NOAA's 47th Climate Diagnostics & Prediction Workshop




Understanding the Connection between Soil Moisture and Safe Water Access Using Earth Observations

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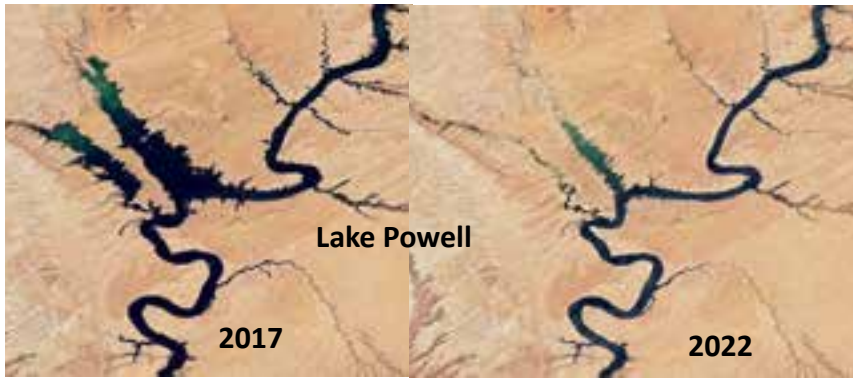
Outline

- ❑ Background
- ❑ Objective
- ❑ Data
- ❑ Study Area
- ❑ Rainfall, Rainfall Extremes and Soil Moisture
- ❑ Land Surface Temperature (LST), LST Extremes and Soil Moisture
- ❑ Soil Moisture and Groundwater Relationship
- ❑ Waterborne Diseases and Soil Moisture Relationship
- ❑ Findings

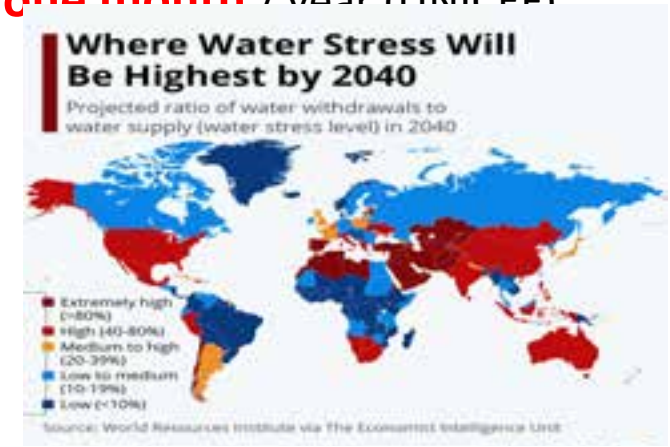
Background

1 in **3** people globally do not have access to safe drinking water (UNICEF, WHO)

4 billion people face **acute water scarcity** for at least **one month** / year (UNICEF)



40% shortfall between forecast demand and available supply of water by **2030**



Over **2 billion** people live in water-stressed countries (WHO)

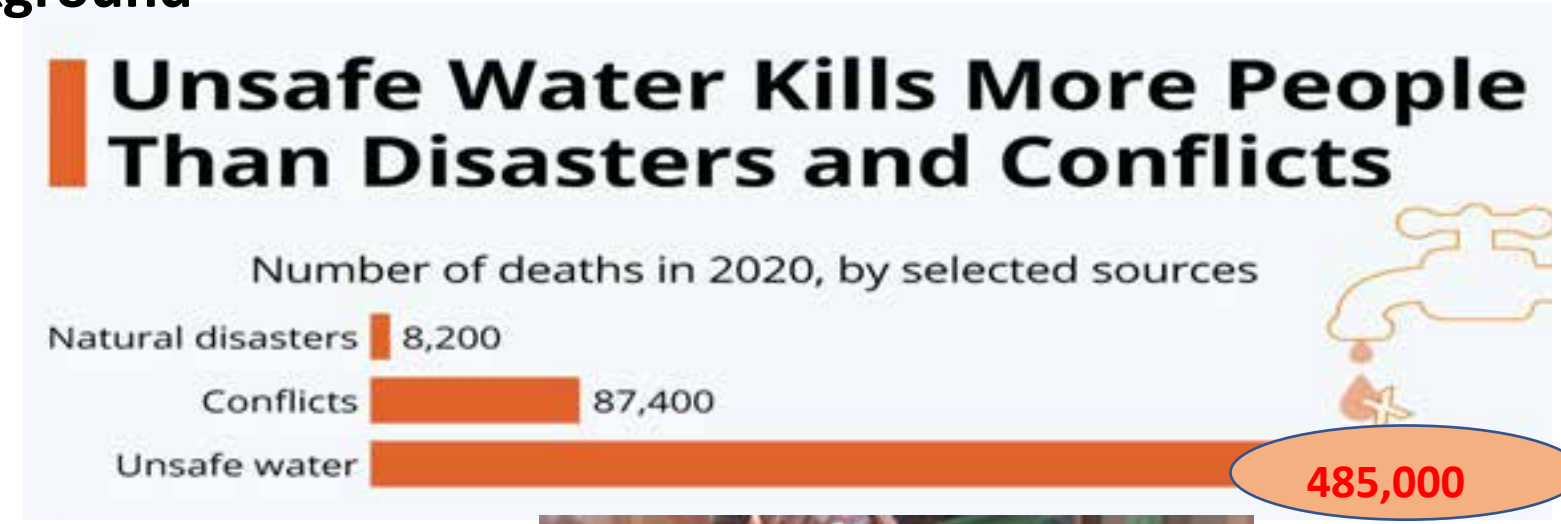
Background

In developing countries, women and girls walk **3.5 miles/day**, carrying **20 liters** of water

