جامعة الملك فهد للبترول والمعادن
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WATER RESOURCES AND WATER CONSUMPTION PATTERN IN SAUDI ARABIA

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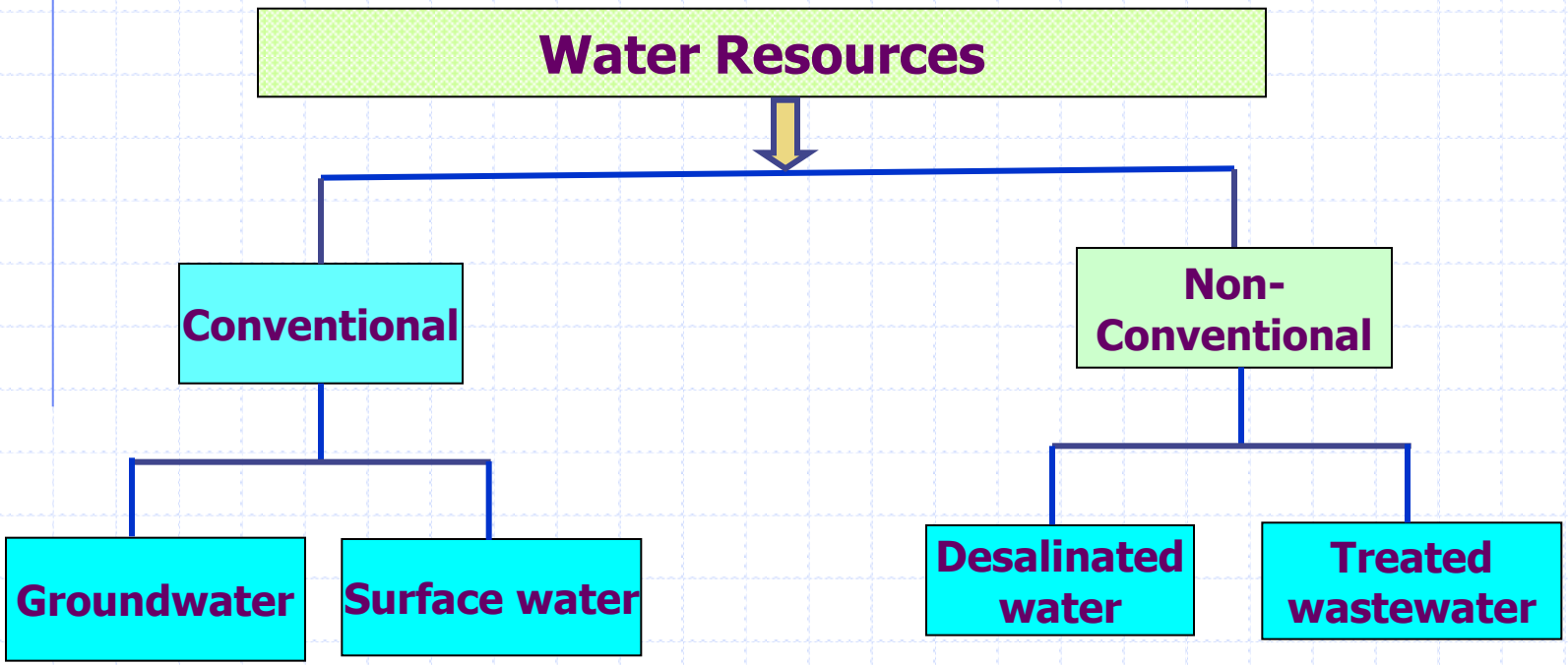
Background

- Saudi Arabia: One of the arid countries in MENA
- Population increased from 6.9 M to 26 M in 39 years
- Low annual rainfall; Country average: ~ 125 mm/yr
- Limited groundwater reserves; Limited surface RO
- Climate change implications

