Water quality assessment using open-source software and data

Sofia La Fuente, Maria Nakkazi, Analy Baltodano, Ann Van Griensven

Workshop on Open Hardware Solutions for Sustainable Development

13 – 17 May 2024 (Cape Town, South Africa)

OVERVIEW

1. Mapping hotspots for present and future water pollution in Africa using SDG indicator 6.3.2

Maria Nakkazi
PhD researcher

OVERVIEW

2. Remote sensing for water quality monitoring

Analy Baltodano
PhD researcher

OVERVIEW

3. Using remote sensing and in-situ observations to investigate climate change responses in African and South American lakes

Sofia La Fuente
Postdoctoral researcher

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MAPPING HOTSPOTS FOR PRESENT AND FUTURE WATER POLLUTION IN AFRICA USING SDG INDICATOR 6.3.2

SUSTAINABLE DEVELOPMENT GOAL 6

Goal 6 recognizes the need for access to water and sanitation for all by 2030.

Indicator 6.3.2 monitors the proportion of bodies of water with good ambient water quality.

Records of 2017-2019, for 97 countries showed that only 60% of the world's monitored water bodies have good ambient water quality (SDG indicator 6.3.2, 2020).

(UNEP, 2021)

CHALLENGES: GLOBAL CHANGE

Climate change accelerated in 2011-2020.
(WMO,2023)

48% wastewater released to the environment
(Jones et al., 2021)

Land use changes
https://oppla.eu/groups/land-use-change

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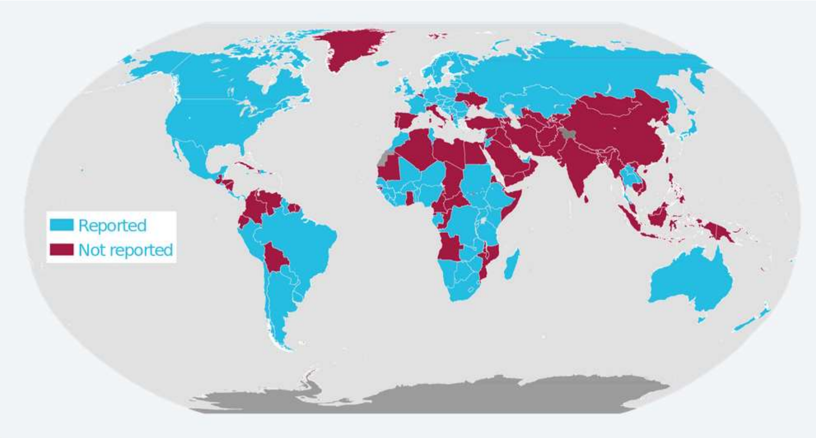
DATA GAP

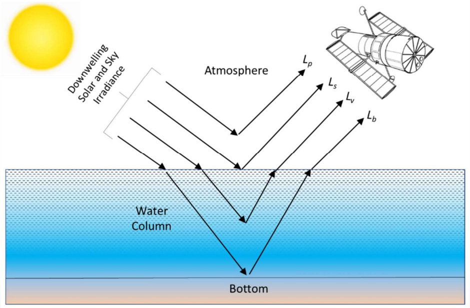


SDG Water Quality Hub,2024

Reporting status: Only 97 countries have reported on this indicator so far.

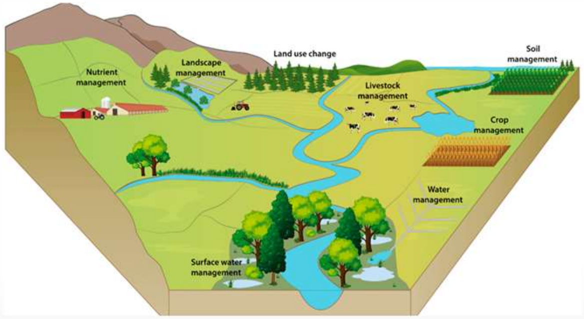
In Africa, the density of stations is 100 times lower than elsewhere in the world.

Remote sensing



In-situ monitoring

Modelling



Studio Lapatsch|Unger

(UNEP, 2016)

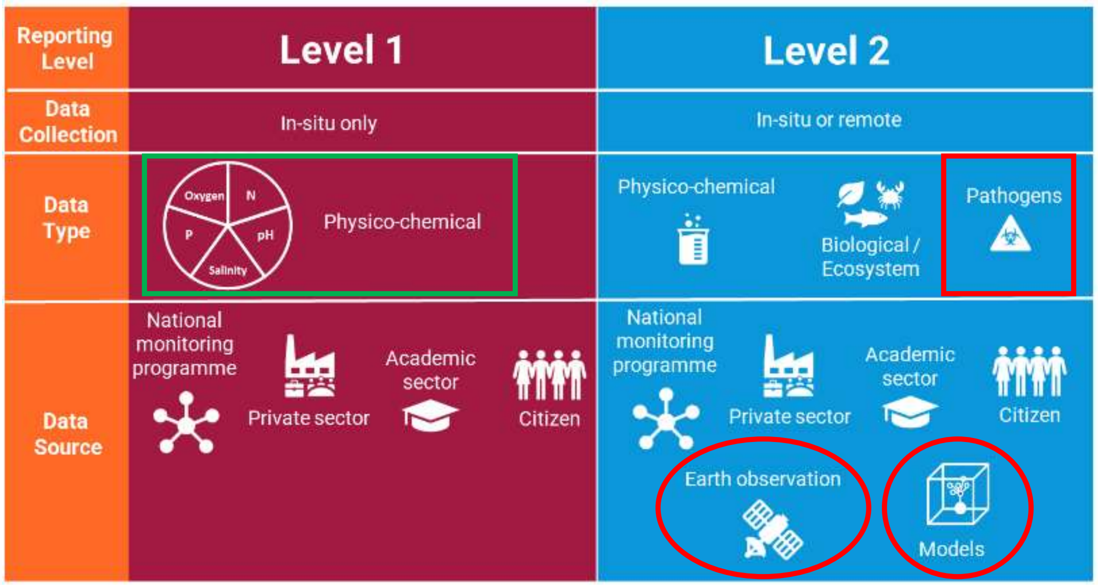
(Kronvang, 2020)

(Hossain, 2021)

MAIN OBJECTIVE

Using models to evaluate the percentage of water bodies with "good ambient water quality" according to thresholds set for 2030 by SDG 6.3.2 indicator

SDG indicator 6.3.2



SDG632_Introduction to SDG Indicator 6.3.2_ Version_20230420

Measured/simulated values of a parameter are compared to respective targets.

If at least 80% of all monitoring data comply with the respective targets, then, the water body is "GOOD".

Together, these parameters = "water quality index" (WQI) generated at country level.

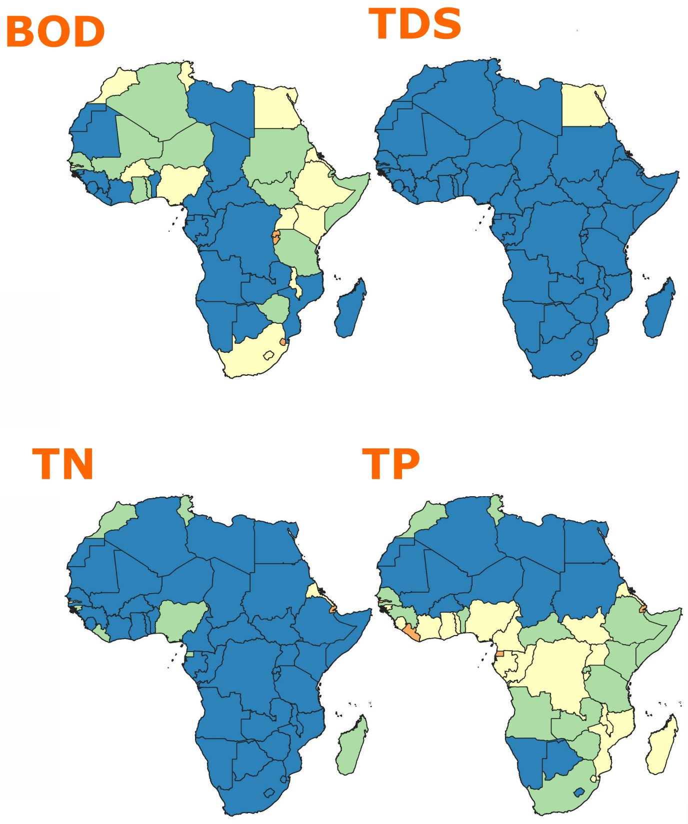
TARGET VALUES

Parameter Group	Parameter	Target Value (upper) – mg/l	References
Level I Parameters			
Salinity	Total Dissolved Solids (TDS)	335	Conversion from EC (Chapman and Kimstach, 1996; Fipps, 2003) Carr and Rickwood (2008); Srebotak et al., (2012); UNEP (2016); WHO (2011)
Nitrogen	Total Nitrogen (TN)	0.7	UN Environment (2017)
Phosphorus	Total Phosphorus (TP)	0.02	UN Environment (2017)
Oxygen	Biological Oxygen Demand (BOD)	4	UNEP (2016)
Level II Parameters			
Pathogens	Fecal Coliforms (FC)	200 (cfu/100ml)	UNEP (2016)

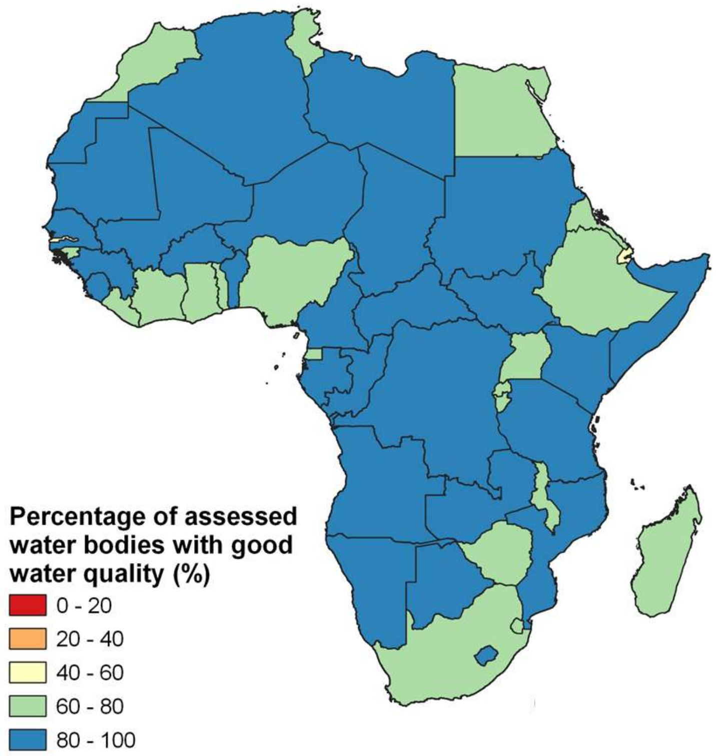
Daily data (2010-2019) from global surface WQ models; *DynQual* (Jones et al., 2023) and SWAT+ model (Nkwasa et al., 2024)