733 Million people live in countries with high and critical level of water stress (SDG report-2022)

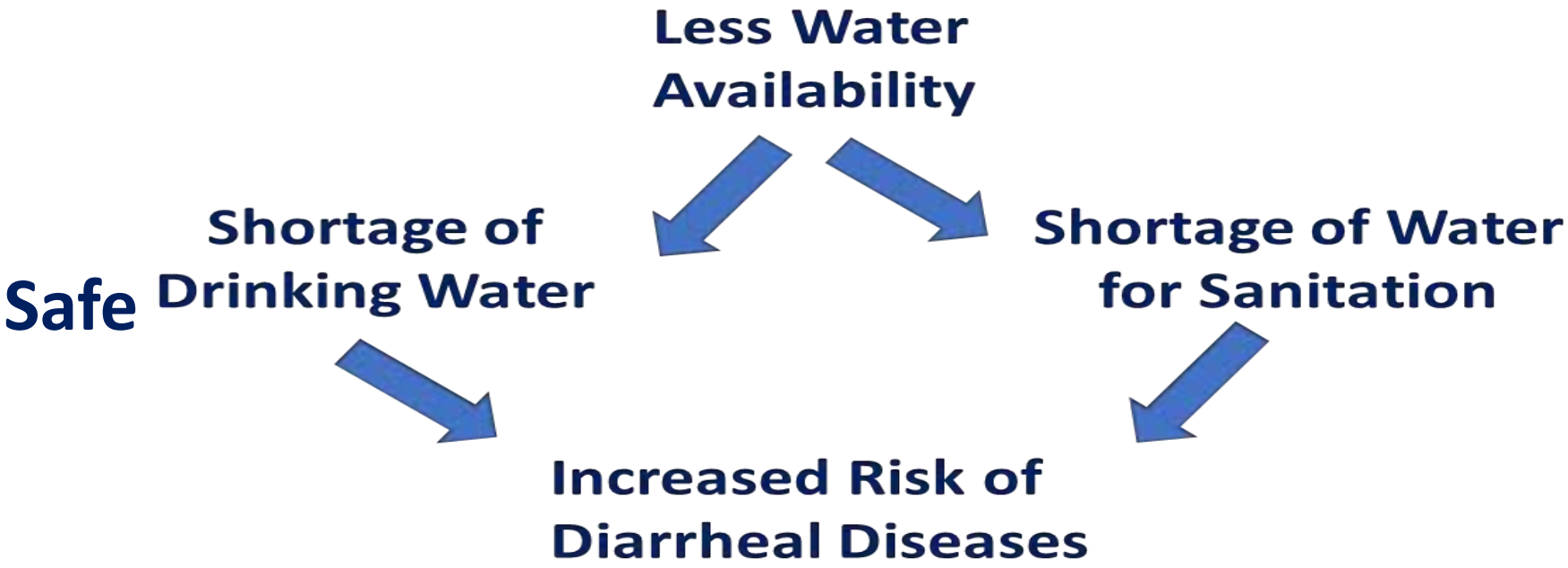
200 million hours/day spent by children and women

Background



At risk of waterborne diseases due to exposure to contaminated water

Background


Less Water Availability
Shortage of Drinking Water
Shortage of Water for Sanitation
Safe
Increased Risk of Diarrheal Diseases

Water Availability other than Rainy season?

Highly seasonal areas? **Data-scarce** regions?

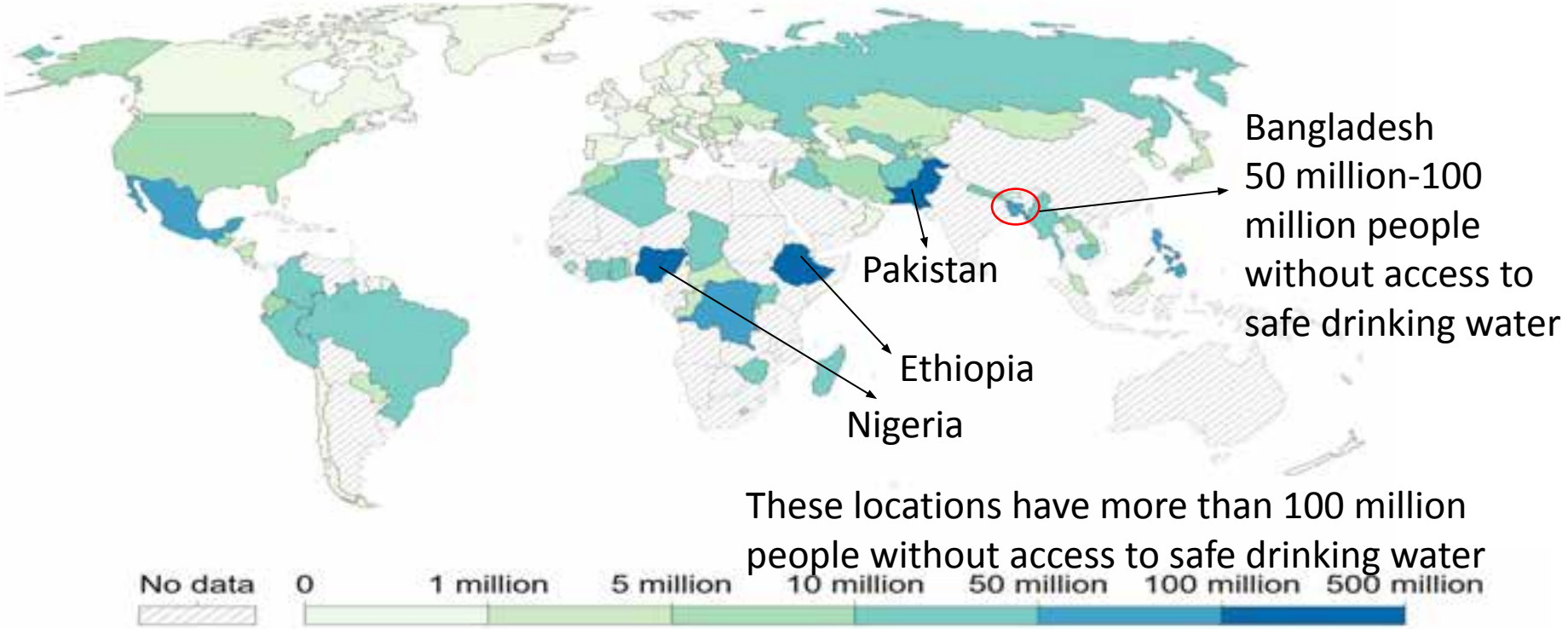
Objective

Can we use soil moisture as a proxy of water availability?

