Appendix

Program Commands

Figure 13. Program commands for contribute bar chart

```
# logistic regression for tiny sample of 30 grid-points in Coral island

read.table("dataCorado.txt",header=TRUE,as.is=TRUE) -> dc
str(dc)
table(dc$luCode43)
table(dc$luCode52)
dc$luCode52 <- ifelse(dc$luCode52=="U201-A405","A405",dc$luCode52)
dc$luCode52 <- ifelse(dc$luCode52=="U201-A405","A405",dc$luCode52)
dc$R52 <- ifelse(dc$luCode52=="A302",1,2)
dc$y1 <- 2-dc$R52
dcs <- subset(dc,dc$x>429.9 & dc$x<430.5 & dc$y>861.0 & dc$y<861.5)
table(dcs$luCode43,dcs$R52)
ds <- as.data.frame(table(dcs$luCode43,dcs$R52))
tab <- table(dcs$luCode43,dcs$R52)
lu43. <- factor(row.names(tab))
glm(family=binomial,tab~lu43.) -> mod0
summary(mod0)
```

Figure 14. Program commands for contribute bar chart

```
# bar chart of results of logistic regression
ymaxBP <- 102
xmaxBP <- 5
clr <- c("pink","brown","green")
xat <- c(1,2.35,3.7)
xlabs <- c("Rubber","Coconut","Forest")

windows(4,4)
par(las=1,oma=c(3.5,2,3.5,1),mar=c(1,0.5,0,0),tcl=0.2,mgp=c(1,0.1,0))
tab <- table(dcs$luCode43,dcs$R52)
pcLU <- 100*tab[,1]/(tab[,1]+tab[,2])
pcMean1 <- 100*sum(tab[,1])/sum(tab)
barplot(pcLU,names.arg="",ylim=c(0,ymaxBP),xlim=c(0,xmaxBP),width=0.7,space=
        0.9,horiz=F,col=clr,cex.axis=1.2,cex.names=0.8,xlab="",cex.lab
        =1,xaxs="i")
abline(h=10*c(1:10),col="grey")
abline(h=pcMean1,col="red",lwd=2)
barplot(pcLU,add=T,names.arg="",cex.axis=1.2,cex.names=0.8,cex.lab=1,
        col=clr,width=0.7,space=0.9)
text(xmaxBP-0.1,pcMean1+2,"mean",cex=1.2,adj=c(1,0))
```

```
axis(side=1,at=xat,lab=xlabs,padj=0.2,cex.axis=1.2,tcl=0)
axis(side=1,at=xat[2],lab=xlabs[2],padj=0.2,cex.axis=1.2,tcl=0)
axis(side=1,at=2.35,lab="Land Use in 2000",padj=2,tcl=0,cex.axis=1.2)
mtext(side=3,adj=-0.31,line=0.5,"% Para Rubber in 2009",cex=1.2)
box()
#----------------------------------------------------
options(contrasts=c("contr.sum","contr.poly"))
# logistic regression models
glm(family=binomial,data=dcs,y1~factor(luCode43)) -> mod1
rez1 <- summary(mod1)
# re-fit model with last predictor level interchanged with first
dcs$luCode43.1 <- ifelse(dcs$luCode43==max(dcs$luCode43),min(dcs$luCode43),
                        ifelse(dcs$luCode43==min(dcs$luCode43),max(dcs$luCode43),
dcs$luCode43))
glm(family=binomial,data=dcs,y1~factor(luCode43.1)) -> mod1a
rez1a <- summary(mod1a)
luCoef <- c(rez1$coef[c(2:3),1],rez1a$coef[2,1])
luSE <- c(rez1$coef[c(2:3),2],rez1a$coef[2,2])

kLu9 <- 0.11216
luCILB9 <- 100/(1+exp(-(kLu9+luCoef-1.96*luSE)))
luCIUB9 <- 100/(1+exp(-(kLu9+luCoef+1.96*luSE)))
luEst9 <- 100/(1+exp(-(kLu9+luCoef)))
sum(luEst9*table(dcs$luCode43))/100
sum(dcs$y1)
ymaxBP <- 102
xmaxBP <- 5
clr <- c("pink","brown","green")
xat <- c(0.99,2.335,3.635)
xlabs <- c("Rubber","Coconut","Forest")

windows(4,4)
par(las=1,oma=c(3.5,2,3.5,1),mar=c(1,0.5,0,0),tcl=0.2,mgp=c(1,0.1,0))
tab <- table(dcs$luCode43,dcs$R52)
pcLU <- 100*tab[,1]/(tab[,1]+tab[,2])