Objective

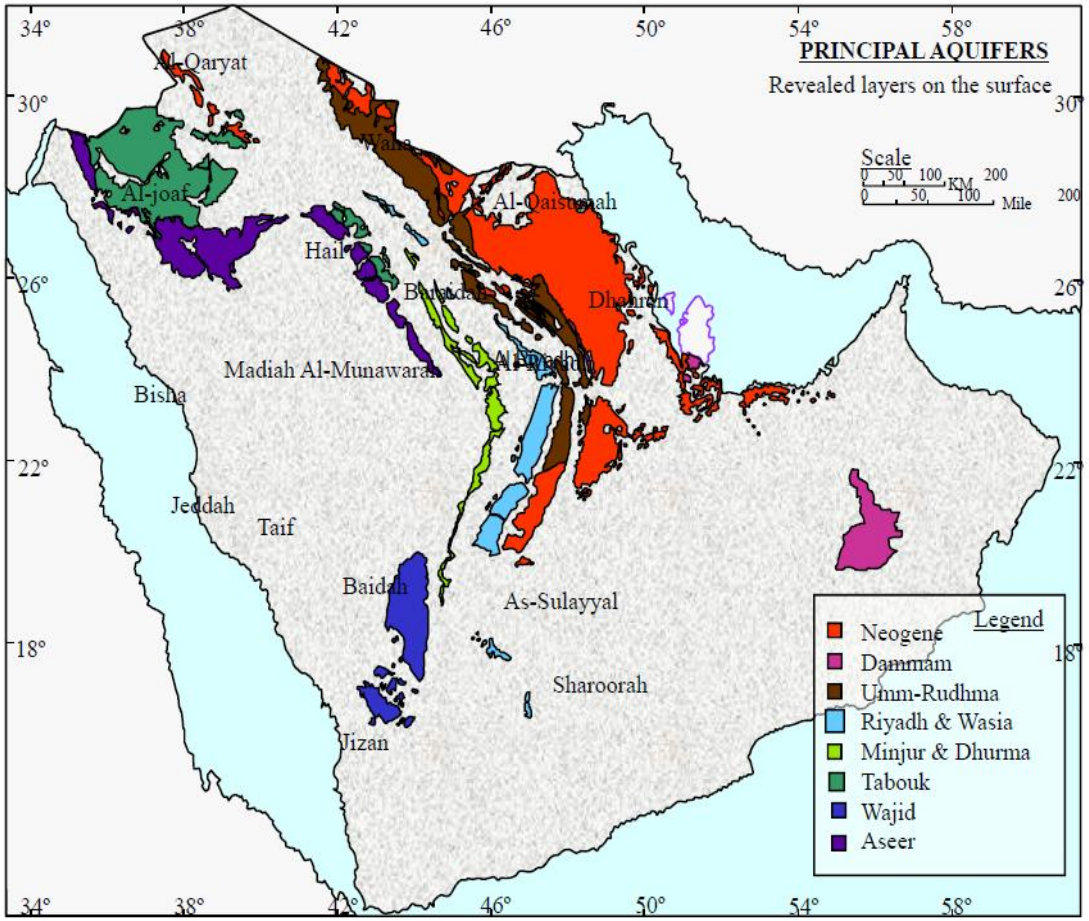
- Characterization of water resources
- Current status of water demands
- Predicting trends for water demands
- Identifying possibility of new sources for water

Water Resources Characterization



Non-renewable Groundwater Sources

- **Major aquifers:**
  - Saq
  - Tabuk
  - Wajid
  - Minjur-Dhurma
  - Biyadh-Wasia
  - Umm er Radhuma
  - Dammam



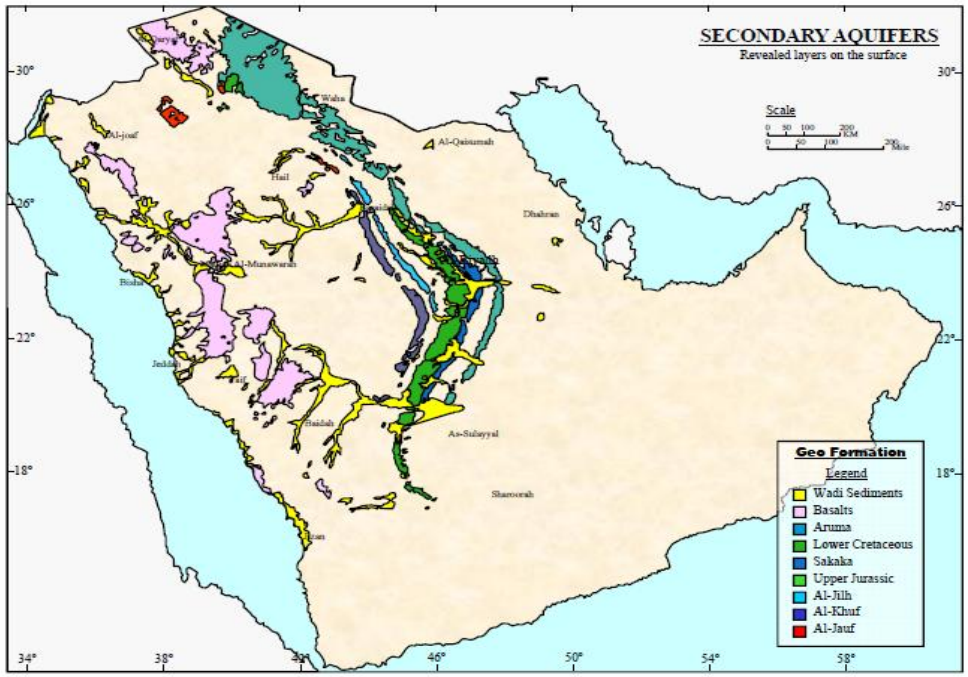
Principal aquifers for groundwater in Saudi Arabia

