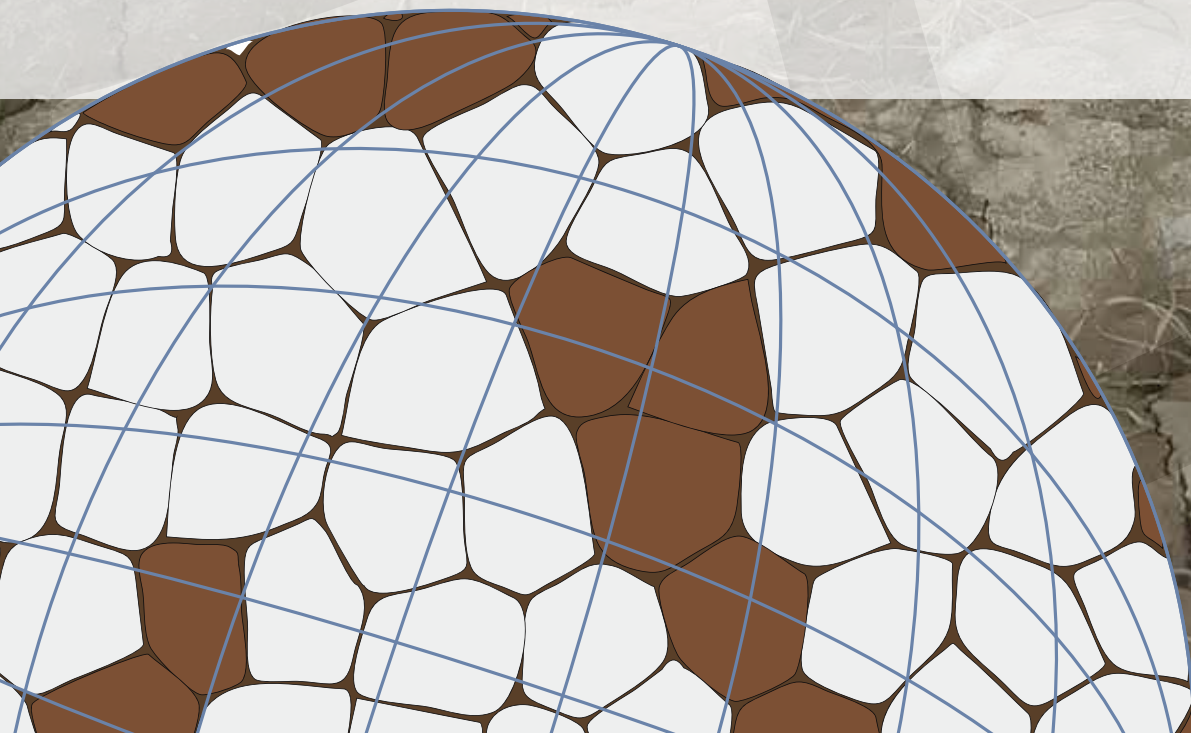**Food and Agriculture Organization of the United Nations**

Global Soil Salinity Map
GSS map

LESSON 4
Spatial modelling of salt-affected soils

GLOBAL SOIL PARTNERSHIP

Global Soil Salinity Map
GSS map

LESSON 4
Spatial modelling
of salt-affected soils

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Contents

Figures

Tables

Summary

This Lesson is the fourth step of the capacity–building program, which is designed to build national capacities as well as harmonize procedures for developing information of salt–affected soils at the national and global levels. The overall goal of this Lesion is to support participants in developing national maps of salt–affected soils. At the end of the lesson, the participants are expected to produce national maps of salt–affected soils in their countries.

