A GIS-based procedure for risk assessment of global transboundary lakes and reservoirs

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1. Introduction

- Lakes and reservoirs – the valuable barometers of the impacts of human activities within their drainage basins.

- Given a limited amount of available resources for the management, lakes must be prioritized based on the level of threats they are exposed to, for which a comprehensive and science-driven assessment is essential.

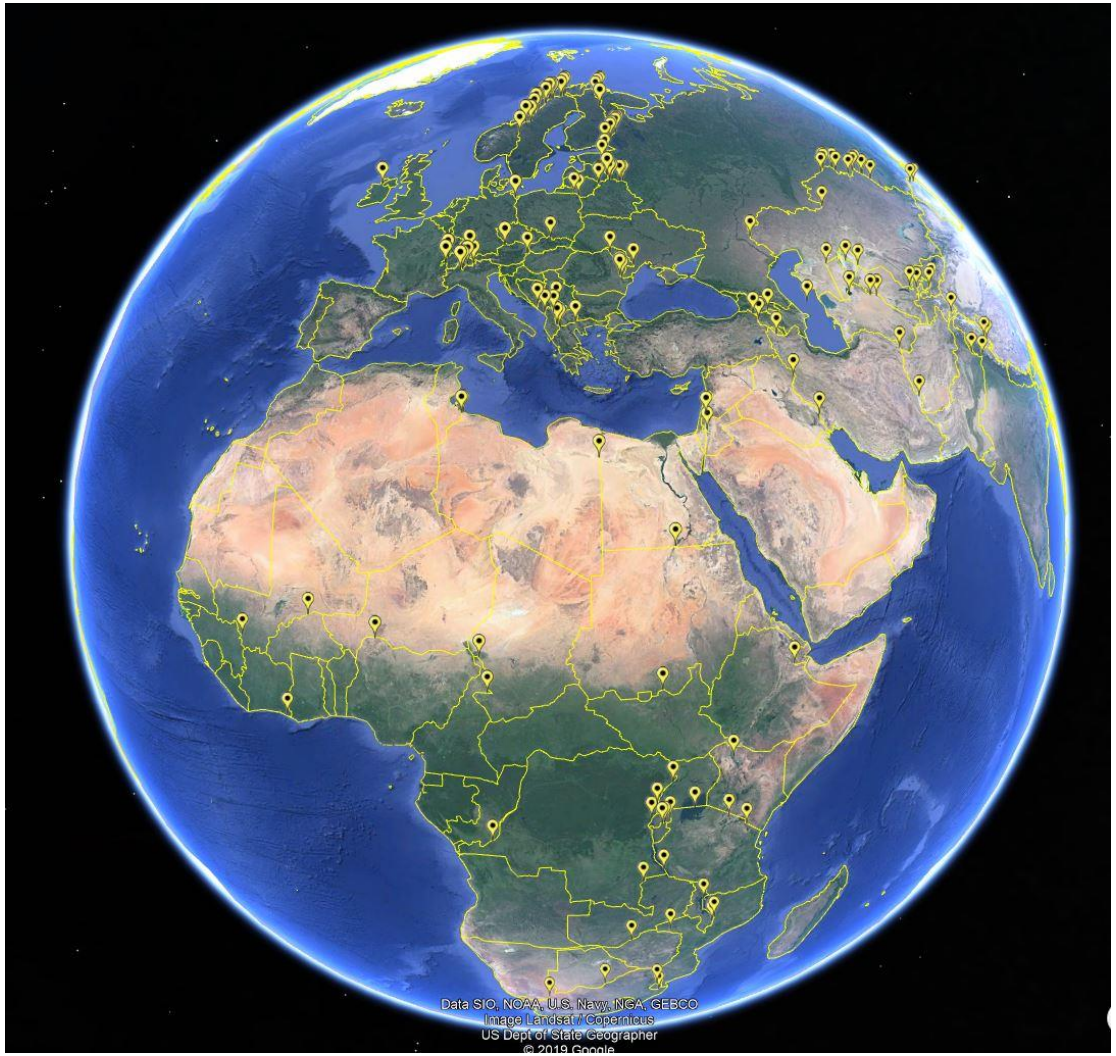
- A GIS-based multi-criteria evaluation technique can be effectively used for risk indexing of the lake-basins.

- As part of the Transboundary Water Assessment Program (TWAP) Lakes Project, global transboundary lakes are ranked in terms of risk defined by the impairment of quality and quantity of lake water based on multiple environmental and socio-economic indicators (criteria).

