APPENDIX A - R code for implementation of EWS #SPATIAL MODEL#

library(rootSolve)

***#insert data#***

data<- read.table("data.txt", header = TRUE)

data$Anopheles

data$Susceptibl

data$m01

data$T

str(data)

is.data.frame(data)

data<-data.frame(data)

MosqNo<-data$Anopheles # number of mosquitos

Suscept<-data$Susceptibl # number of susceptibles

***#Kernel function#***

m01<-data$m01

m02<-data$m02

m03<-data$m03

d1<-data$d1

d2<-data$d2

d3<-data$d3

***#weight factor (decay distance factor suitably calibrated to simulate mosquito behavior)***

theta<-0.001

***#kernel\_function***

m0<-(m01\*exp(-theta\*d1)+m02\*exp(-theta\*d2)+m03\*exp(-theta\*d3))

m0

for (i in 1:393){

if (Suscept==0){m0\_p<-0}

else {m0\_p<-(m0/Suscept)}

}

m0\_p

incidence<-0.1

m0final<-incidence\*m0\_p

m0final

***#calculation of vector capacity and Ro#***

n <- 393

a1 <- rbeta(n, 1, 10)

a <- 0.49\*a1+0.01

b1 <- rbeta(n, 1, 10)

b <- 0.3\*b1+0.2

c <- 0.5

r1 <- rbeta(n, 1, 10)

r <- 0.04\*r1+0.01

v1 <- rbeta(n, 1, 10)

v <- 10\*v1+5

p=393

q=100

M=matrix(seq(1,p\*q), p, q)

g=matrix(NA, p,q) # storage matrix for g

VecCap=matrix(NA, p,q) # storage matrix for vector capacity

Ro=matrix(NA, p,q) # storage matrix for Ro

min\_g<-0.01

for (i in 1:393){

for (j in 1:1000){

g[i,j]<- max(min\_g,1/(-4.4+1.31\*data[i,j]-0.03\*data[i,j]\*data[i,j]))

VecCap[i,j]<-(MosqNo[i]\*(a[i]^2)\*exp(-g[i,j]\*v[i]))/(g[i,j])

Ro[i,j]<-(VecCap[i,j]\*b[i]\*c)/r[i]

}

}

***#calculation of τ#***

# (use Ro estimates from previous step)

Ro\_estimates<- read.table("Ro\_estimates.txt", header = TRUE)

is.data.frame(Ro\_estimates)

Ro<-Ro\_estimates$R0

for (i in 1:393){

lambda1 <- m0final[i]

lambda2 <- Ro[i]

if (Ro[i]<1)

{root<-0}

else

{f <- function (tau, lambda3,lambda4) 1+lambda1-tau-exp(-tau\*lambda2)

toot<- uniroot.all(f, c(0.001, 1), tol = 0.0000001, lambda3=lambda1,lambda4=lambda2)}

print(min(root))

}

write.csv(root, "root.txt")

**APPENDIX B - R code to produce spatial maps for risk parameters#**

library(dplyr)

library(ggmap)

library(caret)

***#Define coordinates of Greece***

greece<- c(left = 20.1500159034, bottom = 34.9199876979, right = 26.6041955909, top = 41.8269046087)

get\_stamenmap(greece, zoom = 5, maptype = "toner-background") %>% ggmap()

# (ALTERNATIVE MAP TYPES: "toner-lite", “terrain-background”, “terrain-labels”, #“terrain-#lines”, “toner”, “toner-2010”, “toner-2011”, “toner-background”, “toner-hybrid”, #“toner-#labels”, “toner-lines”, “toner-lite”, “watercolor”)

***#Dataset of Ro ,tau, E and variation estimates produced from EWS #SPATIAL MODEL#***

data<- read.table("data\_estimates.txt", header = TRUE)

head(data)

***#Show names of variables in dataset***

locs<- subset(data, select = c("lat", "lon","Ro","tau", "E"))

head(locs)

names(locs)

***#Select map terrain for presentation***

height<- max(locs$lat) - min(locs$lat)

width<- max(locs$lon) - min(locs$lon)

sac\_borders<- c(bottom = min(locs$lat) - 0.1 \* height,

top = max(locs$lat) + 0.1 \* height,

left = min(locs$lon) - 0.1 \* width,

right = max(locs$lon) + 0.1 \* width)

map<- get\_stamenmap(sac\_borders, zoom = 9, maptype = "toner-background")

map\_terrain<- get\_stamenmap(sac\_borders, zoom = 9, maptype = "terrain")

***#create R\_0 map with predefined size***

ggmap(map) +

geom\_point(data = locs, mapping = aes(x = lon, y = lat, col= Ro, size= Ro)) +

scale\_color\_distiller(palette = "YlOrRd", direction = 1)+

ggtitle(label="Risk in malaria resurgence in central Greece", subtitle = "year=2018") +

xlab("lon") + ylab("lat")+

theme(plot.title = element\_text( size = 18, face = "bold",hjust = 0.5 ),

plot.subtitle = element\_text(hjust = 0.5, face = "italic"))