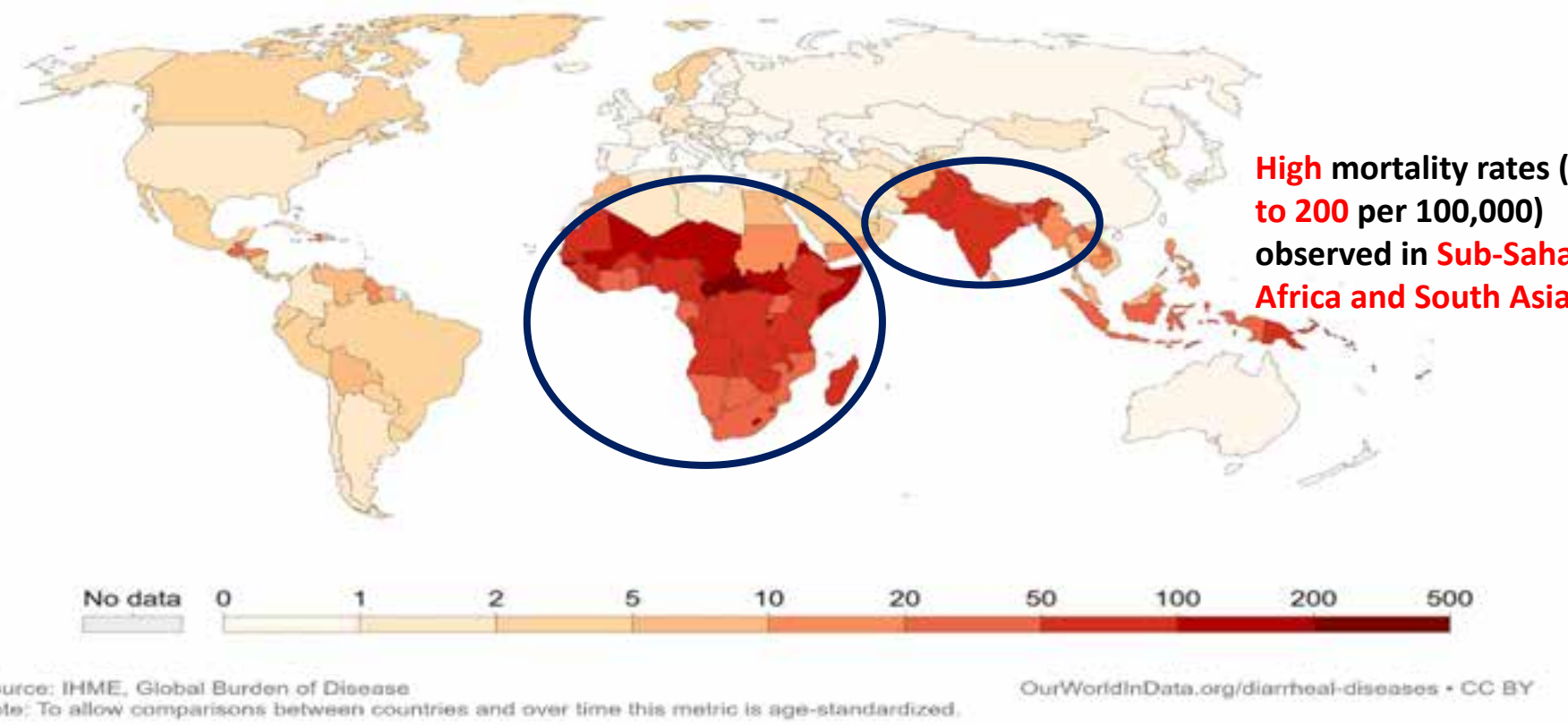
Data

Variables	Data Sources	Spatial Resolution	Temporal Coverage
Soil Moisture	NASA-USDA Enhanced SMAP Global Soil Moisture Data (Soil moisture profile)	10 km x 10 km	2015 to present
Land Surface Temperature (LST)	Moderate Resolution Imaging Spectroradiometer (MODIS) (Day time and Nighttime) MOD11A1.061	1 km x 1 km	2000 to present
Rainfall	Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS)	5 km x 5 km	1981 to present
Liquid Water Equivalent thickness (LWE)	Gravity Recovery and Climate Experiment (GRACE) and GRACE Follow-On (GRACE-FO)	50 km x 50 km	2002 to present
Acute Watery Diarrhea (AWD) Cases	District level surveillance of Directorate General of Health Services (DGHS) of Bangladesh	District Level (64)	2011-2019