Summary outputs from spatial modelling of salt–affected soils

Item	Description		Timeline
Input maps	**Input maps (between 0–30 and 30–100 cm)**		
	Electrical Conductivity	dS/m	
	pH	–	
	Exchangeable Sodium percent	–	
Software	R and its contributed packages		
Maps in geoTiff files	**Outputs**		
	Major types of salt–affected soils	0–30 and 30–100 cm	2 days
	Uncertainty maps of salt–affected soils	0–30 and 30–100 cm	
Accuracy assessment	**Accuracy indices**		
	Kappa index		
	Graph of confusion matrix		

Introduction

1.1   Overview

Salt–affected soils are groups of soils with high content of soluble salts and/or high amounts of sodium ions. The type and concentration of these salts and their drivers are important characteristics and the basis for mapping salt–affected soils. The three main categories for mapping salt–affected soils are: methods based on interpretation of soil–type maps, remote sensing applications, and methods based on soil indicators of salt problems. This Lesson targets the method using soil indicators of salt problems. It focuses on the classification of major types and problem intensity of salt–affected soils using input maps of indicators of salt problems. The Lesson targets national experts with knowledge of and access to indicators of salt–affected soils in their countries. Its outputs are expected to form the database and information for building national soil information of salt–affected soils.

1.2   Objective

The overall objective of this Lesson is to establish national spatial maps of salt–affected soils in each member country.

1.3   Expected outcomes

By the end of this Lesson, the participants are expected to:

i.	Understand the classification of salt–affected soils
ii.	Produce spatial maps of salt–affected soils
iii.	Locate sample points for future monitoring or update of the map of salt–affected soils

2   Activities

2.1   Classifying salt–affected soils

The three major types of salt–affected soils are: saline, sodic, and saline–sodic soils. Table 1 gives popularly used classification schemes for classifying these major types of salt–affected soils.

Table1: Characteristics of salt–affected soils

Soil property	Unit/Symbol	Type of salt–affected soil		
		Saline	Saline–sodic	Sodic
Electrical conductivity	EC_e (dS/m)	> 4	> 4	< 4
Exchangeable sodium Percent	ESP	< 15	> 15	> 15
pH	–	< 8.5	< 8.5	> 8.5
Sodium adsorption ratio	SAR	< 13	> 13	> 13

The *soilassessment* package contains the functions *saltClass* for implementing the classification scheme in Table 1. The input data for this function are the three soil indicators, EC, pH, and ESP. The data be point–data in a spreadsheet dataframe or raster maps.

```
> library(soilassessment)
> predictors$salty=saltClass(predictors$ECse,predictors$PH,predictors$ESP,"FAO")
> summary(predictors$salty)

   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
  1.000   1.000   1.000   1.151   1.000   5.000

> predictors$saltiness=classCode(predictors$salty,"saltclass")
> spplot(predictors["salty"])
> spplot(predictors["saltiness"]) # Figure 1
```
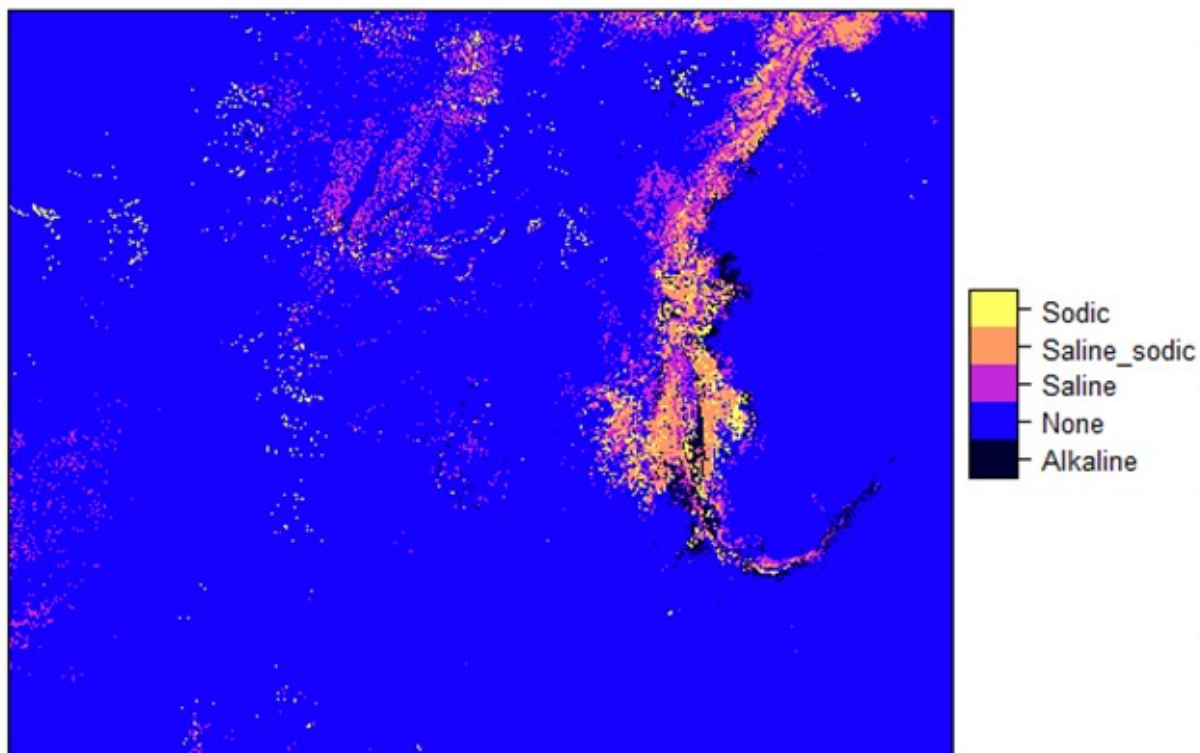