SDG Indicator 6.3.2 Technical Guidance Document No.2 Target Values. 20200508

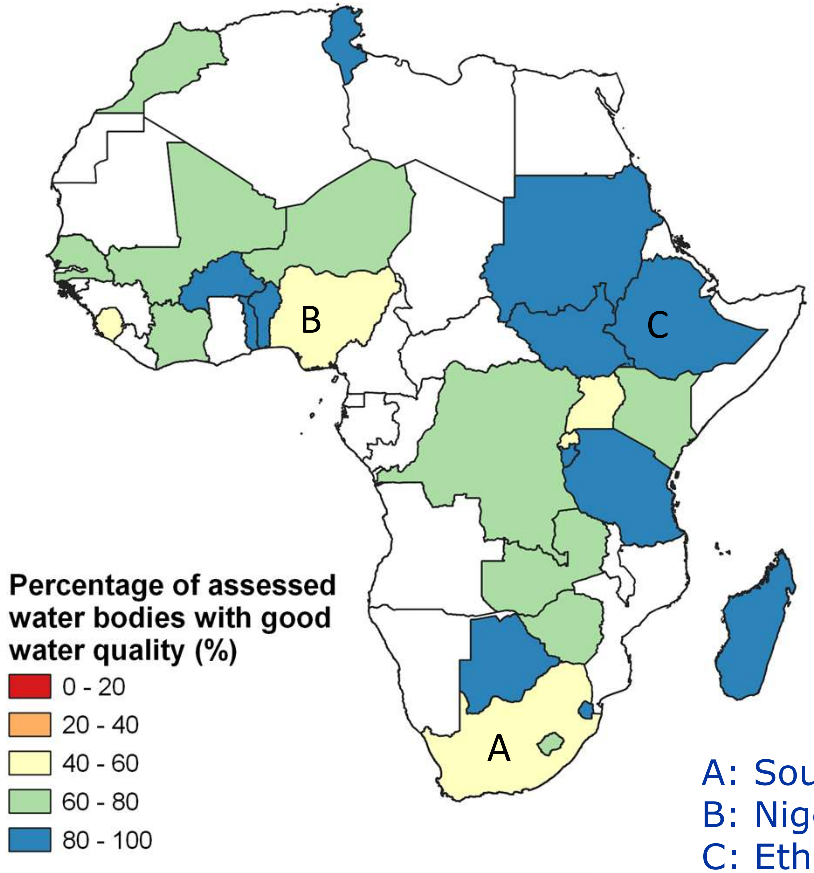
LEVEL I REPORTING



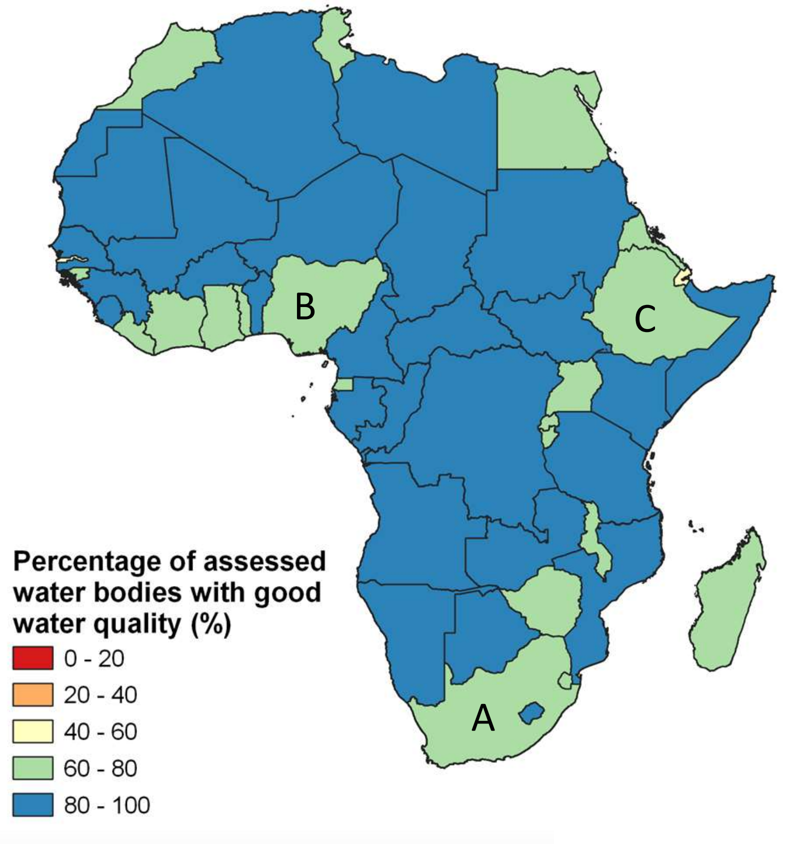
Combined – Water quality index (2010-2019)



WQI from in-situ measurements

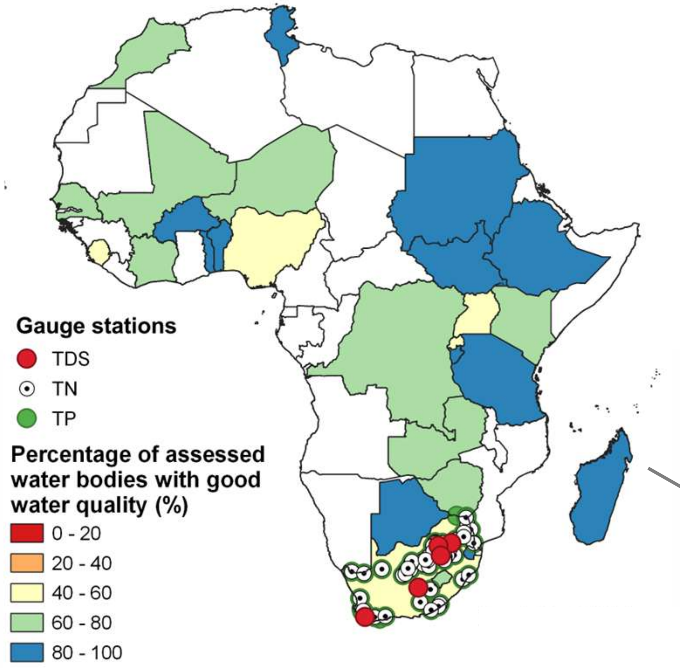


WQI from modelling

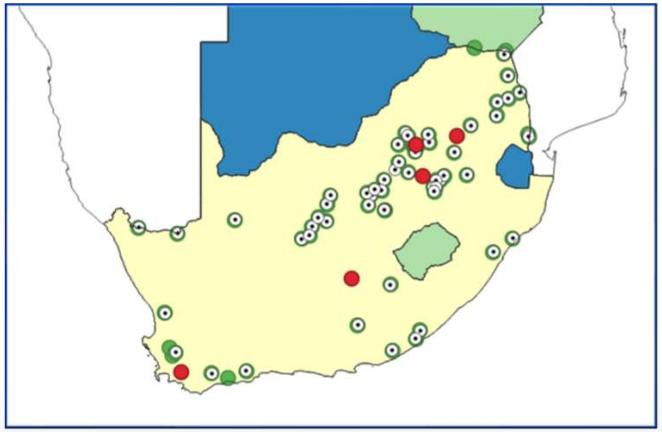


A: South Africa - Higher
B: Nigeria - Higher
C: Ethiopia – Lower

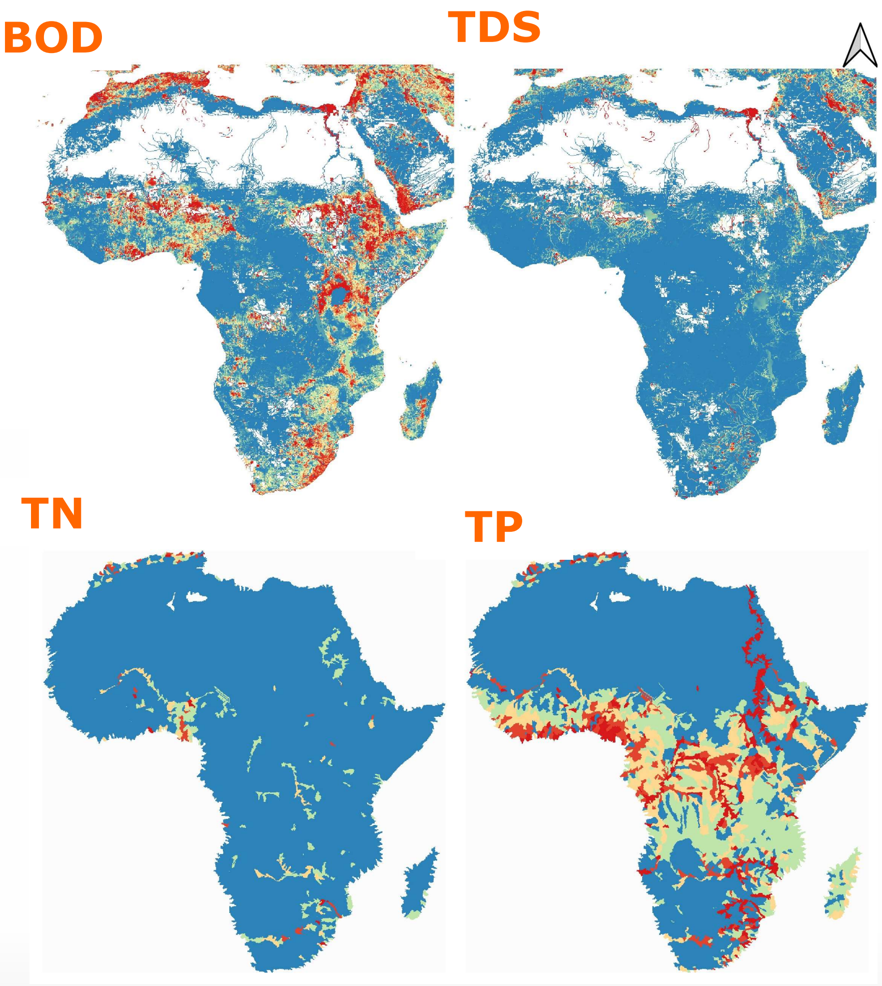
Country level comparison – South Africa



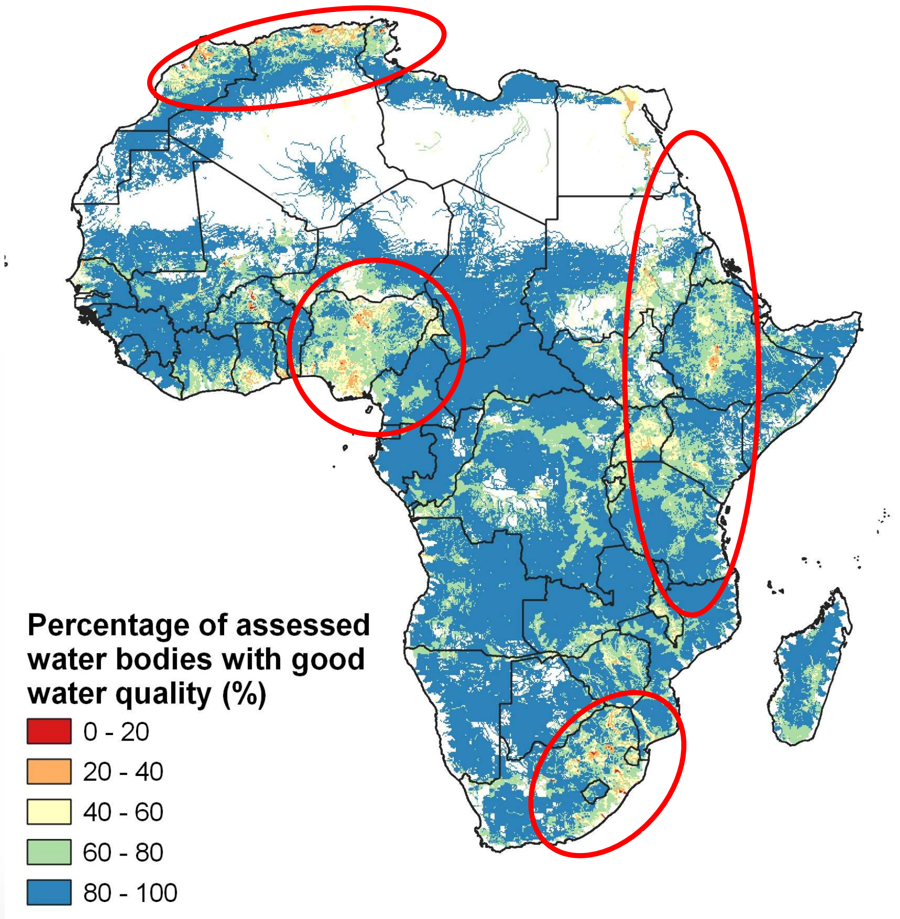
2010-2019		Data Points (Daily)		Mean Water Quality Index - WQI (%)		Correlation Coefficient
Parameter	In-situ gauge stations	Measured	Simulated	Measured	Simulated	
TP	62	4714	226424	0-20	40-60	**0.21**
TN	58	4806	211816	0-20	60-80	**0.28**
TDS	5	112	18260	60-80	80-100	**1.00**



Data source: GEMSTAT database



COMBINED – Water quality index (2010-2019)