pcMean1 <- 100*sum(tab[,1])/sum(tab)
barplot(pcLU,names.arg="",ylim=c(0,ymaxBP),xlim=c(0,xmaxBP),width=0.7,space=
                        0.9,horiz=F,col=clr,cex.axis=1.2,cex.names=0.8,xlab="",cex.lab
                        =1,xaxs="i")
abline(h=10*c(1:10),col="grey")
abline(h=pcMean1,col="red",lwd=2)
barplot(pcLU,add=T,names.arg="",cex.axis=1.2,cex.names=0.8,cex.lab=1,
                        col=clr,width=0.7,space=0.9)
text(xmaxBP-0.1,pcMean1+2,"mean",cex=1.2,adj=c(1,0))
axis(side=1,at=xat,lab=xlabs,padj=0.2,cex.axis=1.2,tcl=0)
axis(side=1,at=xat[2],lab=xlabs[2],padj=0.2,cex.axis=1.2,tcl=0)
axis(side=1,at=2.35,lab="Land Use in 2000",padj=2,tcl=0,cex.axis=1.2)
```

```
for (j in c(1:3)) {
points(c(xat[j],xat[j]),c(luCILB9[j],luCIUB9[j]),type="l",lwd=5,col="blue")
}
points(xat,luEst9,pch=21,cex=1.4,bg="blue")
mtext(side=3,adj=-0.31,line=0.5,"% Para Rubber in 2009",cex=1.2)
box()
options(contrasts=c("contr.sum","contr.poly"))
```

Figure 15.

```
# logistic regression models all of Coral Island
glm(family=binomial,data=dcs,y1~factor(luCode43)) -> mod1
rez1 <- summary(mod1)
# re-fit model with last predictor level interchanged with first
dcs$luCode43.1 <- ifelse(dcs$luCode43==max(dcs$luCode43),min(dcs$luCode43),
                    ifelse(dcs$luCode43==min(dcs$luCode43),max(dcs$luCode43),
                    dcs$luCode43))
glm(family=binomial,data=dcs,y1~factor(luCode43.1)) -> mod1a
rez1a <- summary(mod1a)
luCoef <- c(rez1$coef[c(2:3),1],rez1a$coef[2,1])
luSE <- c(rez1$coef[c(2:3),2],rez1a$coef[2,2])

kLu9 <- -1.79986
luCILB9 <- 100/(1+exp(-(kLu9+luCoef-1.96*luSE)))
luCIUB9 <- 100/(1+exp(-(kLu9+luCoef+1.96*luSE)))
luEst9 <- 100/(1+exp(-(kLu9+luCoef)))
sum(luEst9*table(dcs$luCode43))/100
sum(dcs$y1)
ymaxBP <- 102
xmaxBP <- 5
clr <- c("pink","brown","green")
xat <- c(0.99,2.335,3.635)
xlabs <- c("Rubber","Coconut","Forest")

windows(4,4)
par(las=1,oma=c(3.5,2,3.5,1),mar=c(1,0.5,0,0),tcl=0.2,mgp=c(1,0.1,0))

tab <- table(dcs$luCode43,dcs$R52)
pcLU <- 100*tab[,1]/(tab[,1]+tab[,2])
pcMean1 <- 100*sum(tab[,1])/sum(tab)
barplot(pcLU,names.arg="",ylim=c(0,ymaxBP),xlim=c(0,xmaxBP),width=0.7,space=
                    0.9,horiz=F,col=clr,cex.axis=1.2,cex.names=0.8,xlab="",cex.lab
                    =1,xaxs="i")
abline(h=10*c(1:10),col="grey")
abline(h=pcMean1,col="red",lwd=2)
barplot(pcLU,add=T,names.arg="",cex.axis=1.2,cex.names=0.8,cex.lab=1,
                    col=clr,width=0.7,space=0.9)
text(xmaxBP-0.1,pcMean1+2,"mean",cex=1.2,adj=c(1,0))
```

```
axis(side=1,at=xat,lab=xlabs,padj=0.2,cex.axis=1.2,tcl=0)
axis(side=1,at=xat[2],lab=xlabs[2],padj=0.2,cex.axis=1.2,tcl=0)
axis(side=1,at=2.35,lab="Land Use in 2000",padj=2,tcl=0,cex.axis=1.2)
for (j in c(1:3)) {
 points(c(xat[j],xat[j]),c(luCILB9[j],luCIUB9[j]),type="l",lwd=5,col="blue")
}
points(xat,luEst9,pch=21,cex=1.4,bg="blue")
mtext(side=3,adj=-0.31,line=0.5,"% Para Rubber in 2009",cex=1.2)
box()
```

Figure 16.