Figure 1: Maps of topsoil (0–30 cm) salt–affected soils

Classification of the intensity of salt problems in the soil is expressed using levels of electrical conductivity and exchangeable sodium ions (Table 2).

Table 2: Identifying intensity of salt problems in soil

Salinity (EC$_e$ dS/m)			Sodicity (ESP)		
Intensity	FAO	USDA	Intensity	FAO	Amrhein (1996)[1]
None	< 0.75	0–2	None	< 15	< 6
slight	0.75–2	2–4	Slight	15–30	6–10
Moderate	2–4	4–8	Moderate	30–50	10–15
Strong	4–8	8–16	High/Strong	50–70	15–25
Very Strong	8–15	> 16	Extreme/V. Strong	> 70	> 25
Extreme	> 15				

[1] Amrhein C. 1996. Australian sodic soils: Distribution, properties, and management. Soil Science 161.

```
> predictors$Salt_affected=saltSeverity(predictors$ECse,predictors$PH,predictors$ES
P,"FAO")
> predictors$saltaffectedness=classCode(predictors$Salt_affected,"saltseverity")
> spplot(predictors["saltaffectedness"]) # Figure 2
```
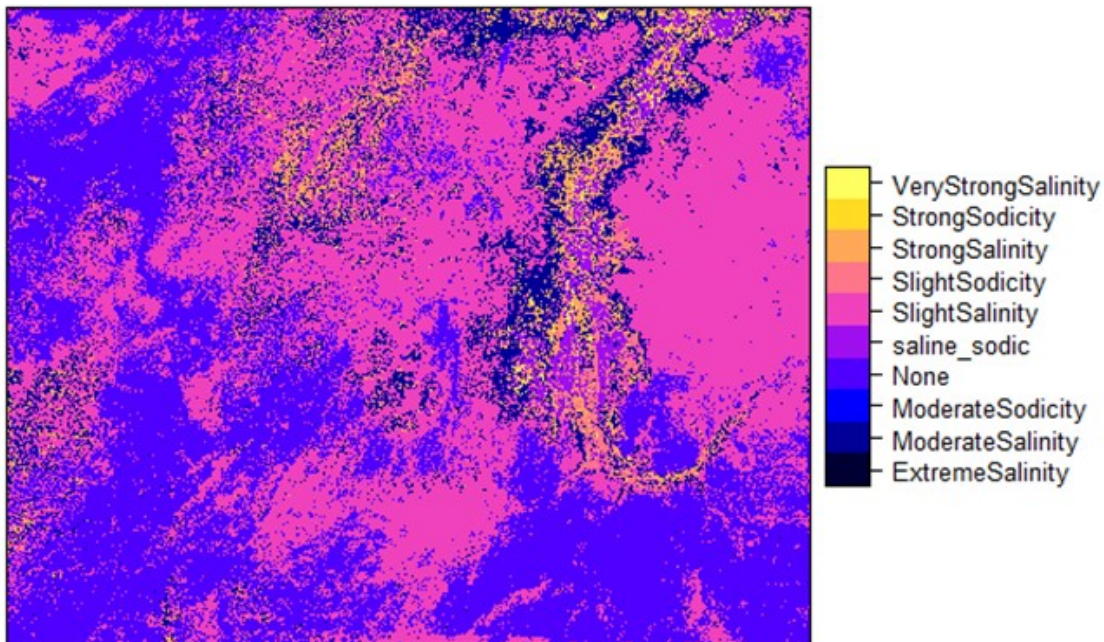