Red Lake, CA /Source: ABC news

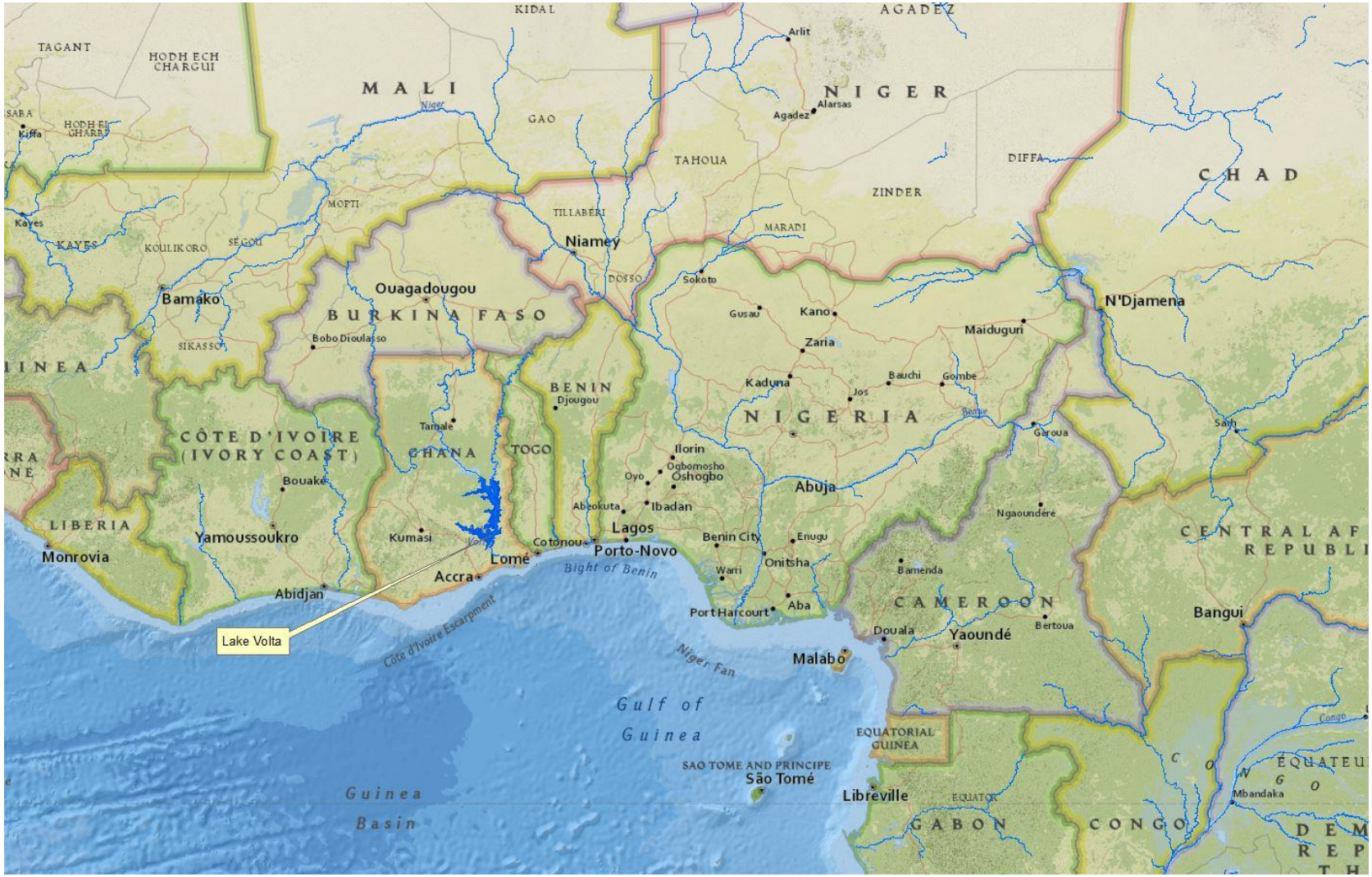
2. Methodology

I. Very first step: Identification and visualization of the TB lakes

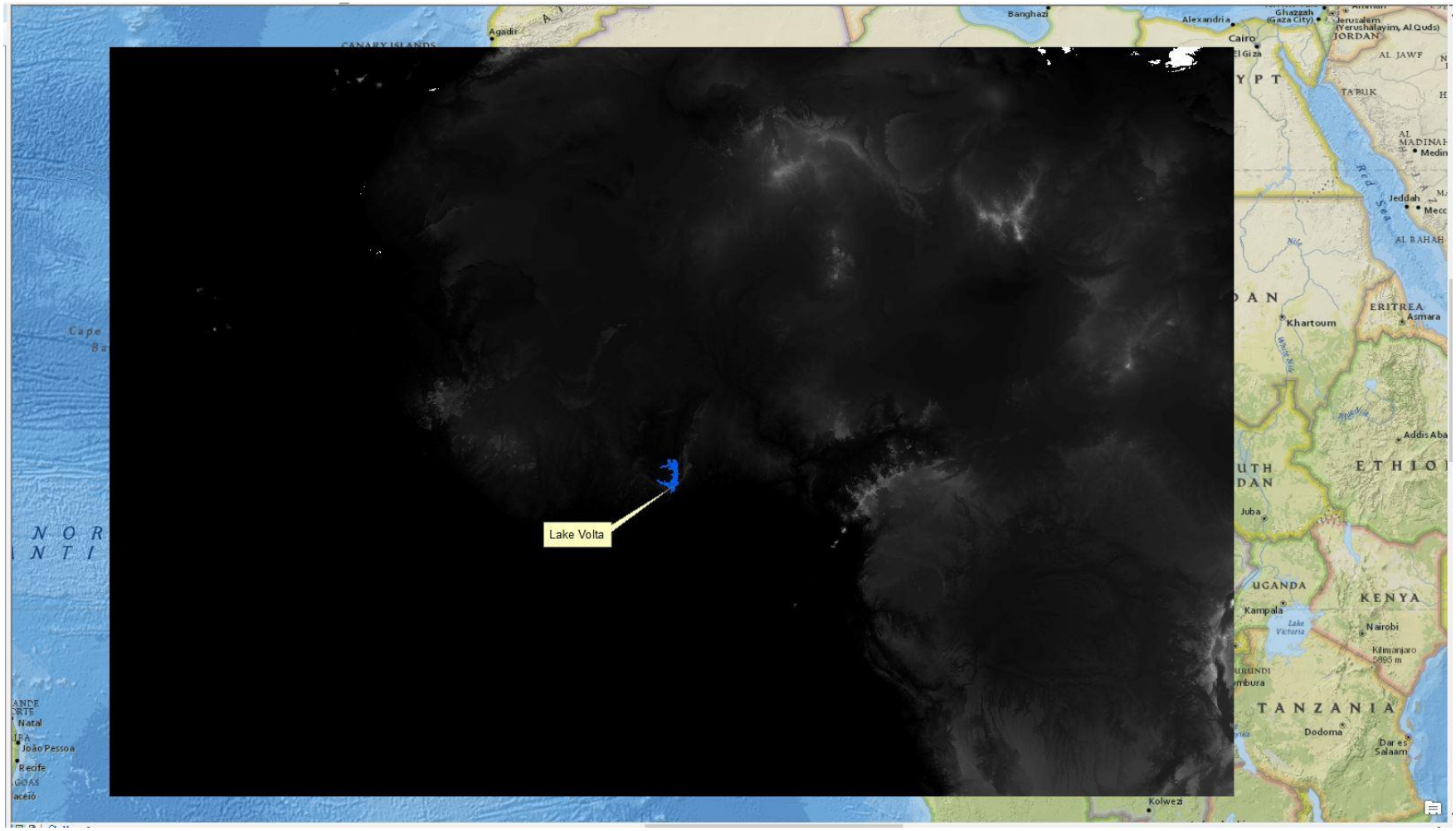


Global TB lakes identified and place marked on Google Earth

