Emerging Global Water Scarcity Challenges

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My Current Research Work

1. Role of viruses in microbial stability of aquatic built environment, Shedd Aquarium, Chicago

2. Fecal pollution source identification, Michigan State, USA
Learning Goal and Objectives

Learning goal:

Describe global water scarcity challenges and potential solutions

Learning Objectives:

1. Understand water quantity and quality and how they relate to water scarcity
2. Identify global emerging water scarcity problems and their potential impact and solutions
3. Determine the role students could play in using innovation and business to contribute to addressing current global water scarcity problems
Topics

Water Quantity & Quality
• Water cycle
• Estimate of global freshwater
• Water use
• Water scarcity
• Global water pollution (Chemical & Biological)
• Emerging global water scarcity challenges

Solving global emerging water scarcity problems
• Role of Students: Potential Jobs in water industry
• Role of science in solving global water scarcity emerging
• Role of business in addressing global water scarcity problems
• Role of Government, private sectors and international institutions
1. The Water Cycle

Water is the infinitely renewable and recycled resource.
The cycle time for groundwater is highly variable and much longer than for Surface Water.
## water quantity

### Estimate of Global Water Cycle

<table>
<thead>
<tr>
<th>Type of water</th>
<th>Location</th>
<th>Volume (millions of cu. Miles)</th>
<th>Percentage of total Volume (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Salt Water</strong></td>
<td></td>
<td></td>
<td>97.0</td>
</tr>
<tr>
<td></td>
<td>Oceans</td>
<td>314.2</td>
<td>(96.4%)</td>
</tr>
<tr>
<td></td>
<td>Saline bodies</td>
<td>2.1</td>
<td>(0.6%)</td>
</tr>
<tr>
<td><strong>Fresh water</strong></td>
<td></td>
<td></td>
<td>2.9</td>
</tr>
<tr>
<td></td>
<td>Ice &amp; Snow</td>
<td>6.9</td>
<td>(2.1%)</td>
</tr>
<tr>
<td></td>
<td>Lakes</td>
<td>0.5</td>
<td>(0.15%)</td>
</tr>
<tr>
<td></td>
<td>Rivers</td>
<td>0.01</td>
<td>(0.003%)</td>
</tr>
<tr>
<td><strong>Atmospheric</strong></td>
<td></td>
<td></td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Evaporation: Sea &amp; Land</td>
<td>0.15</td>
<td>(0.045%)</td>
</tr>
<tr>
<td></td>
<td>Precipitations: over sea and land</td>
<td>0.12</td>
<td>(0.04%)</td>
</tr>
<tr>
<td></td>
<td>Water vapor</td>
<td>0.005</td>
<td>(0.002%)</td>
</tr>
</tbody>
</table>

Source: NOAA [https://www.nwrfc.noaa.gov/info/water_cycle/hydrology.cgi](https://www.nwrfc.noaa.gov/info/water_cycle/hydrology.cgi)
Water Quantity
World Surface Water

The World’s Surface Water
Precipitation, Evaporation and Runoff by Region

North America 18 300 km³
South America 28 400 km³
Africa 22 300 km³
Europe 8 290 km³
Australia and Oceania 7 080 km³
Asia 32 200 km³

Evaporation (%)
Runoff (%)

Water Use: National and Regional Scale

Water Use Varies Significantly on a National and Regional Scale

Water Use

Who uses the most water?

A. Agricultural users
B. Domestic users
C. Industrial users
Water Problems

The most significant water problem in the 21st Century for the US is

A. Freshwater shortages
B. Pollution
C. Disasters
D. Infrastructure
Water Scarcity

• **Water stress**: Water Demand exceeds available water or limited access due to quality deterioration of available water resources

• **Physical**: Water shortage or proximity to water sources

• **Economical**: Lack of investment and human capacity to develop water infrastructure (e.g. treatment, supply, operations & management, etc). Leading to lack of access to water

• **Social**: Absence of the fulfillment of the expectation of access to clean water as a human-right

Source: 2007 – World water day: Coping with water scarcity: Challenges of 21st Century
Trends in Global Water Use by Sector

- Agriculture
- Domestic Use
- Industry

Extraction
Consumption

Difference between the amount of water extracted and that actually consumed.

