MSF or RO	Pretreatment by NF will increase TBT and so increase performance
NF + RO + MSF	

Salinity

- Will effect marine organisms such as population, size and behavior
- concentrations of greater than 5% are Harmful for marine life

Temperature

- Result in lower DO
- Effects the mobile species
- Decrease the time of the eggs development
- Increasing the rate of the population growth

Chemicals

- Eutrophication by Antiscalants
- Ionized and unionized species
- Bury sessile benthic organisms

Water Intakes

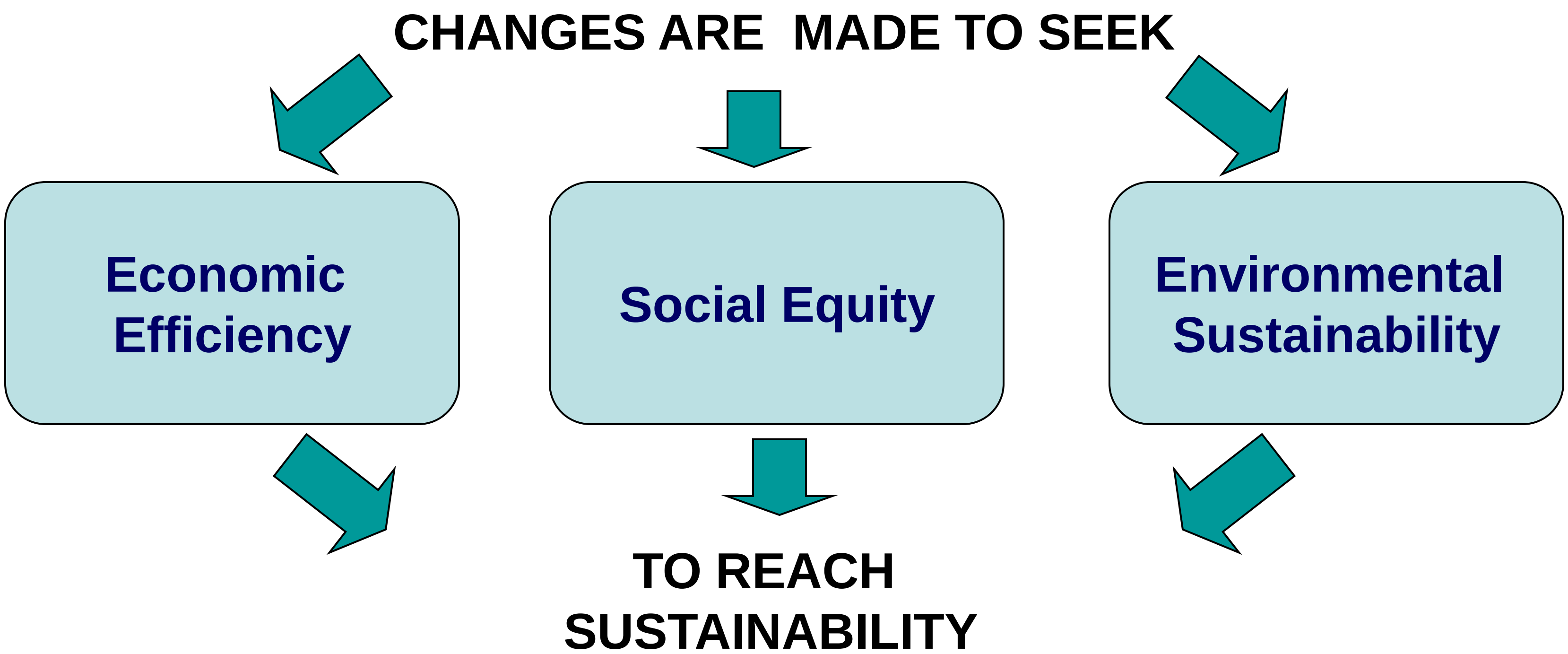
- According to EPA, these intake structures kill at least 3.4 billion fish and other organisms annually. Larger organisms are trapped against the intake screens, and smaller ones, such as fish eggs and larvae, are drawn through the intake screens and destroyed in the cooling system.

- Re-suspension of sediments, Pollutants, Nutrients during construction will change the marine life.

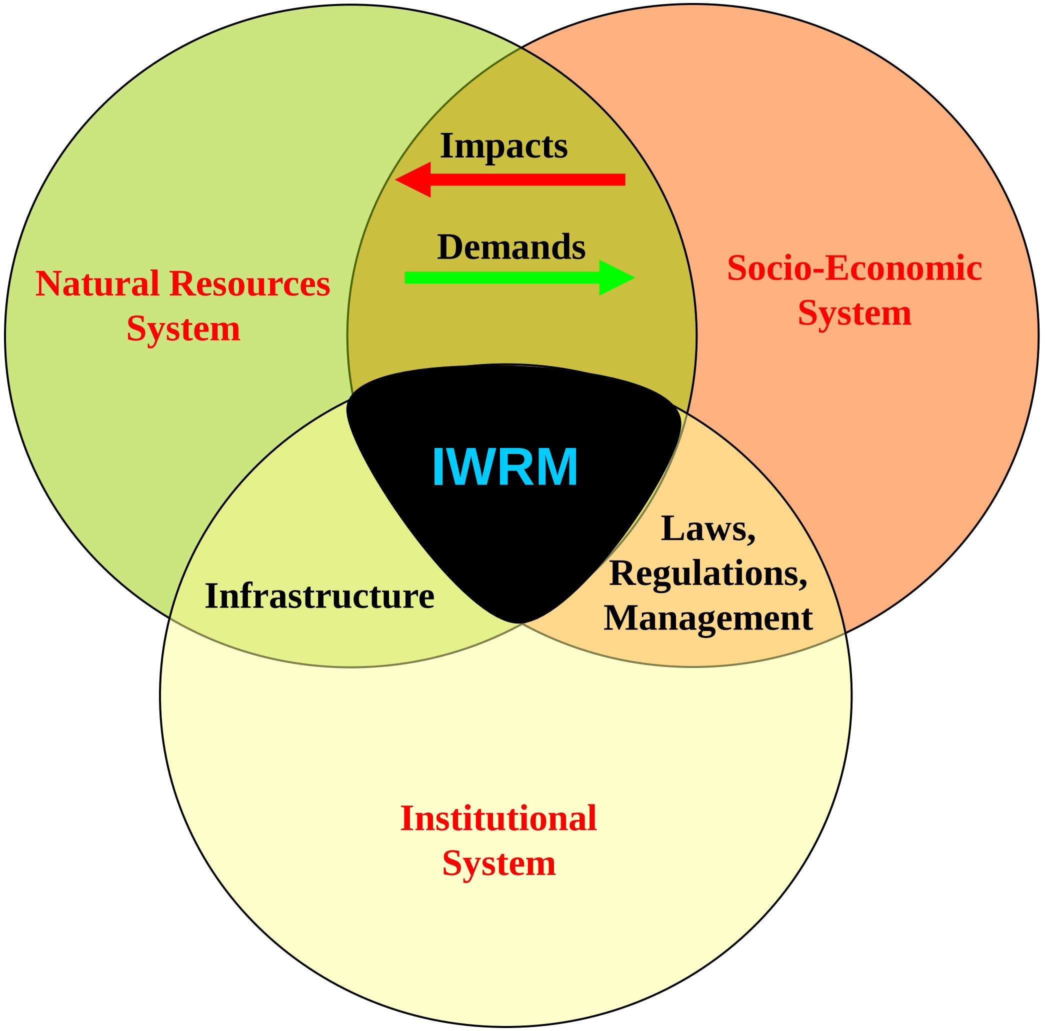
Integrated Water Resources Management

IWRM is a process which promotes the co-ordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (GWP 2000).

