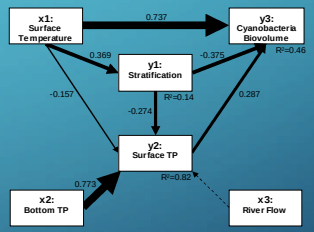
Use of Remote Sensing to Monitor Changes in Water Quality & Storage Volume in a Semi-Arid Eutrophic Reservoir

A case study of the Qaraoun Reservoir-Lebanon



6th Beirut Water Week

IBRAHIM ALAMEDDINE

TRACKING CHANGES IN LAKES AND RESERVOIRS

Lakes and reservoirs ("pearls on a river") affect the quantity and quality of the fresh water consumed and that which reaches the oceans

WATER QUALITY

- UNEP estimates that 30 to 40% of the world's reservoirs and lakes are in a eutrophic state
- Anthropogenic nutrient loading is the main cause of water impairment
- Many of these eutrophic waterbodies face the proliferation of HABs

WATER QUANTITY

- A changing climate is contributing to the alteration of the levels of lakes and reservoirs:
  - Lower water levels in the Great Lakes by increasing rates of evaporation
  - Higher levels in Lake Okeechobee due to increased storm energies
  - Changes in lake ice and turnover and timing of turnover

Monitoring

Manage

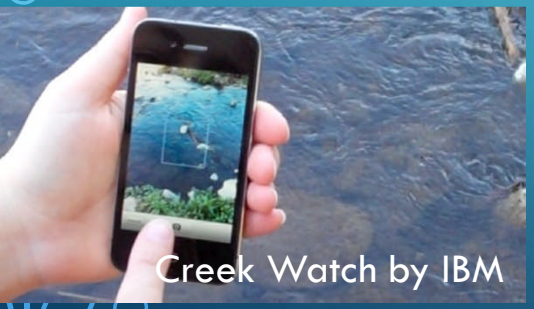
Mitigation

Modelling


Monitoring

Monitoring Lakes and Reservoirs

- **Long-term** in situ water monitoring (quality & quantity) programs are important for proper water management
- Many developing countries lack the funds and political will to implement long-term monitoring programs
- Interest in the use of **nonconventional** methods to generate data to fill information gaps



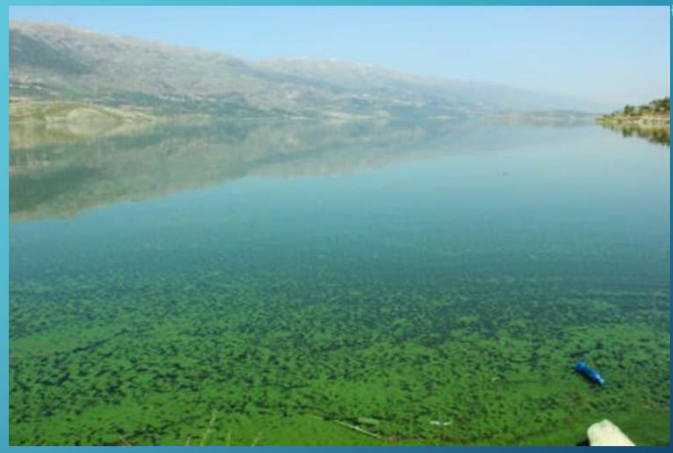
Case Study: Qaraoun Reservoir

- Constructed on largest river in Lebanon
- Dam completed in 1959
- Surface area: 4-12 km^2
- Useful volume: 220 MCM

- Uses:
  - Hydropower generation
  - Irrigation of 68,000 acres
  - Some tourism
  - Small fishing industry
  - Potential for domestic water supply

Qaraoun Reservoir: Water Quality

- No long-term water quality monitoring program
- Sporadic water quality studies:
  - Data spatially and temporally inconsistent
  - High N and P loads
    - Point + non-point
  - Reservoir is often hypereutrophic
  - Recent problem with cyanobacteria (Microcystis & Aphanizomenon blooms)



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Authorities stop pumping from Qaraoun Dam

The Daily Star (Lebanon) 19 Sep 2016

QARAOUN: The Litani Authority announced in a statement it would cease pumping water directly from Qaraoun Lake's dam which provides irrigation to agricultural fields in Tyre and Zahrani. The decision was made in response to the detrimental effects felt by residents of the West Bekaa area who have suffered from pollution and bad smells originating from the contaminated lake.The Qaraoun Lake is an artificial reservoir formed by a dam on the Litani River, Lebanon's longest. It is used for hydropower generation, domestic water supply, and as a source of irrigation. Pollution in the Litani River came to the public eye recently after a large number of dead fish were discovered in the Qaraoun Lake. –

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GALLERIES

Polluted lake to get quick-fix treatment for smells: Abu Faour

The Daily Star (Lebanon) 20 Aug 2016

Health Minister Wael Abu Faour Friday announced a plan to temporarily treat a heavily polluted lake in the Bekaa Valley to reduce foul odors and allow local farmers to resume irrigating crops.