Global Freshwater: What Country Posses the Most

Fewer countries possess 60% of the world’s available fresh water supply:

1. Brazil
2. Russia
3. **China**
4. Canada
5. Indonesia
6. U.S.A.
7. **India**
8. Columbia
9. Democratic Republic of Congo

**Water Used for Irrigation**


Water Withdrawals by Category

- Livestock: <1%
- Self-Supplied Domestic: 1%
- Public Supply: 11%
- Thermoelectric Power: 49%
- Mining: 1%
- Aquaculture: 2%
- Self-Supplied Industrial: 4%
- Irrigation: 31%
Total Water Withdrawals in the USA

- **Public supply, 12%**
  - Water tower, Newton, Kansas

- **Irrigation, 33%**
  - Sprinkler irrigation system, Blaine County, Idaho

- **Aquaculture, 3%**
  - Wild Rose Fish Hatchery, Waushara County, Wisconsin

- **Mining, 1%**
  - Pumpjack in Gove County, Kansas

- **Domestic, 1%**
  - High-efficiency washer and dryer

- **Livestock, 1%**
  - Sheep at water trough on the open range

- **Industrial, 4%**
  - Industrial paper mill in Glynn County, Georgia

- **Thermoelectric P, 45%**
  - Watts Bar Nuclear Powerplant, Rhea County, Tennessee

Fresh Water Stress: Availability vs Future Withdrawal

Water Scarcity: Why?

Changes in Global Population

FROM ONE BILLION TO >9 BILLION

Source: UN World population prospects, 2002)
Country Population Exposed to Water Scarcity

http://growingblue.com/the-growing-blue-tool/
World Populated Areas

Major World River Basins

Major River Basins of the World: Major rivers and basins. Basins selected, derived and adjusted by Global Runoff Data Centre (GRDC), Koblenz 2007, based on HYDRO1K by USGS; Rivers and lakes by GRDC & WHYMAP 2007. GRDC, Koblenz, Germany, 2007.
Projected Water Scarcity in 2025

- Physical water scarcity
- Economic water scarcity
- Little or no water scarcity
- Not estimated
Global Freshwater: Past, Present and Future

- Global freshwater consumption rose six-fold between 1900 and 1995 - more than twice the rate of population growth.

- About one third of the world's population already lives in countries considered to be 'water stressed' - that is, where consumption exceeds 10% of total supply.

- If present trends continue, two out of every three people on Earth will live in that condition by 2025.

- Agriculture is the number one user of water.

Source: Kofi Annan, in We The Peoples, 2000
Fresh Water Resources Are Degrading

Recreational

Drinking

Irrigation

Algal blooms

Ecosystems

In waters used for drinking, fishing, recreation
Water Quality & Health

**Threats**

- Fecal contamination
- Sewage
- Septic tanks
- Combined sewer overflows
- Animal wastes
- Stormwater runoff
- Inadequate infrastructure
- Toxic Algal blooms
- Climate change
- Chemical contaminants

**Consequences**

- Waterborne disease
- Boil orders
- Community Outbreaks (the plane crashes)
- Acute and chronic affects
# Global Water Pollution

One in nine people worldwide doesn’t have access to improved sources of drinking water and one in three lacks improved sanitation.

The major sources of water pollution are from human settlements and industrial and agricultural activities.

<table>
<thead>
<tr>
<th>Source</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sewage</td>
<td>80% of sewage in developing countries is discharged untreated directly into water bodies.</td>
</tr>
<tr>
<td>Industry</td>
<td>Industry dumps an estimated 300-400 MT of polluted waste in waters every year.</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Nitrate from agriculture is the most common chemical contaminant in the world’s groundwater aquifers.</td>
</tr>
</tbody>
</table>

Approximately 3.5 million people die each year due to inadequate water supply, sanitation and hygiene. The biodiversity of freshwater ecosystems has been degraded more than any other ecosystem.