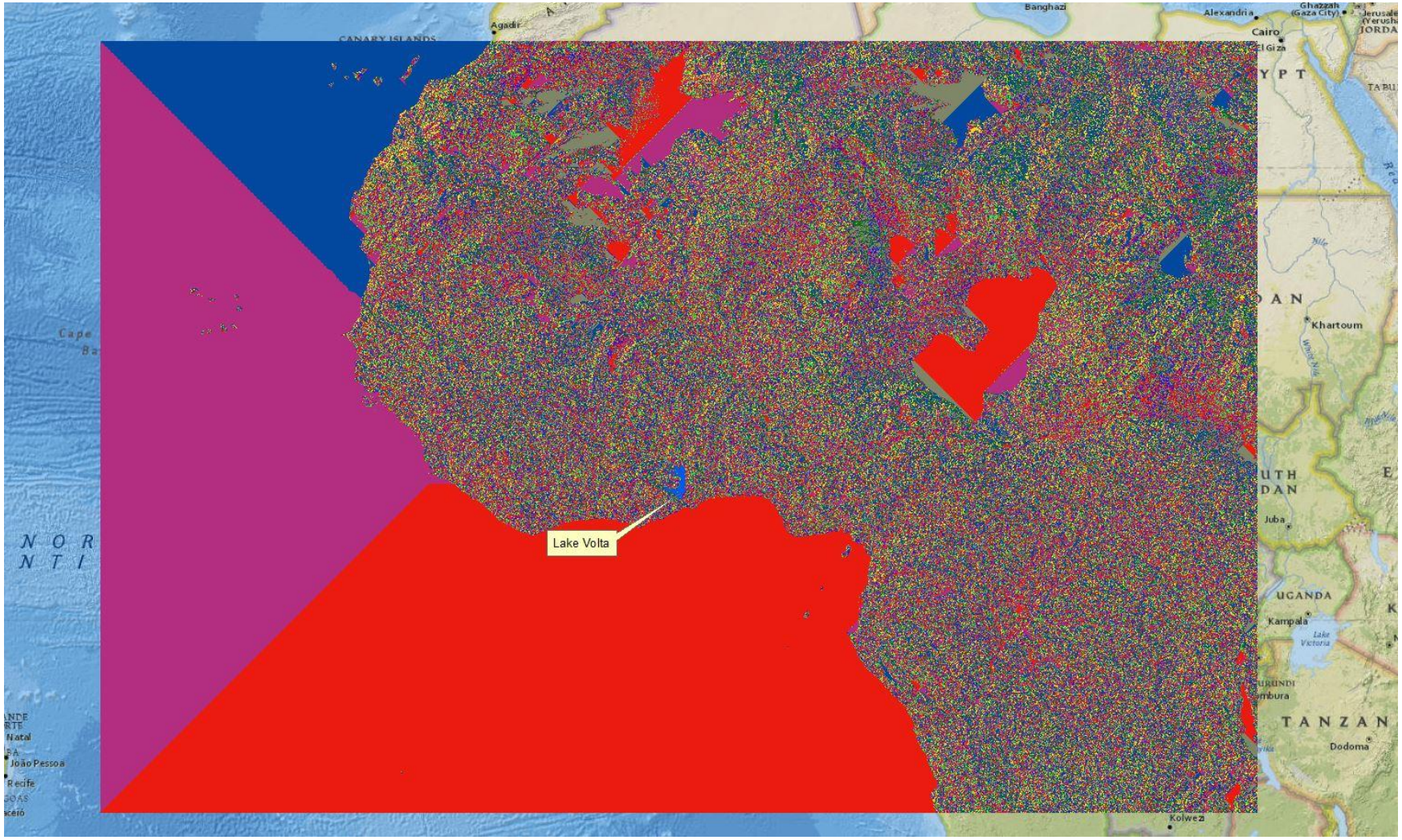
For illustration purpose, Lake Volta, an African Lake selected



II. A DEM-based lake-basin delineation: the first step is to prepare a Digital Elevation Model (DEM) surface for the basin area, e.g. Lake Volta in the below figure.

