Geochemical modeling of a potential future Lake Victoria and the hazards to the surrounding populations in the event of a mass desiccation

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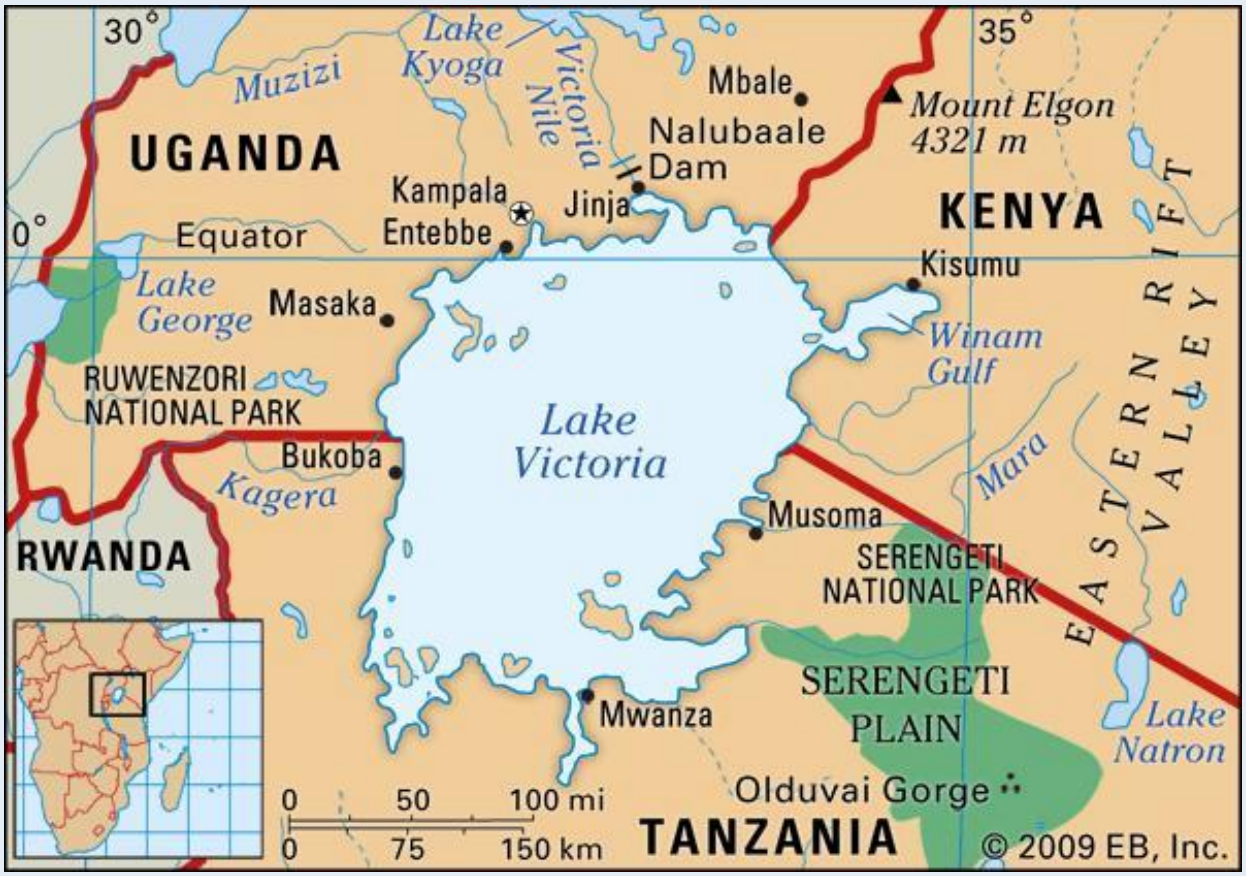
NDSU GEOL 628 Geochemistry