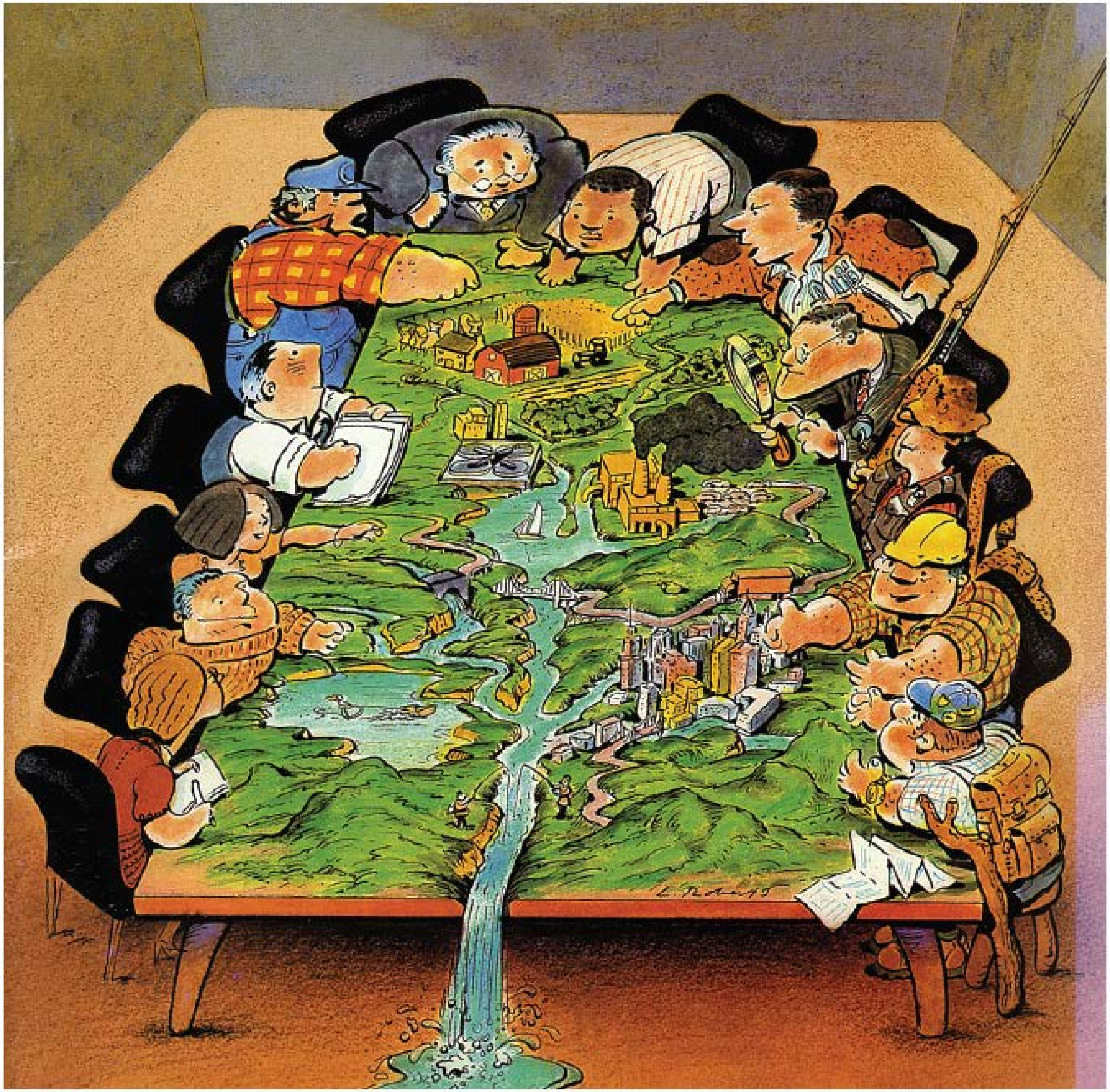
CHANGE AREAS



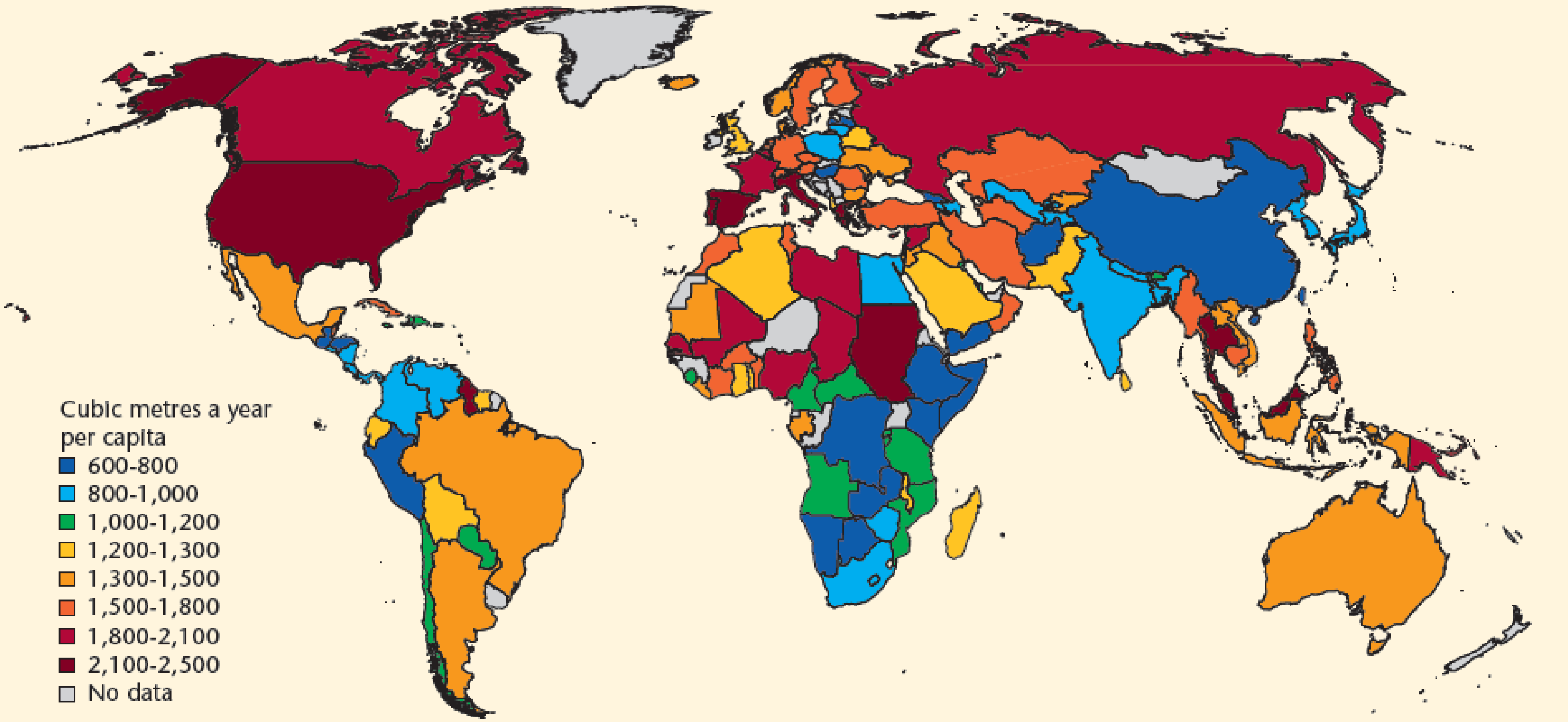
IWRM Concepts:



IWRM

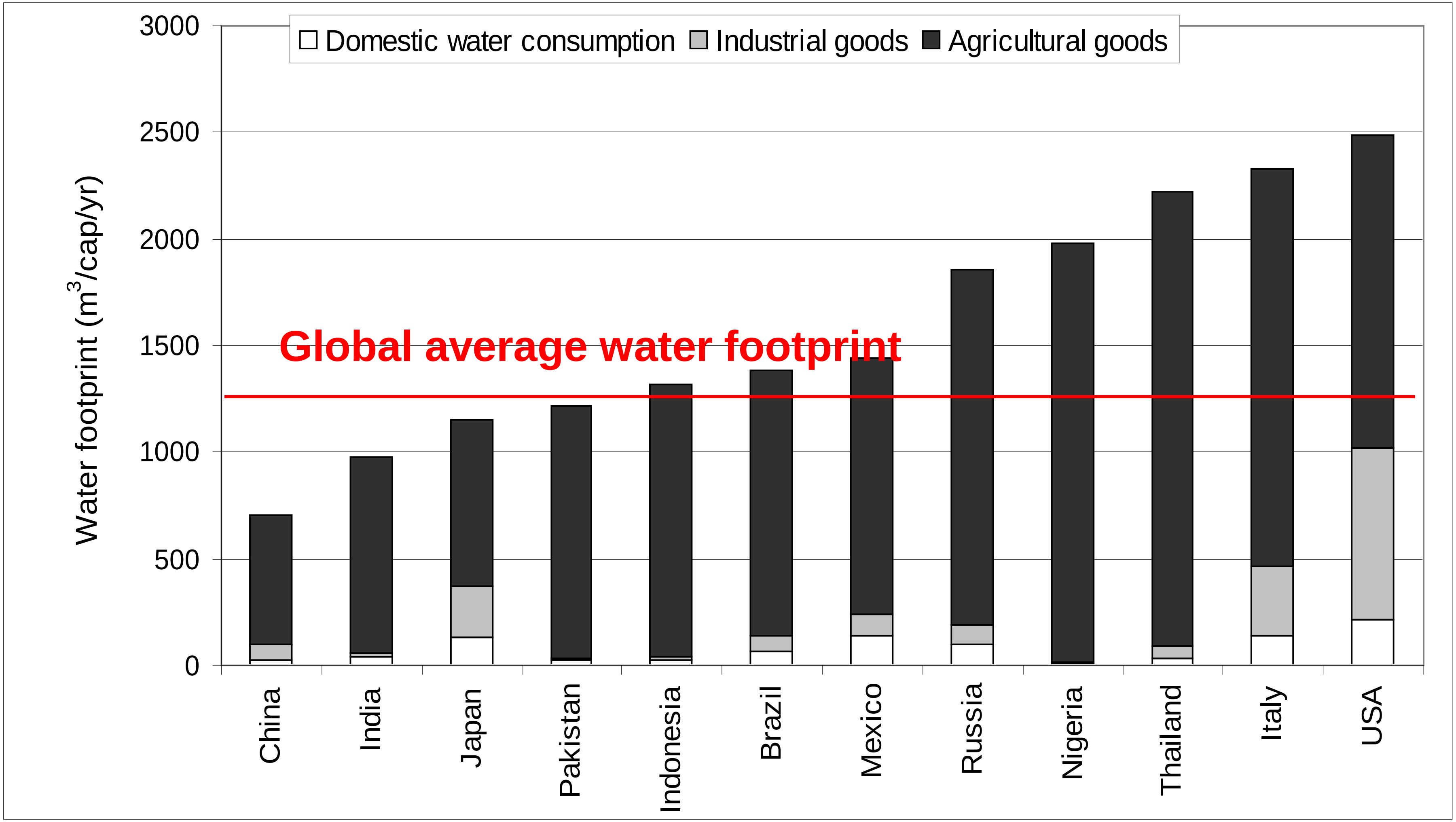


Average national water footprint per capita, 1997-2001



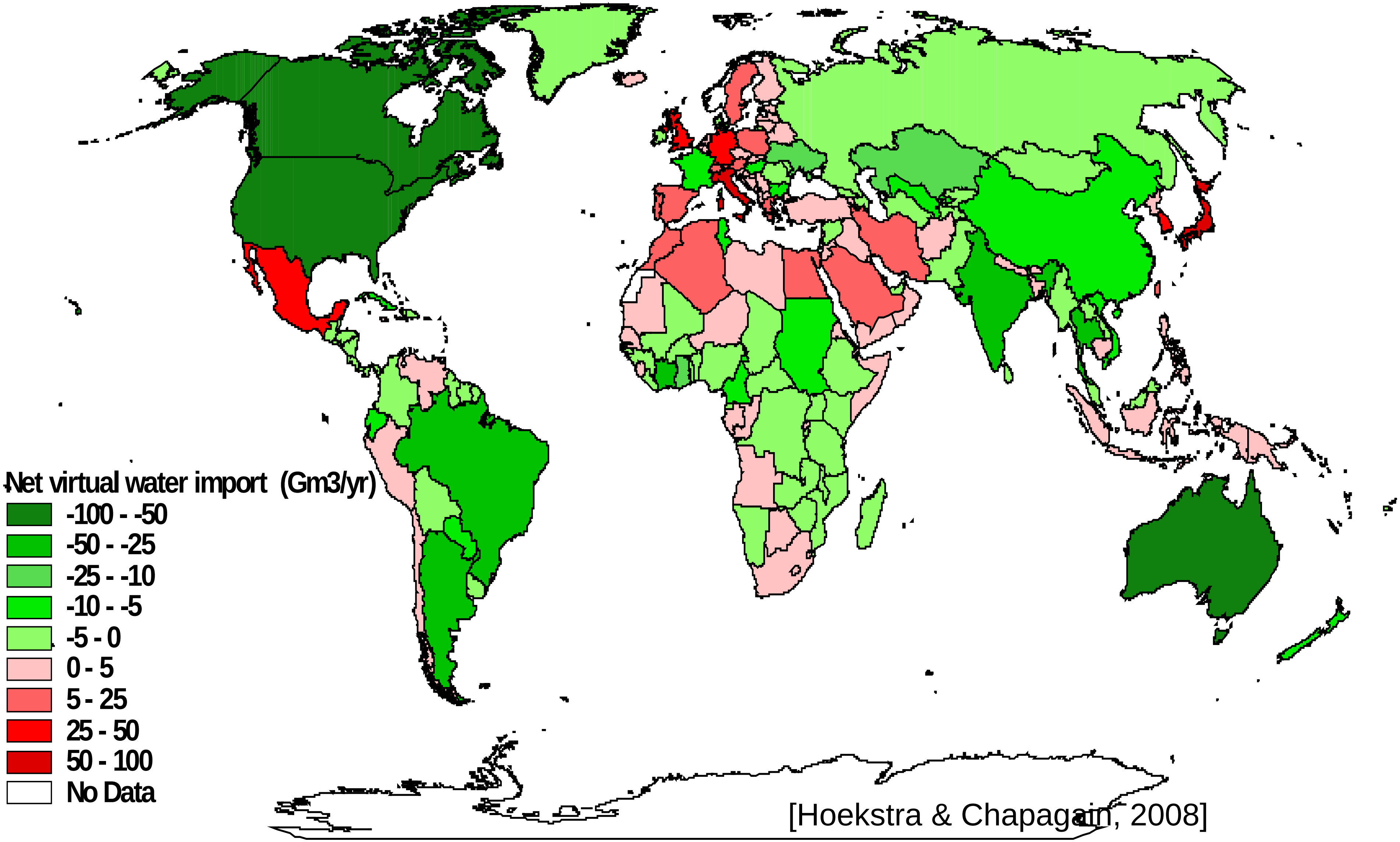
Source: Hoekstra and Chapagain 2008.

Water footprint per capita



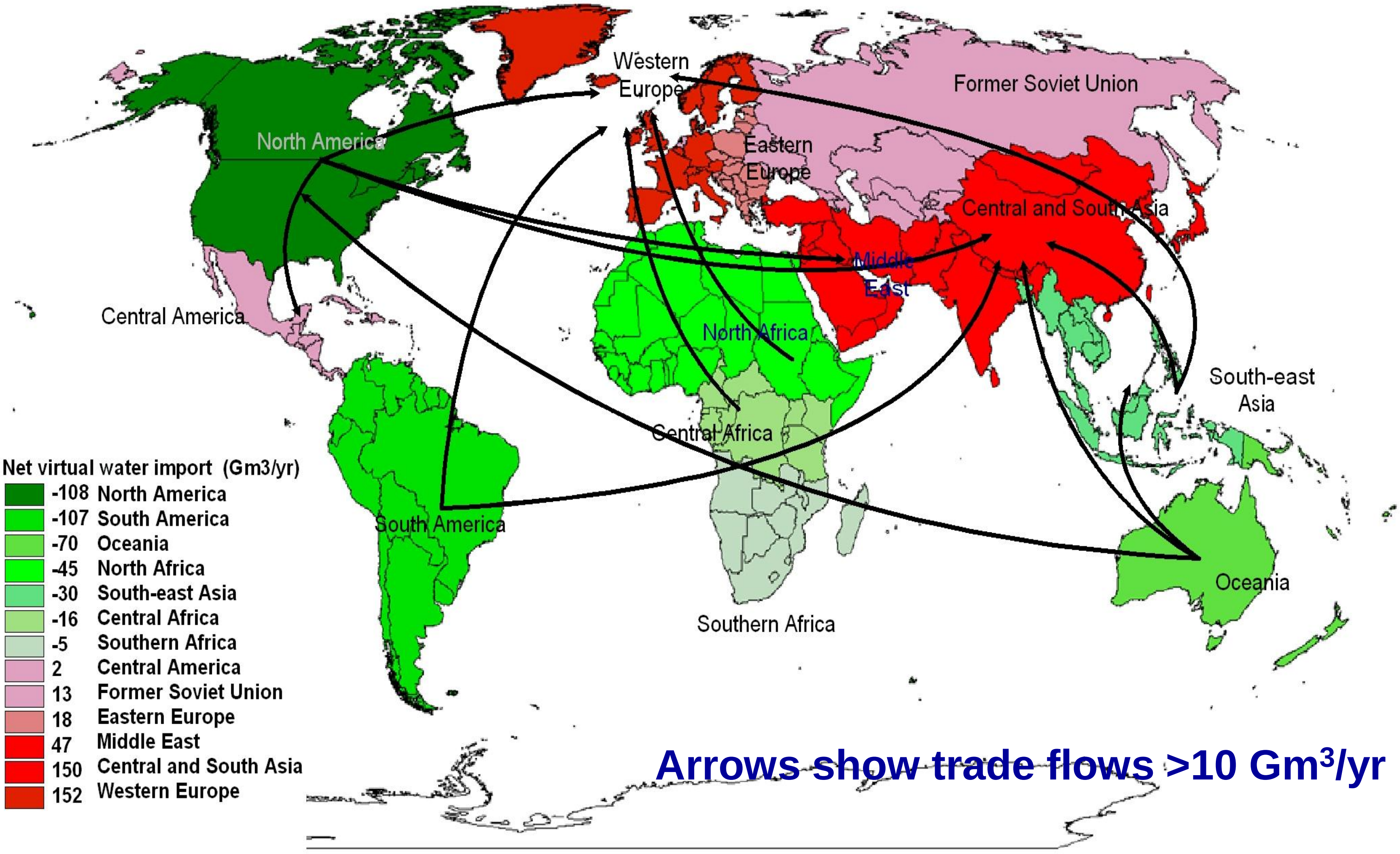
[Hoekstra & Chapagain, 2008]