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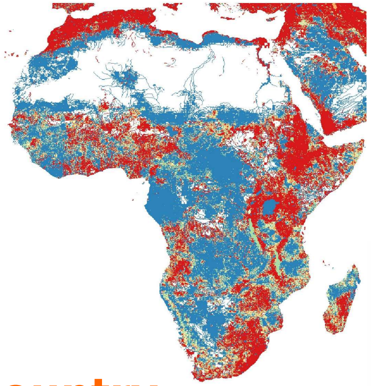
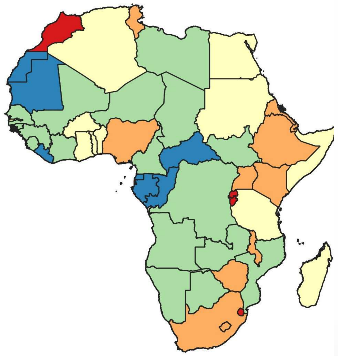
LEVEL II REPORTING

FC - basin

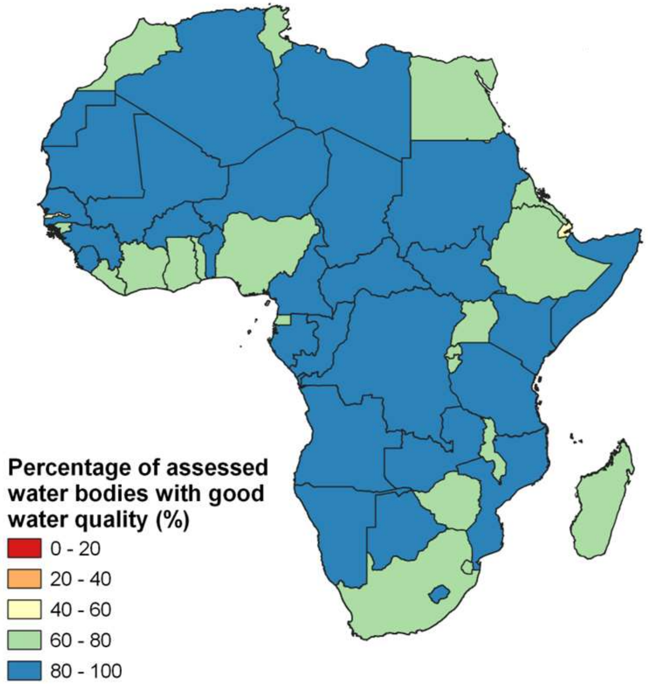


FC - country



WQI with Faecal Coliforms (2010-2019)

WQI without Faecal Coliforms (2010-2019)



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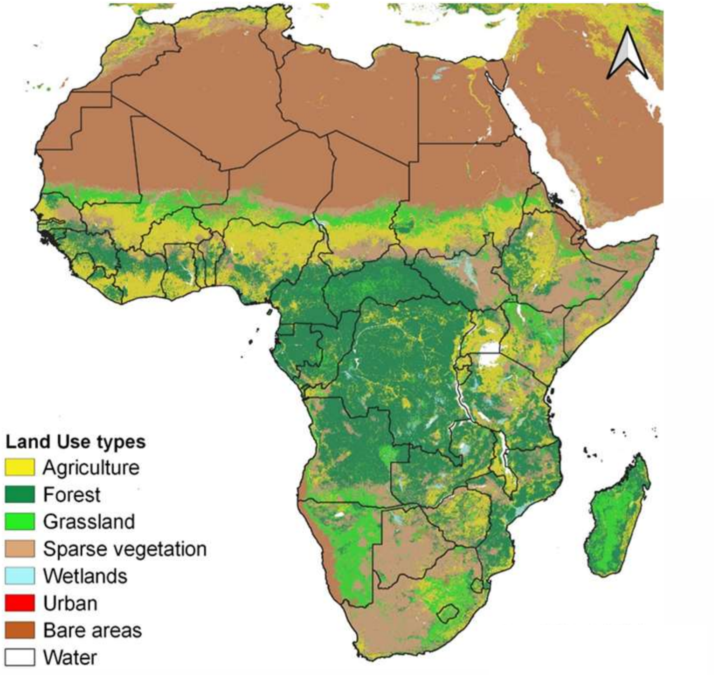
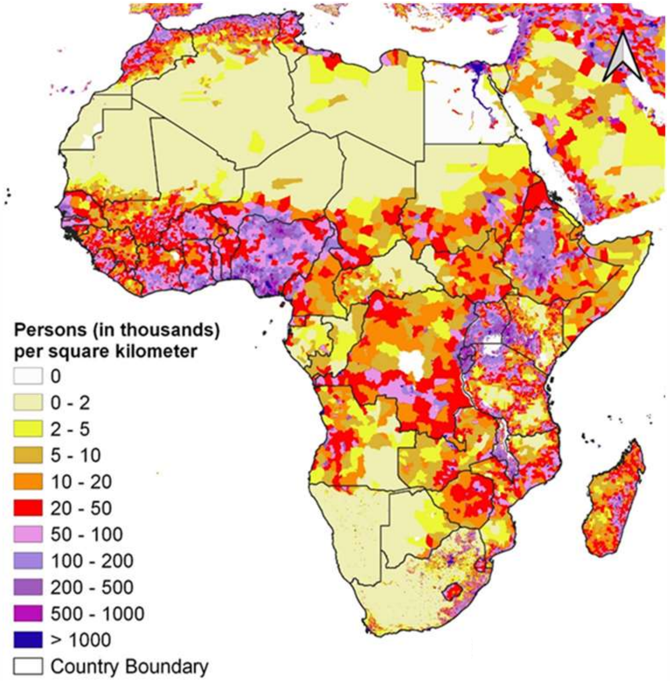
DRIVERS

Land Use - 2015



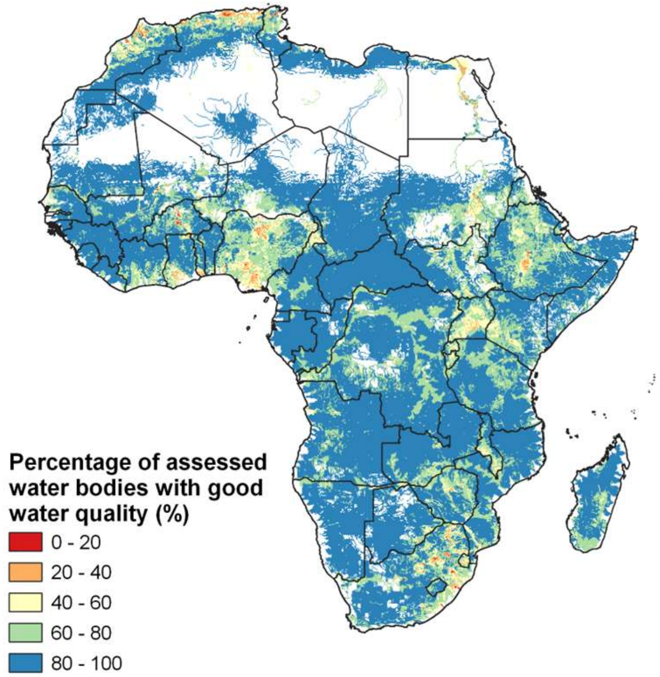
(ESA Land Cover CCI product)

Population Density - 2015

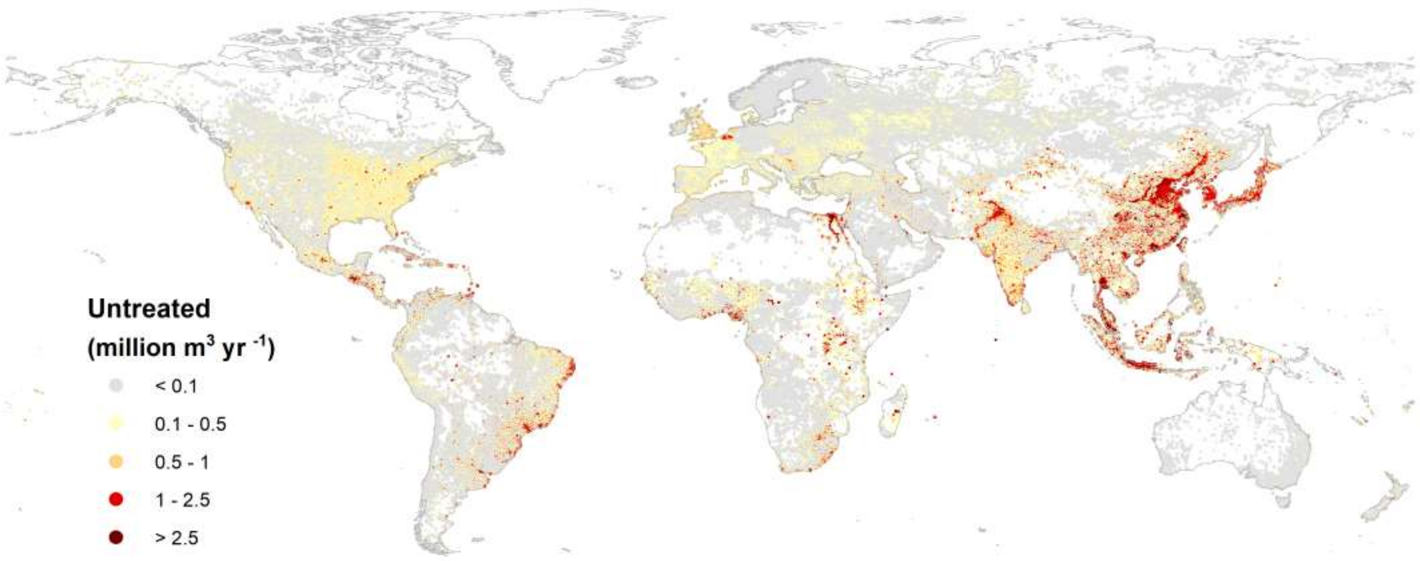


(CIESIN, 2017)

WQI - level I

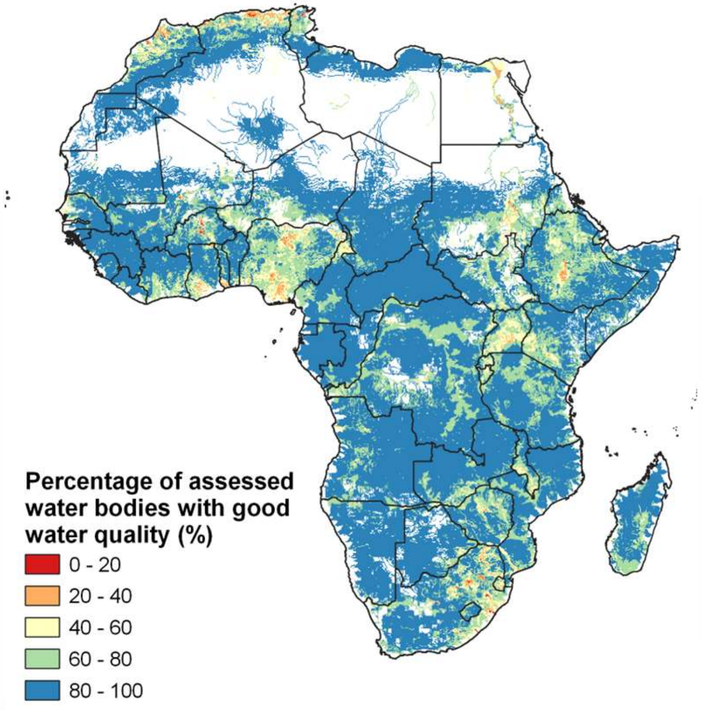


Untreated wastewater flows to the Environment - 2015



(Jones et al., 2021)

WQI - level I



Remarks

1. Modelling can complement in-situ monitoring for reporting progress on SDG 6.3
2. Gridded reporting of the WQI provides more detail than country-based reporting
3. Need to further expand the reporting to level II parameters
4. Anthropogenic activities greatly influence water quality

Next steps

1. Evaluate WQI under future scenarios (up to 2100) and assess if established thresholds would be met
2. Expand study to the global scale