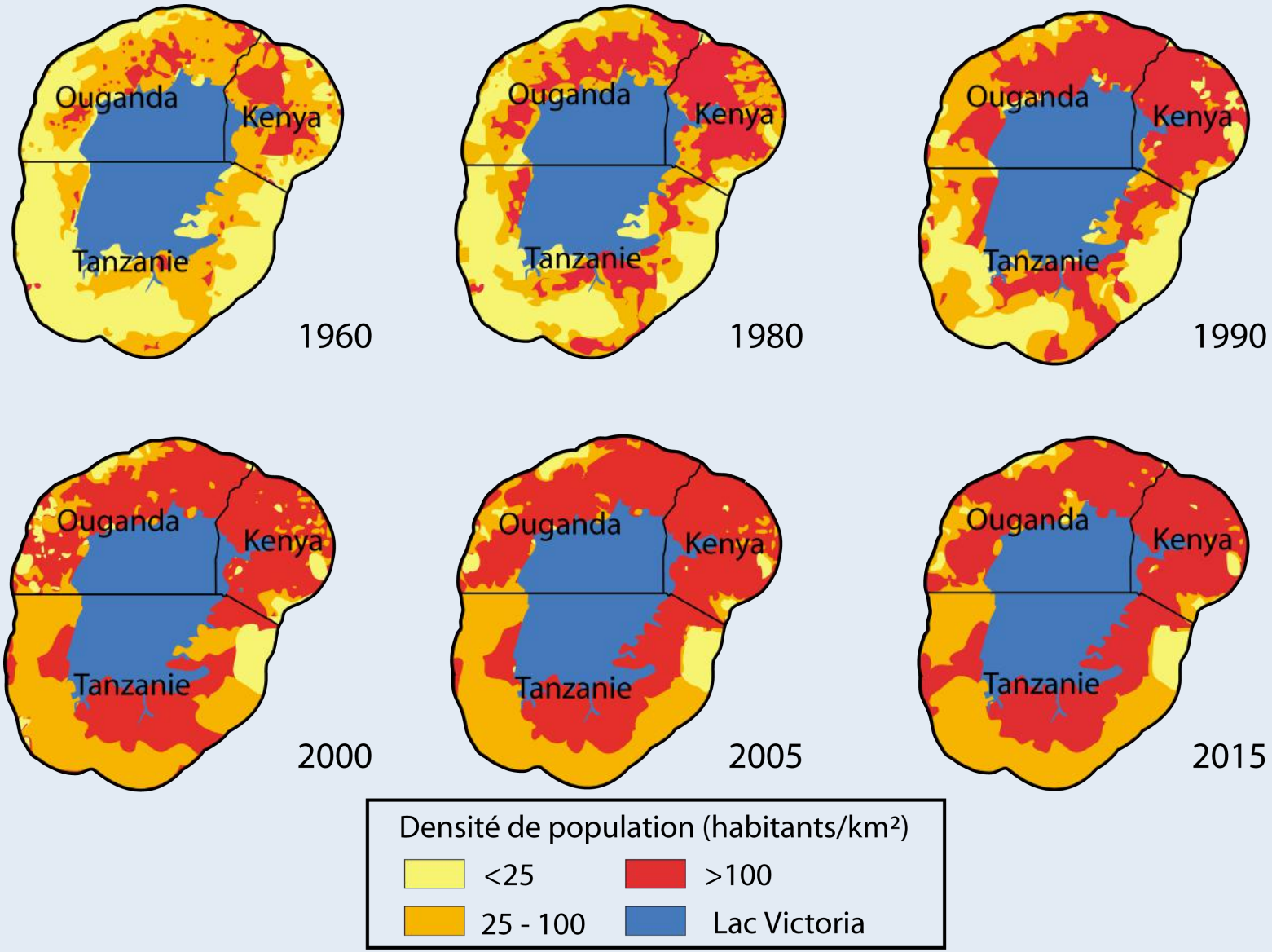
December 2016

Lake Victoria

- Largest young lake in the world
- A major source of food and water for Uganda, Kenya, and Tanzania
- Feeds into a suite of smaller surrounding lakes
- Has a history of desiccation