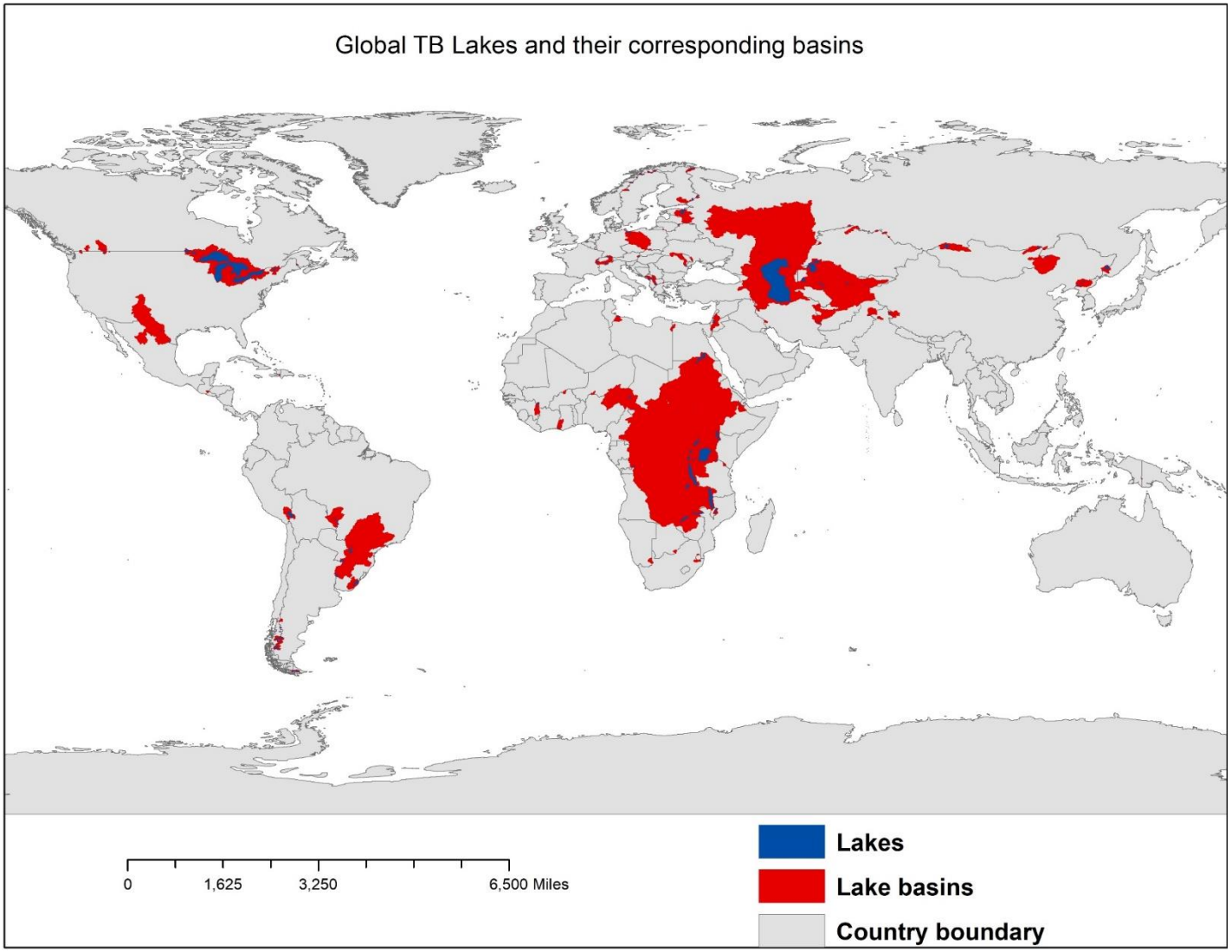


A DEM-based lake-basin delineation: Subsequent steps are to run hydrological GIS tools such as Fill, Flow direction (e.g. below), and Flow Accumulation



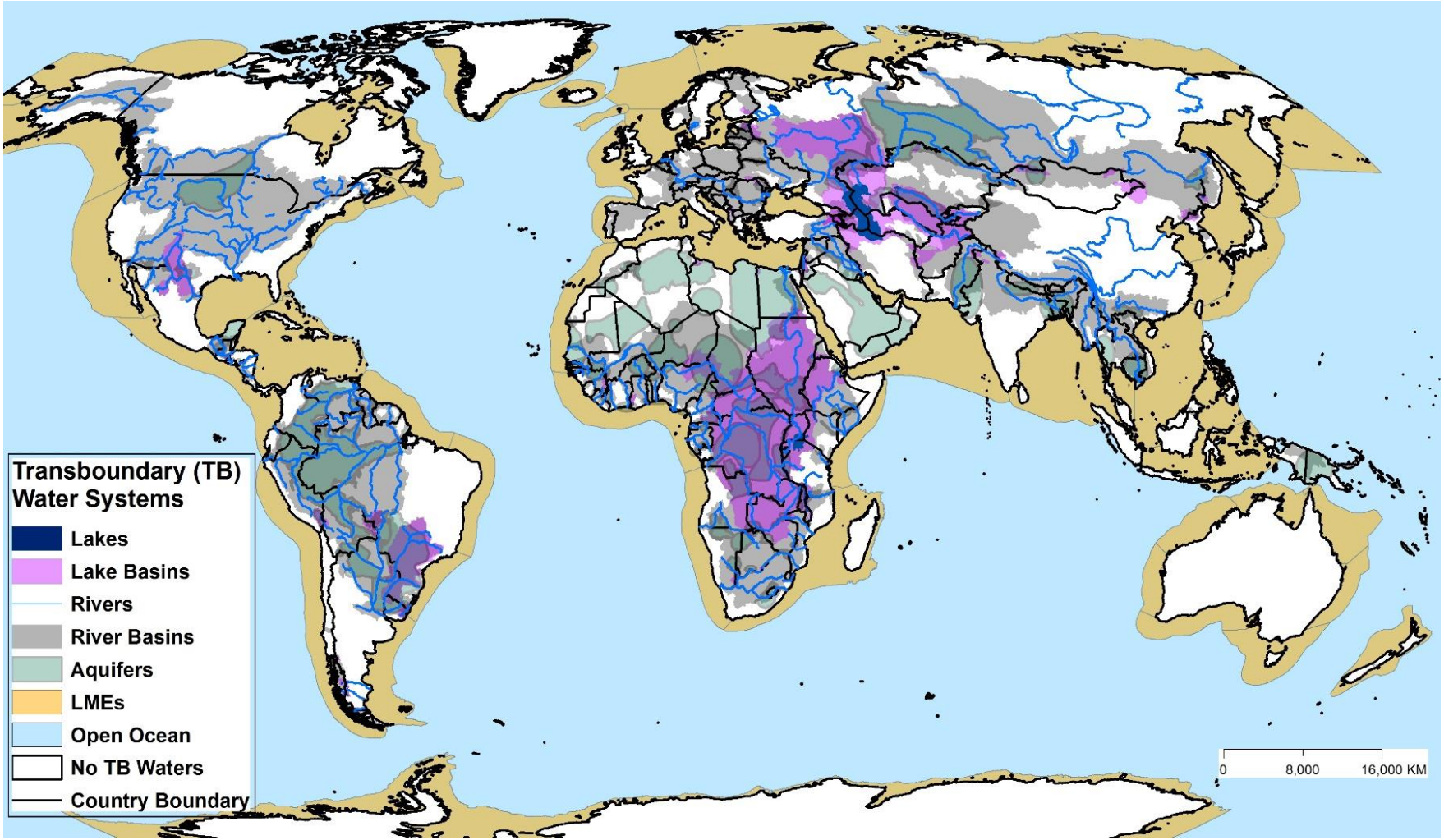
A DEM-based lake-basin delineation: the final step is to run Watershed tool to generate the drainage basin boundary.