Chemical Water Pollution

Sources: Agriculture, Aquaculture, industry, mining, sewage, and urban

Ammonia ($\text{NH}_3$)/Ammonium ($\text{NH}_4$) 
(Agriculture, aquaculture, industry, urban)
Ammonia is highly toxic to fish and can convert into nitrates.

Nitrate ($\text{NO}_3$)/Nitrite ($\text{NO}_2$) 
(Agriculture, industry, aquaculture, sewage)
These can accelerate aquatic plant growth leading to eutrophication.

Toxic metals 
(Mining, urban, industry)
These include arsenic (As), mercury (Hg), selenium (Se) and lead (Pb) and can persist in the environment for decades. They can be poisonous to aquatic life and may slow down their development.

Crude oil (Hydrocarbons (HxCx)) 
(Urban, industry)
This mainly enters the marine environment in oil spills and can have detrimental effects on marine animals, plants and birds.

Phosphorous (P)/Phosphate (PO$_4^{3-}$) 
(Agriculture, urban)
Similar in effect to nitrates, these can also lead to eutrophication of water bodies.

Sulphates/sulphide minerals 
(minerals containing $\text{S}^{2-}$) 
(Mining)
Sulphur dioxide mixes with water particle in the air to form acid. This falls as acid rain leading to acidification of water bodies. Sulphide minerals can be unearthed during the mining process and are a leading cause of acidification of water in mines. When this acidic water is discharged it is known as acid rock drainage. The most common mineral associated with this process is pyrite (FeS$_2$).

https://www.sepa.org.uk/media/120299/chemistry-of-water-pollution.pdf
Cases of Chemical Water Pollution

1. Wastewater from Mining Operations

August 5, 2015
Gold King Mine, Silverton, Colorado, USA

Animas River, Colorado before and after 3 million gal. of toxic mining waste spilled. Heavy metals: Cadmium, Lead, Arsenic, Beryllium, Zinc, Iron, & Copper

November, 2015
Fundao Dam Supporting Samarco mine

Rio Doce River located more than 500 miles from the Samarcno mine to Atlantic Ocean. Heavy metals pollution detected (e.g. mercury and arsenic)


# Cases of Chemical Water Pollution

## 2. Oil Spills

<table>
<thead>
<tr>
<th>Waterbodies or Waterways</th>
<th>Time of Oil spill</th>
<th>Volume (Mil. Gal.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Persian Gulf, Kuwait</td>
<td>Kuwait, January 19, 1991</td>
<td>380</td>
</tr>
<tr>
<td>Gulf of Mexico</td>
<td>British Petroleum, Ixtoc 1, June 3, 1979 to March 23, 1980</td>
<td>210, 140</td>
</tr>
<tr>
<td>Ocean of Trinidad and Tobago</td>
<td>Atlantic Empress, July 19, 1979</td>
<td>90</td>
</tr>
<tr>
<td>Kolva River</td>
<td>Russian, September 8, 1994</td>
<td>84</td>
</tr>
</tbody>
</table>

http://www.thetimes.co.uk/article/ten-of-the-largest-oil-spills-in-history-n3wvf6fnf3m
http://www.newyorker.com/wp-content/uploads/2011/03/110314_r20623_g2048-1200-923-25105205.jpg
3. High Nutrients Load

415 eutrophic and hypoxic coastal systems worldwide. 169 are documented hypoxic areas, 233 are areas of concern and 13 are systems in recovery.