Figure 2: Topsoil (0–30 cm) map of intensity of salt problems

The final map in Figure 2 is exported as a GIS file format for data sharing. Since the export function does not work with factors /character values, the salt classes in the maps are first converted into numeric map–values and then exported. A look–up table (LUT) is necessary to help identify the classes and the unique numeric codes generated for each map–value. The LUT is exported as a text–file.

```
> predictors$Saltclass=as.numeric(predictors$saltaffectedness)
> salinity_LUT30=classLUT(predictors["saltaffectedness"],"saltseverity")

  |===========================================================================| 100%

> writeGDAL(predictors["Saltclass"],drivername = "GTiff","Top0_30saltaffected.tif")
> write.table(salinity_LUT30,file = "saltaffected_LUT30.txt",row.names = FALSE)
```

2.2   Accuracy assessment

Accuracy of classified salt–affected map is assessed using confusion matrix. In this strategy holdout samples are independently classified in terms of types and severity of salt problems in the soil. Classification of the holdout samples should follow the same procedure of harmonization as other input data (that is, harmonization of input indicators and depths 0–30 and 30–100 cm). These classes are then compared to the pixel–extracted classes from the classified maps. The Kappa index is a suitable indicator for reporting the accuracy.

#Import and classify validation dataset

```
> soilv=readOGR(".","validation_harmonized")
> soilv=subset(soilv,soilv$Horizon==1)
> soilv$salt_affected1=saltSeverity(soilv$EC,soilv$pH,soilv$ESP,"FAO")
> summary(soilv$salt_affected1)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
    3.0     6.0     8.0     8.5    11.5    15.0
```

3

```
> soilv$saltaffectedness1=classCode(soilv$salt_affected1,"saltseverity")
> summary(soilv$saltaffectedness1)

 ExtremeSalinity ModerateSalinity ModerateSodicity            None
               3               10                1              18
      saline_sodic    SlightSalinity    SlightSodicity   StrongSalinity
                12               13                16                5
```

After classifying the validation dataset, the dataset is used to extract pixel values of the classified map and compared with the classified validation.

 # Extract the salt classes from the map using the validation samples

```
> soilv=subset(soilv,!is.na(soilv$saltaffectedness1))
> predictors.ovv=over(soilv, predictors)
> soilv$salt_affected=predictors.ovv$Salt_affected
> soilv$saltaffectedness=predictors.ovv$saltaffectedness
```

 # Check the summary of extracted classified pixels

```
> summary(soilv$salt_affected)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
  3.000   6.000   8.000   7.808  10.000  14.000
> summary(soilv$saltaffectedness)
 ExtremeSalinity  ModerateSalinity   ModerateSodicity            None
               1                 7                 0              14
      saline_sodic     SlightSalinity     SlightSodicity   StrongSalinity
                18                15                11              10
   StrongSodicity VeryStrongSalinity
                0                 2
```