Following the method, basin boundaries (i.e. polygons) were generated for all TB lakes.

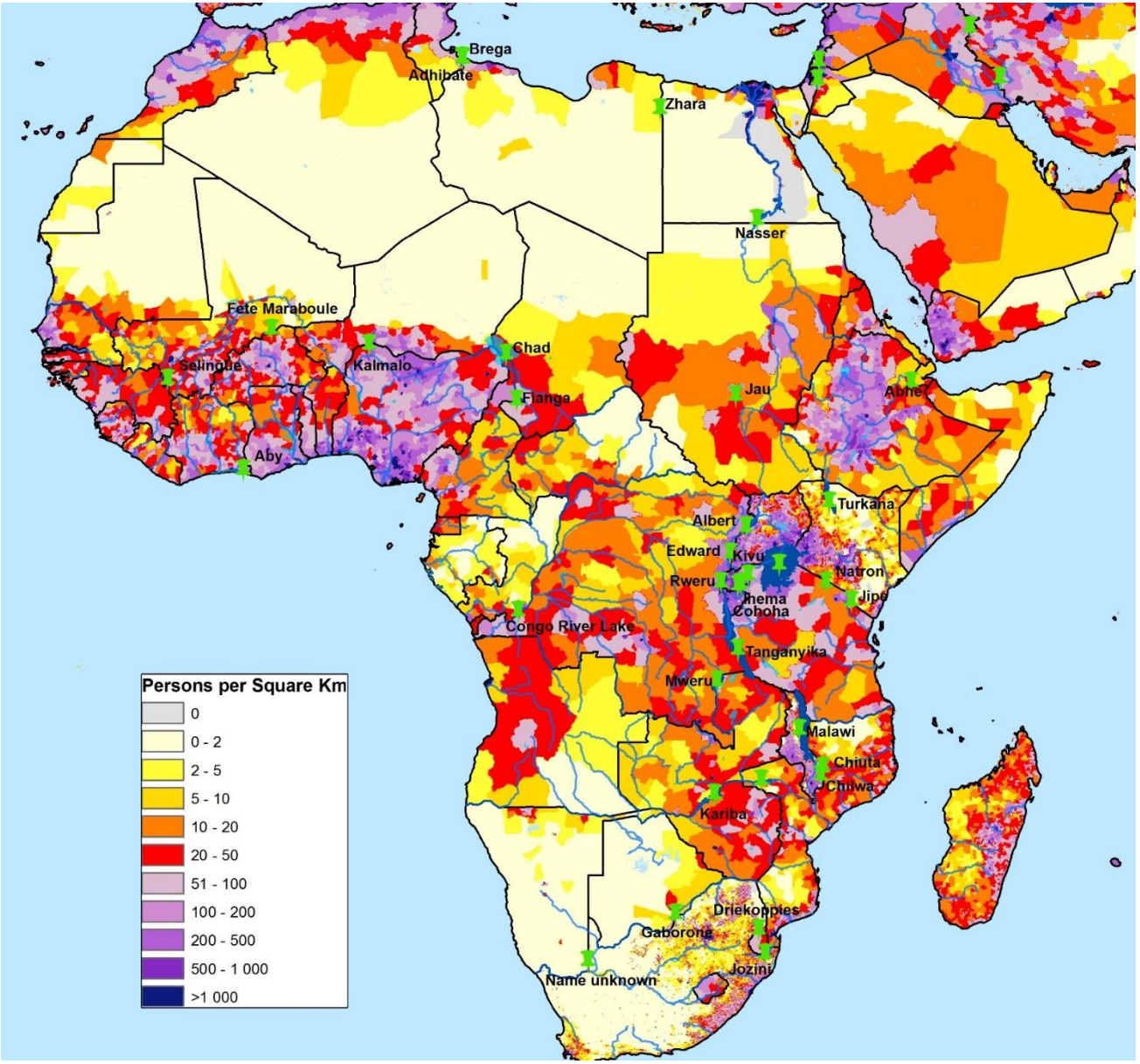


3. Overlaying other data on lake basins

Often times other relevant data can be overlaid on top of the lake basins. For example, the following figure visualizes the spatial interconnection among different waters systems.