People without Safe Drinking Water Access in 2020



Annual Mortality rate from diarrheal diseases per 100,000 in 2019

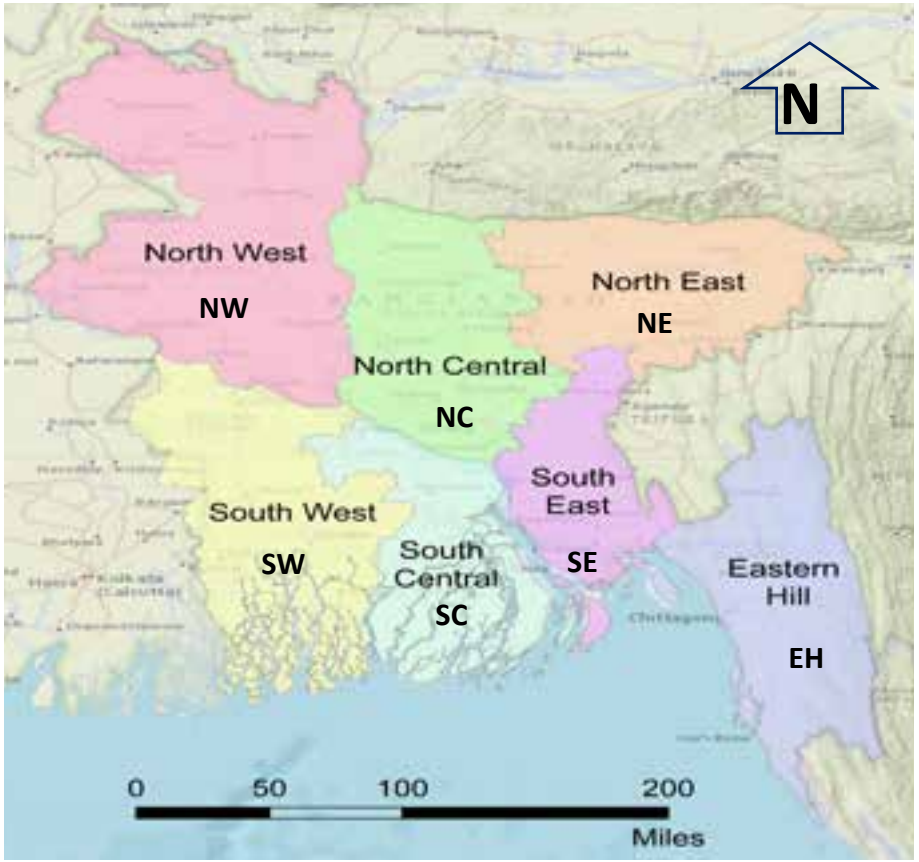


High mortality rates (50 to 200 per 100,000) observed in Sub-Saharan Africa and South Asia

Hydrological Setting of Bangladesh

Hydrological Regions of Bangladesh

- Bangladesh is divided into 7 hydrological regions
- Based on principal river system and environmental characteristics
- Better planning and management of water resources



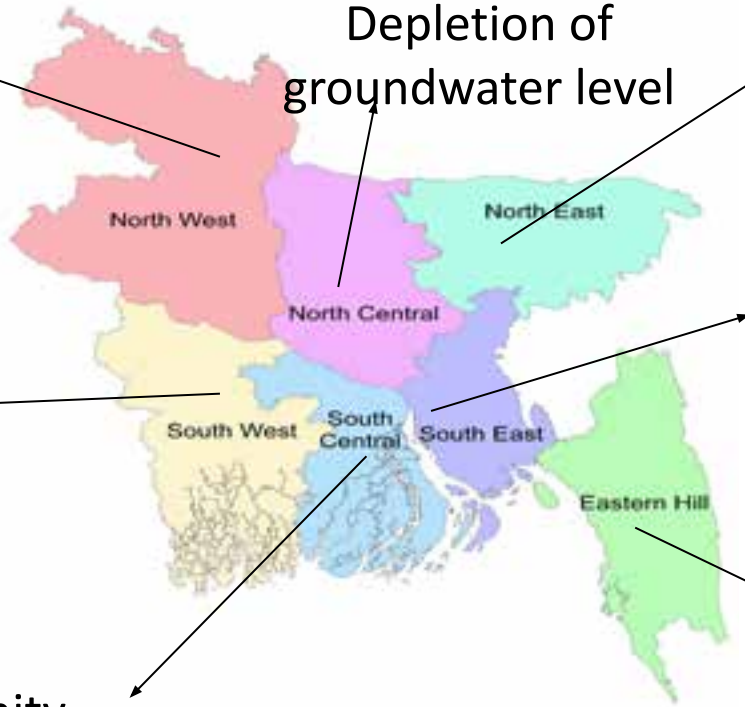
Hydrological Regions of Bangladesh

Characteristics of Hydrological Regions of Bangladesh

- ❑ Drought

Depletion of groundwater level

- ❑ Haor region, bowl-shaped tectonic depression, more than 6000 *haors*
- ❑ Flash flooding
- ❑ High Rainfall
- ❑ Flood
- ❑ Arsenic Contamination

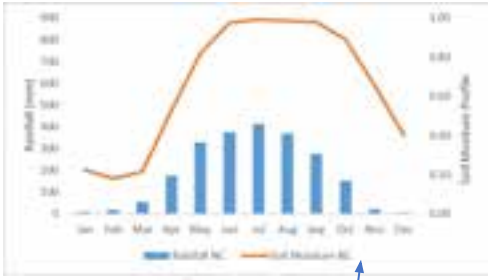


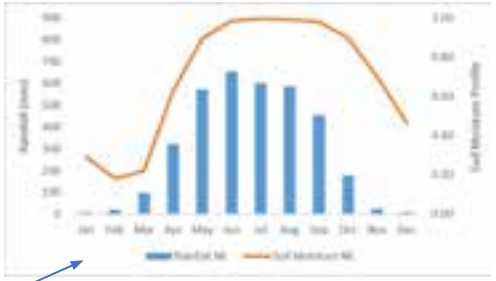
- ❑ Coastal drainage congestion
- ❑ Salinity

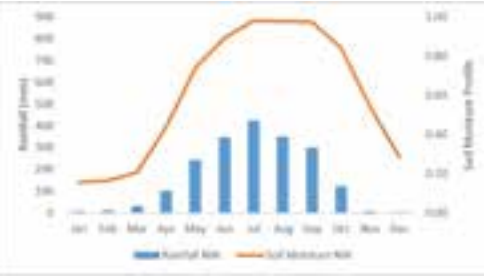
- ❑ Salinity
- ❑ Storm surge

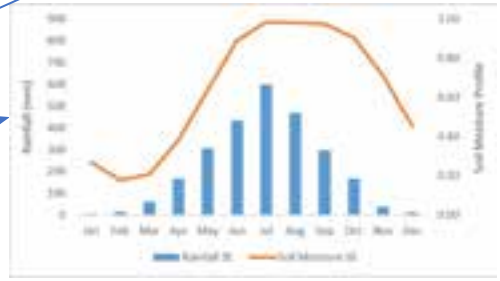
- ❑ Hilly Region
- ❑ Drying up of natural springs