A visual comparison shows that the validation datasets had points classified as extremely saline soil, but the map reported only one pixel. Similarly, three points in the validation datasets had strong salinity class while the map had 10 pixels with strong salinity classes. A graphical plot of the comparison (confusion matrix) gives a clear picture of the accuracy (Figure 3).

```
> agreementplot(confusion(soilv$salt_affected, soilv$salt_affected1),main = "Accura
cy assessment",xlab ="Class codes in holdout samples", ylab = "Class codes in map")
> Kappa(confusion(soilv$salt_affected, soilv$salt_affected1))
            value     ASE       z   Pr(>|z|)
Unweighted 0.4211 0.06384  6.597  4.208e-11
Weighted   0.4780 0.07792  6.135  8.525e-10
```
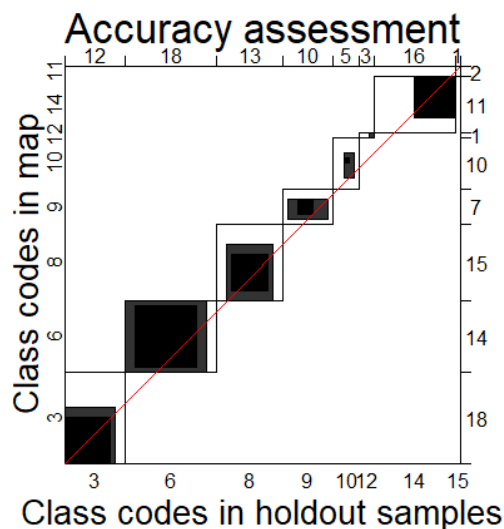

Figure 3: Classification accuracy for salt–affected soils

2.3   Uncertainty assessment

Uncertainty assessment in salt–affected modelling is conceived as estimating uncertainties contributed by input data modelling and uncertainties from the salt–classification model. The Monte Carlo uncertainty propagation approach is used to model both input data uncertainty and classification model uncertainty. This is a three–step approach involving input parameter specification, development of marginal and joint distributions, and simulations for uncertainty propagation. Input parameter specifications comprise definition of the salt–classification model and spatial distribution of mean and variance of the input variables. Spatial distribution of mean and variance are used to train the MC simulations at a set number of simulations/realizations. Usually, MC simulations are more accurate with a higher number of realizations. However, this may cost the analysis computing time for large datasets. A trade–off is necessary to safeguard suitable accuracy while at the same time incurring moderate computing time. A value of 100 is suggested for modelling salt–affected soils. Development of marginal density functions uses statistical distribution parameters and correlation models (crm). Examples of statistical distribution parameters, which depend on the type of distribution, are the mean($\bar{x}$) and standard variation (s) for normal distribution or the scale (λ) and rate (α) for gamma distribution.

The following steps describes the process for preparing the input indicator maps into raster file format, since the modules for uncertainty assessment were developed for the raster file format. The input maps are further converted into spatialPixelsDataFrame to facilitate mathematical operations on dataframes. It is important to check the probability distributions of the input data using the histogram function. Although MC simulations in Figure 4 are not strict on the type of the distribution, normal distribution is easy to sample. It's therefore recommended that normalized distributions be established from the input maps.

 # Convert the input layers into raster files

```
> EC=raster(predictors["ECse"]);names(EC)=c("EC"); EC1=as(EC,"SpatialPixelsDataFrame")
> PH=raster(predictors["PH"]); names(PH)=c("PH"); PH1=as(PH,"SpatialPixelsDataFrame")
> ESP=raster(predictors["ESP"]);names(EC)=c("ESP");ESP1=as(ESP,"SpatialPixelsDataFrame")
>
> ECte=raster(predictors["ECte"]);ECsd=pred_uncerta$pred_sd; names(ECsd)=c("ECsd")
> PHde=raster(predictors["PHt"]);PHsd=pred_uncertb$pred_sd; names(PHsd)=c("PHsd")
> ESPt=raster(predictors["ESPt"]);ESPsd=pred_uncertc$pred_sd; names(ESPsd)=c("ESPsd")
```

 # Obtain sample spatial autocorrelation (Figure 4)

```
> b=nrow(EC1)
> c=trunc(0.01*b)
> jj=EC1[sample(b,c),]
> vrm=autofitVariogram(EC~1,jj)

> plot(vrm)#Note the spatial correlation model and the value of Range parameter
> acf((EC1$EC)) ##Also not the acf0 (at lag 0)
> EC_crm <- makeCRM(acf0 = 0.85, range = 20000, model = "Sph")
> plot(EC_crm, main = "EC correlogram")
```