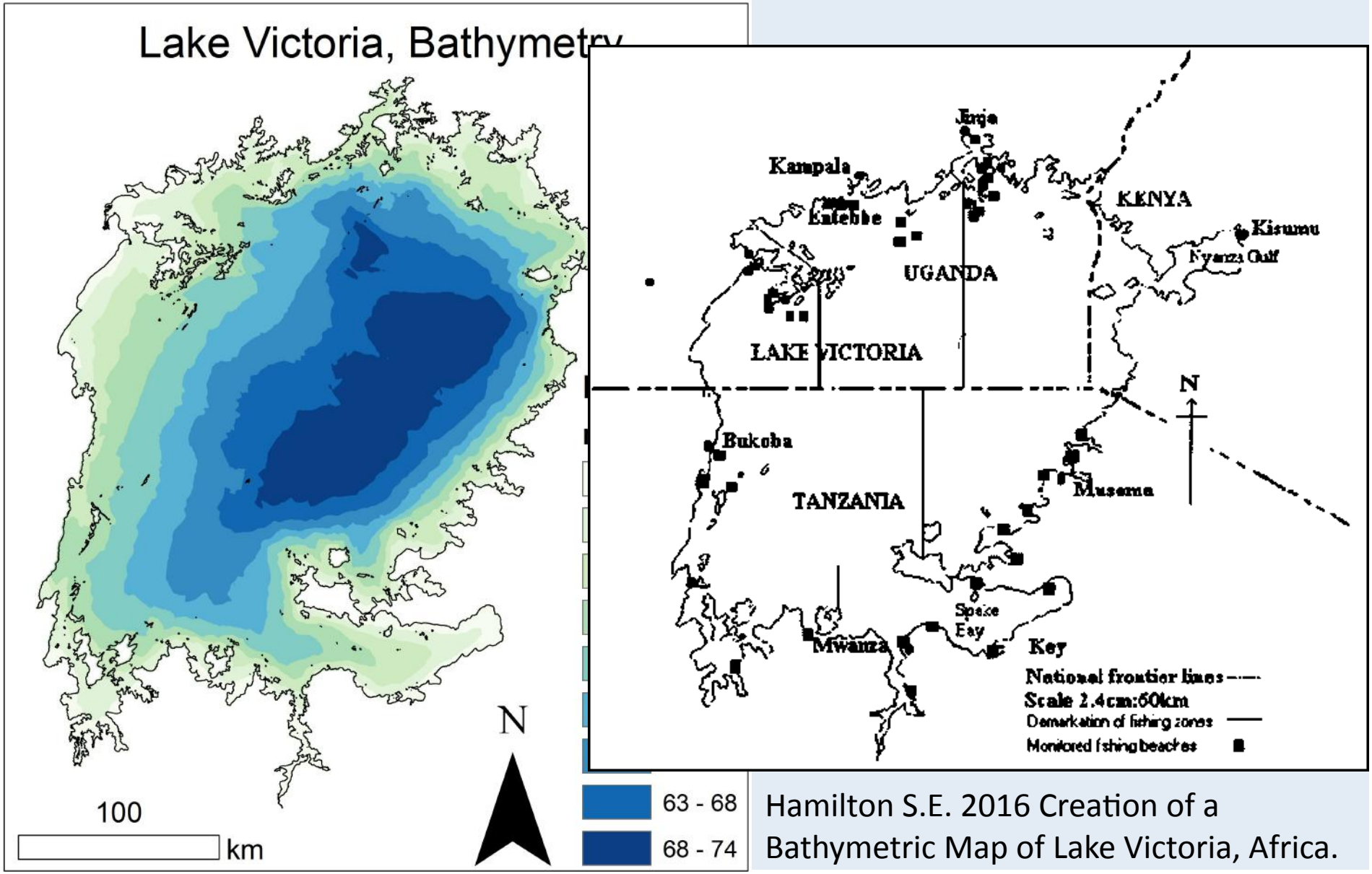


Population density



Source: UNEP, Africas Lakes, Atlas of our changing environment, 2006

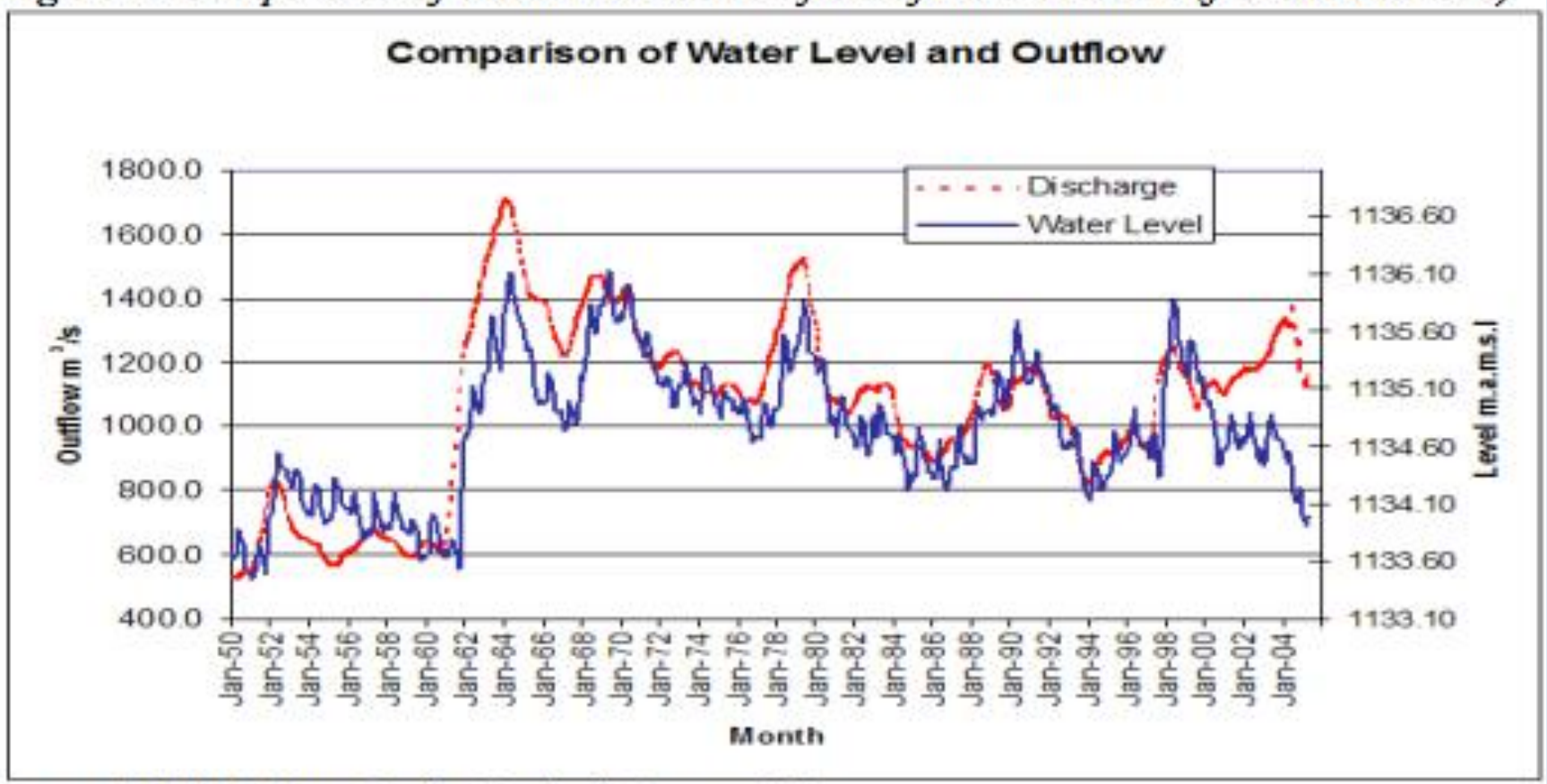
Water Levels



Hamilton S.E. 2016 Creation of a Bathymetric Map of Lake Victoria, Africa.