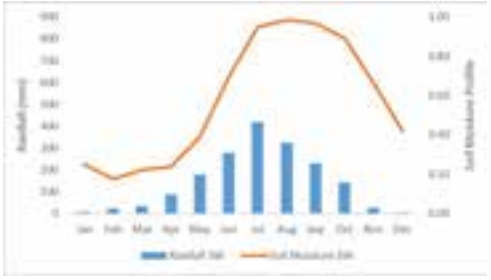
Rainfall & Soil Moisture

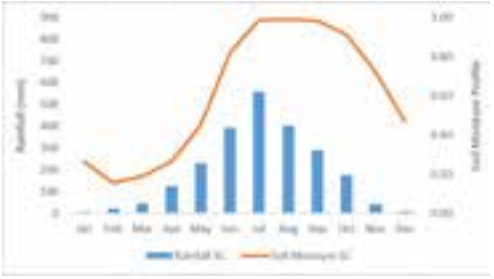


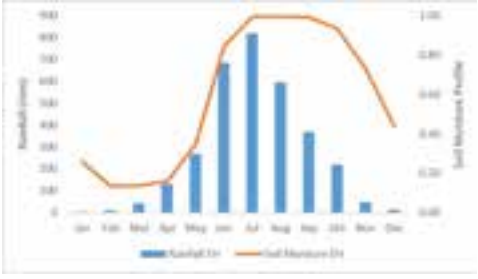












Rainfall's impact on Soil Moisture

Region	Correlation of Soil Moisture Anomaly & Rainfall Anomaly			
	Winter	Spring	Monsoon	PostMonsoon
EH	0.48*	0.51*	0.05	0.61*
SE	0.25	0.31	0.17	0.6*
SC	0.46	0.37	-0.15	0.86***
SW	0.15	0.42	-0.25	0.69**
NW	0.06	-0.27	0.2	0.66**
NC	0.38	0.19	0.14	0.7**
NE	0.12	-0.24	0.25	0.8***

- Higher rainfall is associated with higher Soil Moisture
- In Winter and Spring, Rainfall shows higher correlation with soil moisture than Monsoon
- Very high correlation observed in all regions which are statistically significant in Post monsoon

Rainfall Extreme Indices

Indices	Name	Definition	Unit
Rx1day	Maximum 1-day precipitation	Monthly Maximum 1-day Precipitation	mm
Rx5day	Maximum consecutive 5-day precipitation	Monthly Maximum 5-day Consecutive Precipitation	mm
R10mm	Days with heavy precipitation	Number of days in a month when Precipitation ≥ 10mm	Days
R20mm	Days with very heavy Precipitation	Number of days in a month when Precipitation ≥ 20mm	Days
R50mm	Days with extreme precipitation	Number of days in a month when Precipitation ≥ 50mm	Days
CWD	Consecutive Wet Days (maximum length of wet spell)	Maximum number of consecutive days in a month with Precipitation ≥ 1mm	Days
CDD	Consecutive Dry Days (maximum length of dry spell)	Maximum number of consecutive days in a month with Precipitation < 1mm	Days

Rainfall Extremes Indices' Impact on Soil Moisture

	Winter						
Region	Rx1day_Anomaly	Rx5day_Anomaly	R10mm_Anomaly	R20mm_Anomaly	R50mm_Anomaly	CDD_Anomaly	CWD_Anomaly
EH	0.48*	0.54*	0.36	0.39	nan	0.09	0.66**
SE	0.31	0.34	0.17	0.15	nan	0.26	0.19
SC	0.45	0.72***	0.27	0	nan	0.07	0.53*
SW	0.36	0.49*	0.19	-0.02	nan	-0.21	0.47
NW	-0.01	0.12	nan	nan	nan	0.27	0.02
NC	0.4	0.51*	0.18	-0.03	nan	-0.2	0.13
NE	-0.06	0.31	-0.18	-0.11	nan	-0.12	0.39

	Spring						
Region	Rx1day_Anomaly	Rx5day_Anomaly	R10mm_Anomaly	R20mm_Anomaly	R50mm_Anomaly	CDD_Anomaly	CWD_Anomaly
EH	0.46*	0.54**	0.43	0.42	0.49*	-0.27	0.22
SE	0.34	0.2	0.25	0.01	0.24	-0.16	0.29
SC	-0.13	0.03	0.07	0.29	-0.23	-0.27	0.43
SW	0.37	0.22	0.27	0.19	0.21	-0.37	0.16
NW	0.05	0.16	-0.47*	0.4	-0.37	0.15	0.11
NC	0.26	0.02	0.07	0.25	0.23	-0.07	-0.14
NE	0.24	0.22	-0.15	-0.31	-0.38	0.28	0.19

Winter

- ❑ RX5 shows higher impact than monthly rainfall and other rainfall extremes on SM

Spring

- ❑ RX1 explains SM condition better than other rainfall extremes

**nan occurs as values have no variance*

Rainfall Extremes Indices' Impact on Soil Moisture

	Monsoon						
Region	Rx1day_Anomaly	Rx5day_Anomaly	R10mm_Anomaly	R20mm_Anomaly	R50mm_Anomaly	CDD_Anomaly	CWD_Anomaly
EH	-0.06	0	0.21	0.03	-0.14	-0.35	-0.01
SE	0.06	0.04	0.16	0.24	0.06	-0.29	0.13
SC	-0.2	-0.23	0.1	-0.24	-0.32	-0.33	0.23
SW	-0.35	-0.19	-0.07	-0.4*	-0.2	-0.04	0.02
NW	0.04	-0.08	0.28	0.04	0.15	-0.51**	0.21
NC	0.03	0.04	0	0.21	-0.02	-0.4*	0.16
NE	0.04	0.12	0	0.08	0.13	-0.3	0.04