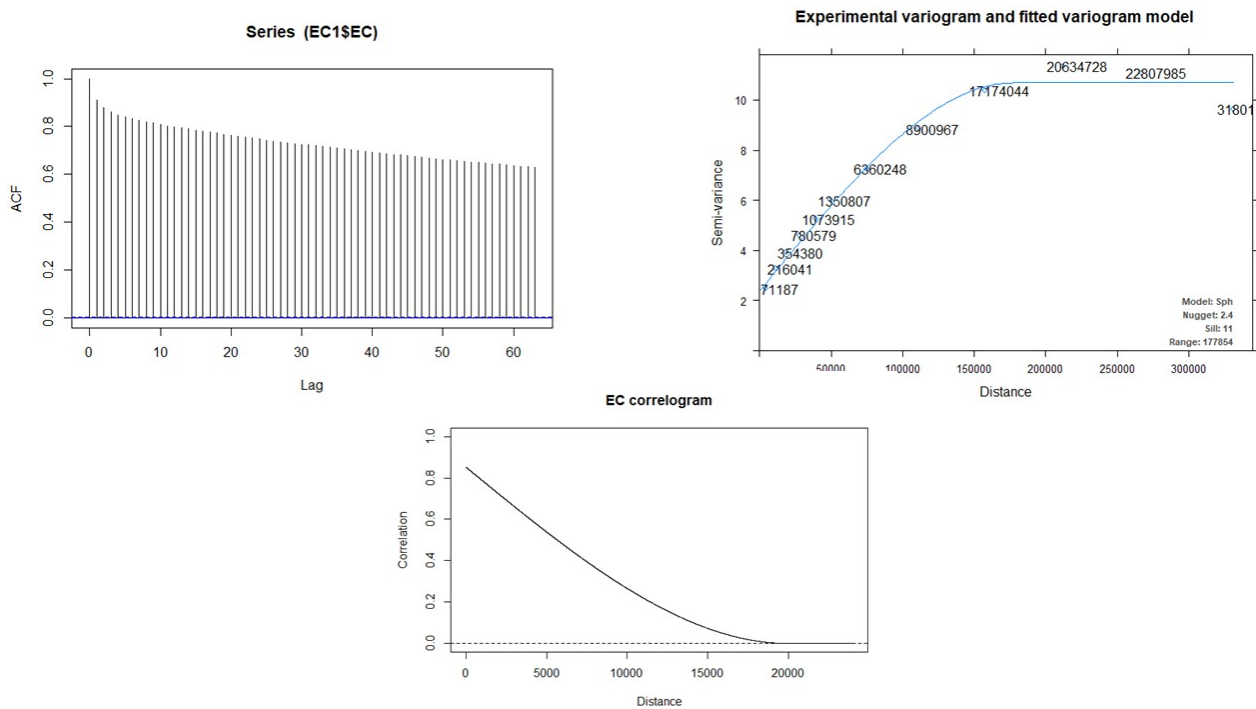The above correlation functions are repeated for all input soil indicators for 0–30 cm and 30–100 cm.

Figure 4: Correlation functions for EC (0–30 cm)

Develop input marginal and joint multivariate uncertainty models for defining MC models

```
> EC_UM=defineUM(distribution="norm",distr_param = c(ECte,ECsd),crm =EC_crm,id = "E
C")
> PH_UM=defineUM(distribution ="norm",distr_param =c(PHde,PHsd),crm =PH_crm,id = "P
H")
> ESP_UM=defineUM(distribution="norm",distr_param=c(ESPt,ESPsd),crm=ESP_crm,id= "ES
P")
> class(EC_UM);class(PH_UM);class(ESP_UM)
[1] "MarginalNumericSpatial"
[1] "MarginalNumericSpatial"
[1] "MarginalNumericSpatial"
```