National virtual water balances



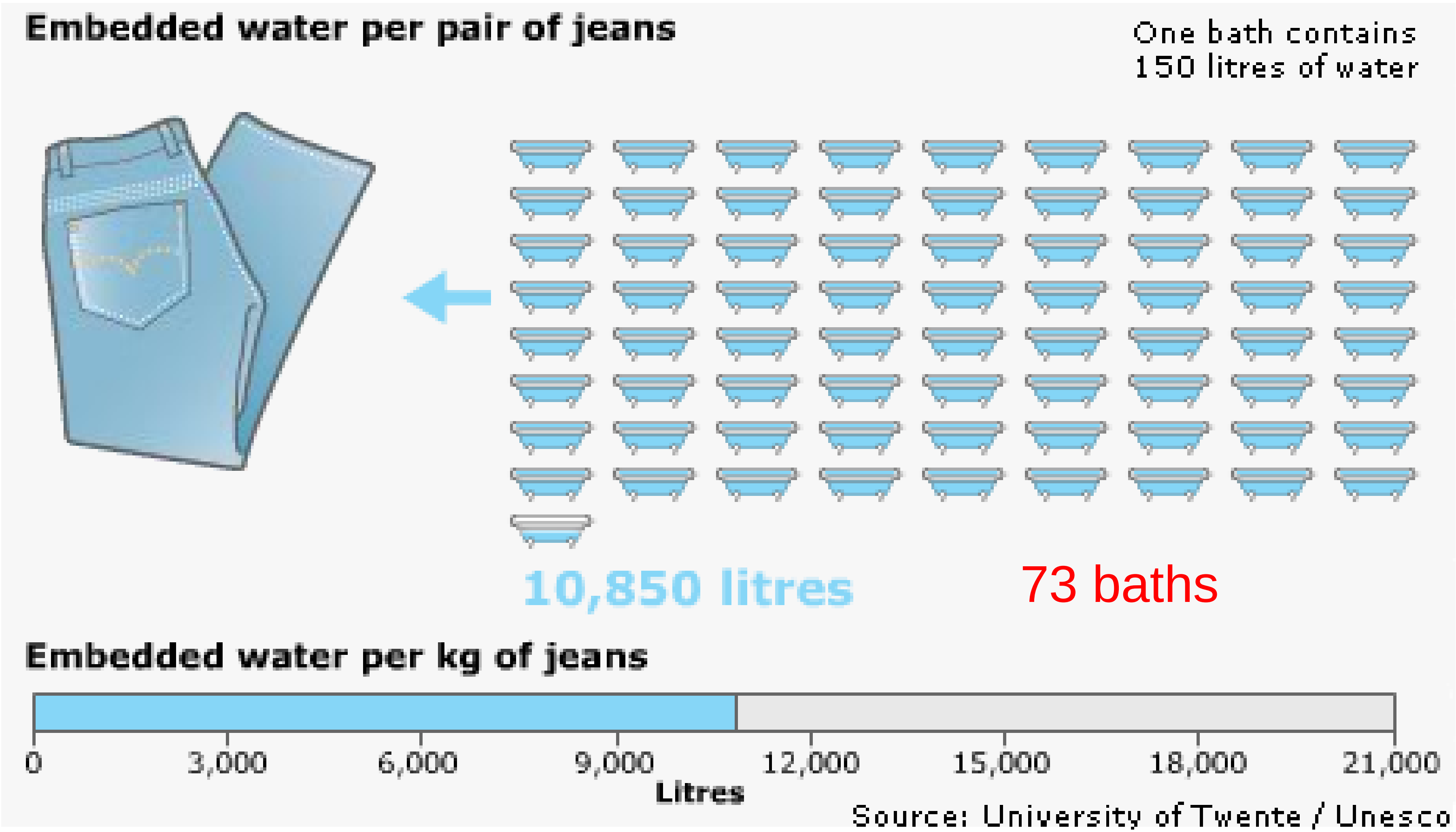
[Hoekstra & Chapagain, 2008]

Regional virtual water balances
(only agricultural trade)



[Hoekstra & Chapagain, 2008]

Virtual Water



73 baths


180
litres
1 kg of
tomatoes


1560
litres
1 kg of
dry pasta


2,400
litres
1 hamburger

1260 litres

22,000 litres/m^2

7,500 litres/kg

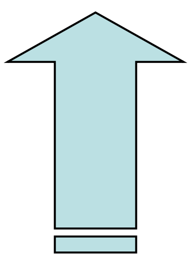
560 litres/g

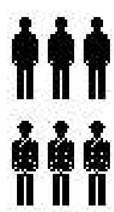
IRAN

- **Area:**
  1.648 million km^2
- **Population:**
  77 million
- **No of provinces:**
  31
- **Average Rainfall:**
  271 mm
- **Neighboring Countries:**
  Afghanistan, Pakistan, Iraq Turkmenistan, Azerbaijan, Armenia, Turkey Arab States in Persian Gulf
- **Language:** **Persian, Azerbaijani, Kurdish, ...**