In a news conference in the western Bekaa Valley district of Rashaya following a meeting with a delegation of local farmers, Abu Faour called on the government to take responsibility in finding a permanent solution to the pollution problem at Qaraoun Lake.

He also warned that pollution at the Litani River poses a national catastrophe targeting every citizen.

Qaraoun Lake is an artificial reservoir formed by a dam on the Litani River, Lebanon's longest river. It is used for hydropower generation, domestic water supply and irrigation.

Abu Faour said his ministry has proposed a quick solution, using a substance that will be placed in the lake to remove the bad odors.

He did not specify what that substance is.

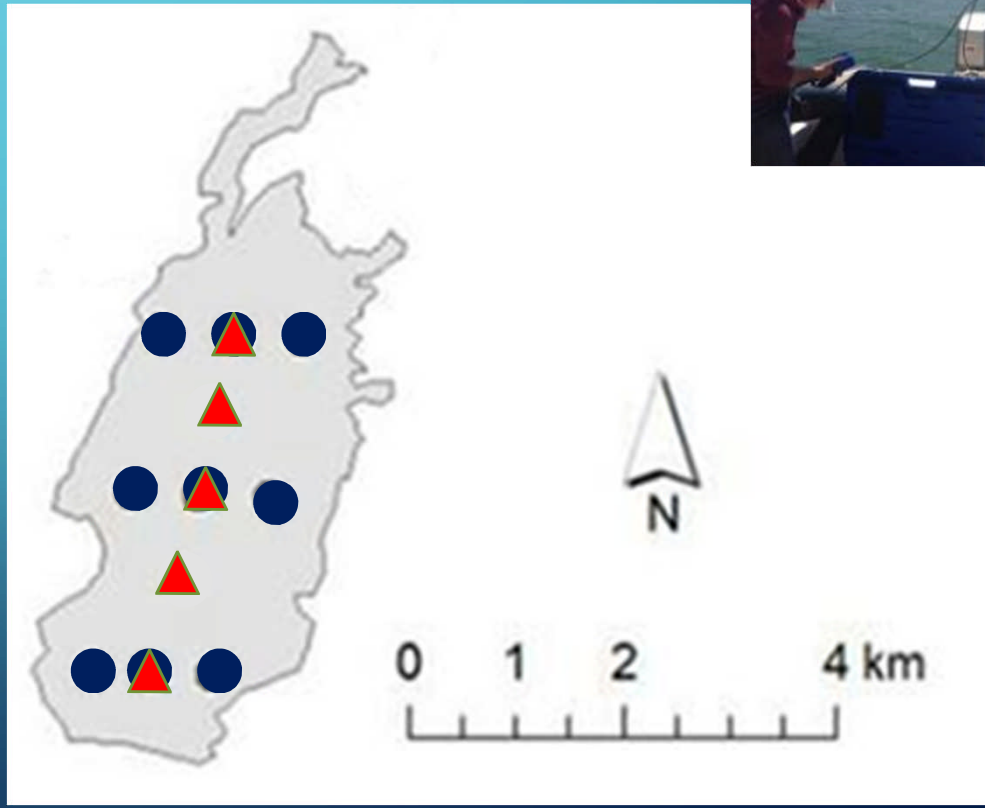
"The current problem is the responsibility of the state. We have proposed solutions for the short term, including ways to clean the flow of water using materials that reduce foul odors and at the same time will allow farmers to grow their crops," he said.