Or indicator data, which are often available in gridded data format, can be overlaid to make a visual assessment, e.g. population density in the below figure



4. Indicator data computation

However, the indicator data values should be computed for each lake basin so that the lakes can be compared in terms of composite score of all indicators included. For example, the factors and indicators we included in the TWAP Lake project are listed in the table on the right.

Indicator/Factor
Average Annual Precipitation (mm)
Average Annual Evapotranspiration (mm)
Relative Water Stress (unitless ratio), a measure of water demand pressures from domestic, industrial and agricultural sectors relative to the local and upstream water supplies.
Nitrogen Loadings (kg/km^2/Year)
Phosphorus Loadings (kg/km^2/Year)
Sediment Loadings (kg/km^2/Year)
Pesticide Loadings (kg/km^2/Year)
Agricultural Water Use (millions of m^3/year), measured as irrigation withdrawals for 2000
Industrial Water Use (millions of m^3/year), industrial usage for 2000
Domestic Water Use (millions of m^3/year), consumed for domestic purpose
Judicial Fragmentation, the number of riparian countries intersecting the basin
GNI Per Capita (in US dollars 2012), i.e. gross national income per capita
Relative Population Pressure, a ratio of lake volume to population within the basin
HDI, i.e. human development index – a ratio ranging between 0-1
Hydrological Position, defined as a ratio of total annual precipitation in the lake basin to the total annual precipitation in the corresponding TB river basin
Lake to Basin Ratio
Lenticity, defined as a ratio of lake area (a proxy for the lake's water volume) to the total annual precipitation within the lake basin

Indicators used in the study and their meaning and sources.

For the statistical comparison, indicator data values are computed for each lake-basin. For example, the following table shows values for some of the indicators for South American TB Lake-basins.

LakeID	Lake name	LakeArea	Annual Precipitation	Relative Water Str	GNI Per Caljta	Pop Density	Urban	Agricultural	Lenticity	Lake to Basin Ra	HDI	Pesti Loading	DamDen	NLoading
1	Roca	16.95	714.8335	0.0001	14355.92	0.0693	0	5.4367	0.0265	0.0309	0.8188	0.98179429	5.6690366	2.65331295
2	Fagnano/Cami	589.02	506.5681	0.0018	17141.14	0.2637	1.4154	0.5213	1.299	0.1667	0.8113	1.164397627	7.23141101	3.19497326
3	Descado	11.18	582.4487	0.0004	14474.2	0.0653	0	0	0.0213	0.0961	0.8185	0.657714883	3.41501966	2.64656476
4	O'Higgins/San Martin	1013.13	660.0795	0.0004	15863.96	0.0425	0	2.01	1.7061	0.0756	0.8147	1.988594174	2.034243	5.23730048
5	Pueyrredon/Cochrane	299.78	346.098	394.8402	15554.9	0.0774	0	1.0489	1.3163	0.0676	0.8156	2.747324106	4.81503902	3.76681107
6	Buenos Aires/General Carre	1768.37	728.9062	0.0012	15293.79	0.4576	0	1.2549	2.6108	0.1156	0.8163	4.689952621	8.20957987	4.57211274
7	Palena/Vinter Lake	139.24	908.2509	0.0005	14464.57	0.3335	0	2.5816	0.1517	0.2687	0.8185	2.241046927	5.559677	1.41478732
8	Interior	5.01	1055.361	0.0022	17187.1	4.3958	1.9427	6.1457	0.0526	0.0015	0.8112	1.624419052	2.91527815	2.26497304
9	Constancia	17.71	1385.5	0.0046	14283.98	3.9661	0	0	0.0125	0.4883	0.819	1.798930473	4.90386269	3.03617949
10	Merin/Mirim	3896.70	1223.091	0.0298	12814.13	4.413	1.2549	34.1743	3.6991	0.0779	0.7691	11.91537022	8.30540624	13.4691368
11	Salto Grande	532.94	1612.93	0.0105	12343.38	15.6424	3.0144	35.9199	0.6829	0.0022	0.7411	9.446082269	7.00128407	8.24542821
12	Lago de Yacyreta	1109.41	1454.207	0.0624	11493.15	54.9901	5.9996	65.5194	10.904	0.0014	0.7295	8.175028502	5.63620245	4.79916864
13	Itaipu	1154.07	1420.653	0.0718	11612.65	56.5096	6.0222	69.6536	9.8589	0.0015	0.7299	14.73661754	12.5601974	9.67784803
14	Caeeres	23.86	1087.372	0.0158	3769.343	2.6857	0.1277	2.1276	0.0192	0.0035	0.6841	4.584205278	2.17937665	2.63001221
15	Baia Vermelha	72.44	1150.7	0.0041	11530.27	3.6547	0	0	0.0534	0.1953	0.7294	6.00209888	2.05468723	2.67439663
16	Mandiore	144.07	1174.766	0.0077	7487.025	0.7138	0	14.1386	0.0706	0.1931	0.7058	7.221989433	2.25295836	2.84326724
17	Gaiba	97.56	1198.397	0.0019	3248.276	0.3791	0	3.8281	0.0497	0.0661	0.681	5.987517075	2.52489444	1.80329421
18	Blanca	5.91	347.0156	0.1008	7270.167	1.3179	0	0	0.0143	0.038	0.7539	7.028080229	3.46324936	7.40479154
19	Uberaba	324.74	1438.253	0.002	10976.89	3.0031	0.6891	24.3535	0.1751	0.0027	0.7262	7.207997969	3.32141762	1.29453343
20	Las Piranas1	19.73	1403.18	0.0013	5778.284	0.7954	0	7.5217	0.1218	0.0004	0.6958	5.399336894	2.69757647	1.51760826
21	Las Piranas2	55.72	1403.271	0.0013	5774.603	0.795	0	7.5263	0.1109	0.0011	0.6958	6.039559056	2.7082924	1.5670823
22	Baia Orion	103.05	1472.318	0.0009	7042.696	0.7084	0	10.1001	0.0749	0.0031	0.7032	6.045621544	2.68932368	1.48173202
23	Name not identifed	27.49	1441.104	0.0014	9874.346	0.9974	0	21.8543	0.0161	0.0024	0.7197	7.051585465	3.57311082	1.00162327
24	Chungarkkota	52.57	717.3124	0.9553	4297.645	36.0134	1.8101	16.5412	9.9123	0.0009	0.7125	6.958912879	4.29079448	7.9218785
25	Baia Grande	93.48	1371.719	0.0002	6360.279	0.5463	0	0	0.0637	0.3287	0.6992	4.321854287	1.40582046	1.55482749
26	Titicaca	7479.94	719.0784	1.0009	4283.889	36.9057	1.8841	15.6501	9.8187	0.132	0.7122	12.66902463	8.23998468	14.0274047
27	Suches	12.58	696.2905	0.0014	5426.525	3.9968	0	0	0.0151	0.0713	0.7328	4.201617426	2.72824383	3.47943818
28	Parinacota	5.59	660.4774	0.0134	5753.668	17.332	0	32.9287	0.002	0.0126	0.7387	5.538348409	3.3258962	6.06004806
29	Guija	36.15	1304.695	0.0303	3200.421	122.9636	9.4718	82.1404	0.0232	0.0137	0.5946	5.917625387	5.55410564	4.97607176

