

## CASE STUDY 1: Mapping the potential geographic distribution of surface water drinking sources in Liberia

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### Introduction:

Achieving universal and equitable access to safe and affordable drinking water for all requires evidence-based assessments to identify the disadvantaged areas and prioritise those with the most needs accordingly. To facilitate drinking water infrastructure development to deliver safe and sustainable water services for all, it is necessary to locate the people still using disadvantaged water services across the country. Surface water at the bottom of WHO/UNICEF Joint Monitoring Programme (JMP)'s water ladder (WHO and UNICEF 2017) refers to drinking water directly from open sources such as a river, stream, lake, dam, pond, canal or irrigation channel. Fetching water from open sources may pick up contaminants and pathogens; without proper treatment before use, it may cause serious health effects. Although conventional geospatial datasets concerning drinking water services generally contain comparatively limited information on surface water sources, more newly released datasets combining machine learning predictive modelling methods makes it possible to predict the potential spatial distribution of specific types of disadvantaged water service such as surface water.

This study uses a novel machine learning algorithm named maximum entropy (MaxEnt) to predict the potential spatial distribution of surface water drinking sources in Liberia. MaxEnt method is based on the maximum entropy principle, which suggests making prediction of the unknown probability distribution by looking for the probability distribution of maximum entropy (i.e. which is most diffused and closest to uniform distribution where the probability for each individual locality within the area of interests tends to be equally likely) bounded by the constraints derived from the obtained presence data (the coordinates of geographic locations where the target objects are observed) and the known environmental conditions across the area of interests. It has been widely applied in biological and ecological studies. Detailed methodological introduction of MaxEnt method can be found in (Phillips *et al.* 2006).

### Data:

#### ● Surface water

In total, 59 water point data describing surface water sources derived from the Water Point Exchange are employed as the observed occurrence sample of surface water, which excluded duplicates and those located within a same 5km x 5km grid cell.

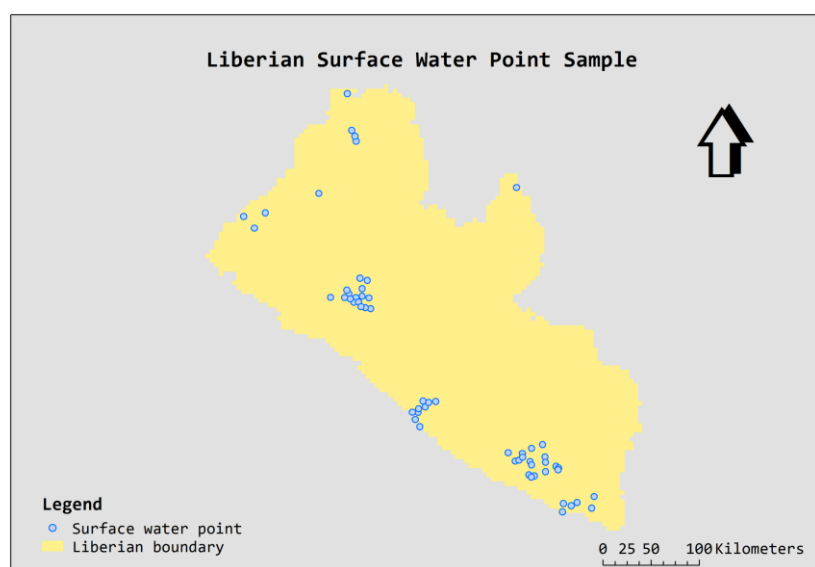


Figure 1 Liberian surface water point sample

## ● Predictive covariates

This study identified 10 predictive covariates (Table 1) that may be importance determinants of the spatial distribution of open source drinking water considering both the availability of surface water resources and socio-economic factors that may reflect the local demands and preferences. For example, Euclidean distance to inland water was calculate to reflect the availability of surface water resources; improved water source coverage was employed to indicate the potential demands on surface water; open defecation surface was used as a proxy of poverty indicator to reflect potential affordability of advanced water supply services. All predictive covariate layers were scaled down to 5km spatial resolution.