Non-renewable Groundwater Sources
Major Concerns

- The proven, probable and possible reserves are 259.1, 415.6 and 760.6 BCM respectively
- 1984 Estimates: Significant fraction might have been exhausted in the past 28 years
- Yearly abstraction of fossil GW: ≥ 11.6 BCM (2009)
- Poor recharge: (~1.28 BCM/yr)
- 394 MCM/yr drains out: Jordan:180; Bahrain: 112: Iraq: 80; Kuwait:20; Qatar: 2

Renewable Surface and Groundwater Sources

- Total internal renewable: ~2.4 BCM/year
- Total surface runoff : 2.2 BCM/year
- Shallow aquifers: e.g., Khuf, Tuwail, Aruma, Jauf, Sakaka
- 302 dams store ~ 1.4 BCM of surface runoff annually



Secondary aquifers for groundwater in Saudi Arabia

Renewable Surface and Groundwater Sources

	Storage		Control		Drinking		Irrigation	
Province	Dams	Capacity	Dams	Capacity	Dams	Capacity	Dams	Capacity
Riyadh	48	72.87	19	19.12				
Makkah	27	58.60	7	234.75	2	42.80		
Madina	14	20.70	6	64.45				
Asir	43	358.81	17	16.59	17	35.99		
Jazan	1	0.25	1	0.15	4	194.17	1	51.00
Najran	8	2.98	4	87.08				
Baha	25	9.62	3	0.14	2	30.50	1	0.50
Qassim	8	5.16	1	1.30				
Tabuk	8	6.63						
Hail	22	11.05	3	1.76				
Northern borders	6	20.65						
Jouf			4					
Column Total	210	567.32	65	425.34	25	303.46	2	51.50

Desalinated Water

- 7.65 MCM desalinated water was produced in 1980
- Approximately 1048 MCM desalinated water in 2009
- Thirteen plants past 25 years
- Different approaches are followed for desalination
- Approximately 3355 MW /year electricity produced

Treated Wastewater

- Approximately 70 wastewater treatment plants
- Total treatment: Over 600 MCM/yr
- Total reuse: 367 MCM in 2009 (Dom: 325; Agr: 42)
- Generation of domestic wastewater ~ 1500 MCM/yr
- Mostly discharged in land, sand dunes, wadies and sea
- Possibility of groundwater contamination
- Human exposure to contaminants from TWW reuse

Trends of Water Consumption
Domestic Water

- Water demands in 2009: 2330 MCM
- An average increase of 2.1%/year
- Municipal water subscribers: From 1999 to 2008: 687813 to 844243 (2.1%/year increase)

Forecasting Municipal Water Subscribers:

$$Log_{10}(Y_s) = C_o + K(X+1)$$

Y_s = number of subscribers at X years from 1999
C_o = coefficient of the equation 1 (e.g., 5.817 for Saudi Arabia);
K = slope of Equation 1 (0.01101 for Saudi Arabia); X = no. of years after 1999.

Trends of Water Consumption
Domestic Water

- Forecasting persons/Subscriber:

$$P_X = P_o(1+rX)$$

P_X = persons per subscriber at X years from 1999; P_o = persons per subscriber in 1999 (e.g., 31.08 persons/subscriber for Saudi Arabia); r = rate of increase per year (e.g., 0.007/year for Saudi Arabia); X = number of years after 1999.