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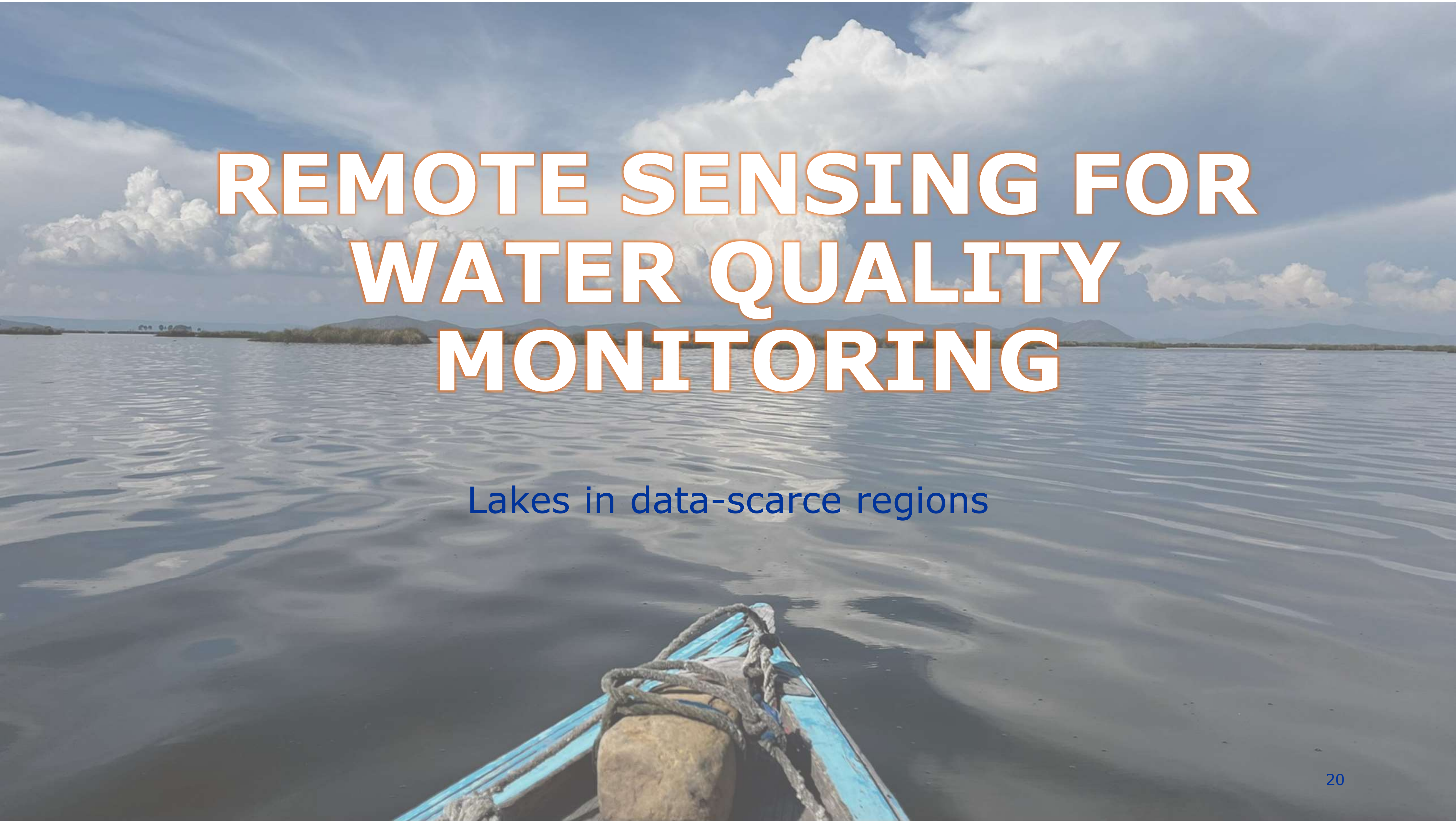
QUESTIONS?

Maria Theresa Nakkazi

maria.theresa.nakkazi@vub.be



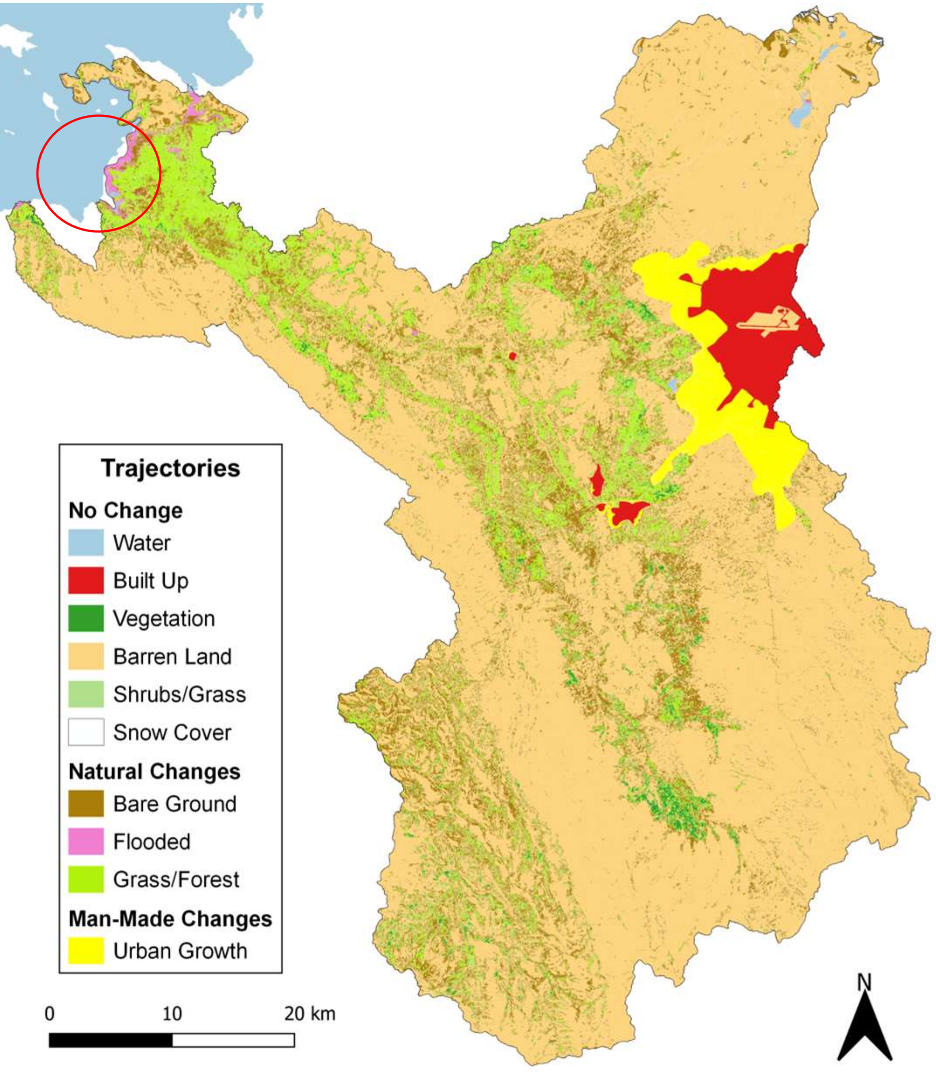
REMOTE SENSING FOR WATER QUALITY MONITORING

Lakes in data-scarce regions

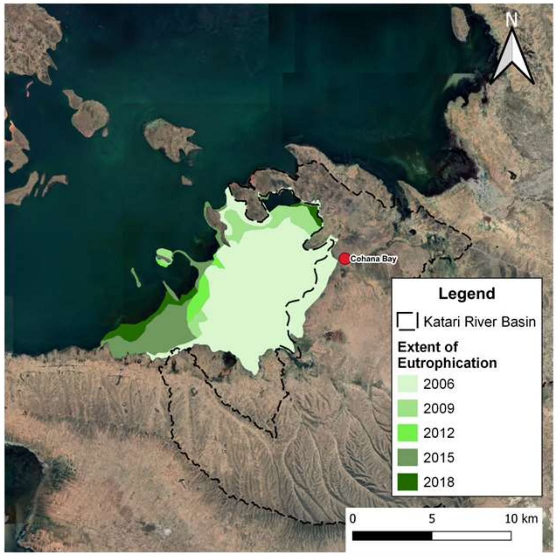
LAKE TITICACA

- Largest lake in Latin America
- Indigenous communities living on its shores suffer from poor water quality
- Pressures for water quality:
  - Mining
  - Wastewater and solid waste from rapid urban growth and industry
  - Agriculture and farming
- Importance:
  - Fishing
  - Irrigation
  - Sociocultural importance

Goal: Determine whether citizen science water quality data is good for remote sensing calibration/validation

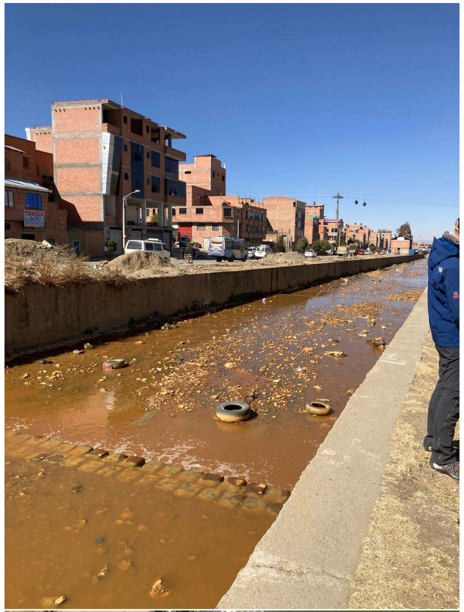


- Remote sensing has been used to detect land cover changes and relate them to eutrophication
- 123% expansion of urban areas [2006-2018] with an increasing trend ($p < 0.05$) at a rate of 8 km^2/year
- Increase of 1.7 km^2/year of eutrophicated areas was calculated at the outlet of the basin



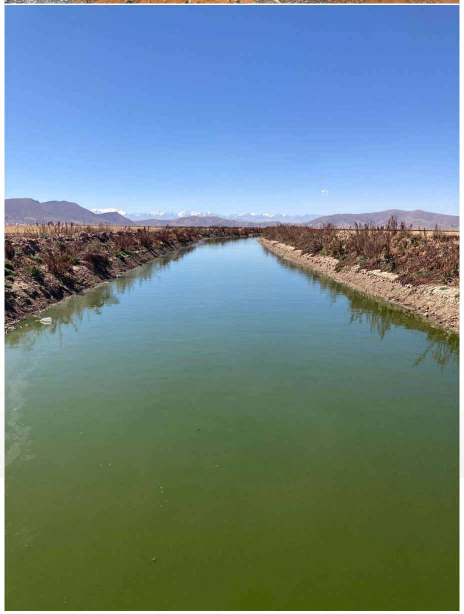
Baltodano et al. (2022) https://doi.org/10.3390/w14071021