Abu Faour said he has agreed with

YOU CAN'T MANAGE WHAT YOU DON'T MEASURE

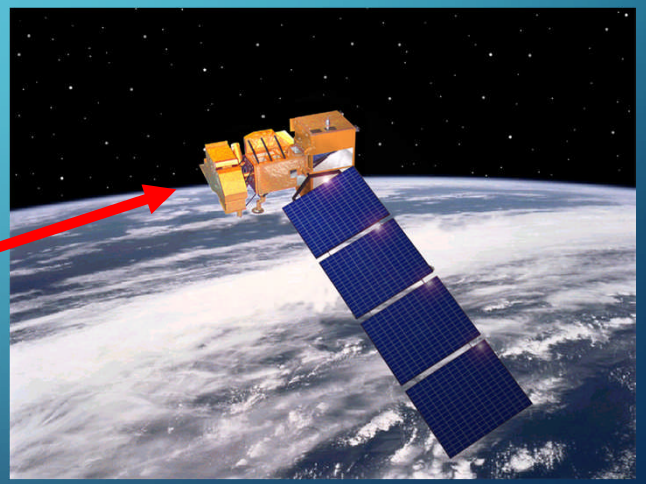
Monitoring Program

- Started an ***in situ*** water quality monitoring program (2013-2017)
- Sampling every **24 days**
- Sampling include:
  - **Chlorophyll-a**
  - **Algae species**
  - **TSS**
  - **SDD**
  - **Water Temperature**
  - **Dissolved Oxygen**
  - **Nutrients**
  - **pH, Cond, TDS**



Synchronizing with Satellite Overpasses

- In situ water quality sampling program synchronized with the Landsat 7 and Landsat 8 overpasses
- Sampling occurres ±2 hours of overpass



Monitoring via Remote Sensing

- Landsat data collected for each sampling day:
  - 30 m resolution
  - Record: from 1982 to present
  - Free
  - Some useful bands for water quality analysis (not the best option for water quality)

Algorithm Development and Testing

Model Screening

- Explore models based on band ratios
- Build empirical (regression) based models

Model Calibration

- Fit Landsat TM and ETM algorithms
- Evaluate models based on significance, R^2 and AIC

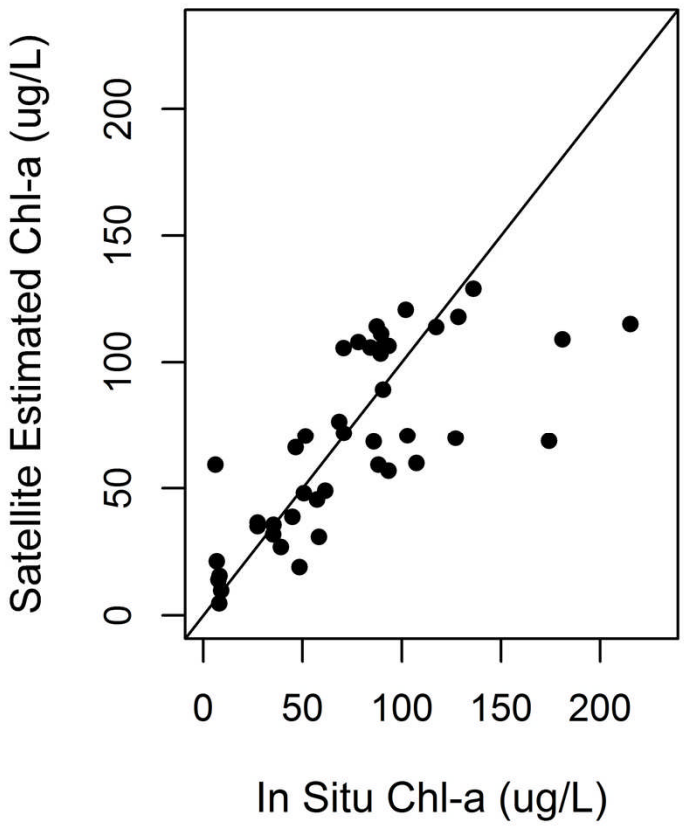
Model Validation

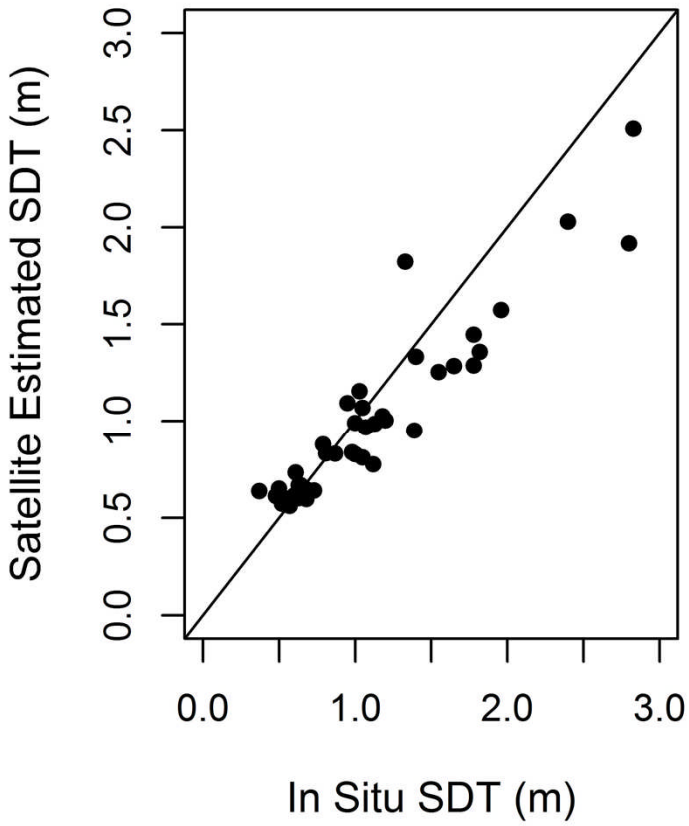
- Cross-validation + verification: ensure no over-fitting
- Hindcasting