```
# logistic regression models - Separate West and East
# logistic regression for sample of 424 grid-points in Coral island

read.table("dataCorado.txt",header=TRUE,as.is=TRUE) -> dc
table(dc$luCode43)
table(dc$luCode52)
dc$luCode52 <- ifelse(dc$luCode52=="U201-A405","A405",dc$luCode52)
dc$luCode52 <- ifelse(dc$luCode52=="U201-A405","A405",dc$luCode52)
dc$R52 <- ifelse(dc$luCode52=="A302",1,2)
dc$y1 <- 2-dc$R52

dcs <- subset(dc,dc$x>429.9 & dc$x<430.5 & dc$y>861.0 & dc$y<861.5)
table(dcs$luCode43,dcs$R52)
ds <- as.data.frame(table(dcs$luCode43,dcs$R52))
tab <- table(dcs$luCode43,dcs$R52)
lu43. <- factor(row.names(tab))

# create barchart with CIs
#-----------------------------------------------
ymaxBP <- 102
xat <- c(1.35,3.7,6.1)
xlabs <- c("Rubber","Coconut","Forest")
# logistic regression models
lu <- dcs$luCode43
dcs$lu.loc <- ifelse(lu=="A302" & loc=="west",1,
                     ifelse(lu=="A302" & loc=="east",2,
                     ifelse(lu=="A405" & loc=="west",3,
                     ifelse(lu=="A405" & loc=="east",4,
                     ifelse(lu=="F101" & loc=="west",5,
                     ifelse(lu=="F101" & loc=="east",6,0))))))
options(contrasts=c("contr.sum","contr.poly"))
glm(data=dcs,family=binomial,y1~factor(lu.loc)) -> mod0
dcs$lu.loc1 <- ifelse(dcs$lu.loc==1,99,dcs$lu.loc)
glm(data=dcs,family=binomial,y1~factor(lu.loc1)) -> mod1
rez0 <- summary(mod0)
rez1 <- summary(mod1)
```

```
luCoef <- c(mod0$coef[c(2:6)],mod1$coef[6])
luSE <- c(rez0$coef[c(2:6),2],rez1$coef[6,2])
kLu9 <- -1.63406
luCILB9 <- 100/(1+exp(-(kLu9+luCoef-1.96*luSE)))
luCIUB9 <- 100/(1+exp(-(kLu9+luCoef+1.96*luSE)))
luEst9 <- 100/(1+exp(-(kLu9+luCoef)))
sum(luEst9*table(dcs$lu.loc)/100)
sum(dcs$y1)
luCILB9 <- c(luCILB9[1:2],NA,luCILB9[3:4],NA,luCILB9[5:6])
luCIUB9 <- c(luCIUB9[1:2],NA,luCIUB9[3:4],NA,luCIUB9[5:6])