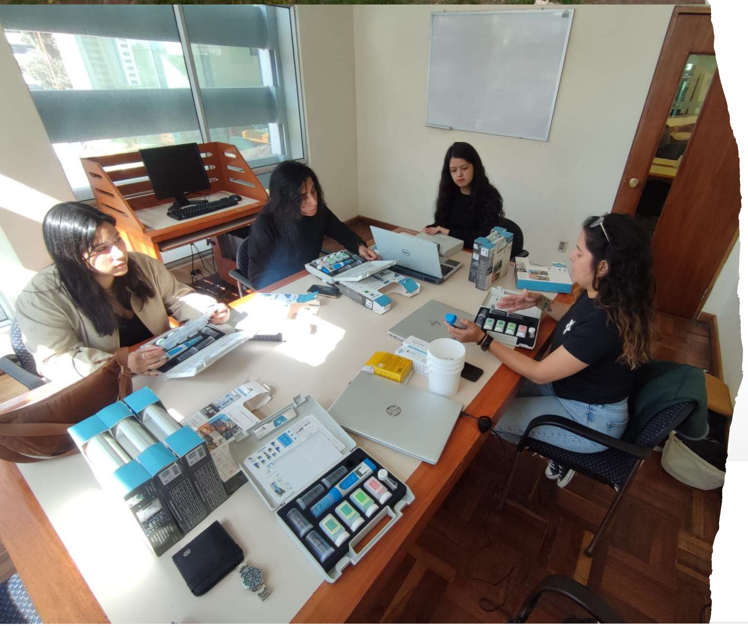
Sources



Citizens involved

Impacts



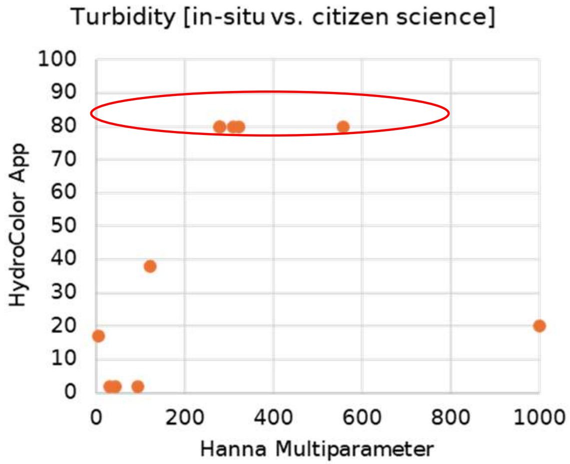


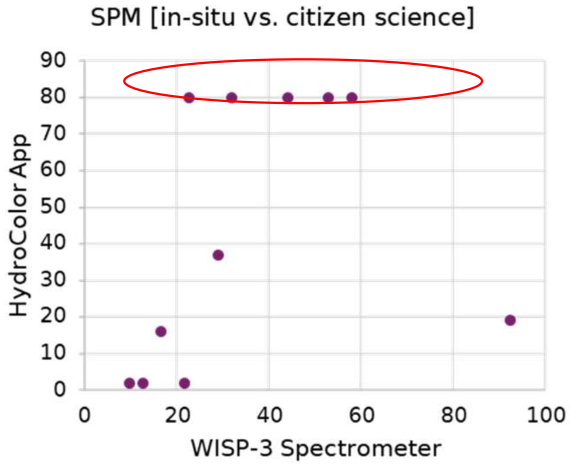
- Water quality monitoring campaign [March 2024]
  - In situ water quality measurements (multiparameter)
  - In situ water surface reflectance measurements (spectrometer)
- Citizen science component
  - High school students involved in the campaign
  - Use of water quality apps to measure reflectance (HydroColor)
  - Use of conventional methods for water quality measurements (multiparameters/test strips)

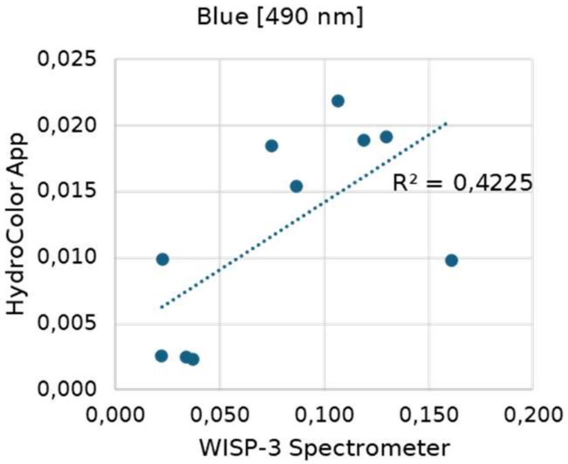
PRELIMINARY RESULTS

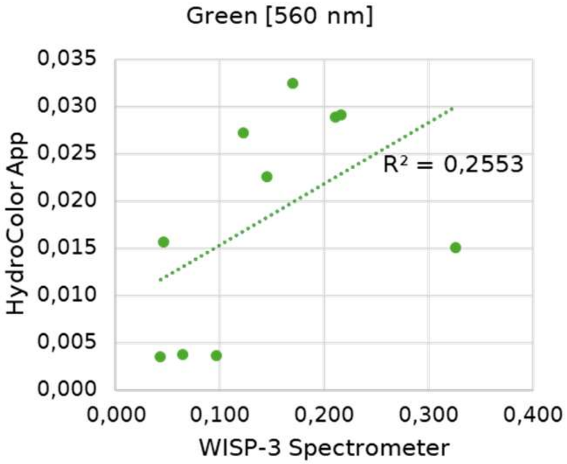
- Maximum concentrations reached due to very turbid waters
- Not so strong correlations
- More sampling campaigns still ongoing

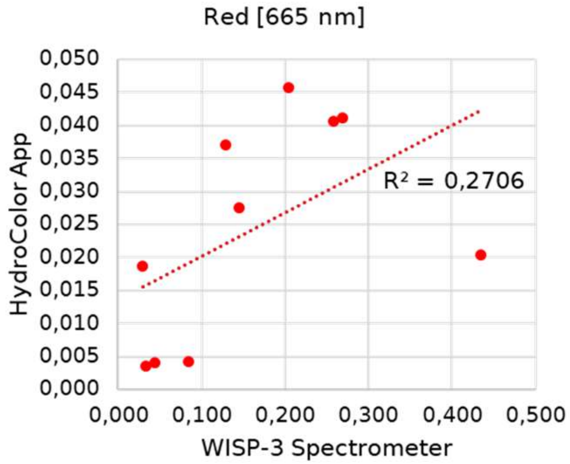
- Better outcomes with reflectances, which is crucial for proper atmospheric correction and subsequent water quality calculations