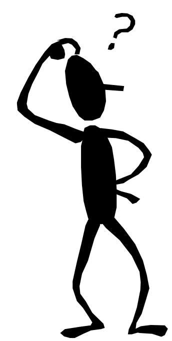
Population growth

1961



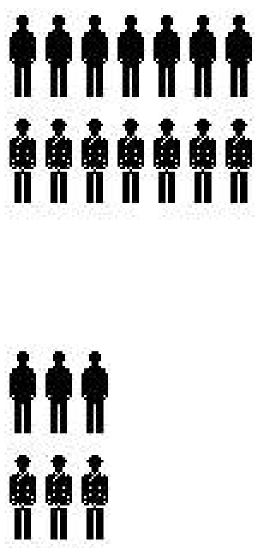


24.3



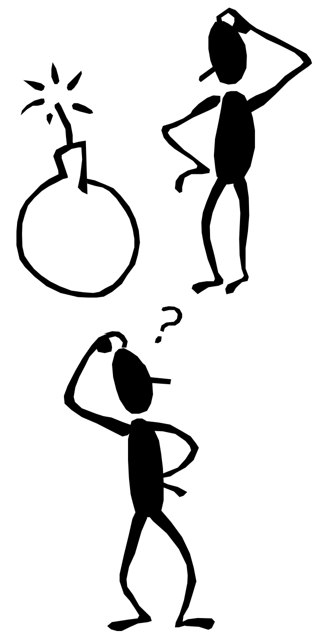
Unit: Million inhabitants

Population growth



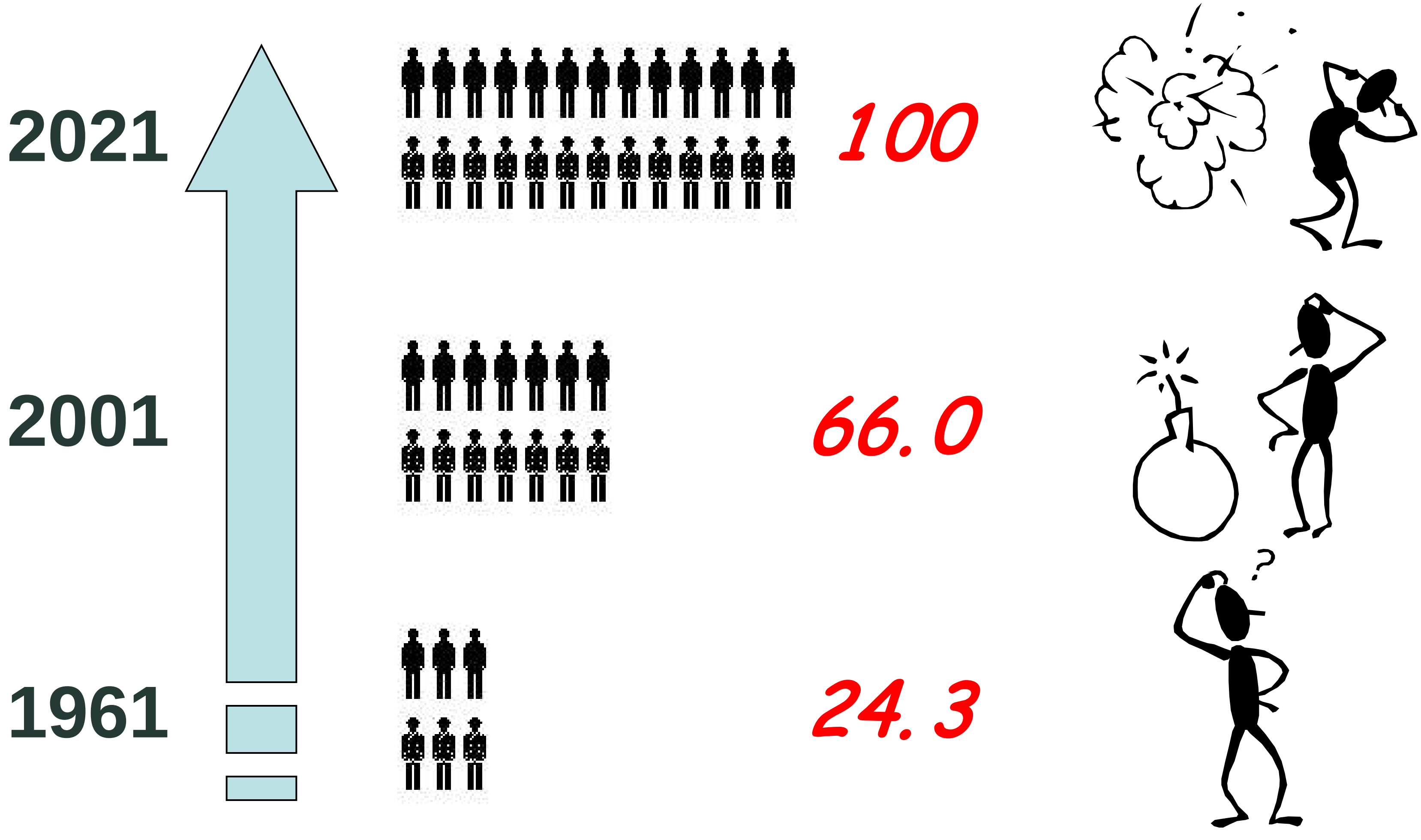
2001 — *66.0*

1961 — *24.3*



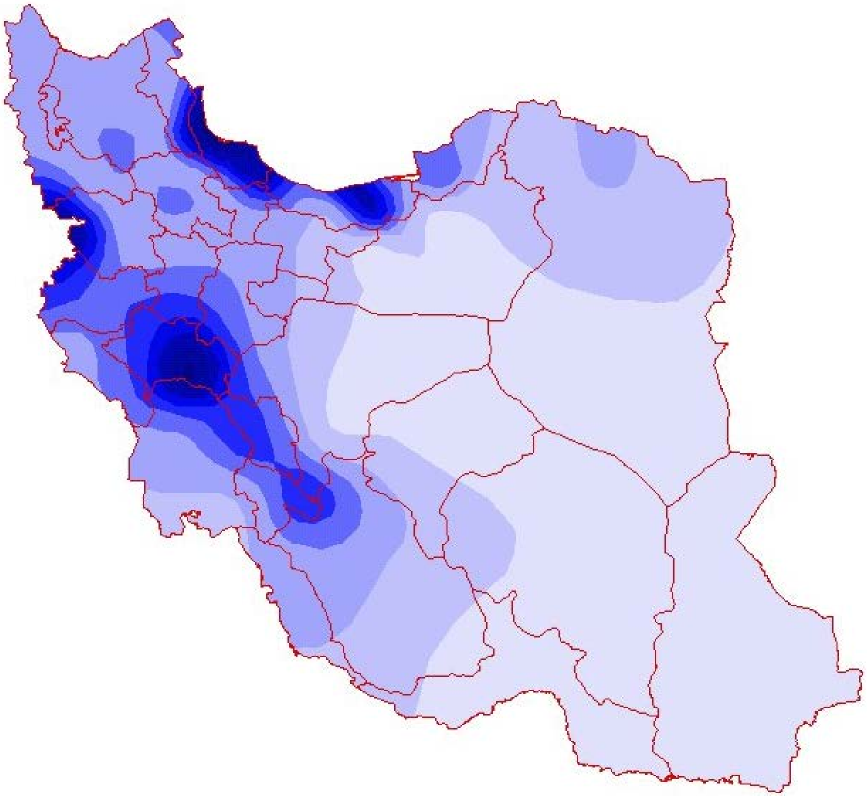
Unit: Million inhabitants

Population growth



Unit: Million inhabitants

Water Resources



Water Resources

Source of Water	Volume (BCM)
precipitation	412
evapotranspiration	282
renewable water resources	130
recharge of groundwater resources by precipitation and surface flows	38
available surface flows	92

Year	Annual Renewable Water availability (cubic meters/capita)
1956	7000
2001	2000
2021	1300


Lake Urmia
The Hamoun
Caspian Sea
GARAGUM
TURKMENISTAN
Ashgabat
Mary
Bayramaly
Garagum Canal
Chärjew
Naxçıvan
Van
Khvoy
Ahar
Tabrīz
Ardabīl
Urmia
Mīāneh
Rasht
Gonbad-e Qābūs
Bojnūrd
Shirvān
Qūchān
Zanjān
Chālūs
Gorgān
Āmol
Mashhad
Qazvīn
Karaj
Tehrān
Semnān
Sabzevār
Torbat-e Heydarīyeh
Torbat-e Jām
Irbīl
KORDESTĀN
ZANJĀN
Sanandaj
Halabjah
SEMNĀN
DASHT-E KAVIR
Herāt
Hamadān
Qom
Malāyer
Kermānshāh
Īlām
LORESTĀN
Arāk
Kāshān
OSTĀN-E KHORĀSĀN
Qā'en
AFGHAN
Baghdād
ĪLĀM
Khorramābād
ESFAHĀN
Nā'īn
Bīrjand
Farāh
Al Hillah
Ad Dīwānīyah
Esfahān
IRAN
Dezfūl
Masjed-e Soleymān
Lashkar Gā
Shūshtar
Īzeh
Yazd
YAZD
DASHT-E LŪT
Al 'Amārah
Ahvāz
Zābol
An Nāşirīyah
Bandar-e Khomeynī
Zarand
Yāsūj
Rafsanjān
Kermān
Al Başrah
KHŪZESTĀN
Shahr-e Babak
KERMAN
KUWAIT
Shīrāz
Zāhedān
Ganāveh
Būshehr
Borāzjān
FĀRS
Sīrjān
Fasā
Dārāb
Jīroft
Jahrom
SĪSTĀN VA BALŪCHESTĀN
BIA
Bandar-e 'Abbās
HORMOZGĀN
Manama
Persian Gulf
Gulf of Oman
BALUCHIST
QATAR
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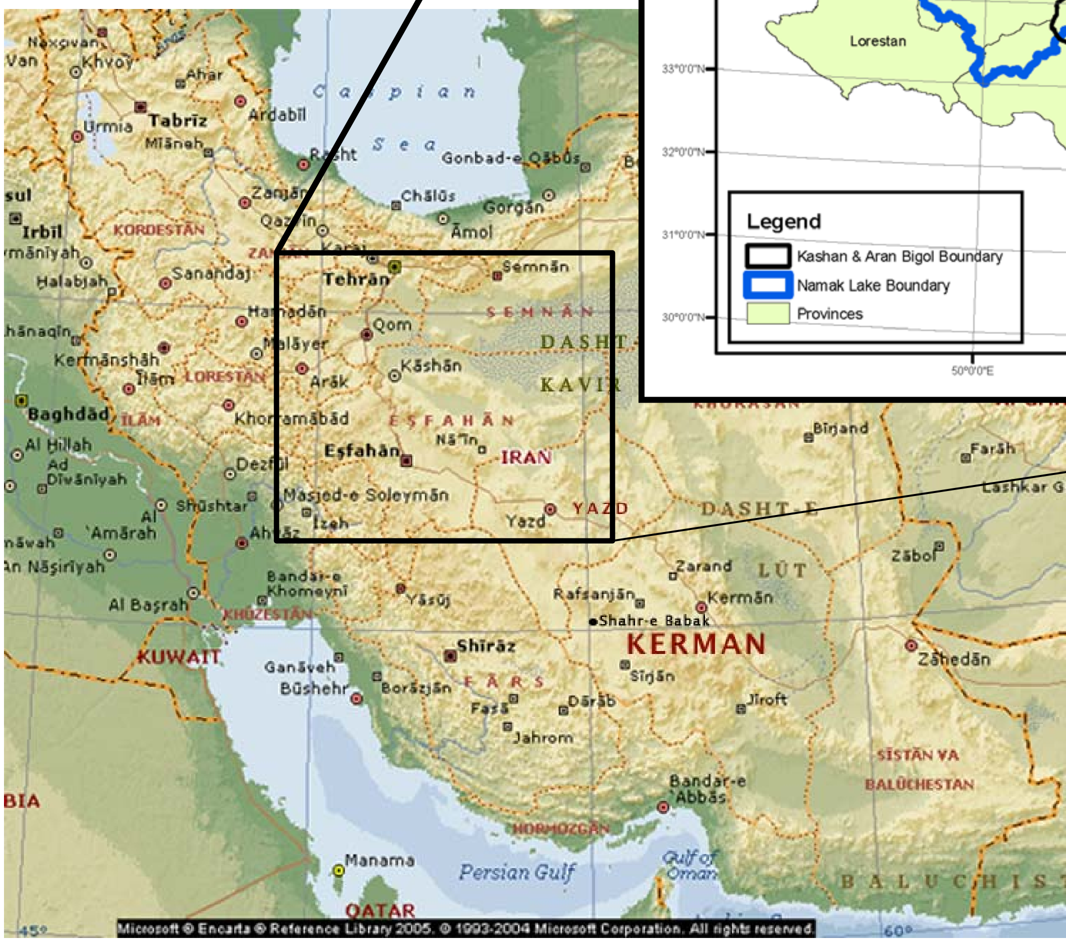
Case