ymaxBP <- 102
xmaxBP <- 10.5
clr <- c("yellow","grey70","white")
colours <- rep(clr,3)[1:8]
xat <- c(1.6,5,8.4)
taan <- function(x) {
 y <- ifelse(is.finite(x),100*(1+sqrt(x/100)-sqrt(1-x/100))/2,NaN)
 return(y)
}
windows(4,5)
par(las=1,oma=c(3.5,2,3.5,1),mar=c(1,0.5,0,0),tcl=0.2,mgp=c(1,0.1,0))
ylab <- c(0,20,40,60,80,100)
ytick <- ylab
xC <- c(0.72,1.89,3.07,4.34,5.49,6.72,7.87,9.16)
tab <- table(dcs$lu.loc,dcs$y1)
pcLU.loc <- 100*tab[,2]/(tab[,1]+tab[,2])
pcLU.loc <- c(pcLU.loc[1:2],0,pcLU.loc[3:4],0,pcLU.loc[5:6])
Mean1 <- 100*sum(tab[,2])/sum(tab)
barplot(pcLU.loc,names.arg="",ylim=c(0,ymaxBP),xlim=c(-1,xmaxBP),yaxt="n",
                        horiz=F,col=colours,cex.axis=1.2,cex.names=0.8,xlab="",cex.lab
=0.9,xaxs="i")
abline(h=ytick,col="grey")
abline(h=Mean1,col="red",lwd=2)
barplot(pcLU.loc,add=T,names.arg="",cex.axis=1.2,cex.names=0.8,cex.lab=0.9,
                        yaxt="n",col=colours)
axis(side=1,at=xat[c(1,3)],lab=xlabs[c(1,3)],padj=0.1,cex.axis=1.2,tcl=0)
axis(side=1,at=xat[2],lab=xlabs[2],padj=0.1,cex.axis=1.2,tcl=0)
axis(side=1,at=5,lab="Land Use in 2000",padj=1.8,tcl=0,cex.axis=1.2)
legend("topright",inset=c(0.02,0.01),leg="mean",lwd=2,cex=1.2,
                        x.intersp=0.4,col="red",bg="ivory",y.intersp=0.9)
legend("topright",inset=c(0.02,0.24),leg=c("West","East"),pch=22,
        pt.bg=clr,pt.cex=2,cex=1.2,bg="ivory",y.intersp=0.9,x.intersp=0.7)
for (j in c(1:8)) {
      points(c(xC[j],xC[j]),c(luCILB9[j],luCIUB9[j]),type="l",lwd=5,col="blue")
      }
points(xC[c(1,2,4,5,7,8)],luEst9,pch=21,cex=1.4,bg="blue")
```

```
axis(side=2,at=ytick,lab=ylab,cex.axis=1.2)
mtext(side=3,adj=-0.22,line=0.3,"% Rubber in 2009",cex=1.2)
box()
mtext(outer=T,side=3,adj=0.5,line=1.8,cex=1.3,"Coral Island")
```

Figure 17. Program commands for contribute land-use change in 1967-1985.