Source: Water Quality team and Dr. Bob Diaz at the Virginia Marine Institute.
Microbial Water Quality

Types of Waterborne Pathogens

- Hepatitis A
- Norovirus
- E. coli O157:H7
- Salmonella
- Salmonella typhi
- Shigella
- Campylobacter
- Vibrio cholerae
- Cryptosporidium
- Giardia
- Schistosomatidae
The Risk to Human Health

- **~19 Million** waterborne illnesses /yr for community water systems in the US
  - **5.4 M** illnesses from groundwater
  - **13 M** illnesses from surface water systems. (Reynolds et al. 2008)

- **12 Million** cases/yr  
  (Colford et al. 2006)

- **16 Million** cases/yr  
  (Messner et al. 2006)

Grand Rapids, Michigan’s Millennium Park closed early for cleaning Wednesday evening after an outbreak of Norovirus sickened about 100 people last weekend. The Kent County Health Department says test results received Wednesday confirmed that some of the park visitors suffered from Norovirus after visiting the park on Friday or Saturday. But tests indicated the park’s water bacteria level measured safe. Health workers are still trying to ascertain the virus source.
2. Cyanobacteria

The toxin that shut off Toledo’s water? The feds don’t make you test for it.

By Todd C. Frankel August 11 2014
Follow @tcfrankel The Washington Post

A sample glass of Lake Erie water is photographed near the Toledo water intake crib in Lake Erie. (Haraz N. Ghanbari/Associated Press)
TOLEDO, Ohio -- Widespread groundwater contamination on a Lake Erie resort island was the likely source of illnesses that sickened hundreds last summer, the Ohio health department said Tuesday.

Several sources, including septic tanks, have tainted the South Bass Island's groundwater over a long period, and the contamination may have been worsened last summer because of a season of heavy rains, a health department report said.

The outbreak of gastrointestinal illness sickened about 1,400 tourists and residents, ending the tourist season early for many businesses.

MSU assisted with the investigation. Identified virus contamination and potentially a new and emerging bacteria.
Cost of Water Recreation Related Illnesses

= 

$2.9$ Billion per Year in the USA

90 million cases of gastrointestinal, respiratory, ear, eye and skin-related illnesses per year in the U.S. are associated to swimming, paddling, boating and fishing

The cost for recreational water related illness per case $9.5$ to $303,000$ (mild illness to the most severe illnesses)

Only $10$ million per year allocated for beach protection

https://today.uic.edu/illnesses-caused-by-recreation-on-the-water-costs-2-9-billion-annually-in-the-us

Source: DeFlorio-Barker et al. 2018
## Water Scarcity

### Water Scarcity can be Identified through:

- Declining groundwater tables
- Reduced river flows
- Shrinking lakes
- Heavily polluted waters
- Increase in supply and treatment costs
- Intermittent supplies and conflicts over water

### Future challenges leading to increase in water scarcity

- Population and economic growth
- Increase in demands for agricultural products and biofuels
- Increase in water pollution
- Increase in poverty
- Climate change
Drought: Cape Town, South Africa

- Total population: 3,776,000
- Day zero: estimated to be April 22, 2018
  - Dam level projected to reach **13.5%**. Current levels: **22.2%**
  - Water consumption per person per day: **50 Liters**
  - 87 (23 gallons) Liters per Household will be reduced to 25 Liters (6.6 gallons) per household

[https://upload.wikimedia.org/wikipedia/commons/0/02/Africa_location_map.svg](https://upload.wikimedia.org/wikipedia/commons/0/02/Africa_location_map.svg)

April 28/2017 Steenbras dam at 31.6% Capacity
Dam Water Storage Capacity

Water Dams Supplying the City of Cape Town

Government Action

- Water rationing enforcement and tracking water usage
- Community campaign on using less water

Emerging Global Water Scarcity Problems

- Increasing Population (e.g. 9 Billions in 2050)
- Increase of standard of living in developing countries
- Economic growth needs: Domestic, Agriculture, & Industry
- Increase in waterborne illnesses
- Deterioration of ecosystems
- Water infrastructure for supply and energy
What Can You Do? Providing Solutions to Global Water Scarcity Problems

Potential Jobs

- **Water resources management**: Integrated, sustainable, restoration and remediation

- **Water infrastructure**: Building new, maintaining and operating existing water systems

- **Water related services**: water supply, wastewater management, sanitation, water-food-energy nexus, policy, community engagement

- **Innovative solutions across water sector and related services**

http://unesdoc.unesco.org/images/0026/002614/261424e.pdf
Role of Government, Private Sectors and International Institutions

Global Water Declaration in their 2013 Chengdu, China forum

Principals:

• Water security means minimizing water related risks
• Demand management is essential for water security
• Water security is threaten by population and economic growth, lack of water resources and appropriate water supply infrastructure, unsustainable inefficient and wasteful water use and climate change
• Joint action to improve global water security must involve responses including policy, education, research and the good professional practice

Role of Governments

• Institutions are essential to play the coordination role required to provide the poor with the basic water and sanitation services
• Governments should coordinate the collective effort required to invest in infrastructures to harness the potential of water for economic development in areas such as food, energy and urban development
• Governments should coordinate efforts of matching water demands from all the areas of the economy with the amount and quality of water that nature can sustainably provide

Role of Science in Solving Global Water Scarcity Emerging Problems

• Advance in Water Technologies:
  • Membrane technology
  • Desalination technology
  • Enhancing water storage
  • Development of small-scale decentralized technologies
  • Improve rainwater harvesting and micro-irrigation technology
  • Develop salt-resistant and drought-resistant crops

• Science for Managing Water for Agricultural and Environmental Purposes

• Improved Climate Modeling

http://www.pnas.org/content/102/44/15715
Role of Business in Addressing Global Water Scarcity Challenges

1. Global Market for Water and Wastewater Treatment Technology

2012 = $47.7 billion.

2013 = $53.1 billion

2014 = $59.2 billion

2019 = $96.3 billion

Compound annual growth rate (CAGR) of 10.2% for the period of 2014 to 2019.

Role of Business in Addressing Water Scarcity

2. Global Market for Wastewater-recycling and Reuse Technologies

- 2009 to 2012 markets increased from nearly $6.7 billion to $9.5 billion
  Equivalent to a compound annual growth rate (CAGR) of 12.6%.
- 2012 to 2017 markets are expected to increase from $9.5 billion to $23.4 billion
  Reflecting a five-year CAGR of 19.7%.

Singapore Changi water reclamation plant
Recycled water is turned to bottled water or sold to industries as pure water for Manufacturing use

Role of Business in Addressing Water Scarcity

3. Global Market for Sludge Treatment and Odor Control Equipment

- 2011 to 2012: $5.3 billion reached $5.5 billion

- 2012 to 2017: $5.5 billion to $7 billion with an estimated 4.7% with a compound annual growth rate (CAGR)

Deer Island Wastewater Treatment Plant
Boston, Massachusetts, USA
Methane gas produced from sludge saves $15M in fuel oil costs and $2.8M in electricity savings annually.

Thank You !
Resources

- Global water scarcity: Risks and challenges for business
- Global sustainable development goals
- UN Water and Global water development reports
- Global water initiative
- The role of science in solving the world's emerging water problems
  [http://www.pnas.org/content/102/44/15715](http://www.pnas.org/content/102/44/15715)
- Water pollution
  [https://www.nrdc.org/issues/water-pollution](https://www.nrdc.org/issues/water-pollution)
  [http://www.water-pollution.org.uk/types.html](http://www.water-pollution.org.uk/types.html)
- US Environmental Protection Agency (EPA)
  [https://www.epa.gov/wqc/microbial-pathogenrecreational-water-quality-criteria](https://www.epa.gov/wqc/microbial-pathogenrecreational-water-quality-criteria)
  [https://www.epa.gov/environmental-topics/water-topics](https://www.epa.gov/environmental-topics/water-topics)
- World water crisis statistic
  [https://thewaterproject.org/water-scarcity/water_stats](https://thewaterproject.org/water-scarcity/water_stats)
Flint Michigan

- Population in Flint peaked in 1960 at ~200,000
- Population now <100,000. Water usage is down by 2/3, so water spends much more time in system than is conventional
- Vulnerable, low-income residents
- Many older houses have lead services lines and/or plumbing (estimated at 15,000)
- Some distribution mains are thought to be lead

Slide provided by Dr. Susan Masten
Environmental Engineering
Michigan State University
Background

• The Flint plant was completed in 1954.

• Flint has purchased water from Detroit Water and Sewage Department (DWSD) since 1967.