Algorithm Development and Calibration

- A total of **103** surface samples were used
- In situ data matched with Landsat data within a 30 m buffer around each sampling station (averaged)
- Models developed using stepwise regressions
  - Reduce overfitting
  - Allow for the incorporation of a seasonality terms in the model
  - All models were validated using **4-fold cross validation**

Model Validation





$$\text{Chl-a} = e^{\alpha + \beta \frac{Blue - Red}{Green}}$$

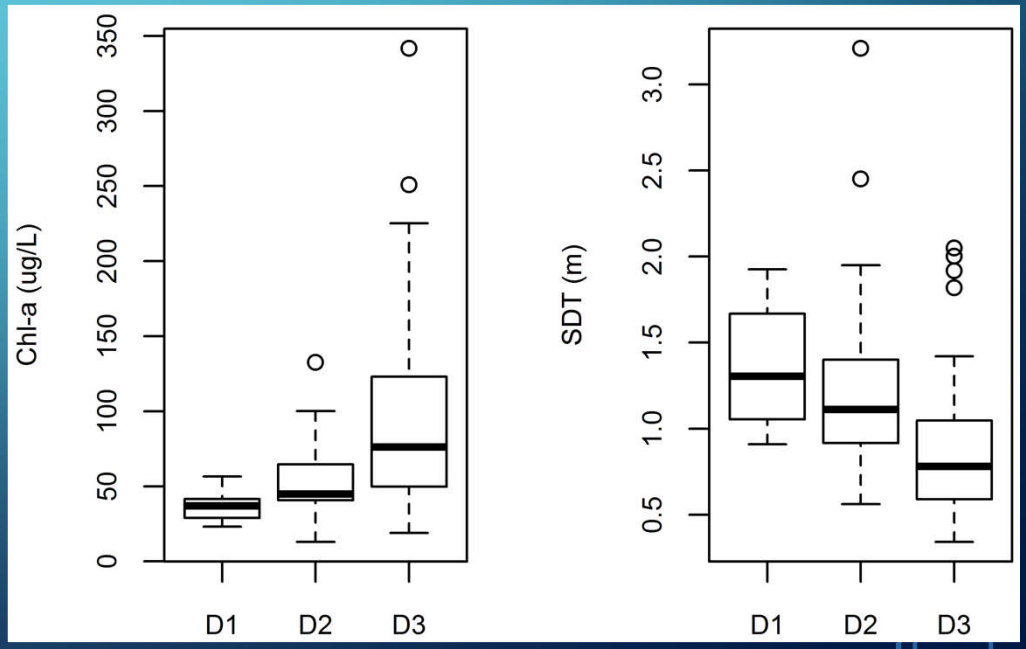
$$\text{SDT} = e^{\alpha + \beta \frac{Blue}{Red} + \gamma Seasonality}$$

Hindcasting

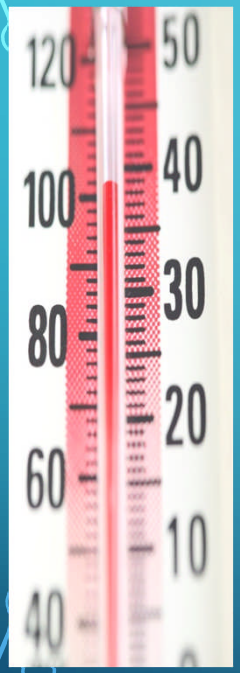
- Applied the developed ETM+ algorithms to **Landsat 7, 5 and 4** image records
- Data were also used to calculate the **Carlson's Trophic State Index** of the reservoir
- Data compiled for the lake over 3 decades (D1 = 1984–1995, D2 = 1996–2005, D3 = 2006–2015)
- Conduced statistical analysis to assess change patterns in the reservoir over the study period
  - ANOVA + non-parametric analysis
  - Trend-analysis + Regression analysis