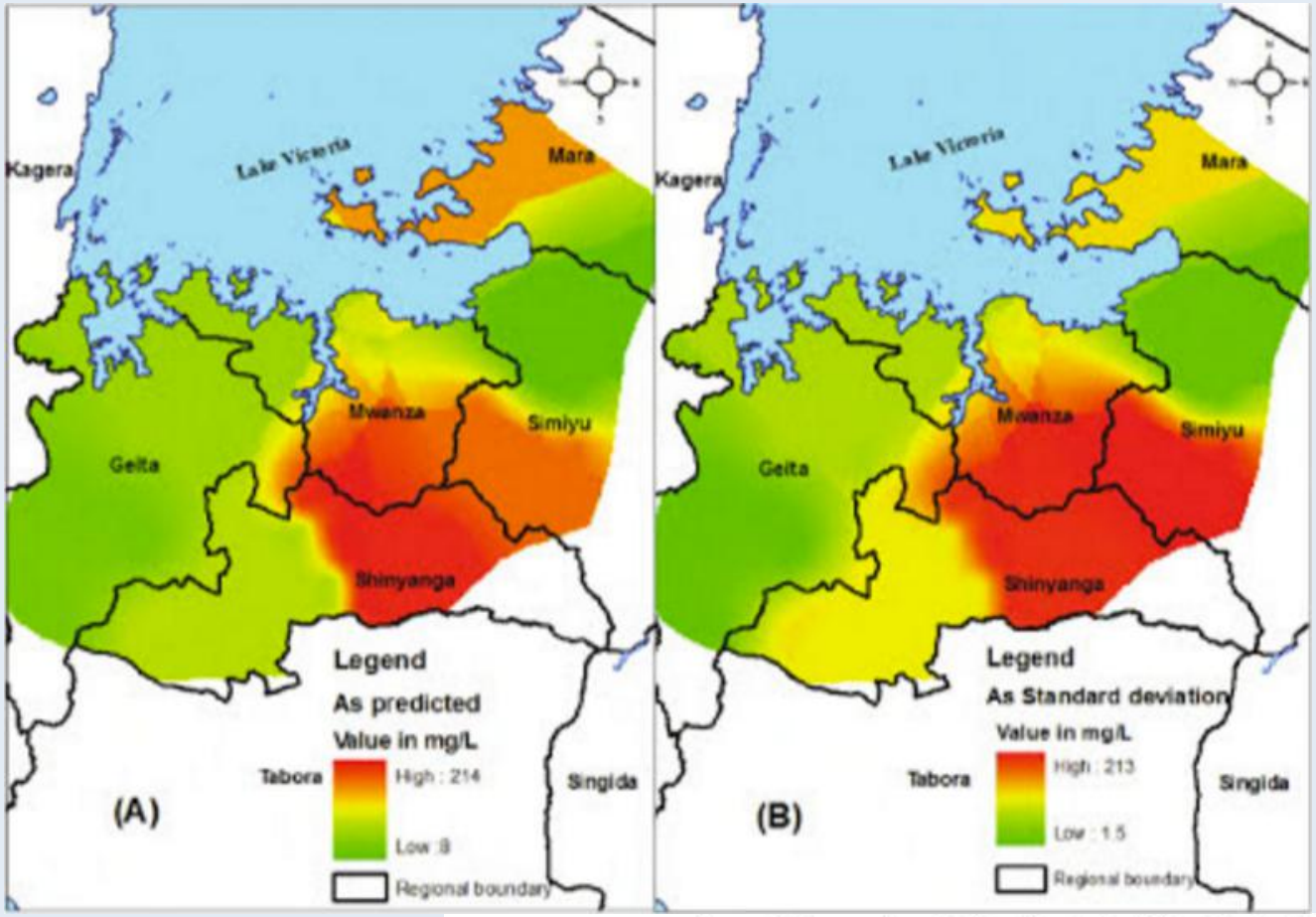
Water Levels

Figure 1: Comparison of water level and outflow of Lake Victoria (from 1950-2005)



Source: LVEMP Water Quality Synthesis Report, 2005

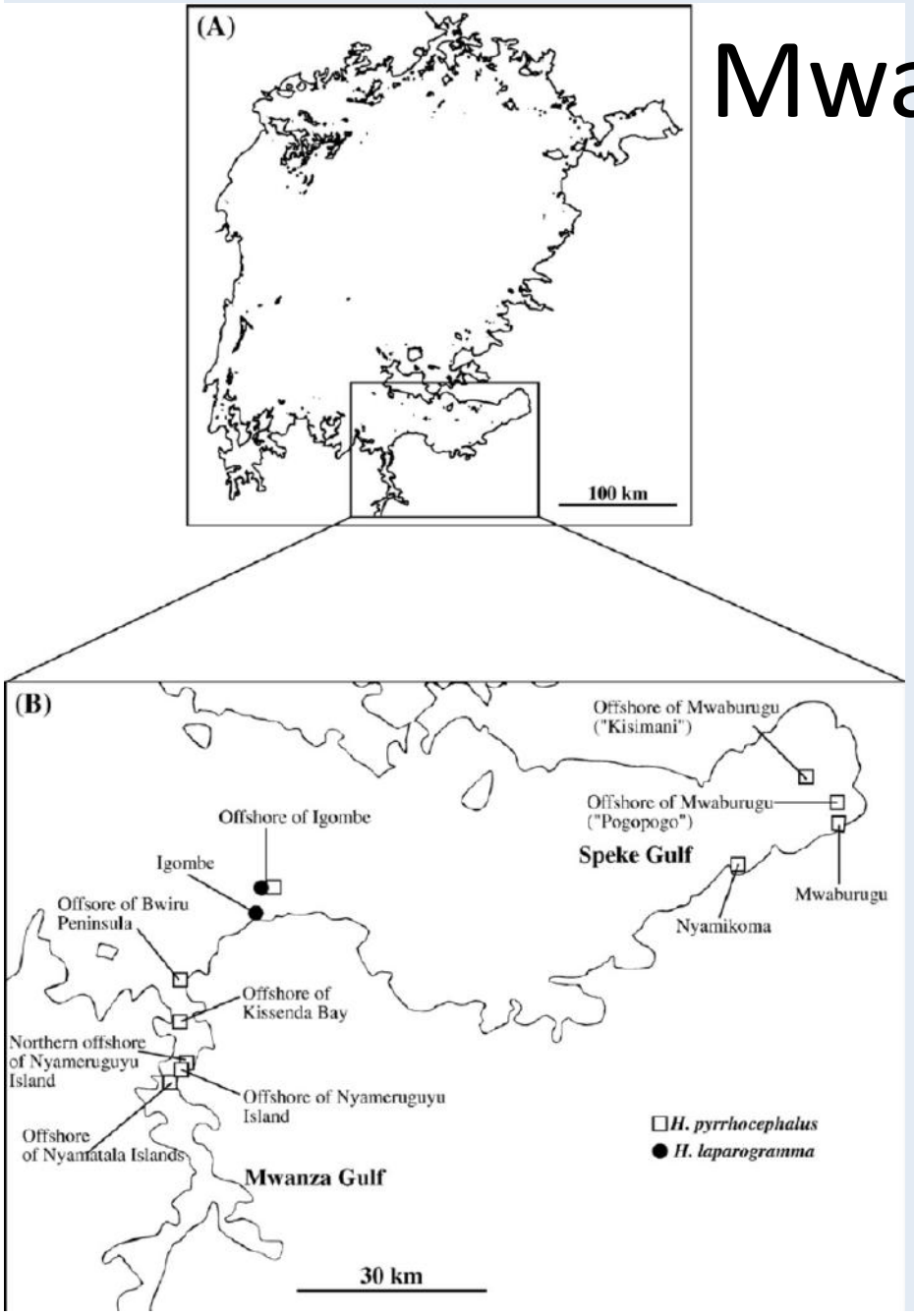
Arsenic Contamination



Arsenic Research and Global Sustainability – Bhattacharya, Vahter, Jarsjö, Kumpiene, Ahmad, Sparrenbom, Jacks, Donselaar, Bundschuh & Naidu (Eds)
© 2016 Taylor & Francis Group, London, ISBN 978-1-138-02941-5