In the next step, these indicator values are normalized (i.e. standardized) into the same ranking scale such as 0 to 1.

Lakes	Relative Water Stress	Nitrogen Loading	Phosphorus Loading	Sediment Loading	Pesticide Loading	Incident BD Threat	Adjusted HWS Threat	Incident HWS Threat	Human Water Stress	Dam Density	Soil Salination	Impervious Survaces	Cropland
Nasser	0.023147	0.69897461	0.399834305	0.6735937	0.632545	0.42034346	0.61256284	0.16464877	0.66462034	0.637698	0.6881564	0.38333291	0.416419
Itaipu	0.202336	0.07125034	0.415470034	0.7595051	0.443841	0.62710291	0.73129666	0.37803388	0.710215688	0.863268	0.5117659	0.56647611	0.55448
Yacyreta	0.197245	0.0623762	0.427445322	0.7560999	0.439035	0.62817609	0.73273319	0.38046223	0.705507457	0.862123	0.4890832	0.54892164	0.560221
Nakuru	0.151019	0.59927368	0.261163205	0.7697322	0.898114	0.59585607	0.75115561	0.28455794	0.846618652	0.620223	0.8783538	0.24925192	0.540218
Volta	0.164219	0.68807983	0.266574293	0.7703636	0.897348	0.59546107	0.75251853	0.28664288	0.844701588	0.612825	0.8773319	0.24800833	0.545285
TonleSap	0.957928	0.01616012	0.318762392	0.5197827	0.327523	0.38483796	0.74169856	0.19789295	0.751909554	0.382849	0.5046952	0.29408646	0.619205
Mekong	0.217794	0.03418288	0.545811653	0.5848966	0.424548	0.41387707	0.72942865	0.21911073	0.647088766	0.52095	0.4845032	0.29609701	0.549848

Then, these indicators are combined to get the composite risk/threat score for each lake.

Lakes	Relative Water Stress	Nitrogen Loading	Phosphorus Loading	Sediment Loading	Pesticide Loading	Incident BD Threat	Adjusted HWS Threat	Incident HWS Threat	Human Water Stress	Dam Density	Soil Salination	Impervious Survaces	Cropland	Composite Score
Nasser	0.023147	0.69897461	0.399834305	0.6735937	0.632545	0.42034346	0.61256284	0.16464877	0.66462034	0.637698	0.6881564	0.38333291	0.416419	**0.493528974**
Itaipu	0.202336	0.07125034	0.415470034	0.7595051	0.443841	0.62710291	0.73129666	0.37803388	0.710215688	0.863268	0.5117659	0.56647611	0.55448	**0.525772424**
Yacyreta	0.197245	0.0623762	0.427445322	0.7560999	0.439035	0.62817609	0.73273319	0.38046223	0.705507457	0.862123	0.4890832	0.54892164	0.560221	**0.522263793**
Nakuru	0.151019	0.59927368	0.261163205	0.7697322	0.898114	0.59585607	0.75115561	0.28455794	0.846618652	0.620223	0.8783538	0.24925192	0.540218	**0.572733631**
Volta	0.164219	0.68807983	0.266574293	0.7703636	0.897348	0.59546107	0.75251853	0.28664288	0.844701588	0.612825	0.8773319	0.24800833	0.545285	**0.580719967**
TonleSap	0.957928	0.01616012	0.318762392	0.5197827	0.327523	0.38483796	0.74169856	0.19789295	0.751909554	0.382849	0.5046952	0.29408646	0.619205	**0.462871699**
Mekong	0.217794	0.03418288	0.545811653	0.5848966	0.424548	0.41387707	0.72942865	0.21911073	0.647088766	0.52095	0.4845032	0.29609701	0.549848	**0.436010556**

The last column shows the composite risk/threat score (level) for the selected lake basins based on a non-weighted linear combination method, i.e. without using any weights, meaning that all the indicators/factors are given the same amount of importance.

The computed composite risk can be visualized as a risk/threat map in GIS.