	PostMonsoon						
Region	Rx1day_Anomaly	Rx5day_Anomaly	R10mm_Anomaly	R20mm_Anomaly	R50mm_Anomaly	CDD_Anomaly	CWD_Anomaly
EH	0.52	0.49	0.55*	0.53	0.45	-0.4	0.49
SE	0.43	0.51	0.36	0.76**	0.34	-0.22	0.58*
SC	0.69**	0.64**	0.64**	0.67**	0.56*	-0.13	0.56*
SW	0.63**	0.44	0.85***	0.29	0.14	-0.53	0.34
NW	0.69**	0.78***	0.34	0.47	0.25	-0.41	0.64**
NC	0.63**	0.7**	0.78***	0.66**	0.21	0.05	0.62*
NE	0.65**	0.77***	0.59*	0.67**	0.42	-0.32	0.3

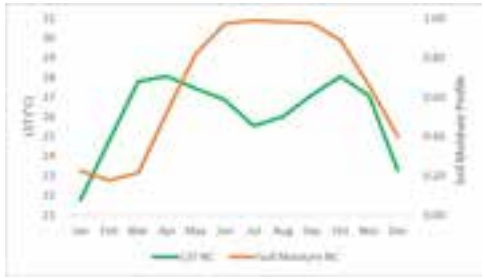
Monsoon

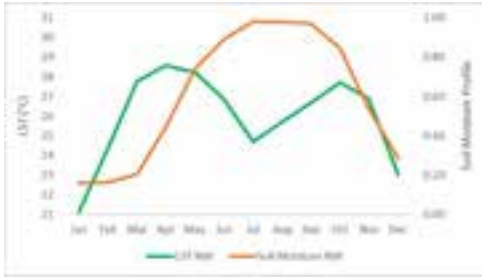
- Neither monthly rainfall nor rainfall extremes show strong impact on soil moisture increase.
- Only CDD shows higher negative impact on soil moisture in monsoon

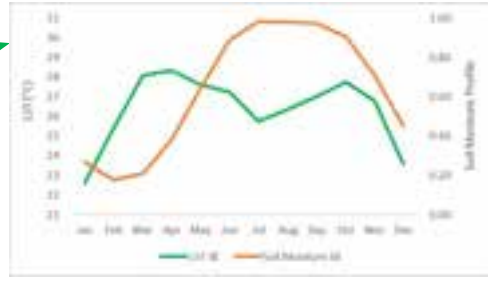
Post Monsoon

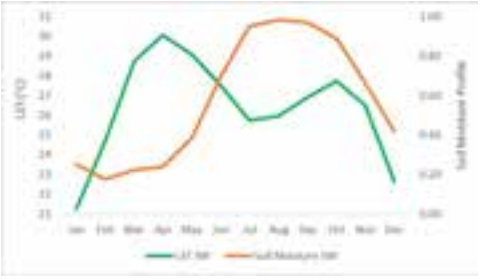
- Statistically significant very high positive correlations observed
- Extremely heavy rainfall (Rx50) has less impact on SM increase than other extremes
- CWD has more positive impact on SM

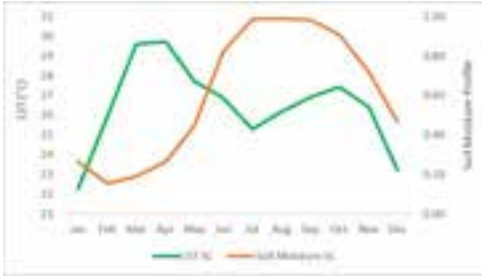
LST & Soil Moisture

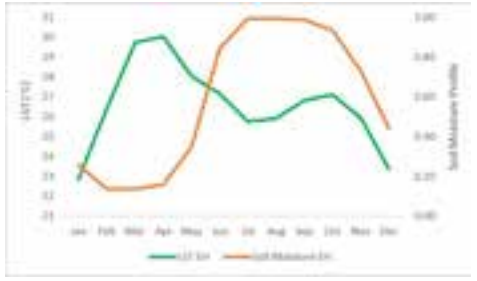












LST's impact on Soil Moisture

Region	Correlation of Soil Moisture Anomaly & Land Surface Temperature (LST) Anomaly			
	Winter	Spring	Monsoon	PostMonsoon
EH	-0.13	-0.36	-0.39*	0.09
SE	-0.15	-0.36	0.00	-0.36
SC	-0.16	-0.01	-0.11	-0.43
SW	-0.07	-0.32	-0.33	-0.49
NW	-0.26	-0.53**	-0.31	-0.45
NC	-0.21	-0.44	-0.07	-0.48
NE	-0.17	-0.12	0.18	-0.29

- Higher LST is associated with lower Soil Moisture
- Spring & Post Monsoon have high temperature
- High temperature causes higher Evapotranspiration and that lower the soil moisture
- Spring and Post Monsoon show higher correlation than other seasons

LST Extreme Indices

Indices	Name	Definition	Unit
TXx	Maximum daytime temperature	Monthly maximum value of daily daytime temperature	°C
TXn	Minimum day time temperature	Monthly minimum value of daily daytime temperature	°C
TNx	Maximum nighttime temperature	Monthly maximum value of daily nighttime temperature	°C
TNn	Minimum nighttime temperature	Monthly minimum value of daily nighttime temperature	°C
T_Span <21	Cold Spell	Maximum number of consecutive days in a month with nighttime temperature < 21°C	Days
T<21	Cooler Nights	Number of days in a month when nighttime temperature < 21°C	Days
T_Span >31	Warm Spell	Maximum number of consecutive days in a month with daytime temperature > 31°C	Days
T>31	Warmer Days	Number of days in a month when daytime temperature > 31°C	Days

LST Extreme Indices' Impact on Soil Moisture

Region	Winter							
	Max Day Temp	Min Day Temp	Max Night Temp	Min Night Temp	Warm Spell	Warm Days	Cold Spell	Cold Days
EH	-0.16	-0.08	-0.07	0.11	-0.16	-0.16	-0.01	0.11
SE	0.05	-0.08	0.16	-0.51*	nan	nan	-0.43	-0.27
SC	-0.08	-0.24	0.06	-0.16	-0.27	-0.27	-0.1	-0.18
SW	-0.15	0.01	-0.1	0.15	nan	nan	0.09	-0.08
NW	-0.55*	-0.35	-0.36	-0.06	nan	nan	0.11	0.1
NC	-0.2	-0.38	-0.16	-0.16	nan	nan	0	0.23
NE	-0.14	-0.15	0.2	0.31	nan	nan	0.14	0.31