Arsenic occurrence in groundwater sources of Lake Victoria basin in Tanzania

J. Ijumulana[1,2], F. Mtalo[2], P. Bhattacharya[1,3] & J. Bundschuh[4]



Mwanza Gulf

One of the shallowest areas

- In danger during a desiccation event

The Gulf is a major source of fishing, water, and tourism

Groundwater run off from nearby mining is becoming increasingly dangerous, with an influx of heavy metals entering this area

The brine lakes of East Africa

- Many of the nearby lakes in the Lake Victoria area are considered brine lakes.
- Analysis of the geochemistry of these brine lakes can provide evidence for potential pathways for the future of Lake Victoria's Mwanza Gulf.
  - With climate change increasing rapidly, a recovery of water levels is not expected
  - As Lake Victoria desiccates, relative levels of already dangerous pollutants will rise, affecting both the food and water sources to the ever growing surrounding populations

Lake Victoria as a brine lake

- The desiccation of Lake Victoria from current levels to Lake Katwe levels would potentially be devastating for the local populations
  - Geochemical models could provide information as to how quickly the effects would become harmful
- Geochemical modeling was done using Phreeqci3 software based on previous modeling from *Kasedde et al., 2012*.
- Original models were done on the brine lake, Lake Katwe

Lake Katwe

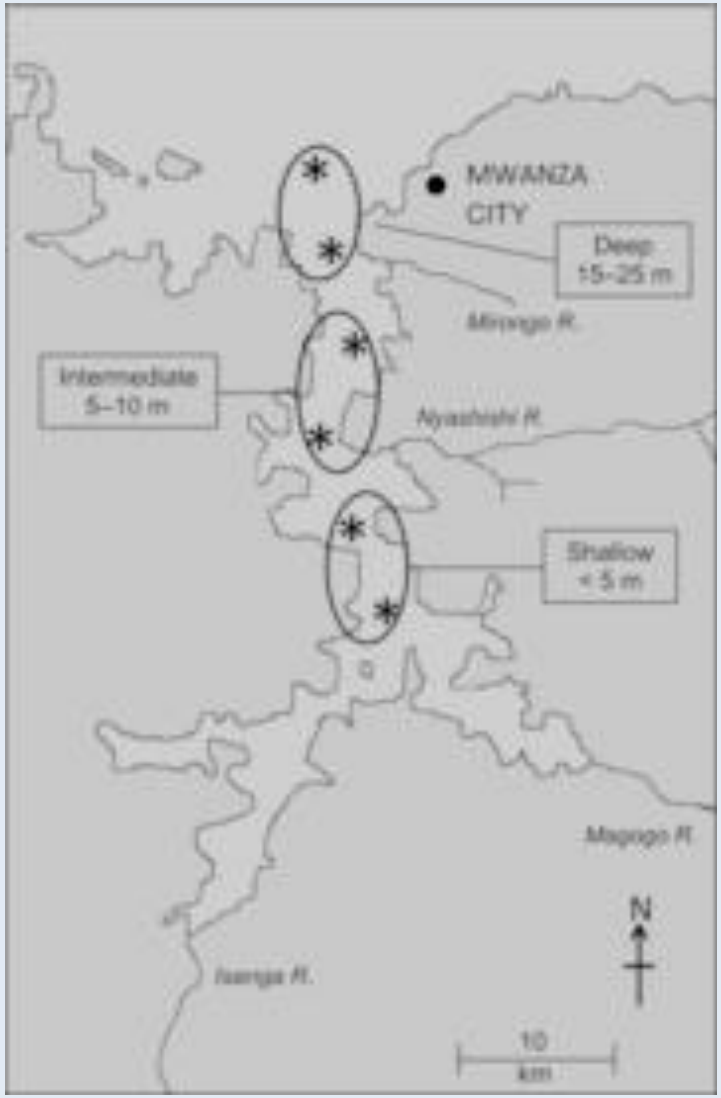
- Lake Katwe
  - Size: 2.5km^2
  - Max depth:
    - Rainy: 1.49m
    - Dry: 1.5m
  - Avg depth:
    - Rainy: 1.06m
    - Dry: .928m

Concentration data from:

Kasedde et al. 2014., Characterization of brines and evaporites of Lake Katwe, Uganda. *Journal of African Sciences.* **91** 55-65.