- Forecasting Municipal Water Demands:

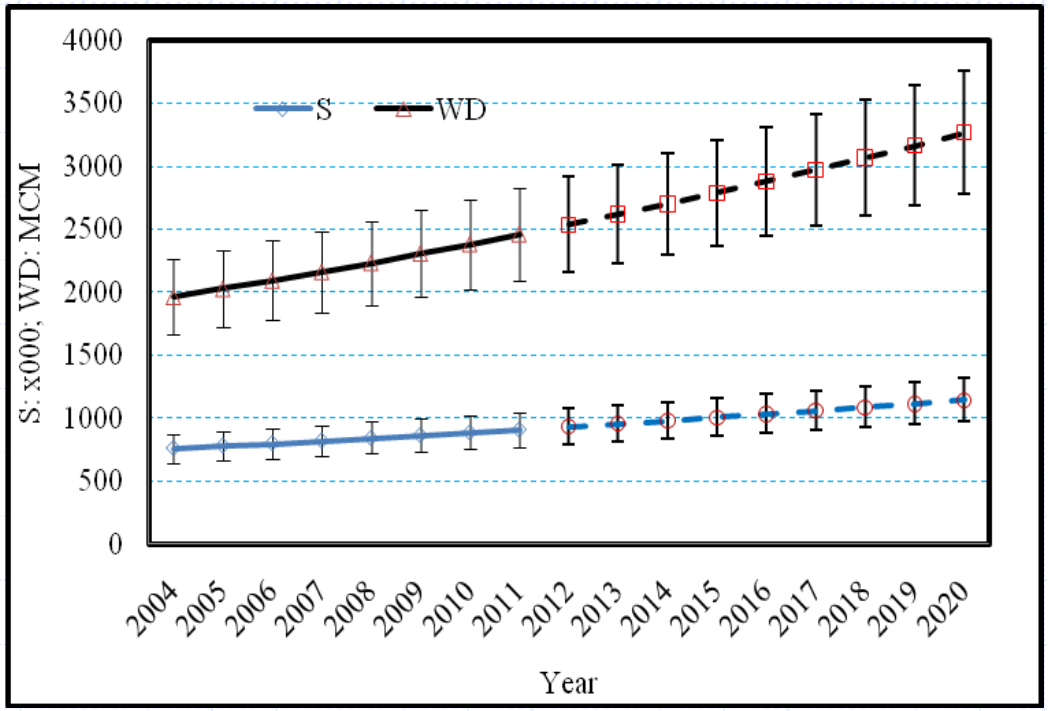
$$WD_{DOM} = W_{USE} \times P_X \times Y_s$$

WD_{DOM} = domestic water demands (m^3/yr); W_{USE} = water demands/person/yr (m^3); P_X = number of persons/subscriber in year X after 1999; Y_s = No. of subscribers for that year.

Trends of Water Consumption
Domestic Water

- The predicted demands are 1966 and 2307 MCM in 2004 and 2009
- The actual water demands were 2100 and 2330 MCM, respectively
- Predicted the domestic water demands in 2014 as 2704 MCM, which is 2583 MCM in the MOEP estimates

Domestic water demands in Saudi Arabia
S: Subscribers in thousands;
WD: Water demands in MCM;
dotted lines for future forecast)



Trends of Water Consumption
Domestic Water

Equations	State/Country	Parameter values	R^2
$Log_{10}(Y_s) = C_o + KX$ $P_X = P_o(1 + rX)$	Saudi Arabia	[C_o = 5.817; K = 0.01101]; [P_o = 31.08; r = 0.007]	0.89; 0.76
	Qasim	[C_o = 4.654; K = 0.020]; [P_o = 28.02; r = 0.005]	0.98;0.66
	Asir	[C_o = 4.172; K = 0.012]; [P_o = 34.7; r = 0.004]	0.94;0.67
	Al-Khobar	[C_o = 4.384; K = 0.016]; [P_o = 27.34; r = 0.009]	0.69;0.62
	Dammam	[C_o = 4.57; K = 0.014]; [P_o = 28.06; r = 0.006]	0.98;0.81
	Taif	[C_o = 4.569; K = 0.008]; [P_o = 33.2; r = 0.006]	0.96;0.73
	Makkah*	[C_o = 4.773; K = 0.007]; [P_o = 30.3; r = 0.015]	0.96*;0.72
	Yanbu	[C_o = 3.899; K = 0.016]; [P_o = 34.7; r = 0.009]	0.86;0.66
	Madinah	[C_o = 4.699; K = 0.008]; [P_o = 29.08; r = 0.011]	0.63;0.62
	Jeddah	[C_o = 5.133; K = 0.008]; [P_o = 30.3; r = 0.012]	0.81;0.57
	Riyadh	[C_o = 5.384; K = 0.013]; [P_o = 29.8; r = 0.009]	0.89;0.74

*X should be replaced by (X-1)