- Daytime temperature shows negative impact on soil moisture in Winter

**nan occurs as values have no variance*

LST Extreme Indices' Impact on Soil Moisture

Region	Spring							
	Max Day Temp	Min Day Temp	Max Night Temp	Min Night Temp	Warm Spell	Warm Days	Cold Spell	Cold Days
EH	-0.26	-0.05	-0.5*	-0.57**	-0.01	-0.23	0.33	0.38
SE	-0.15	-0.44	0.22	-0.08	0.01	-0.08	0.34	0.4
SC	-0.21	-0.26	-0.21	-0.17	-0.02	0.1	-0.05	0.24
SW	-0.02	-0.12	-0.18	-0.44	-0.26	-0.22	0.23	0.33
NW	-0.71***	0.43	-0.13	-0.44	-0.35	-0.36	0.62**	0.22
NC	-0.32	-0.15	-0.03	-0.04	-0.01	-0.23	-0.09	0.15
NE	-0.52*	-0.08	0.16	-0.2	-0.42	-0.29	-0.22	-0.08

- Max day temp shows moderately high negative impact on soil moisture in Spring
- Warm days (T>31°C) and warm spell have negative impact on soil moisture in Spring
- Cold spell (days when T<21°C) in spring has positive impact on soil moisture, longer cold spell is associated

**nan occurs as values have no variance*

LST Extreme Indices' Impact on Soil Moisture

Region	Monsoon							
	Max Day Temp	Min Day Temp	Max Night Temp	Min Night Temp	Warm Spell	Warm Days	Cold Spell	Cold Days
EH	-0.2	-0.05	-0.26	0.13	-0.02	-0.06	-0.14	-0.58***
SE	0.05	0.13	0.19	0.37	0.04	-0.13	-0.16	-0.66***
SC	-0.39*	0.02	0.11	0.06	-0.29	-0.36	-0.1	-0.48**
SW	-0.25	-0.09	-0.13	0.04	-0.1	-0.26	0.04	0.05
NW	-0.21	0.05	0.45**	0.02	-0.1	-0.17	0.22	0.08
NC	-0.09	0.42*	0.15	0.17	-0.05	-0.17	0.1	-0.03
NE	-0.08	0.03	0.48**	-0.03	-0.13	-0.05	nan	0.17

- Maximum daytime Temperature shows negative association with soil moisture increase
- Maximum Nighttime Temperature shows positive association with soil moisture increase
- Cold days (T<21°C) in southern part shows negative impact in monsoon

*nan occurs as values have no variance

LST Extreme Indices' Impact on Soil Moisture

Region	PostMonsoon							
	Max Day Temp	Min Day Temp	Max Night Temp	Min Night Temp	Warm Spell	Warm Days	Cold Spell	Cold Days
EH	0.56*	-0.09	0.36	-0.2	nan	nan	0.1	-0.28
SE	-0.22	0.22	0.42	0.41	-0.37	-0.37	0.04	-0.86***
SC	-0.66**	0.36	0.2	0	-0.17	-0.17	-0.03	-0.72**
SW	-0.79***	-0.04	0.15	0.46	-0.45	-0.44	-0.1	-0.71**
NW	-0.45	-0.69**	0.25	0.02	-0.45	-0.45	-0.55*	-0.42
NC	-0.36	-0.31	0.46	0.27	-0.33	-0.32	-0.71**	-0.38
NE	0.37	-0.24	0.57*	0.12	-0.17	-0.17	-0.64**	-0.69**

- Maximum day Temperature shows moderately high negative impact on soil moisture
- Higher the Warm Spell (days when T>31°C), lower the soil moisture
- Warmer days (T>31°C) have negative on soil moisture
- Cold spell (days when T<21°C) has negative impact on soil moisture, shorter cold spell is associated with more soil moisture

**nan occurs as values have no variance*

Impact of Extreme Indices on Soil Moisture

Variables	Winter	Spring	Monsoon	Post Monsoon
Rainfall	RX1day, RX5 day, CWD	RX1day	CDD	RX1day, RX5 day, R10mm, R20mm, R50mm, CWD, CDD
Temperature	Min day temp (TXn)	Max day temp (TXx), Warm days (T>31°C), Cold spell (days when T<21°C)	Maximum Nighttime Temperature (TNx), Cold days (T<21°C)	Maximum day Temperature (TXx), Maximum Nighttime Temperature (TNx), Warm Spell (days when T>31°C), Warmer days (T>31°C), Cold spell (days when T<21°C)