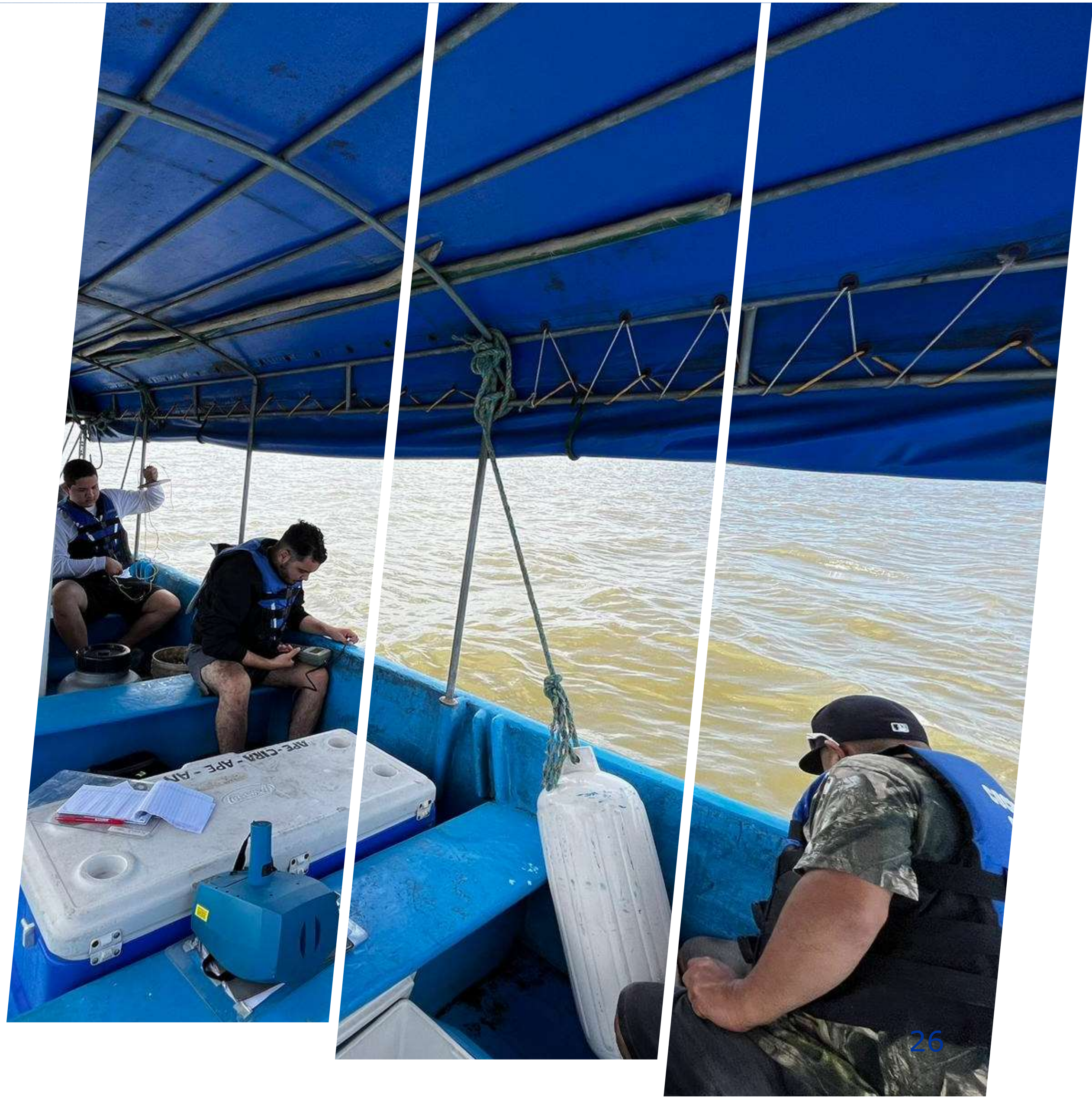




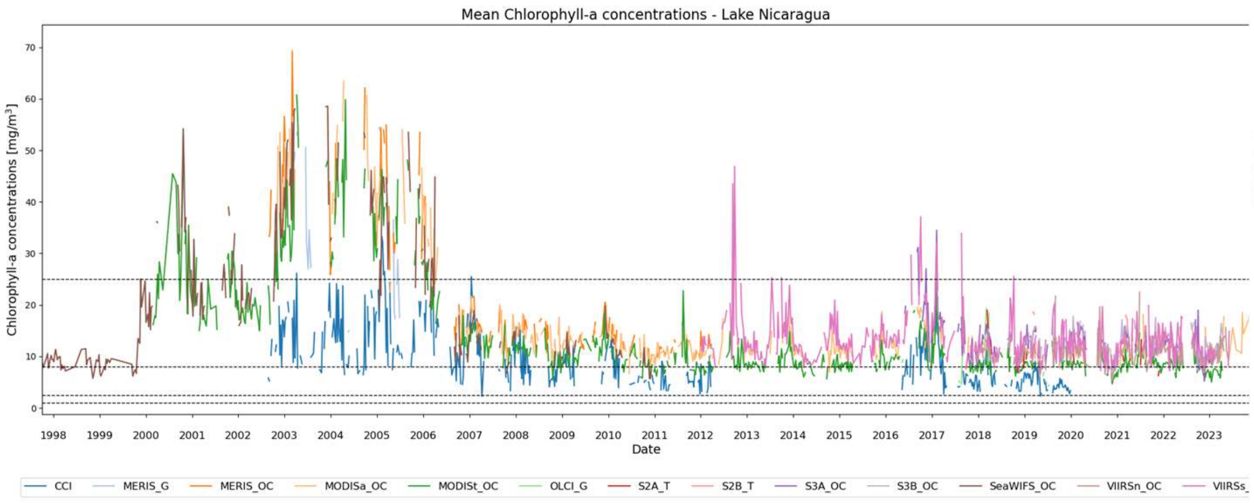
LAKE NICARAGUA

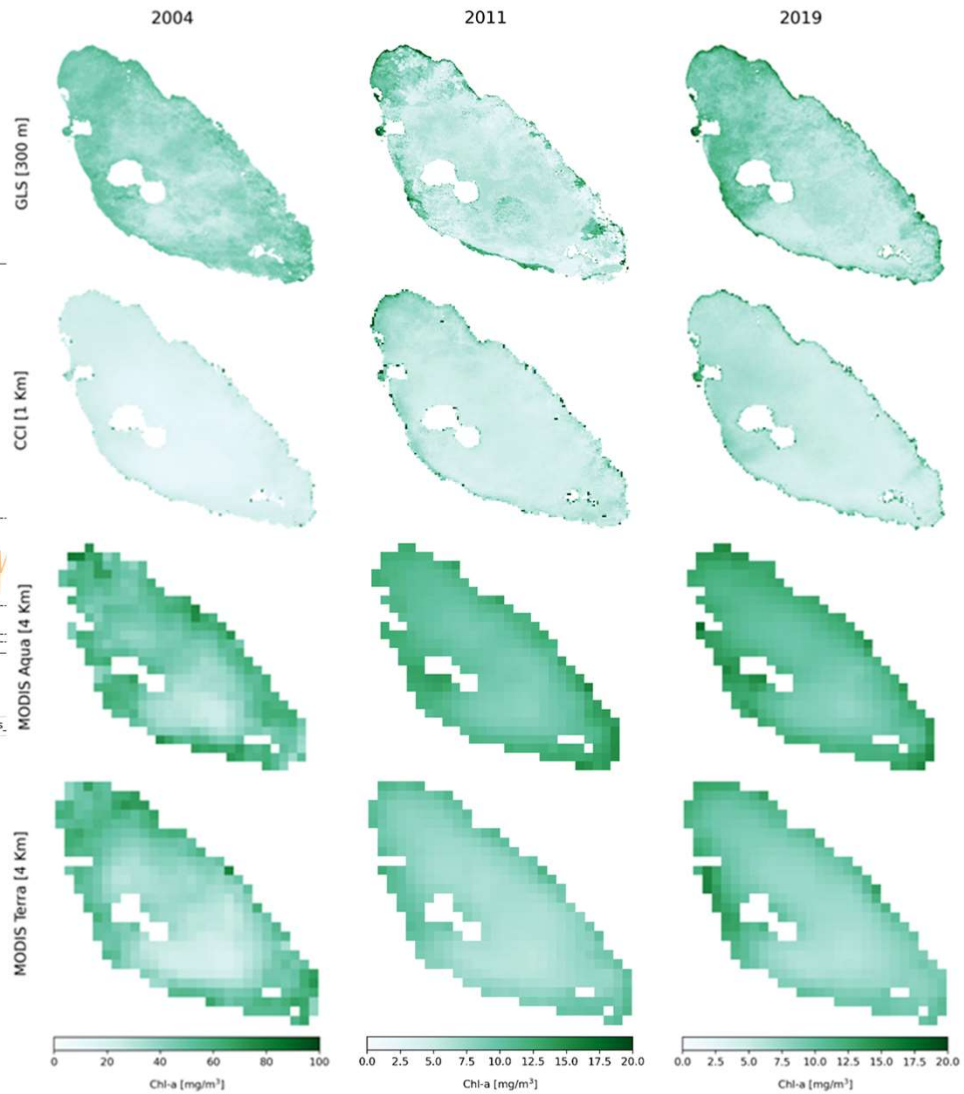
- Largest lake in Central America
- Water quality is poorly monitored
- Pressures for water quality:
  - Tourism
  - Wastewater discharge
  - Pesticides/sediments from agriculture
  - Fishing farms
- Importance:
  - Irrigation
  - Drinking water source for some cities

Goal: Determine which combination of algorithms provides the most accurate results when applied to satellite data to monitor water quality continuously



LAKE NICARAGUA





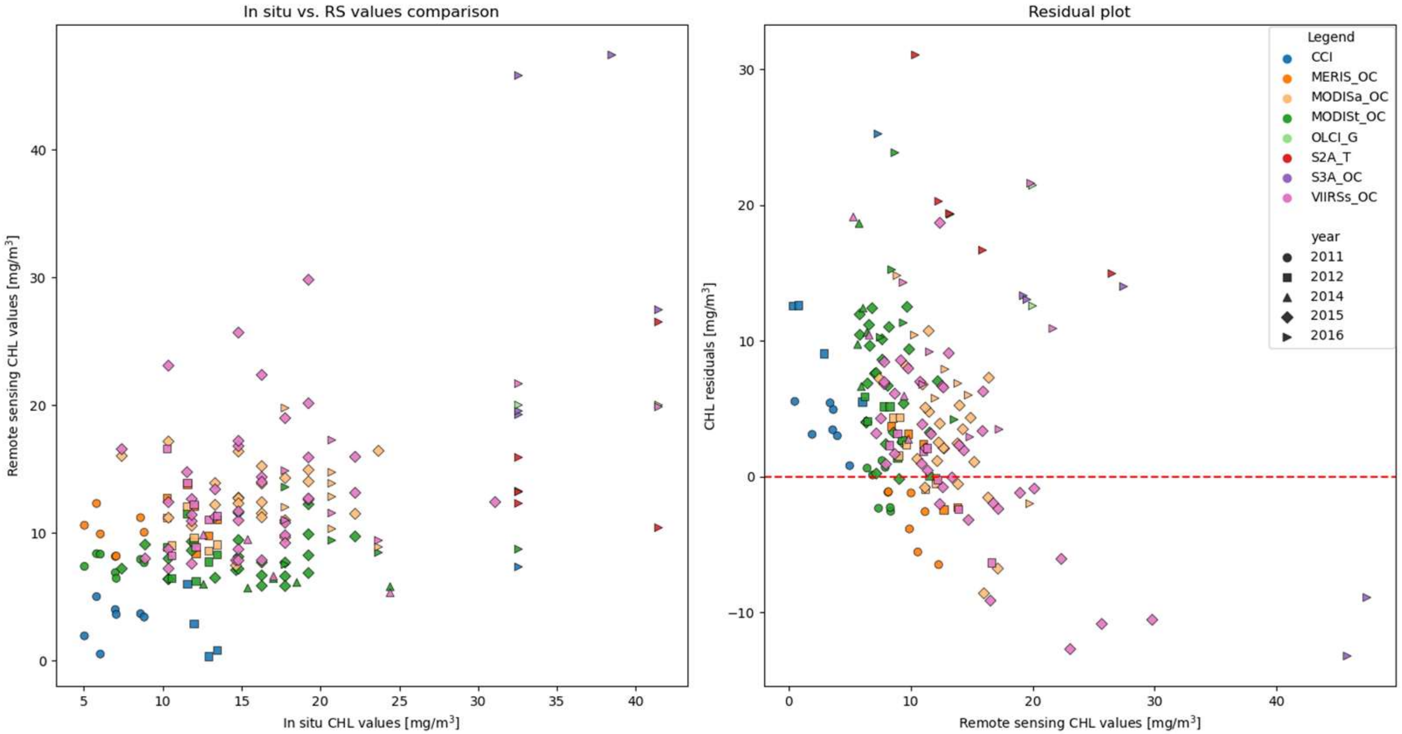
- Products show a good agreement in magnitude through the years
- Concentrations have decreased through time [hypereutrophic → eutrophic]
- Spatial resolution of the product affects its ability to capture hotspots of high concentrations

Product	MAE	MSE	RMSE	MAPE	PBIAS	r	R^2
CCI	7,60	98,39	9,92	*64,09*	*64,09*	**0,48**	**0,23**
MERIS_OC	**2,77**	**10,71**	**3,27**	36,95	-25,78	0,21	0,04
MODIS_A_OC	4,60	32,15	5,67	**28,50**	15,74	*0,11*	*0,01*
MODIS_T_OC	7,02	77,93	8,83	41,88	36,53	0,27	0,07
OLCI_S3A_OC	12,49	159,39	12,63	35,69	**10,16**	0,23	0,05
OLCI_TSI	17,00	308,71	17,57	45,16	45,16		
S2A_T	*20,45*	*449,90*	*21,21*	56,76	56,76	0,40	0,16
VIIRS_S_OC	5,72	56,19	7,50	33,78	12,23	0,25	0,06

However, when compared with the limited in situ data, results are not that good.

- More outliers and a wider range of derived values as the in-situ concentration increase
- Residuals of the products indicate heteroscedasticity

Baltodano et al., (under review)



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- Water quality monitoring campaign [February 2024]
    - Water samples for the lab
    - In situ water quality measurements (multiparameter)
    - In situ water surface reflectance measurements (spectrometer)
    - Use of water quality apps to measure reflectance (HydroColor)

Next steps…

Two-step calibration/validation

- ▶ Atmospheric correction algorithms comparison with water surface reflectance
- ▶ Water quality algorithms with lab/in situ measurements

Application of best performing algorithms to satellite data that provide best spatial/temporal resolution for the case study

QUESTIONS?

Analy Baltodano Martinez

baltodano.martinez.analy@vub.be

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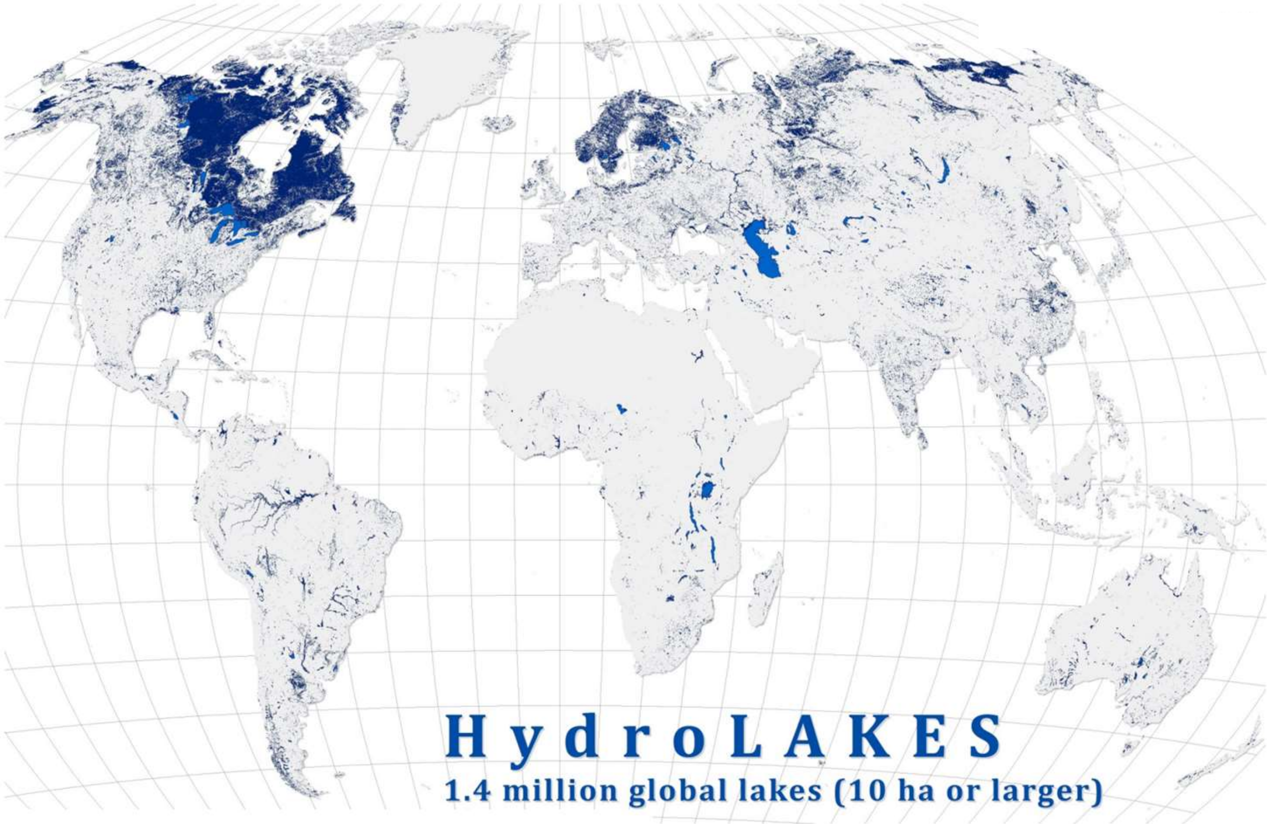
USING REMOTE SENSING AND IN-SITU OBSERVATIONS TO INVESTIGATE CLIMATE CHANGE RESPONSES IN AFRICAN AND SOUTH AMERICAN LAKES

SOFIA LA FUENTE

BACKGROUND

- 100 million lakes in the world
- Hold 87% of the surface freshwater available on earth
- Provide essential ecosystem services to society



Messager et al. (2016)


Valuing Lake Ohrid
Enabling
Transboundary Cooperation
& Integrated Water Resources Management
in the extended DRIN RIVER BASIN
gef
Global Water Partnership
CO2 sequestration
$2.4 mil
CO_2
Tourism &
Recreation
$191.4 mil
Hydropower
generation
$55.5 mil
Drinking Water
$5.8 mil
Medicinal herbs
$5.8 mil
Agriculture
$17.5 mil
Food
$5.8 mil
Timber, fuelwood
$3.7 mil
https://www.gwp.org/en/GWP-Mediterranean/WE-ACT/News-List-Page/2021/valuing-lake-ohrid/

INTERNATIONAL EFFORTS

GLEON
global lake ecological observatory network

African Center for Aquatic Research and Education
ACARE

ISIMIP
Inter-Sectoral Impact Model Intercomparison Project

IAGLR International Association for Great Lakes Research

LACAN
RED LATINOAMERICANA Y CARIBEÑA DE LIMNOLOGÍA

Many more…

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ISIMIP – LAKE SECTOR

ISIMIP
Inter-Sectoral Impact Model Intercomparison Project

- Multi-model (ensemble) approach to simulate **key lake physical properties** under historic and future scenarios
- **Water temperature** is the most important property in lakes that has crucial role in the energy and chemical budget of lakes.