• The source of the DWSD water is Lake Huron and treated at the Fort Gratiot plant.
Timeline

- **April 25, 2014** Flint River changeover ceremony
- **April 30, 2014** DWSD Water line closed
- **June 2014** Complaints regarding water quality begin (smell, taste, discoloration)
- **August 14, 2014** Flint water tests positive for E coli. Boil water advisories issued two days later. Problems continue with three boil water advisory notices issued in a 22-day span in summer
- **Summer 2014** 29 cases of Legionellosis
- **October 13, 2014** GM engine plant announces that it will stop using Flint water
Timeline

• **November 2, 2014** City increases hydrant flushing to address red water concerns

• **December 16, 2014** City receives official violation notice from DEQ for violations of the Safe Drinking Water Act for total trihalomethanes

Photo courtesy of: Erin Brochovitch

Slide provided by Dr. Susan Masten
Environmental Engineering
Michigan State University
Timeline

• **February 2015**: City of Flint tests water of Lee Ann Walters and finds 104 ppb and 397 ppb. Iron level > 3.3 mg/L (> LOQ)
  
  • Water was filtered at the home
  • Sampling done after flushing
  • Internal plumbing found to be plastic, a portion external service line found to be galvanized iron pipe; the rest was lead

• **February 25, 2015**: Lee Ann Walters contacts Region 5 EPA regarding her concerns over lead levels in her water. Miguel del Toral calls the results alarming

• **June 2015** Second violation of D/DBP Rule

Slide provided by Dr. Susan Masten
Environmental Engineering
Michigan State University
Timeline

• **August 31, 2015** Prof. Marc Edwards, VA Tech says Flint drinking water is "very corrosive" and "causing lead contamination in homes"

  • 20% of the 120 samples exceeded the U.S. EPA lead action level of 15 ppb

  • 42% of the 120 samples had lead levels that were >5 parts per billion, "which suggests a serious lead-in-water problem" according to Prof. Edwards

Slide provided by Dr. Susan Masten
Environmental Engineering
Michigan State University
Timeline

• September 24, 2015  Dr. Mona Hanna-Attisha releases study showing that the number of Flint infants and children with elevated blood lead levels have increased since the switch to Flint River Water

Slide provided by Dr. Susan Masten
Environmental Engineering
Michigan State University
Timeline

• **October 16, 2015** Flint switches back to “Detroit” water which comes from Lake Huron

• **December 9, 2015** Flint starts adding additional phosphate to increase the concentration from 1 to 2.5 mg/L for corrosion control

http://flintwaterstudy.org/page/2/

Slide provided by Dr. Susan Masten
Environmental Engineering
Michigan State University
Health Impacts

- Public complained of gastrointestinal, respiratory and skin ailments
- Lead poisoning
- Neurological impacts on children
- *Legionella* cases
Role of Science in Solving Global Water Scarcity Emerging Problems

1. Advance in Water Technologies

- **Membrane technology**: use of membrane bioreactors to improve water and wastewater treatment
- **Desalination technology**: Improve treatment of seawater and recovery of used irrigation water
- **Enhancing water storage**: Develop new solutions for water storage to respond to temporal variability in precipitation
- **Development of small-scale decentralized technologies**: Increase productivity of water at basin level
- **Improve rainwater harvesting and microirrigation technology**
- **Develop salt-resistant and drought-resistant crops**

http://www.pnas.org/content/102/44/15715
2. Science for Managing Water for Agricultural and Environmental Purposes

• Use of advanced irrigation technologies and improve irrigation efficiency in water use

• Develop optimum management strategies that incorporate humans, ecosystems, fresh and ground water

• Develop new integrated basin-wide water management strategies

http://www.pnas.org/content/102/44/15715
3. Improved Climate Modeling

• Improve the degree of reliability of forecasts of future change in weather at local and region levels

• Develop new models in hydrologic modeling to understand response of aquifers to change in snow-melt and runoff patterns

• Develop new models to better understand large-scale of hydrologic and climatological process

http://www.pnas.org/content/102/44/15715