```
# phuket101828.Rcm
# Plot digitized land-use change for Phuket for 1967, 1975 & 1985

# ----------------------function to compute area of a polygon
area <- function(X) {
 X <- rbind(X,X[1,])
 x <- X[,1]
 y <- X[,2]
 lx <- length(x)
 sum((x[2:lx]-x[1:lx-1])*(y[2:lx]+y[1:lx-1]))/2
}

setwd("g:/phuket")
read.table("phuket1001dig.txt",h=T,as.is=T) -> lu1001
read.table("phuket1002dig.txt",h=T,as.is=T) -> lu1002

lu10 <- rbind(lu1001,lu1002)
rm(lu1001,lu1002)
lu10$luCode[is.na(lu10$luCode)] <- "Z0"
read.table("phuket1801dig.txt",h=T,as.is=T) -> lu1801
read.table("phuket1802dig.txt",h=T,as.is=T) -> lu1802
lu18 <- rbind(lu1801,lu1802)
rm(lu1801,lu1802)

lu18$luCode[is.na(lu18$luCode)] <- "Z0"

read.table("phuket2801dig.txt",h=T,as.is=T) -> lu2801
read.table("phuket2802dig.txt",h=T,as.is=T) -> lu2802

lu28 <- rbind(lu2801,lu2802)
rm(lu2801,lu2802)
lu28$luCode[is.na(lu28$luCode)] <- "Z0"

xmin <- min(lu10$x,lu18$x,lu28$x); xmax <- max(lu10$x,lu18$x,lu28$x)
ymin <- min(lu10$y,lu18$y,lu28$y); ymax <- max(lu10$y,lu18$y,lu28$y)

xmax <- xmax+5
read.table("phuket10OK.txt",h=T,as.is=T) -> Rdata10
read.table("phuket10OK.xy",h=T,as.is=T) -> Rxy10
```

```
read.table("phuket18OK.txt",h=T,as.is=T) -> Rdata18
read.table("phuket18OK.xy",h=T,as.is=T) -> Rxy18
read.table("phuket28OK.txt",h=T,as.is=T) -> Rdata28
read.table("phuket28OK.xy",h=T,as.is=T) -> Rxy28

x <- Rxy28$x
y <- Rxy28$y
Rxy28$x <- -180.8+1.43*x+0.21*y-0.0005*x*y
Rxy28$y <- 42.1-0.1*x+0.9475*y+0.000125*x*y
x <- Rxy18$x
y <- Rxy18$y
Rxy18$x <- x-0.3
Rxy18$y <- y+0.2
Rxy10$x <- x-0.3
Rxy10$y <- y+0.2

clr <- c("wheat","palegreen","wheat3","grey70","burlywood",        # colours for land-
        use groups
        "grey70","orange","green","grey70","goldenrod",
        "greenyellow","olivedrab3","chartreuse4","seagreen2",
        "yellow","red","black","grey30","sienna2","pink",
        "indianred","grey","lightskyblue","slateblue","white")

luCh <- lu10$luCode
nCh <- nchar(luCh)
lu10$luCode <- paste(toupper(substr(luCh,1,1)),substr(luCh,2,nCh),sep="")
luCh <- lu18$luCode
nCh <- nchar(luCh)
lu18$luCode <- paste(toupper(substr(luCh,1,1)),substr(luCh,2,nCh),sep="")
luCh <- lu28$luCode
nCh <- nchar(luCh)
lu28$luCode <- paste(toupper(substr(luCh,1,1)),substr(luCh,2,nCh),sep="")

luC <- unique(c(lu10$luCode,lu18$luCode,lu28$luCode))
luC <- luC[order(luC)]
luClr <- cbind(luC,clr)

tA10 <- table(lu10$luCode)   # area in hectares of each land-use type
tA10 <- as.data.frame(tA10)
names(tA10)[1] <- "luCode"
tA18 <- table(lu18$luCode)
tA18 <- as.data.frame(tA18)
names(tA18)[1] <- "luCode"
tA28 <- table(lu28$luCode)
tA28 <- as.data.frame(tA28)
names(tA28)[1] <- "luCode"
```

```
merge(tA10,tA18,by.x="luCode",by.y="luCode",all.x=T,all.y=T) -> tA
merge(tA,tA28,by.x="luCode",by.y="luCode",all.x=T,all.y=T) -> tA

tA[is.na(tA)] <- 0
tA$luCode <- as.character(tA$luCode)
tA <- tA[order(tA$luCode),]
names(tA)[4] <- "Freq.z"