Mwanza Gulf of Lake Victoria

- Mwanza Gulf
  - Size: 500km^2
  - Max Depth: ~25m
  - Min Depth: <5m



Concentration data for Lake Victoria from:
Kasedde et al. 2014., Characterization of brines and evaporites of Lake Katwe, Uganda. *Journal of African Sciences.* **91** 55-65.
Machiwa, JF. 2003., Metal Concentrations in Sediment and Fish of Lake Victoria near and away from catchments with gold mining activities. *Tanz. J. Sci.* **29 (2)** 43-54.

Geochemical Modeling Considerations

- Lake Victoria is stratified, with the high salinity at the bottom
  - Mwanza is a shallow area and with very low salinity

Assumption for modeling: If the deepest point of Lake Victoria desiccates to the (current) level of the Mwanza Gulf, it will be highly saline

Geochemical Modeling Considerations

- The influx of heavy metals into Mwanza Gulf waters and sediments is increasing

Assumption for modeling: The low levels of heavy metals in the Mwanza Gulf will be close to equivalent to the levels in the deeper parts of Lake Victoria as groundwater continues to flow into the larger body

Geochemical Modeling Considerations

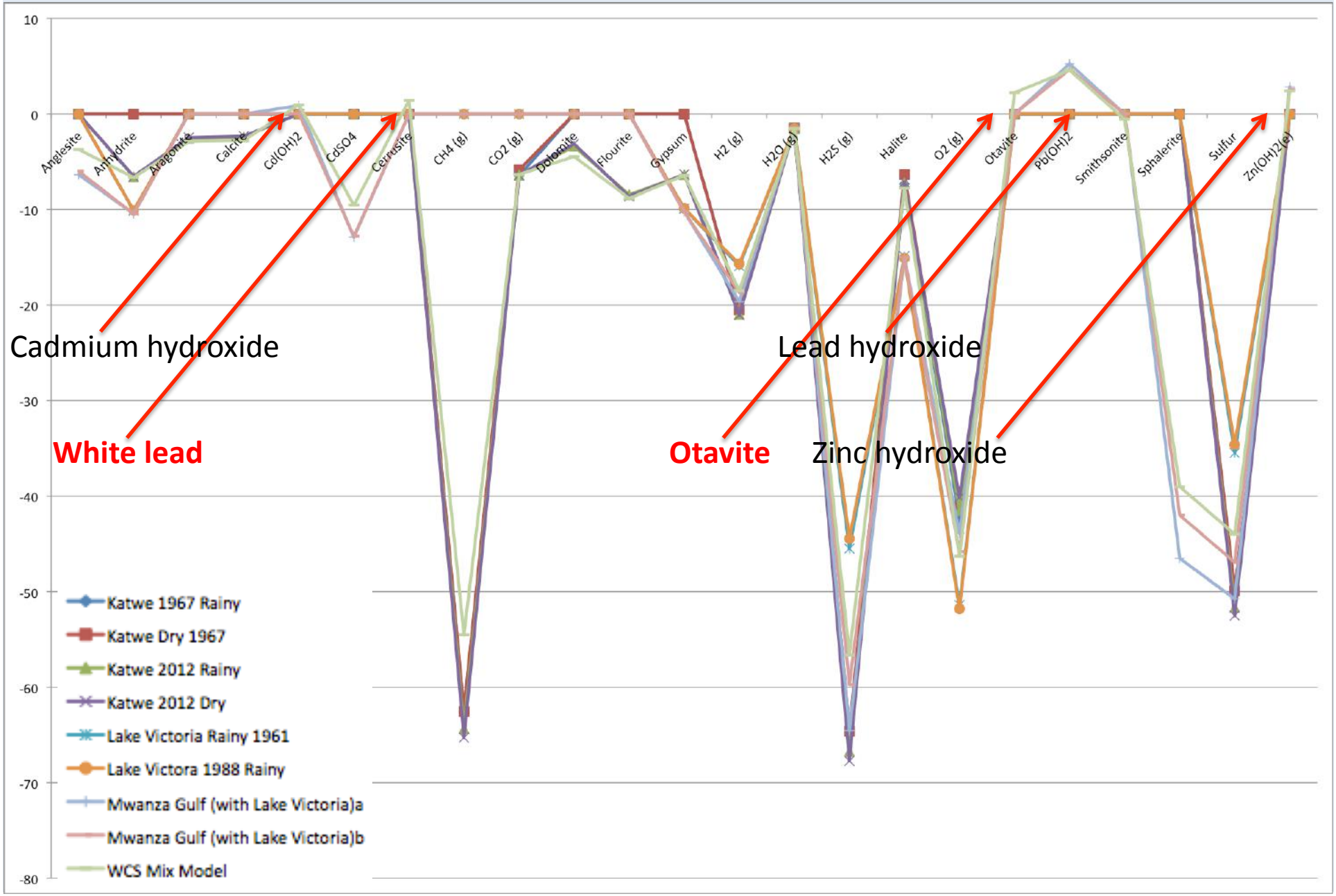
- With these assumptions, a model for the geochemical structure of a future Lake Victoria can be constructed:
  - Mixing model
    - Solution 1: Lake Katwe
      - Average values of the 3 deepest points during the rainy season
    - Solution 2: Lake Victoria/Mwanza Gulf
      - Includes heavy metals from mining run-off