***#create R\_0 map focused on the coordinates of the data points***

qmplot(x = lon, y = lat, col= Ro, size= Ro, data = locs, maptype = "terrain",

geom = "point") +

scale\_color\_gradient(low = "blue", high = "red")+

ggtitle(label="Risk in malaria resurgence in central Greece", subtitle = "year=2018") +

xlab("lon") + ylab("lat")+

theme(plot.title = element\_text( size = 18, face = "bold",hjust = 0.5 ),

plot.subtitle = element\_text(hjust = 0.5, face = "italic"))

***#create R\_0 heat map with points***

ggmap(map\_terrain)+

stat\_density2d(data = locs, aes(x = lon, y = lat ,fill = stat(nlevel)),

geom = "polygon",bins=100) +

geom\_point(data = locs, mapping =aes(x = lon, y = lat, col= Ro)) +

scale\_color\_gradient(low = "blue", high = "red")+

scale\_fill\_gradient(low = "yellow", high = "orange")+

ggtitle(label="Risk in malaria resurgence in central Greece", subtitle = "year=2018") +

xlab("lon") + ylab("lat")+

theme\_grey(base\_size = 10)+

theme(plot.title = element\_text( size = 16, face = "bold",hjust = 0.5 ),

plot.subtitle = element\_text(hjust = 0.5, face = "italic"))+

guides( size=FALSE, alpha=FALSE)+

labs(color="Ro",fill="density")

***#create τ map with predefined size#***

ggmap(map) +

geom\_point(data = locs, mapping = aes(x = lon, y = lat, col= tau, size= tau)) +

scale\_color\_distiller(palette = "YlOrRd", direction = 1)+

ggtitle(label="Risk in malaria resurgence in central Greece", subtitle = "year=2018") +

xlab("lon") + ylab("lat")+

theme(plot.title = element\_text( size = 18, face = "bold",hjust = 0.5 ),

plot.subtitle = element\_text(hjust = 0.5, face = "italic"))

***#create τ map focused on the coordinates of the data points***

qmplot(x = lon, y = lat, col= tau, size= tau, data = locs, maptype = "terrain",

geom = "point") +

scale\_color\_gradient(low = "blue", high = "red")+

ggtitle(label="Risk in malaria resurgence in central Greece", subtitle = "year=2018") +

xlab("lon") + ylab("lat")+

theme(plot.title = element\_text( size = 18, face = "bold",hjust = 0.5 ),

plot.subtitle = element\_text(hjust = 0.5, face = "italic"))

***#create τheat map with points***

ggmap(map\_terrain)+

stat\_density2d(data = locs, aes(x = lon, y = lat ,fill = stat(nlevel)),

geom = "polygon",bins=100) +

geom\_point(data = locs, mapping =aes(x = lon, y = lat, col= tau),alpha=1) +

scale\_color\_gradient(low = "blue", high = "red")+

scale\_fill\_gradient(low = "yellow", high = "orange")+

ggtitle(label="Risk in malaria resurgence in central Greece", subtitle = "year=2018") +

xlab("lon") + ylab("lat")+

theme\_grey(base\_size = 10)+

theme(plot.title = element\_text( size = 16, face = "bold",hjust = 0.5 ),

plot.subtitle = element\_text(hjust = 0.5, face = "italic"))+

guides( size=FALSE, alpha=FALSE)+

labs(color="tau",fill="density")

***#create E(infections) map with predefined size***

ggmap(map) +

geom\_point(data = locs, mapping = aes(x = lon, y = lat, col= E, size= E)) +

scale\_color\_distiller(palette = "YlOrRd", direction = 1)+

ggtitle(label="Risk in malaria resurgence in central Greece", subtitle = "year=2018") +

xlab("lon") + ylab("lat")+

theme(plot.title = element\_text( size = 18, face = "bold",hjust = 0.5 ),

plot.subtitle = element\_text(hjust = 0.5, face = "italic"))

***#create E(infections) map focused on the coordinates of the data points***

qmplot(x = lon, y = lat, col= E, size= E, data = locs, maptype = "terrain",

geom = "point") +

scale\_color\_gradient(low = "blue", high = "red")+

ggtitle(label="Risk in malaria resurgence in central Greece", subtitle = "year=2018") +

xlab("lon") + ylab("lat")+

theme(plot.title = element\_text( size = 18, face = "bold",hjust = 0.5 ),

plot.subtitle = element\_text(hjust = 0.5, face = "italic"))

***#create E(infections) heat map with points***

ggmap(map\_terrain)+

stat\_density2d(data = locs, aes(x = lon, y = lat ,fill = stat(nlevel)),

geom = "polygon",bins=100) +

geom\_point(data = locs, mapping =aes(x = lon, y = lat, col= E),alpha=1) +

scale\_color\_gradient(low = "blue", high = "red")+

scale\_fill\_gradient(low = "yellow", high = "orange")+

ggtitle(label="Risk in malaria resurgence in central Greece", subtitle = "year=2018") +

xlab("lon") + ylab("lat")+

theme\_grey(base\_size = 10)+

theme(plot.title = element\_text( size = 16, face = "bold",hjust = 0.5 ),

plot.subtitle = element\_text(hjust = 0.5, face = "italic"))+

guides( size=FALSE, alpha=FALSE )+

labs(color="E",fill="density")