KASHAN



Tehrān
Qom
Kāshān
Esfahān
Semnān
Arāk
IRAN
Caspian Sea
Persian Gulf
Gulf of Oman
KERMAN
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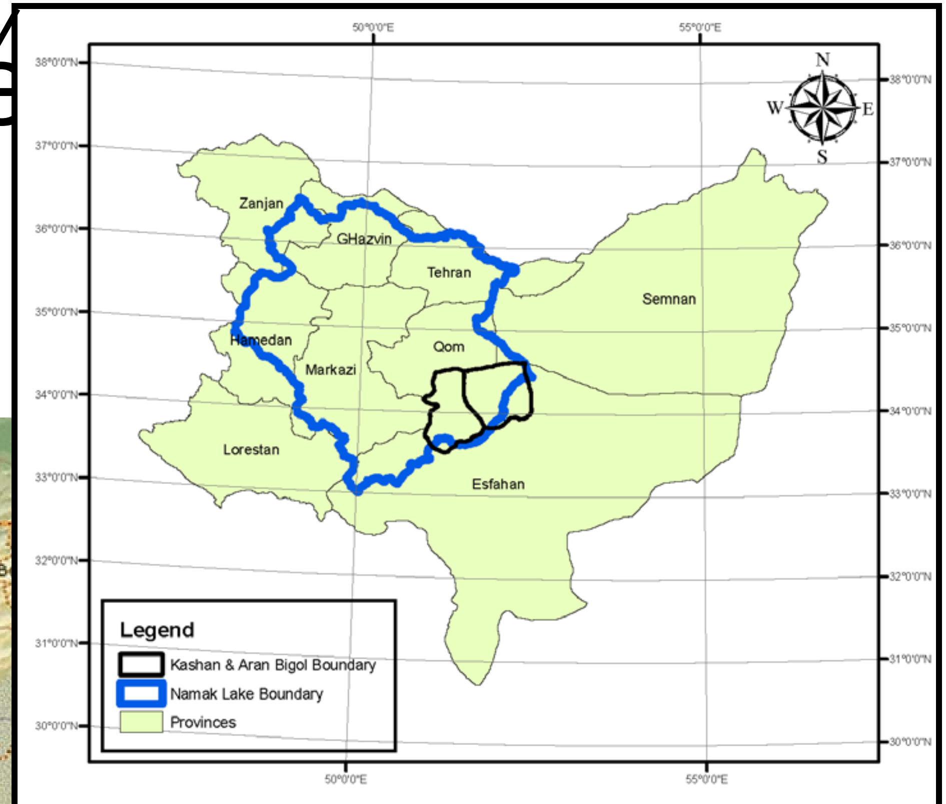
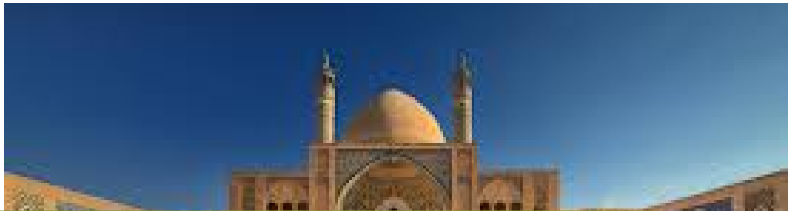
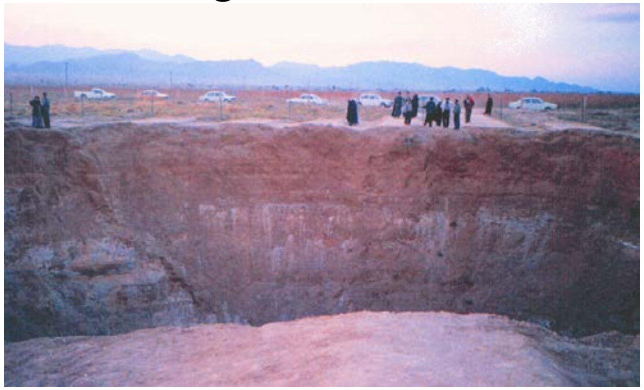


Zanjan
GHazvin
Tehran
Semnan
Hamedan
Qom
Markazi
Lorestan
Esfahan
Legend
Kashan & Aran Bigol Boundary
Namak Lake Boundary
Provinces
N
S
E
W
50°0'0"E
55°0'0"E

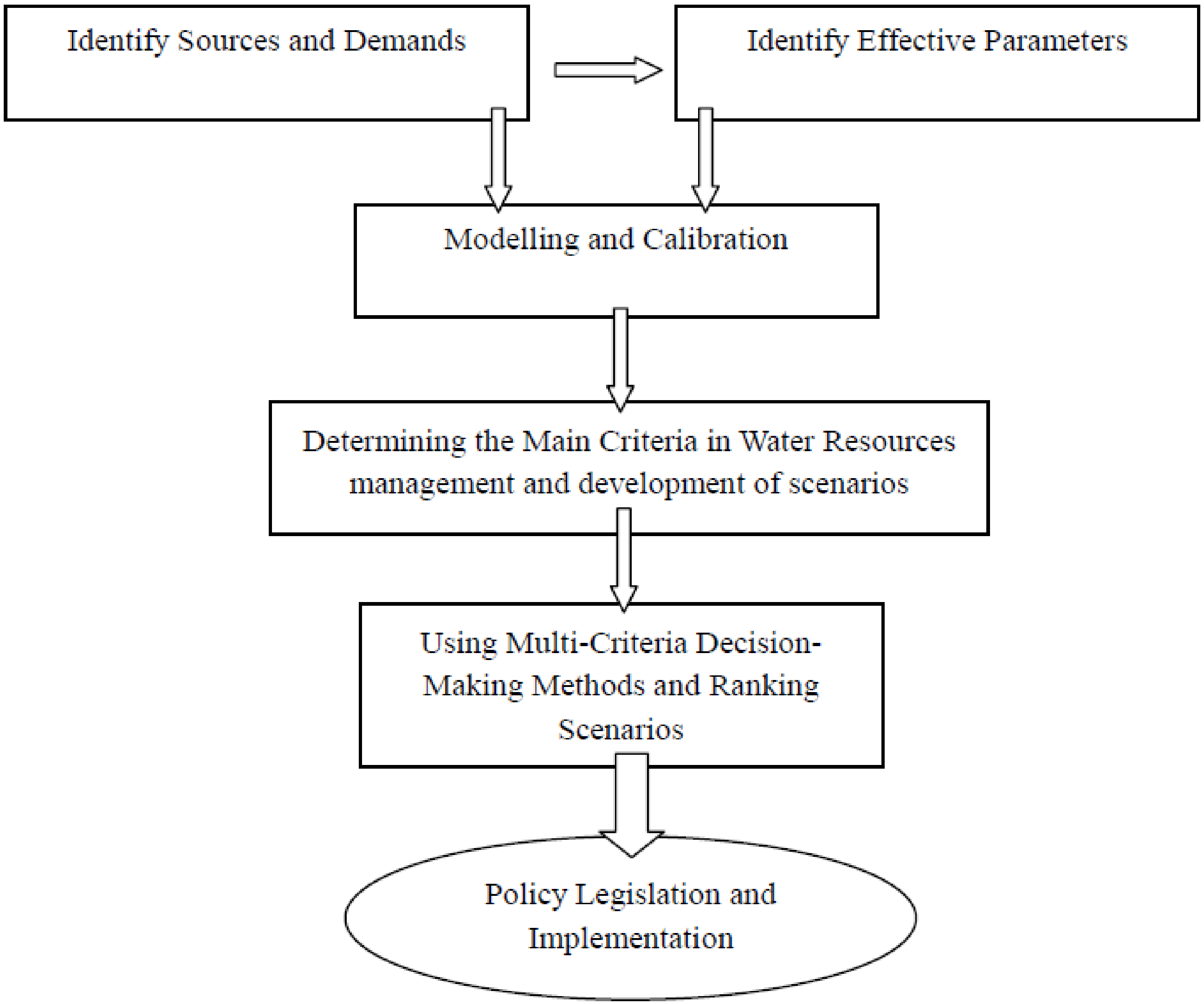
KASHAN

- Dry zone in Central IRAN plateau
- Rich culture
- Historical background
- Hotspot for tourism industry
- Production of the finest Rosewater
- Renowned Persian carpets
- Water resources limitations
- Excessive pressures on groundwater resources





Application of the Toolbox



Sources and Demands

Main Demands,2006(MCM)

Drinking water	Industry	Agriculture
33.98	5.89	387.29

- 90 % of water demand in agriculture
- 8% for drinking and 2 % for industry
- compared to the total supply available there is no balance between supply and demand in the region.