Soil Moisture and Groundwater Relationship

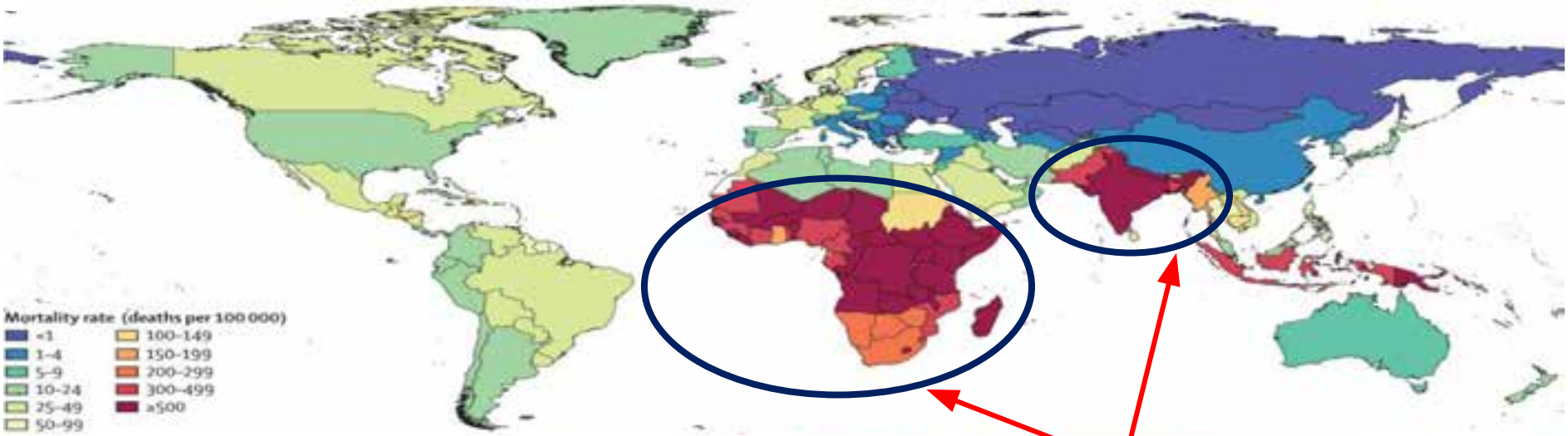
Region	Correlation of Soil Moisture Anomaly & Liquid Water Thickness (groundwater) Anomaly			
	Winter	Spring	Monsoon	PostMonsoon
EH	0.09	0.5*	-0.07	0.29
SE	0.04	0.37	-0.18	0.57*
SC	0.21	-0.16	-0.11	0.05
SW	0.71***	-0.13	-0.09	0.48
NW	0.61**	0.12	0.04	0.24
NC	0.13	0.16	0.1	0.67**
NE	0.15	0.38	-0.01	0.44

Region	Groundwater & Soil Moisture Correlation
EH	0.93***
SE	0.88***
SC	0.9***
SW	0.88***
NW	0.8***
NC	0.81***
NE	0.77***

- For timeseries, strong positive association between soil moisture and groundwater
- For seasonal anomaly, overall positive correlation with some exceptions

Water Crisis is a Health Crisis

- Around **771 million** people without **safe water** access **Globally**
- Nearly 1 million people die/year from water, sanitation and hygiene- (WASH) related diseases



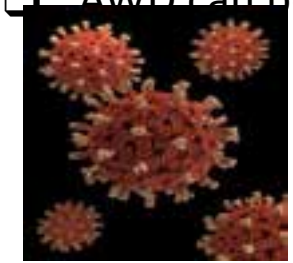
200 to ≥500 deaths per 100,000

Under-5 Diarrhea Mortality Rate per 100,000 in 2016

Troeger et al., 2018

Waterborne Diseases

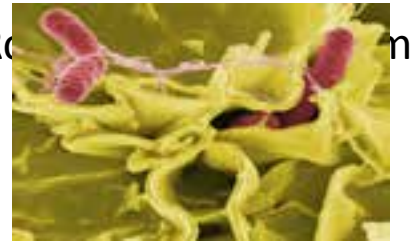
- 2,195 children die due to diarrhea everyday globally
- Diarrhea is 3 or more episodes of loose stool in 24 hours
- Acute Watery Diarrhea (AWD) is a diarrheal disease with an increase of water content, volume, or frequency of stool
- AWD can be caused by Vibrio cholerae, Ro mone



Rotavirus

Shigella

Image Source: CDC



Salmonella

Image Source: Wikipedia

E. Coli

Water and Waterborne Diseases Relationship

$$\text{Prevalence} = \frac{\text{Total disease cases during a given time period}}{\text{Population during the same time period}} \times 100{,}000$$

Region	Correlation with AWD Anomaly							
	Winter				Spring			
	SM	GW	Rx1	TXx	SM	GW	Rx1	TXx
EH	0.09	0.24	-0.15	0.14	-0.12	-0.47**	-0.19	0.39**
SE	0.2	0.02	-0.32	0.26	0.08	-0.65***	-0.63***	0.24
SC	-0.21	-0.2	0.26	0.1	0.26	-0.65***	-0.04	0.17
SW	-0.56**	0.04	-0.33*	0.17	-0.32	-0.59***	-0.41**	0.49***
NW	-0.04	0.14	-0.15	0.08	-0.68***	-0.59***	-0.24	0.5***
NC	-0.49*	0.12	0.12	0.06	-0.48*	-0.41**	-0.5***	0.31
NE	-0.25	-0.34*	0.16	0.09	-0.3	-0.53***	-0.24	0.52***

Region	Correlation with AWD Anomaly							
	Monsoon				PostMonsoon			
	SM	GW	Rx1	TXx	SM	GW	Rx1	TXx
EH	-0.08	0.04	0.04	-0.13	0.44	-0.28	0.05	0.25
SE	0.03	-0.2	0.1	-0.04	-0.06	-0.39	-0.1	-0.21
SC	-0.24	-0.1	0.36**	0.12	-0.51	0.24	-0.34	0.65***
SW	-0.18	-0.08	0	0.19	-0.12	0.2	-0.27	-0.21
NW	0.1	-0.12	0.35**	0.17	0.12	0.37	-0.25	0.03
NC	-0.25	-0.08	-0.18	-0.23	-0.38	-0.25	0.17	-0.35
NE	-0.23	-0.21	-0.19	0.08	-0.28	-0.16	-0.27	0.51**

Applications

Eos

ABOUT SPECIAL REPORTS TOPICS PROJECTS NEWSLETTER SUBMIT TO EOS

Satellites and Cell Phones Form a Cholera Early-Warning System

A new initiative combines satellite data with ground observations to assess and predict the risk of cholera outbreaks in Bangladesh's vulnerable populations.

By A. S. Akanda, S. Aziz, A. Jutla, A. Huq, M. Alam, G. U. Ahsan, and R. R. Colwell 27 March 2018

URI News
External Relations and Communications

From satellite to smartphone, app warns public of unsafe water

App creates early-warning risk maps based on environmental conditions

Findings

- ❑ Soil Moisture can be used as a proxy of water availability

- ❑ This finding can help to build resilience public health vulnerability

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