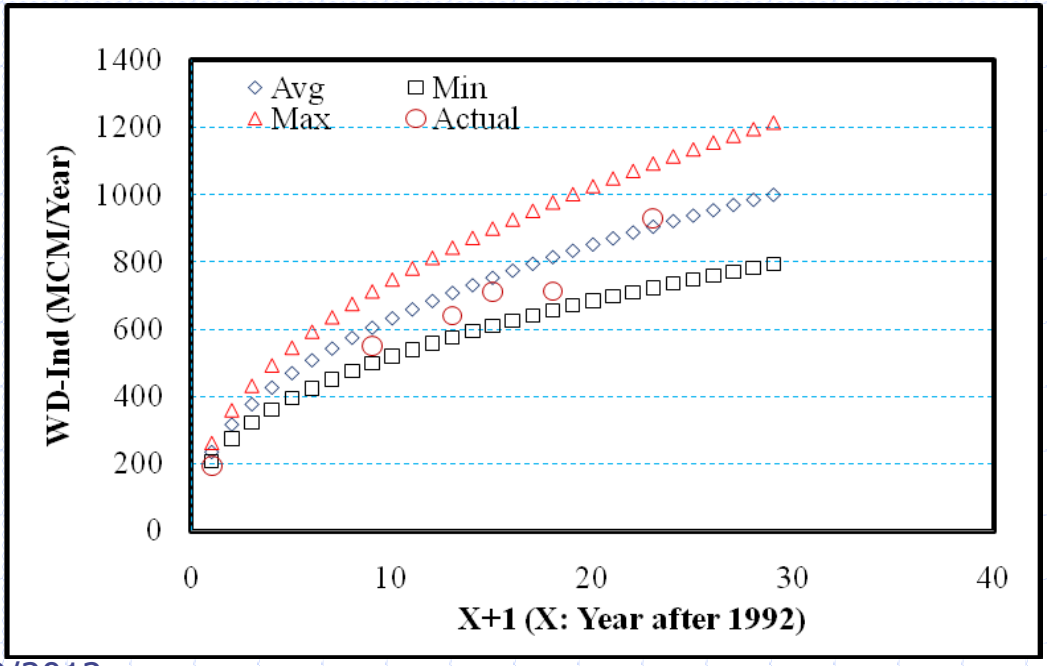
Domestic water demand predictions

Trends of Water Consumption
Industrial Water

- Forecasting Industrial Water Demands:

$$WD_{IND} = a \times (Y+1)^b$$

WD_{IND} = water demands for industrial purpose (MCM/year); a = 235.06 (range: 207.29–262.83 as the 95 percentile C.I. value); b = 0.43 (range: 0.399–0.455 as the 95 percentile C.I. value); Y = year after 1992.



Industrial water demand predictions

Trends of Water Consumption
Agricultural Water

Agricultural water demand was 17530 and 15464 MCM/year in 2004 and 2009, respectively (-2.5%/yr)

- Forecasting Agricultural Water Demands:

$$WD_{AGR} = a \times e^{b(Z+1)}$$

WD_{AGR} = water demands for agriculture (MCM/year); a = 18287.5 (range: 18018.3–18558.5 as the 95 percentile C.I. value); b = 0.033 (range: 0.029–0.039 as the 95 percentile C.I. value); Z = year after 2004

Trends of Water Consumption
Agricultural Demands: Major Concern

- Planned reduction of agricultural water demands: Predictive trend is sensitive the plan of MOEP.
- Increase in temperature: 1.8°C–4.1°C from 2011 to 2050
- Reference evapotranspiration increase: 10.3%–27.4%
- Temp. change of 1°C may change agricultural water demands by 2%–4% in Saudi Arabia
- Possible increase in agricultural water demands by 5%–15% in by 2050 for the same productions.

Sustainable WR Management

- **Increase of Desalination plants:**
  - 30 in operation; Planned for 44 by 2014
  - How many plants can be supported
- **Channeling:**
  - Needs adequate water reserves and significant cost
- **TWW Reuse**
  - Comprehensive reuse DWW ~ 1630 MCM/yr
- **Rainwater harvesting:**
  - Approximately 245 BCM rainfalls annually
  - Most rainfall occurs in west, south/south-western parts
  - In the south, 500 mm/yr rainfall is common
  - Direct harvesting from rooftop needs to be evaluated

Summary ,Conclusions, Recommendation

- Characterized water resources and water demands
- Predicted nonlinear trends for water demands in domestic, industrial and agricultural sectors
- Better understanding of groundwater reserves
- Predicting crop water requirements/irrigation practices
- Maximize domestic wastewater collection and reuse TWW
- Evaluate rainwater harvesting at rooftops
- Effects of climate change on agricultural water demands

Thanks for listening