Water supply volumes in 2006(MCM/Year)

Ground water	Surface water	Golab tunnel
314.13	29.55	6

- No noticeable permanent rivers
- Extreme pressure on groundwater
- An average loss of approximately 0.5 meter in Kashan aquifer annually
- Inter basin water transfer

Main Criteria and Scenario Development

Generate scenarios:

1. Allocation priority
2. Agriculture conditions
3. Rate of population growth
4. Demand Management (reducing consumption per capita)
5. Wastewater reuse and loss management
6. Increasing the amount of transferred water through Golab tunnel
7. Changes in the Industry sector

Multi-Criteria Decision-Making

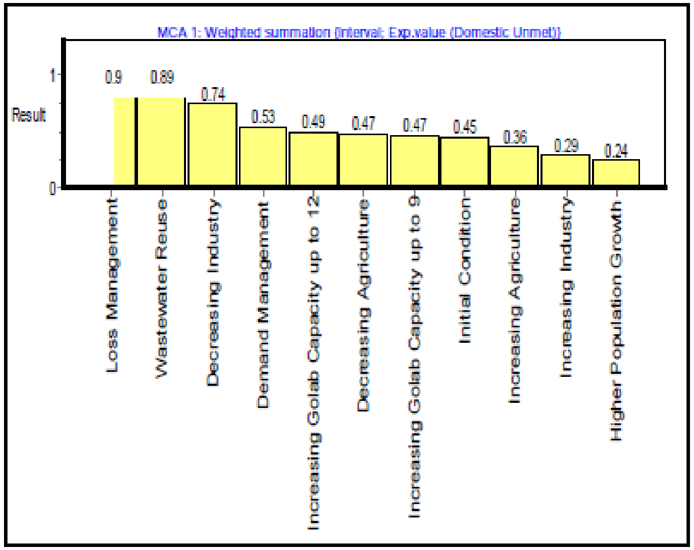
Resulting scenarios were considered individually as well as in overlapping formats to evaluate their rankings using MCDM approach based on both quantitative and non-quantitative criteria upon which implementation measures may be deducted and adopted.

Results

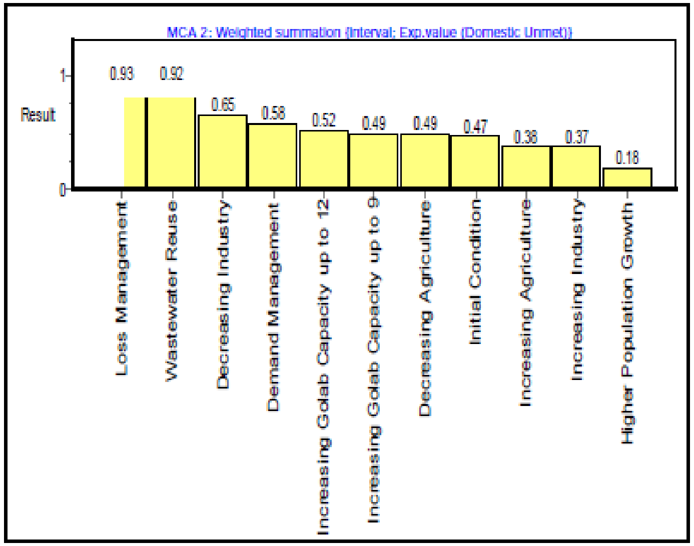
Weight effects based on unmet demand, Definite 2

MCA4	MCA3	MCA2	MCA1	Order
Agriculture Unmet demand	**Drinking water Unmet demand**	**Drinking water Unmet demand**	**Drinking water and Industry Unmet demand**	**1**
Drinking water and Industry Unmet demand	**Agriculture Unmet demand**	**Industry Unmet demand**	**Agriculture Unmet demand**	**2**
-	**Industry Unmet demand**	**Agriculture Unmet demand**	**-**	**3**

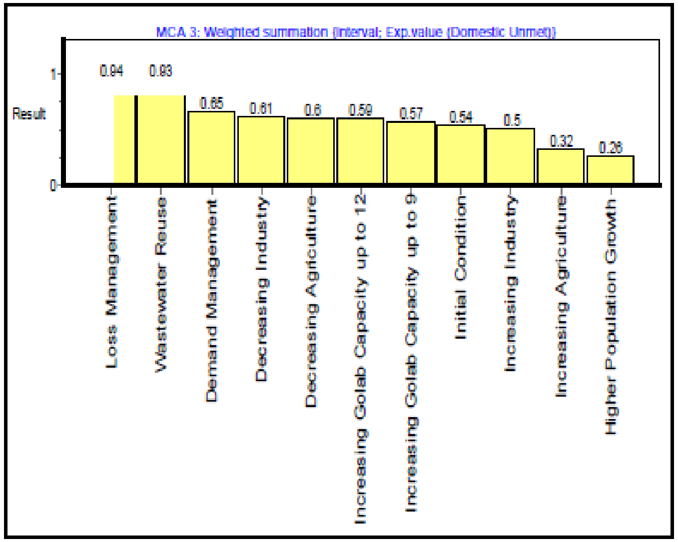
Results



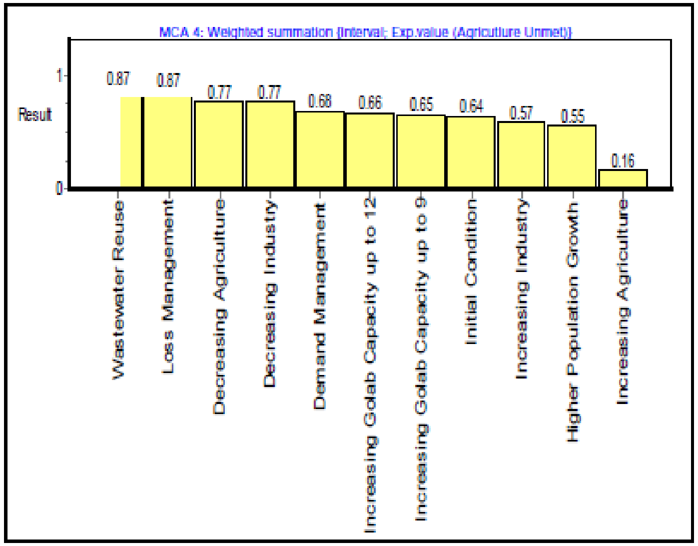
MCA 1: Weighted summation (interval; Exp.value (Domestic Unmet))
Result
1
0
0.9
0.89
0.74
0.53
0.49
0.47
0.47
0.45
0.36
0.29
0.24
Loss Management
Wastewater Reuse
Decreasing Industry
Demand Management
Increasing Golab Capacity up to 12
Decreasing Agriculture
Increasing Golab Capacity up to 9
Initial Condition
Increasing Agriculture
Increasing Industry
Higher Population Growth



MCA 2: Weighted summation (interval; Exp.value (Domestic Unmet))
Result
1
0
0.93
0.92
0.65
0.58
0.52
0.49
0.49
0.47
0.38
0.37
0.18
Loss Management
Wastewater Reuse
Decreasing Industry
Demand Management
Increasing Golab Capacity up to 12
Increasing Golab Capacity up to 9
Decreasing Agriculture
Initial Condition
Increasing Agriculture
Increasing Industry
Higher Population Growth



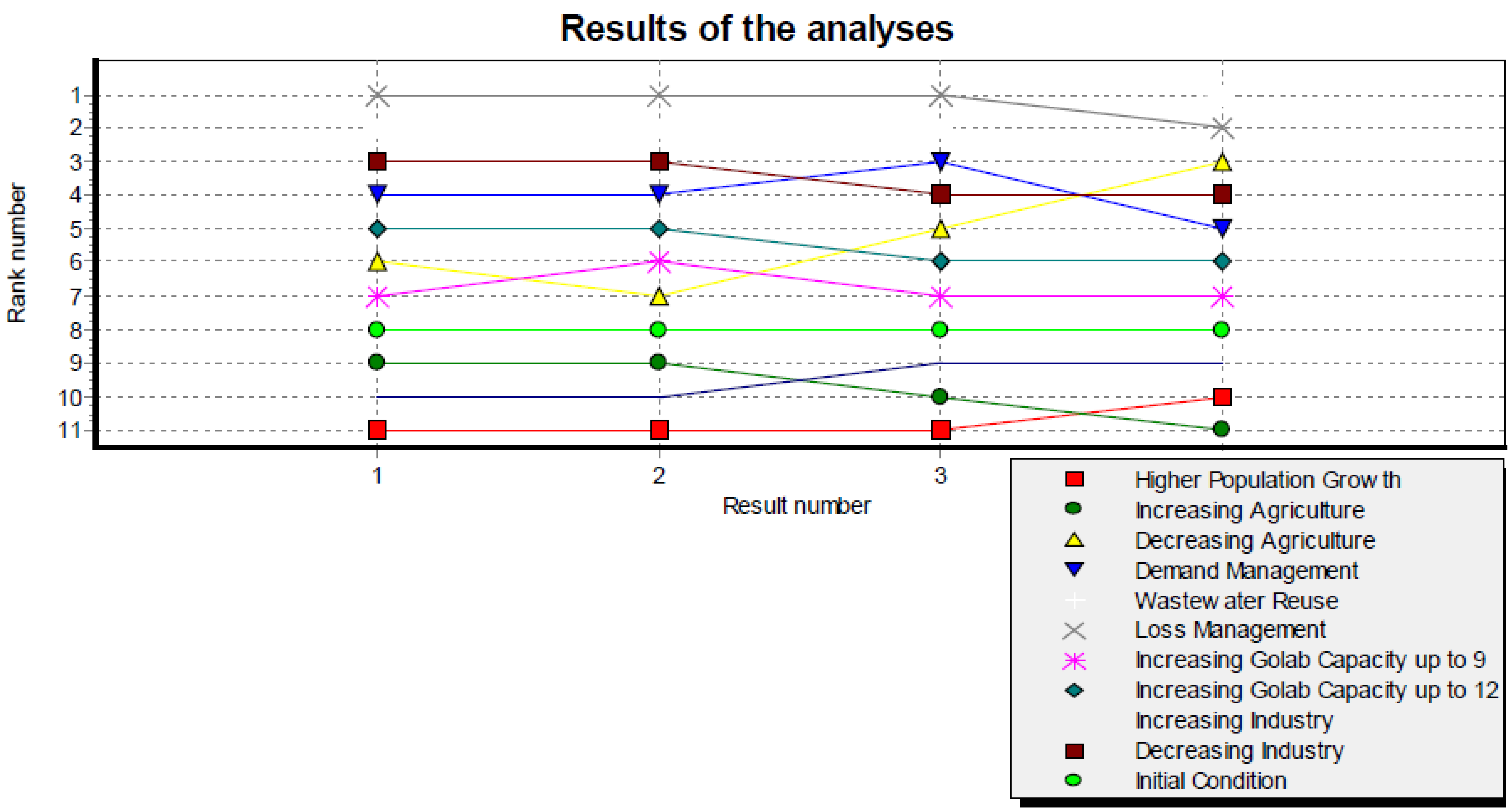
MCA 3: Weighted summation (interval; Exp.value (Domestic Unmet))
Result
1
0
0.94
0.93
0.65
0.61
0.6
0.59
0.57
0.54
0.5
0.32
0.26
Loss Management
Wastewater Reuse
Demand Management
Decreasing Industry
Decreasing Agriculture
Increasing Golab Capacity up to 12
Increasing Golab Capacity up to 9
Initial Condition
Increasing Industry
Increasing Agriculture
Higher Population Growth