Worst Case Scenario Model

```
SOLUTION 1
        pH 9.71 charge
        temp 24.3
        pe
        density 1.15
        units mg/L
        Br .457
        Ca .0042
        C 36.7 as CO3-2
        Cl 43.67
        F .03
        Mg 0.0498
        K 11.33
        Na 68.07
        S 32.07 as SO4-2
SOLUTION 2
        pH 7.2 charge
        temp 25
        pe
        density
        units mg/L
        Cd 1.55
        Ca .0052
        Cl .0036
        Cu 39.85
        Pb 40.85
        Mg 0.0024
        K .0037
        Na .00908
        S .0013 as SO4-2
        Zn 145.8
        As 6.3
END
```

Phase	SI	log IAP	log KT	
Anglesite	-3.70	-11.50	-7.79	PbSO4
Anhydrite	-6.65	-11.01	-4.36	CaSO4
Aragonite	-2.90	-11.24	-8.33	CaCO3
Calcite	-2.76	-11.24	-8.48	CaCO3
Cd(OH)2	0.97	14.62	13.65	Cd(OH)2
CdSO4	-9.55	-9.63	-0.09	CdSO4
Cerrusite	1.41	-11.73	-13.13	PbCO3
CH4(g)	-54.51	-57.36	-2.86	CH4
CO2(g)	-6.33	-7.80	-1.46	CO2
Dolomite	-4.46	-21.55	-17.08	CaMg(CO3)2
Fluorite	-8.85	-19.45	-10.60	CaF2
Gypsum	-6.43	-11.01	-4.58	CaSO4:2H2O
H2(g)	-18.50	-21.65	-3.15	H2
H2O(g)	-1.52	-0.00	1.52	H2O
H2S(g)	-56.61	-57.61	-0.99	H2S
Halite	-7.78	-6.20	1.58	NaCl
O2(g)	-46.30	-49.19	-2.89	O2
Otavite	2.23	-9.87	-12.10	CdCO3
Pb(OH)2	4.59	12.76	8.16	Pb(OH)2
Smithsonite	-0.57	-10.57	-10.00	ZnCO3
Sphalerite	-39.01	-50.64	-11.63	ZnS
Sulfur	-44.00	-39.11	4.89	S
Zn(OH)2(e)	2.42	13.92	11.50	Zn(OH)2

Saturation Indexes



Oversaturation in Mixed Model

- Otavite, cadmium hydroxide → Cadmium carbonate, a carcinogen
- Zinc hydroxide → Hazardous if ingested in large quantities (zinc poisoning)
- Cerussite→ Also known as “white lead”, found in lead paints (lead poisoning)
- Lead hydroxide → Hazardous if ingested in large quantities (lead poisoning)

Possibilities of desiccation recovery

- Previous Pleistocene desiccation has been suggested to have been a driver for the adaptive radiation of the Lake Victoria Cichlids, which as of recently are facing massive extinction rates
  - Radiation occurred in remnant brine pools
  - This is only beneficial if large-scale removal of pollutants occurs
    - Not likely possibly at this point
  - There must also be a slow-down or reversal of climate change
    - I hope this is possible at this point

More likely future of Lake Victoria

- Loss of income from exports
- Illness from increased concentration of contaminants, including arsenic, fecal matter, and mercury ingested through water and fish
- Downfall of fishing industry and major losses to area farming

Caveats

- Water chemistry data for all of Lake Victoria are few and far between, and usually only focus in on specific areas.
- Lake Katwe is historically well sampled unlike many of the surrounding lakes, but is much smaller
- Pollutants are known to be hazardous from Lake Victoria, but proper research and cleanup efforts are expensive in a poverty stricken area and there has been little to no regulation on the water quality of the Lake, so data on past pollutants (and current) have rarely been recorded

Main Sources

- Concentration data from:
  - Kasedde et al. 2014., Characterization of brines and evaporites of Lake Katwe, Uganda. *Journal of African Sciences.* **91** 55-65.
  - Machiwa, JF. 2003., Metal Concentrations in Sediment and Fish of Lake Victoria near and away from catchments with gold mining activities. *Tanz. J. Sci.* **29(2)** 43-55.