Table 1

Covariate	Data Name	Data Source	Data Type	Format	Resolution
Distance to inland water	Digital Chart of the World (DCW)	Environmental Systems Research Institute, Inc. (ESRI)	categorical vector	Shapefile	-
Elevation	ASTER GDEM Version 2	Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA)	continuous raster	Geotiff	30 m
Slope	ASTER GDEM Version 2	Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA)	continuous raster	Geotiff	30 m
Annual rainfall	WorldClim Clobal Climate Data version 1.4	Museum of Vertebrate Zoology, University of California (Hijmans <i>et al.</i> 2005)	continuous raster	Geotiff	1 km
Depth to groundwater	Equilibrium Water Table Africa Model version 2	Fan et al. (2013)	continuous raster	NetCDF	1 km
Distance to villages	Open Street Map (OSM)	OpenStreetMap Foundation (OSMF) & Contributors (OpenStreetMap Foundation (OSMF) & Contributors 2017)	categorical vector	Shapefile	-
Distance to roads	Open Street Map (OSM)	OpenStreetMap Foundation (OSMF) & Contributors (OpenStreetMap Foundation (OSMF) & Contributors 2017)	categorical vector	Shapefile	-
% population with access to improved water source	DHS Modelled Surfaces	Gething et al. (2015)	continuous raster	Geotiff	5 km
% population with no toilet	DHS Modelled Surfaces	Gething et al. (2015)	continuous raster	Geotiff	5 km
Land cover	MODIS Land Cover Type (MCD12Q1) version 5.1	University of Maryland & the Pacific Northwest National Laboratory (Collins and Emanuel 2014)	Land cover, categorical raster	Geotiff	500 m

We clipped all layers to the same spatial extent, and removed large water bodies and sea to ensure our analysis considered terrestrial areas only. Pre-processed covariate layers alongside other data used in this case study can be downloaded from <https://geoterry.github.io/GEOWAT-SDGinsights/downloads.html>.

### Sampling bias:

Kernel density surface was calculated based on obtained surface water point sample to be used as bias files in order to handle the potential sampling bias. A pixel with higher density value indicates that it received a greater survey effort. Such bias file could reflect variation in survey effort and MaxEnt therefore uses it as a weighting layer to ensure that the target water points are observed in locations with particular covariate conditions is due to such conditions are favourable, rather than due to these locations received greater survey efforts.

### Model building:

The MaxEnt model building can be carried out using different software such as ArcMap, R, etc. In this example, we recommend to use a small size open source software package named 'MaxEnt' developed by Steven J. Phillips and colleagues for ecological niche modelling, which can be freely downloaded from [http://biodiversityinformatics.amnh.org/open\\_source/maxent/](http://biodiversityinformatics.amnh.org/open_source/maxent/). For model building, 70% of the surface water presence points were randomly selected to train the model, whilst the remainder were set aside for testing the model performance. We generated 1,000 background points by randomly selecting points within the full spatial extent defined in Liberia (where large water bodies were excluded). We repeated the sampling of training and background points 50 times and then computed the aggregated prediction and performance analysis. All available functional transformations (i.e. linear; quadratic; product; threshold; hinge; and discrete) of the predictive covariates (namely features) were used to constrain the relative probability distribution which is being computed in order to capture the potential complicated relationships between the predictive covariates and surface water points. In addition, we used the logistic output (a logistic transformation of the raw output which is monotonically related and gives an identical relative probability ranking) of the MaxEnt model for better illustration. The MaxEnt modelling embedded Monte Carlo cross-validation (Dubitzky *et al.* 2007), where obtained water point samples were randomly split for training and testing for ten replicated runs. Evaluation of model performance was carried out using Area Under the Receiver Operator Curve (AUC; DeLong *et al.* 1988). An AUC value of 1 reflects perfect discriminatory power of the model; 0.5 indicates that the prediction failed to capture any patterns and is no better than a random distribution; AUC above 0.75 indicates a potentially useful discrimination of the model (Elith 2000, Phillips and Dudík 2008). The changes in regularised gains (percent contribution) and changes in training AUC based on permuted data (permutation importance) were used to evaluate the contribution of each predictive covariate to the MaxEnt prediction.

#### How to run model with MaxEnt software:

- 1. Samples:** select the surface water sample file ('lbr\_wpt\_surface.csv' in the 'sample' folder);
- 2. Environmental layers:** select the folder ('covariates' in the 'case1' folder) holding the predictive covariates; set the 'lbr\_cov10\_land\_cover' layer as 'Categorical' (rather than the default 'Continuous');
- 3.** Select 'Create response curves' to generate response curves for the covariates; select 'Do Jackknife to measure variable importance' if a systematic assessment of covariate contribution is desired;
- 4.** Set up the 'Output directory' to a preferred location;
- 5.** Go to detailed settings (Basic, Advanced, and Experimental) by click 'Settings';
- 6. Basic:** select 'Random seed' so different random training/test samples and background points will be used for each run; set 30 to 'Random test percentage' then 30% of the surface water samples will be set aside to test the model performance; set 1000 to the 'Max number of background points'; set 'Replicates' as 10; set 'Replicated run type' as 'Subsample' so replicate sample sets will be chosen by removing random test percentage without replacement to be used for evaluation;
- 7. Advanced:** disselect 'Write output grids' so only the summarised output grids will be generated; select 'Bias file' from the folder ('bias' in 'case1') holding the bias layer file 'lbr\_bias.asc';
- 8. Experimental:** select 'Write background predictions' to have record of background points of each run.