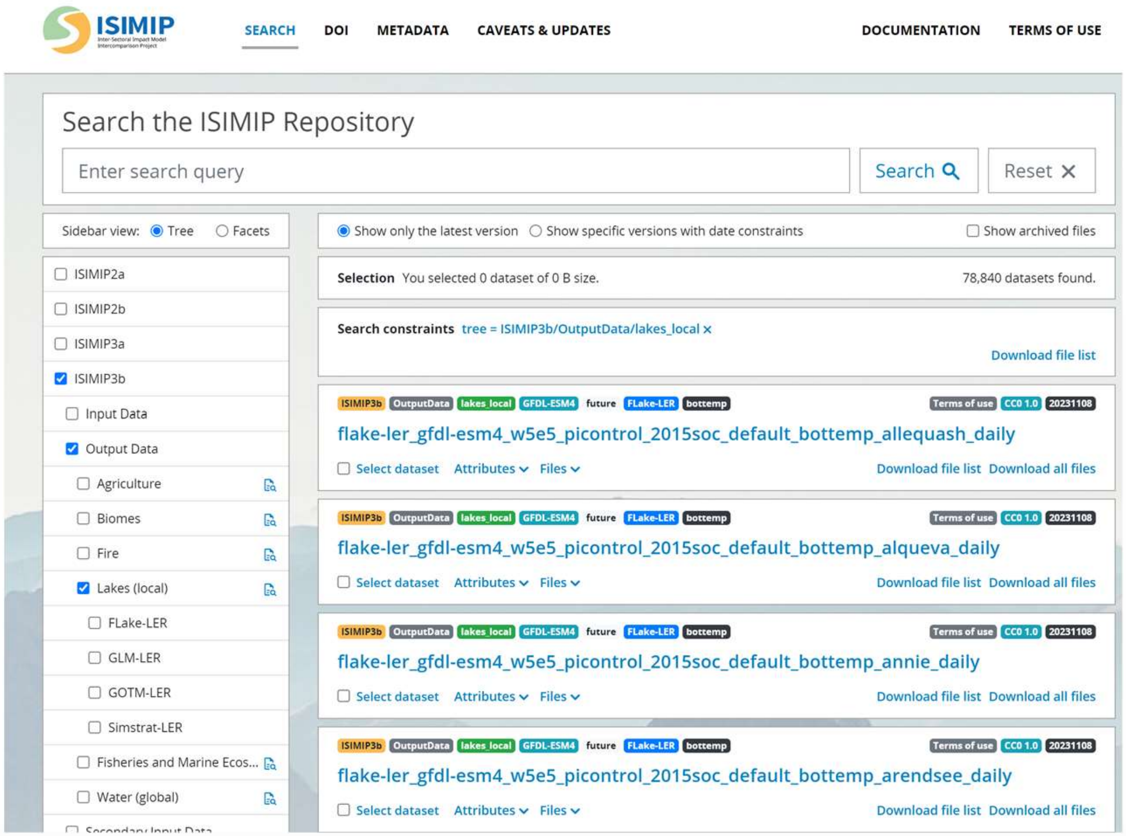
Table 4. Common output variables reported by local (L) and global (G) models participating in the Lake Sector of ISIMIP2a/b. The variable watertemp is a full water temperature profile. Naming of lake models and variables are ordered in an alphabetical order (see Table S4 for a list of full variable names).

Impact model	albedo	bottemp	Extcoeff	ice	icetemp	Icethick	lakeheatf	lakeicefrac	latentheatf	Lup	momf	sedheatf	sensheatf	snowtemp	snowthick	strat	surftemp	swup	thermodepth	turbdiffheat	watertemp
Air2water 4par (L)																	•		•*		
Air2water 6par (L)																	•		•*		
ALBM (G)						•	•		•	•	•	•	•		•			•			•
ALBM (L)						•	•		•	•	•	•	•		•			•			•
CLM4.5 (G)								•													•
FLake (L)		•		•	•	•	•		•	•	•	•	•			•	•		•		•
GLM (L)	•	•		•		•										•	•		•		•
GOTM (G)																					•
GOTM (L)	•	•														•	•		•		•
LAKE (G)	•	•	•			•	•	•	•	•	•		•		•		•	•	•		•
MyLake (L)	•			•		•	•		•			•	•		•	•			•		•
Simstrat (G)	•	•			•	•	•	•	•	•			•		•		•	•	•		•
Simstrat (L)		•		•		•	•		•	•			•		•	•	•	•	•		•
VIC-Lake (G)	•			•	•	•			•	•			•	•	•	•	•	•	•		•

Golub et al. (2022)

ISIMIP – LAKE SECTOR

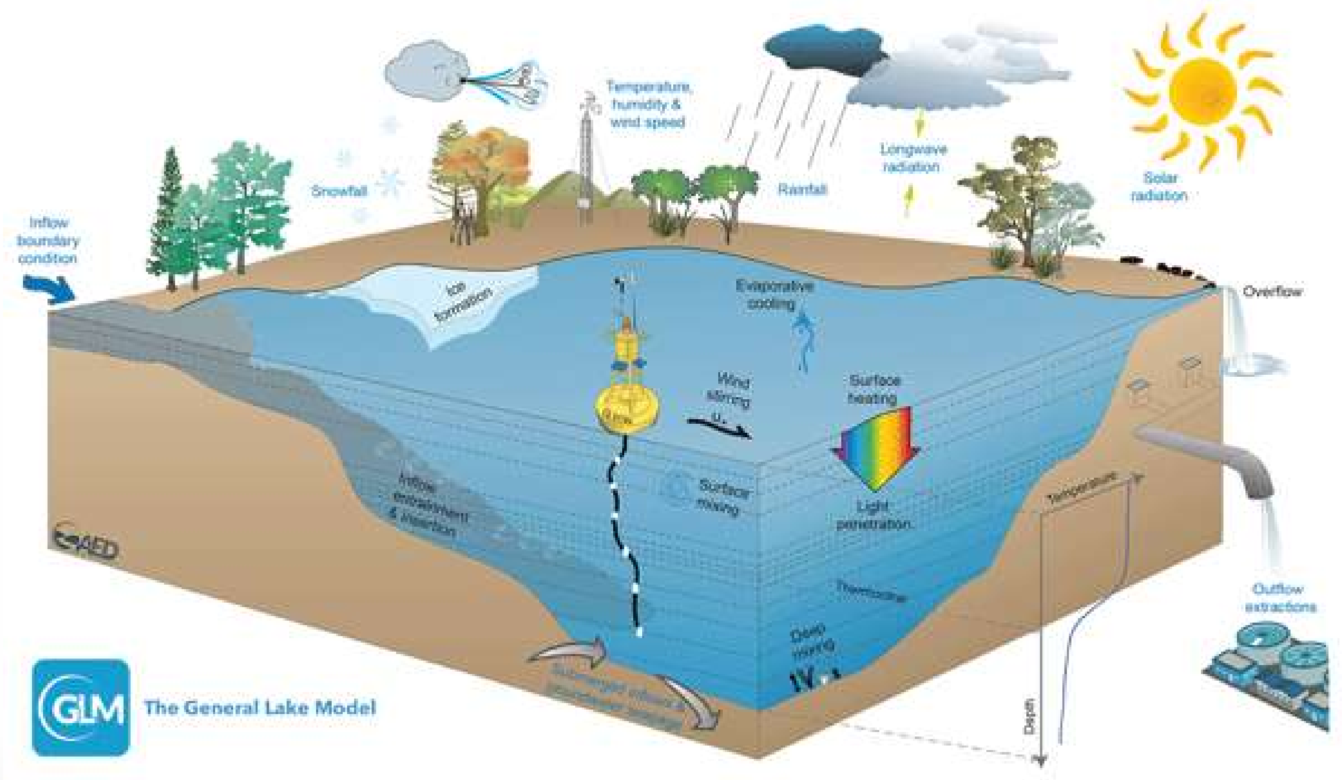
- Free to download
- Easy to use
- Allows comparisson with other sectors (Agriculture, water, crops)



https://www.isimip.org/

ISIMIP LAKE SECTOR

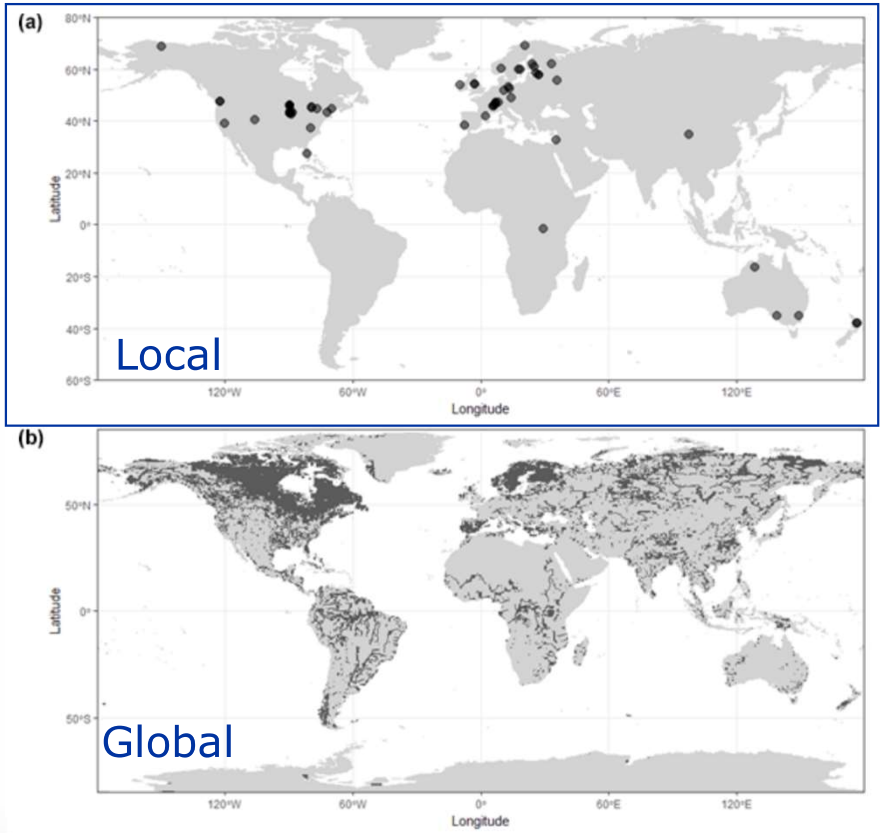
- Meteorological data
- Water temperature profiles
- Water transparency
- Lake bathymetry



Hipsey et al. (2019)