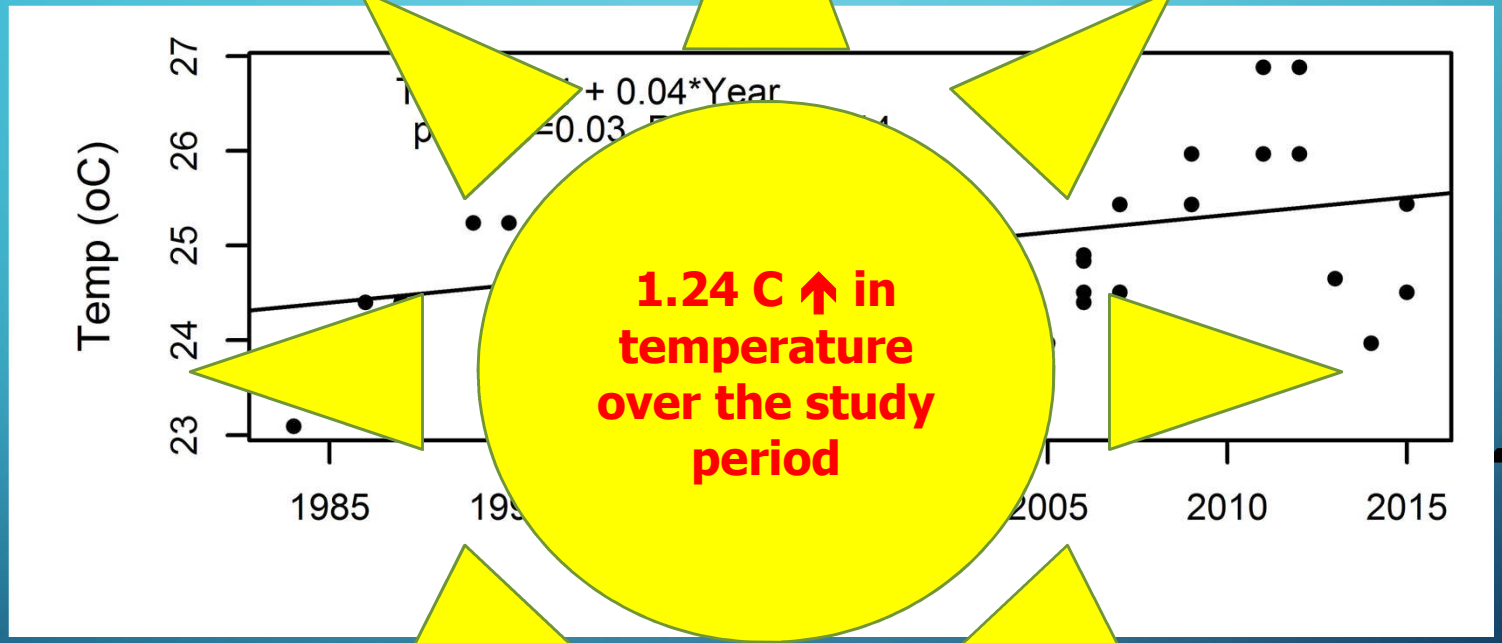
Trend Analysis: Eutrophication

- Reservoir has been in a **eutrophic** (TSI 50–70) to hypereutrophic (TSI > 70) state throughout the past **3 decades**
- Statistically significant differences in reservoir's eutrophic status across the 3 decades in the summer season
  - Chl-a concentrations **increased** by **>163 %** between D1 and D3
  - SDT levels dropped by **>58 %**
  - Summer variance of water quality increased in the last decade (D3) too



Trend Analysis: August Skin Temperature





1.24 C ↑ in temperature over the study period

Increased temperature → Increased evaporation + HAB events

Trend Analysis: Water Volume

- Summer reservoir volume significantly ↑ from the first decade (mean = 54.2 MCM) to the second decade (mean = 76.3 MCM), with volumes decreasing slightly again in the last decade
- A significant increase in reservoir volume was observed in March (with an average increase of 5.1 MCM/yr, R^2 = 0.77)
  - Points to a hydrological shift with earlier peak volumes
  - Historically, reservoir's maximum volume was attained in April; yet in recent years it has shifted to March

Conclusions

- Qaraoun Reservoir is a reservoir experiencing change and degradation
  - Increase in summer eutrophication indicators over past 10 years
  - Increase in water temperatures for the month of August
  - Shift in peak volume from April to March

- Management implications for remote sensing hindcast work are broad:
  - Define baseline data
  - Evaluate the success of water pollution abatement programs
  - Manage expectations of water body improvements under different management actions

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