## Results:

The following maps in Figure 2 show the 5km resolution predicted potential spatial distribution of surface water sources in Liberia. This is merely a simplified model for the illustration of this idea. A comparatively precise model can be conducted at finer resolution with sufficient geospatial data and a systematic conceptual framework identifying technical and socio-economic factors that may affect the distribution of specific water sources. The output surface can be interpreted as relative probability of the presence of surface water drinking sources. Such prediction should not directly replace national scale water point inventory or nationally representative household surveys. However, it could give a brief indication of the likely spatial distribution of specific type of water sources in areas where data is lacking.

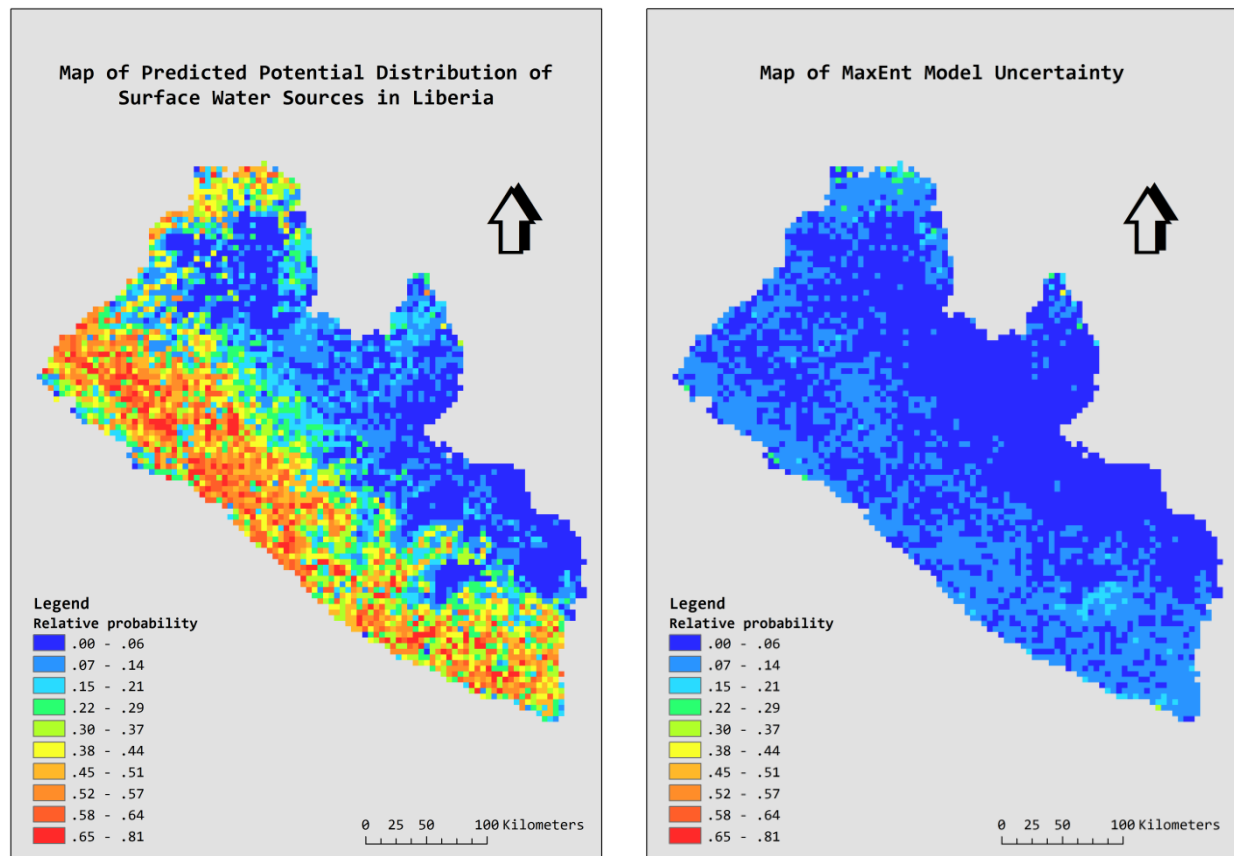


Figure 2 Output of the MaxEnt prediction

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