#Get the correlation values and use them in defining the Monte Carlo Uncertainty Mode (MUM)

```
> cor(values(ECte),values(PHde)); cor(values(ECte),values(ESPt)); cor(values(PHde),
values(ESPt))
[1] 0.5511048
[1] 0.3204495
[1] 0.2859129

>  salinityMUM  =  defineMUM(UMlist  =  list(EC_UM,  PH_UM,  ESP_UM),  cormatrix  =
  matrix(c(1,     cor(values(ECte),values(PHde)),     cor(values(ECte),values(ESPt)),
  cor(values(ECte),     values(PHde)),     1,     cor(values(PHde),     values(ESPt)),
  cor(values(ECte), values(ESPt)), cor(values(PHde), values(ESPt)),1), nrow = 3, ncol
  = 3))

> class(salinityMUM)
[1] "JointNumericSpatial"
```

Possible realizations are now developed after setting the Monte Carlo Uncertainty models (MUM). 100 level is set for simulating the MC simulations.

```
> MC <- 100
> input_sample = genSample(UMobject = salinityMUM, n = MC, samplemethod = "ugs",  n
max = 20, asList = FALSE)
Linear Model of Coregionalization found. Good.
[using unconditional Gaussian cosimulation]
```

 # Compute input sample statistics

```
> EC_sample = input_sample[[1:MC]]
> PH_sample = input_sample[[(MC+1):(2*MC)]]
> ESP_sample = input_sample[[(2*MC+1):(3*MC)]]
> EC_sample_mean <- mean(EC_sample)
> PH_sample_mean <- mean(PH_sample)
> ESP_sample_mean <- mean(ESP_sample)

> EC_sample_sd <- calc(EC_sample, fun = sd)
> PH_sample_sd <- calc(PH_sample, fun = sd)
> ESP_sample_sd <- calc(ESP_sample, fun = sd)
```

#Plot the realizations

```
> par(mfrow=c(2,2),mar = c(1, 1, 2, 2), mgp = c(1.7, 0.5, 0), oma = c(0, 0, 0, 1),
+     las = 1, cex.main = 1, tcl = -0.2, cex.axis = 0.8, cex.lab = 0.8)
> plot(EC_sample_mean, main = "Mean of ECt realizations", xaxt = "n", yaxt = "n")
> plot(PH_sample_mean, main = "Mean of PHt realizations", xaxt = "n", yaxt = "n")
> plot(ESP_sample_mean, main = "Mean of ESPt realizations", xaxt = "n", yaxt = "n")
```
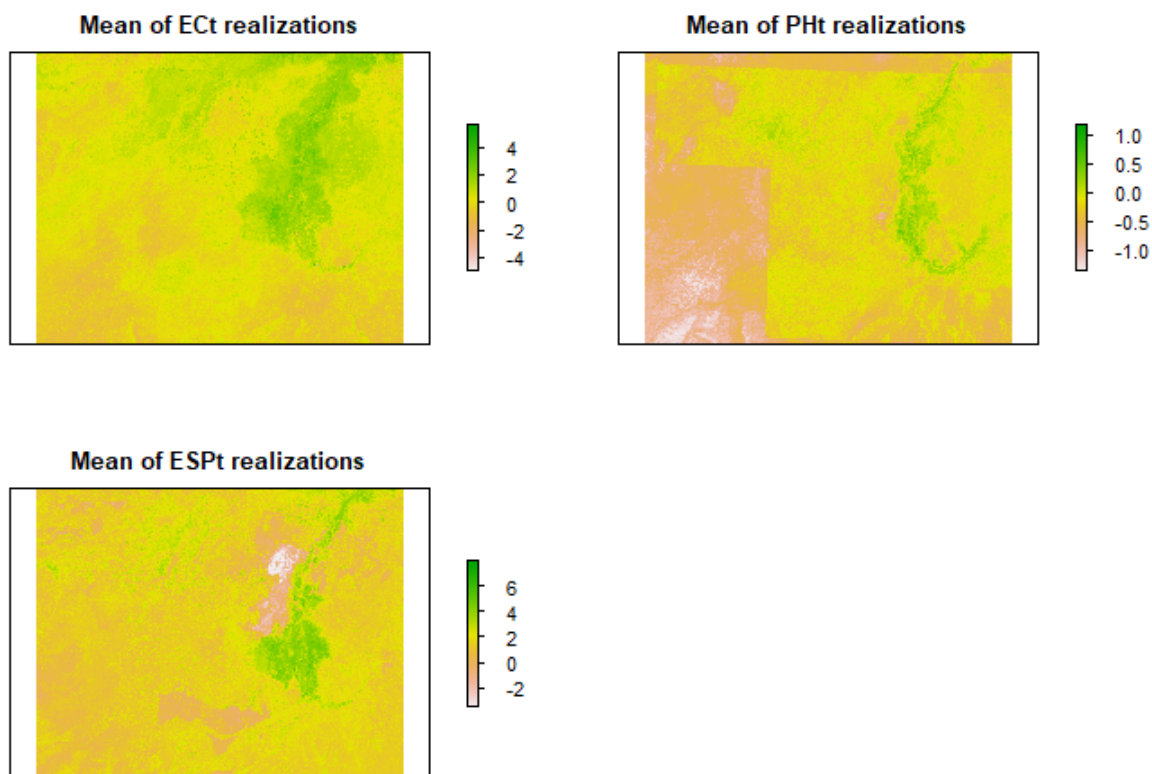