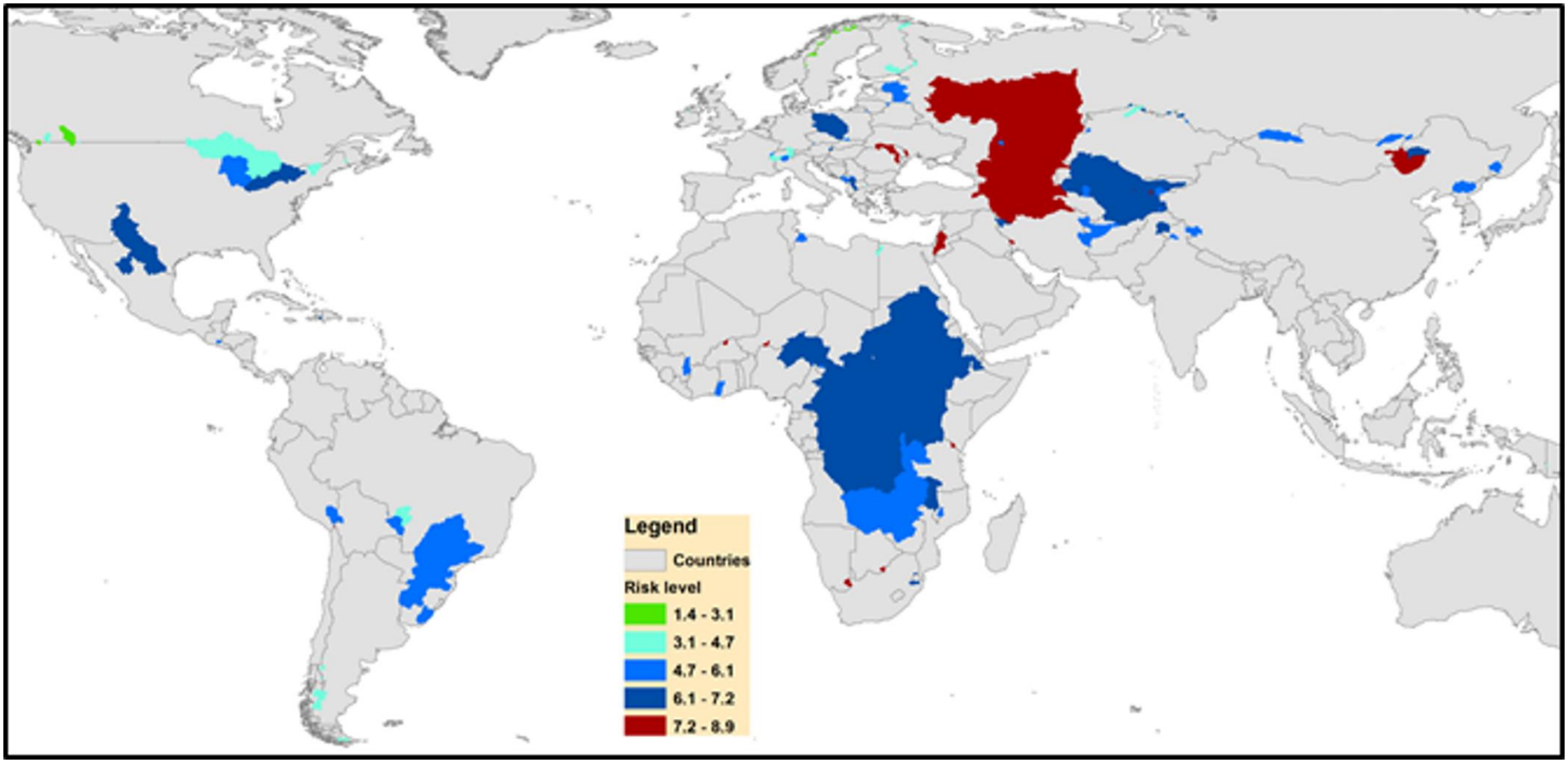


Figure 3: Map showing global TB lake basins ranked based on risk measured in terms of impaired quantity and quality of the lake water.

Conclusion

- As part of the TWAP Lakes Project, this presentation illustrates how a comprehensive database of global TB lake basins has been developed. The risk ranking carried out in the study is expected to assist national and international agencies such as Global Environmental Fund (GEF) to prioritize their fund allocation and management projects.

- The results (derived based on a non-weighted linear combination scores for a selected set of indicators) show that Lake Ranseren along with the cluster of other small-sized lakes bordering Norway and Finland is the least degraded TB lentic water body. On the other hand, Lake Kalmalo at the border between Nigeria and Niger is at the highest risk. Overall, the lakes in desert areas and with higher population densities within the basins are in highly degraded condition, thereby wanting the prioritized management efforts.

- The illustrations presented here do not represent the actual final results and conclusion of the TWAP Lakes Project. It describes a part of the methodology adopted for the project. For detail, refer to Rast at al. (2016).

Selected references

- Lehner, B., Verdin, K., Jarvis, A. (2006): HydroSHEDS Technical Documentation. World Wildlife Fund US, Washington, DC. Available at hhttp://hydrosheds.cr.usgs.gov.
- Vorosmarty, C.J. , McIntyre, P.B. , Gessner, M.O., Dudgeon, D., Prusevich, A., Green, P., Glidden,S., Bunn, S.E., Sullivan, C.A., Reidy Liermann, C., and Davies, P.M., 2010. Global threats to human water security and river biodiversity, Nature *467, 555-561.*
- Rast, W., Nakamura, M., Dahal, K., and Lin, H., 2016. Transboundary Lakes and Reservoirs: Status and Future Trends. Transboundary Waters Assessment Programme (TWAP), UNEP office, Nairobi, Kenya. http://geftwap.org/water-systems/lake-reservoir-basins