ISIMIP – LAKE SECTOR

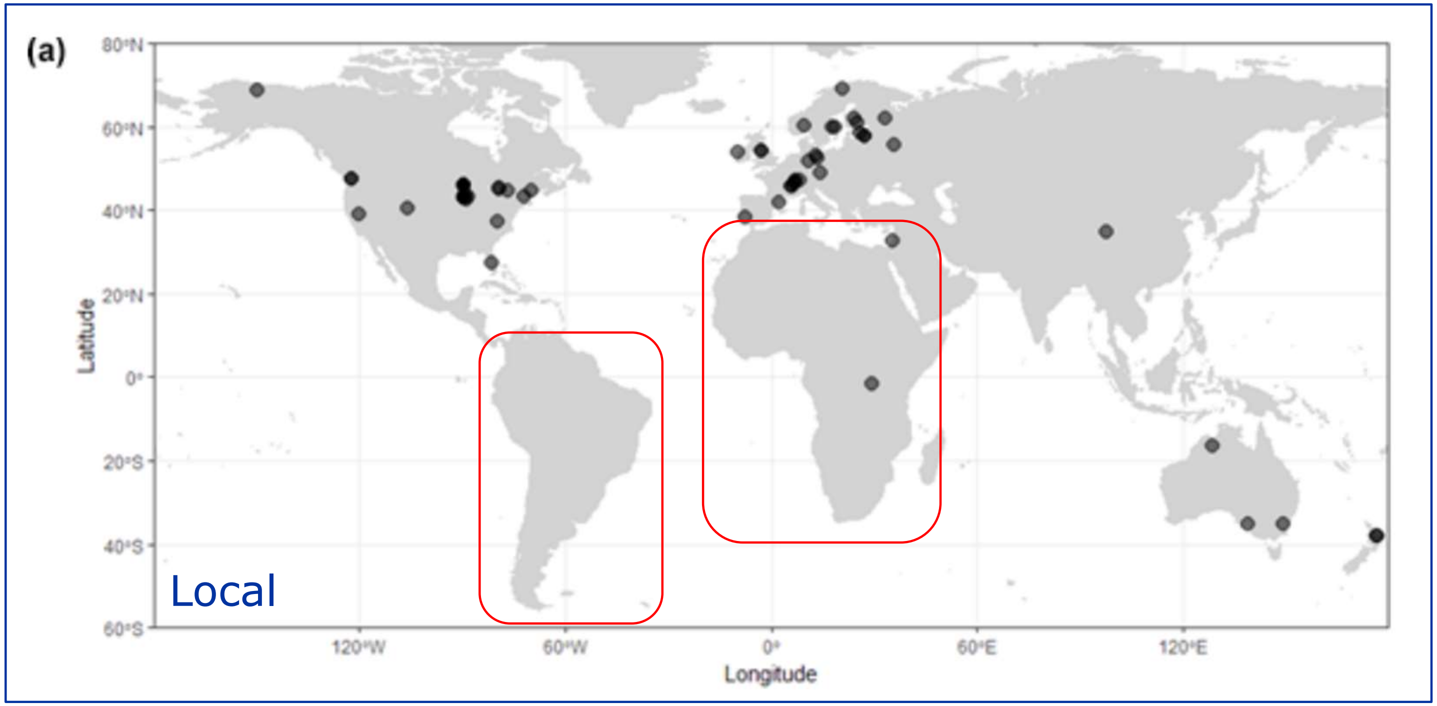
- Local simulations
  - In-situ observations (water temperature profiles, bathymetry, water transparency)
- Global simulations
  - Representative lakes within a 0.5 x 0.5° grid



Golub et al. (2022)

ISIMIP – LAKE SECTOR

- ISIMIP 2b
  - > 60 lakes
  - Very few tropical lakes
  - **One lake in Africa**
  - **None in South America**



Golub et al. (2022)

CHALLENGES

- Lack of funding
- Very low in the agenda
- And on top of that…

https://www.enttoday.org/article/how-to-find-research-funding-options-even-in-the-covid-19-era/

CHALLENGES

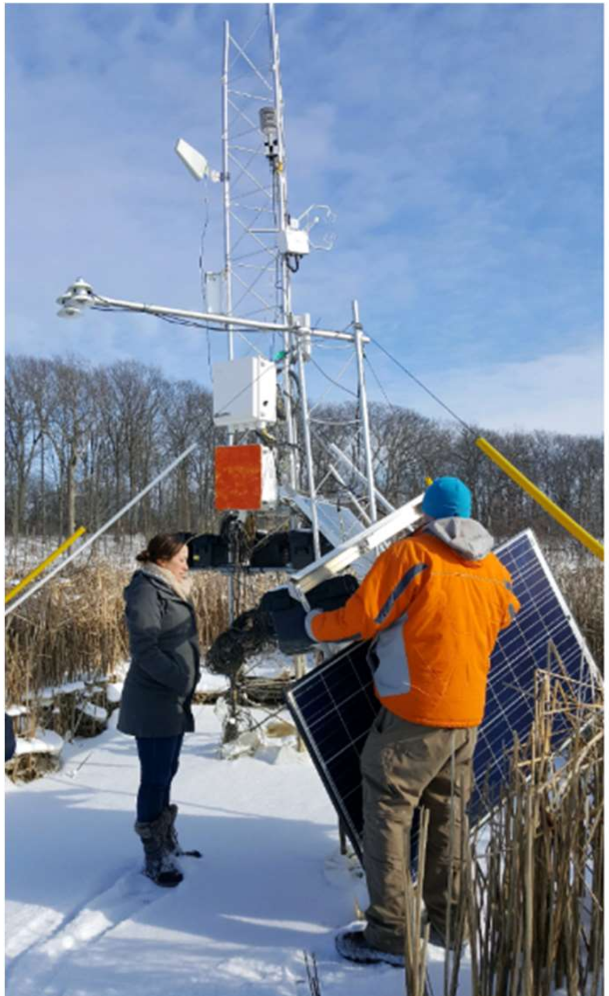
https://www.mtu.edu/unscripted/2022/02/michigan-tech-scientist-and-students-collaborate-in-first-great-lakes-winter-grab.html

CHALLENGES

“Old Woman Creek hits all the high notes of an ideal scientific location”

“**BUT** the tradeoff for that is an operationally challenging location.

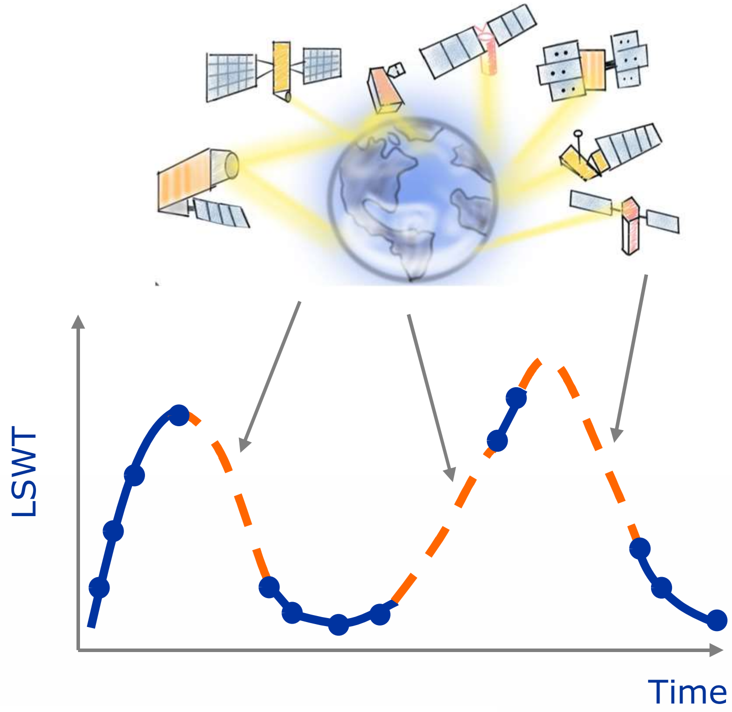
It takes a 20-minute canoe ride (or longer if the lake-effect wind kicks up) to reach the tower. There is no dry ground anywhere around the tower, with water levels fluctuating between 30 and 100 cm above the soft mud.”



https://ameriflux.lbl.gov/note-from-the-flux-site-a-happy-story-of-spring-in-old-woman-creek-us-owc/

MIND THE GAP

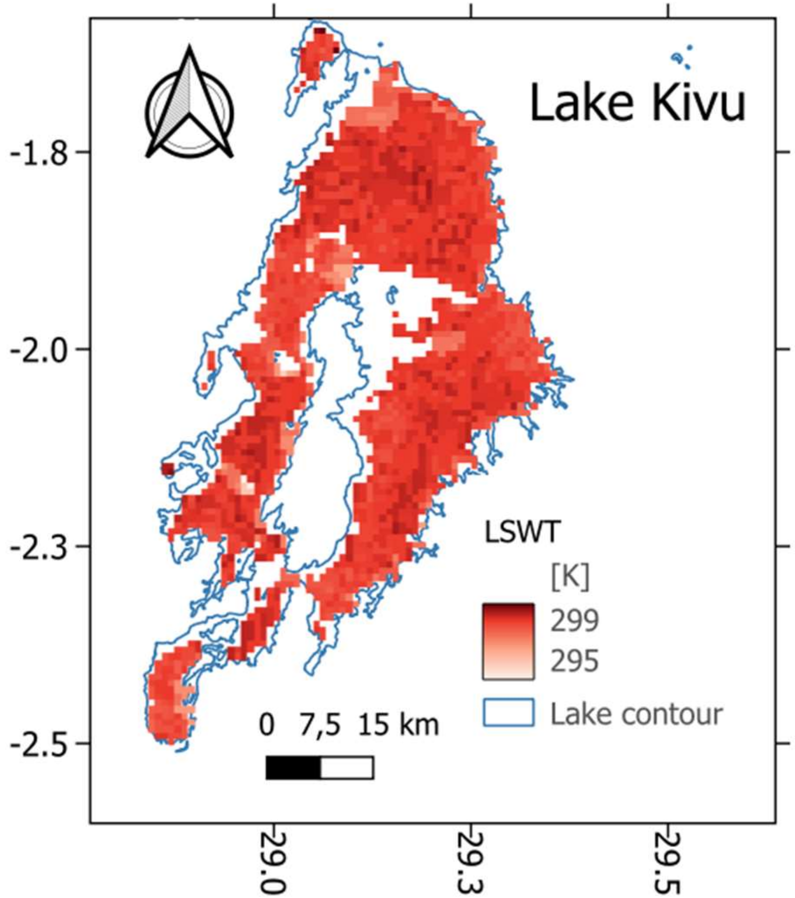
- Use in-situ observations of African and South American lakes
- Use available satellite and open sources to fill missing gaps (Sentinel2 and CCI lakes)
- With the completed time-series simulate historic and future changes in African and South American lakes

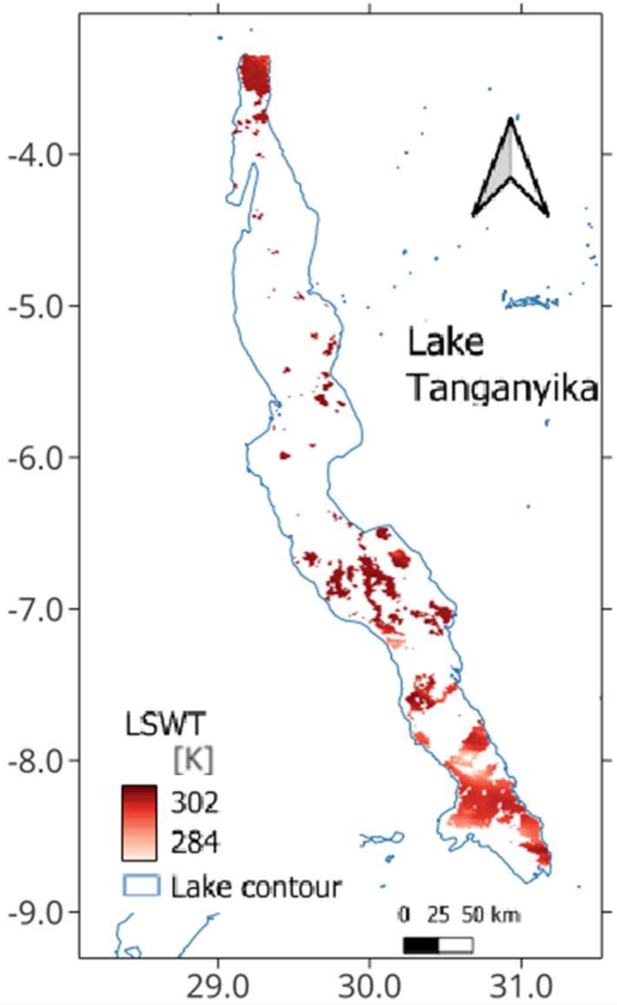


global lake ecological observatory network

ISIMIP
Inter-Sectoral Impact Model Intercomparison Project

VRIJE UNIVERSITEIT BRUSSEL


Lake Kivu
-1.8
-2.0
-2.3
-2.5
29.0
29.3
29.5
LSWT
[K]
299
295
0 7,5 15 km
Lake contour


Lake Tanganyika
-4.0
-5.0
-6.0
-7.0
-8.0
-9.0
29.0
30.0
31.0
LSWT
[K]
302
284
Lake contour
0 25 50 km

NEXT STEPS

- First meeting scheduled for the first weeks of June
- Call for in-situ lake water temperature observations
- Organising the project objectives, working groups
- Timeline of the project


THANK YOU FOR YOUR ATTENTION
QUESTIONS?
sofia.la.fuente@vub.be