Figure 5: Simulated realizations of normalized input soil indicators

Note that the MC simulations were done on the normalized input soil indicators. It's possible to sample from non–normalized data. However, a harmonized statistical distribution is preferred.

 # Uncertainty propagation through the classification model

The uncertainty propagation model is used to determine how uncertainties in input soil indicators propagate through the classification model into the final classified map.

```
> Salinity_model_raster <- function (EC1,PH1,ESP1){
+     ww=EC1
+     ww=raster(ww)
+     ww$salt=saltSeverity(values(EC1),values(PH1),values(ESP1),"FAO")
+     ww=ww$salt; names(ww)=c("salt")
+     ww
+ }

> v <- list()
> v[[1]] = map(1:100, function(x){input_sample[[x]]})
> v[[2]] = map(101:200, function(x){input_sample[[x]]})
> v[[3]] = map(201:300, function(x){input_sample[[x]]})
> input_sample=v
> salinity_sample=propagate(realizations=input_sample,model=Salinity_model_raster,n
=MC)
```

#Determine the uncertainty in final classified map

```
> samplelist <- list()
> samplelist [[1]] = map(1:100, function(x){input_sample[[x]]})
> samplelist [[2]] = map(101:200, function(x){input_sample[[x]]})
> samplelist [[3]] = map(201:300, function(x){input_sample[[x]]})
> input_sample= samplelist
> salinity_sample = propagate(realizations = input_sample, model =
Salinity_model_raster, n = MC)

> salinity_sample <- raster::stack(salinity_sample)
> names(salinity_sample) <- paste("salt.", c(1:nlayers(salinity_sample)), sep = "")
> salinity_freq = modal(salinity_sample, freq=TRUE)
> salinity_prop = salinity_fre/100
> salinity_SErr = sqrt(salinity_prop*(1-salinity_prop)/100)
> CL=0.95
> z_star=round(qnorm((1-CL)/2,lower.tail=F),digits = 2)
> salinity_MErr=z_star*salinity_SErr
```

The final output is exported to a GIS file format for data sharing.

```
> writeRaster(salinity_MErr,filename="Salinity_ME.tif",format="GTiff")
```

3   Resources

The following resources are useful for implementing the activities during data collection:

- References
    - Technical guidelines and cookbook for mapping salt–affected soils (GSP–Secretariat@fao.org)
    - Country guidelines and specifications for global mapping of salt–affected soils
- Data sources: Input maps of soil indicators of salt problems
- R Software and its contributed packages

4   Outputs

Each participant is expected to produce the following at the end of this lesson:

1. Spatial maps (0–30 and 30–100 cm) of salt–affected soils
2. Uncertainty maps (0–30 and 30–100 cm) of salt–affected soils
3. Map accuracy for 0–30 and 30–100 cm maps of salt–affected soils

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