MCA 4: Weighted summation (interval; Exp.value (Agriculture Unmet))
Result
1
0
0.87
0.87
0.77
0.77
0.68
0.66
0.65
0.64
0.57
0.55
0.16
Wastewater Reuse
Loss Management
Decreasing Agriculture
Decreasing Industry
Demand Management
Increasing Golab Capacity up to 12
Increasing Golab Capacity up to 9
Initial Condition
Increasing Industry
Higher Population Growth
Increasing Agriculture

Results

Comparison of Scenarios Ranking



Results

Scenarios ranking for unmet demand in 2041(MCM)

Scenario	Industry	Agriculture	Drinking water	Rank
Wastewater reuse and loss management	6.49	226.6	0.38	1
Wastewater reuse	6.49	221.52	0.93	2
Demand Management	21.49	311.87	26.32	3
Reduce industrial activity	0.00	310.4	39.59	4
Reduce cultivated regions	21.49	35.53	39.59	5
Increasing the amount of transferred water through Golab tunnel to 12 MCM	21.49	306.92	33.27	6
Increasing the amount of transferred water through Golab tunnel to 9 MCM	21.49	308.94	36.27	7
Initial condition (Reference scenario)	21.49	311.4	39.59	8
Develop industry sector	32.92	311.4	39.59	9
Increase cultivated regions	21.49	1357.5	39.59	10
Higher population growth	21.49	311.17	72.91	11

Results

Scenarios combinations ranking in 2041(MCM)

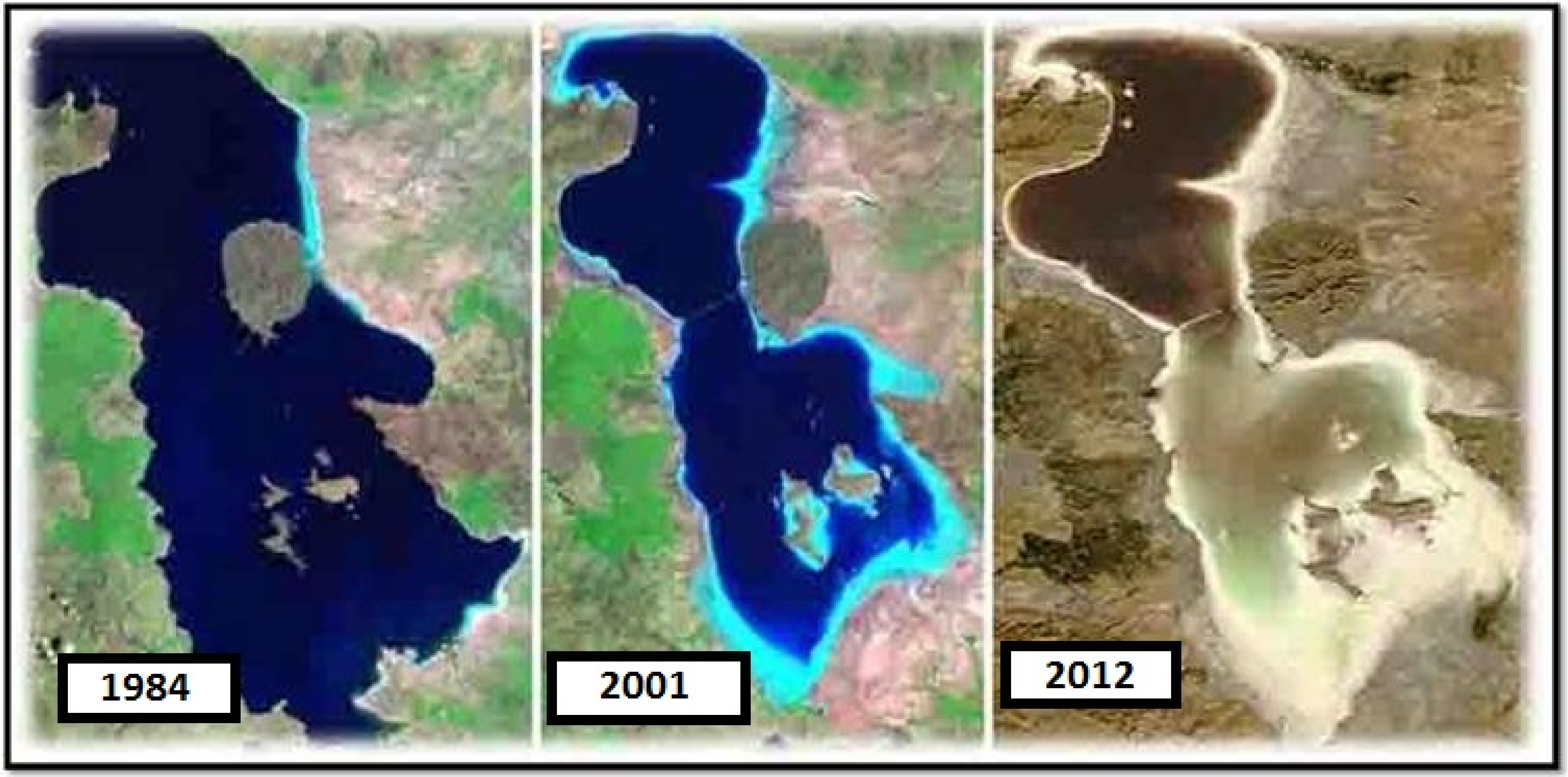
Combined Scenarios	Industry	Agriculture	Drinking water	Rank
Higher population growth+ Demand Management+ Increasing the amount of transferred water through Golab tunnel to 12 MCM+ Develop industry sector+ Reduce cultivated regions+ Wastewater reuse and loss management	11.52	29.20	0.35	1
Highe population growth + Demand Management+ Increasing the amount of transferred water through Golab tunnel to 12 MCM+ Wastewater reuse	6.49	220.95	0.88	2
Higher population growth+ Increase cultivated regions + Demand and loss Management + Increasing the amount of transferred water through Golab tunnel to 12 MCM	6.49	1054.04	0.35	3
Increase cultivated regions + loss management	6.49	1054.6	0.37	4
Increase cultivated regions + Wastewater reuse	6.49	1049.5	0.93	5
Reference scenario (Initial condition)	21.49	311.4	39.59	6
Increase cultivated regions + Demand Management	21.49	1357.62	26.32	7
Higher population growth + Demand Management+ Increasing the amount of transferred water through Golab tunnel to 12 MCM	21.49	306.92	46.04	8
Higher population growth + Demand Management	21.49	311.17	52.04	9

Conclusions

- ✓ Integrated water resources management approach is needed to ascertain sustainability
- ✓ Development of an IWRM toolbox facilitates appropriate decision making
- ✓ Individual approaches such as demand management, wastewater reuse, loss management, industrial water demand management and inter-basin water transfer through desalination should be investigated in integration to generate a multi scenarios situation based on varying priorities of water use


Thank you
for your attention

Lake Urmia



The Hamouns