windows(13,8)
par(mfrow=c(1,3),las=1,tcl=0,oma=c(1.8,1.3,1.8,0.5),mar=c(0.2,0.3,0,0),mgp=c(1.1,0
        .1,0))
plot(1,type="n",xlim=c(xmin,xmax),ylim=c(ymin,ymax),             # plot data for
        1967
        xaxs="i",yaxs="i",xlab="",ylab="",xaxt="n",cex.axis=0.9)
xat <- (xmin+xmax)/2
axis(side=1,cex.axis=0.9,padj=-0.4)
axis(side=1,at=xat,lab="UTM-E(km)",padj=1,cex.axis=1)
mtext(side=3,line=0.1,adj=-0.07,"UTM-N(km)",cex=0.7)
mtext(side=3,line=0.1,adj=0.5,"Phuket: 1967",cex=0.8)
plotIDs <- Rdata10$plotID
plotIDs <- plotIDs[order(Rdata10$area,decreasing=T)]

lc <- lu10$luCode
lu10$clr <- ifelse(lc==luC[1],clr[1],ifelse(lc==luC[2],clr[2],ifelse(lc==luC[3],clr[3],
        ifelse(lc==luC[4],clr[4],ifelse(lc==luC[5],clr[5],ifelse(lc==luC[6],clr[6],
        ifelse(lc==luC[7],clr[7],ifelse(lc==luC[8],clr[8],ifelse(lc==luC[9],clr[9],
        ifelse(lc==luC[10],clr[10],ifelse(lc==luC[11],clr[11],ifelse(lc==luC[12],clr[12
        ],
        ifelse(lc==luC[13],clr[13],ifelse(lc==luC[14],clr[14],ifelse(lc==luC[15],clr[15
        ],
        ifelse(lc==luC[16],clr[16],ifelse(lc==luC[17],clr[17],ifelse(lc==luC[18],clr[18
        ],
        ifelse(lc==luC[19],clr[19],ifelse(lc==luC[20],clr[20],ifelse(lc==luC[21],clr[21
        ],
        ifelse(lc==luC[22],clr[22],ifelse(lc==luC[23],clr[23],ifelse(lc==luC[24],clr[24
        ],
        ifelse(lc==luC[25],clr[25],"purple"))))) ))))) ))))) ))))) )))))

points(lu10$x,lu10$y,pch=22,cex=0.2,col=lu10$clr)
for (i in plotIDs) {
 pi <- subset(Rxy10,Rxy10$plotID==i)
 di <- Rdata10$luCode[Rdata10$plotID==i]
 polygon(pi$x,pi$y,border="dimgrey")
}
grid(col="dimgrey")
abline(h=850+5*c(1:11),lty="13",col="dimgrey")
box()
```

```
luC10 <- ifelse(luC=="UNCLAS","unclas",luC)
luG <- paste(luC10," (",tA$Freq.x,")",sep="")
len1 <- nchar(luG[1])-1
luG[1] <- paste(substr(luG[1],1,len1)," ha)",sep="")
legend("bottomright",luG,ncol=1,inset=c(0.005,0.002),fill=clr,cex=1,bg="white",
        x.intersp=0.4,y.intersp=0.7)

# plot change from 1967 to 1975-------------------

plot(1,type="n",xlim=c(xmin,xmax),ylim=c(ymin,ymax),yaxt="n",
        xaxs="i",yaxs="i",xlab="",ylab="",xaxt="n")
axis(side=1,cex.axis=0.9,padj=-0.4)
axis(side=1,at=xat,lab="UTM-E(km)",padj=1,cex.axis=1)

mtext(side=3,line=0.1,adj=0.5,"Land-use change: 1967-1975",cex=0.8)

plotIDs <- Rdata18$plotID
plotIDs <- plotIDs[order(Rdata18$area,decreasing=T)]

lc0 <- lu10$luCode
lc1 <- lu18$luCode
lc <- ifelse(lc1==lc0,"Z0",lc1)

lu18$clr <- ifelse(lc==luC[1],clr[1],ifelse(lc==luC[2],clr[2],ifelse(lc==luC[3],clr[3],
        ifelse(lc==luC[4],clr[4],ifelse(lc==luC[5],clr[5],ifelse(lc==luC[6],clr[6],
        ifelse(lc==luC[7],clr[7],ifelse(lc==luC[8],clr[8],ifelse(lc==luC[9],clr[9],
        ifelse(lc==luC[10],clr[10],ifelse(lc==luC[11],clr[11],ifelse(lc==luC[12],clr[12
        ],
        ifelse(lc==luC[13],clr[13],ifelse(lc==luC[14],clr[14],ifelse(lc==luC[15],clr[15
        ],
        ifelse(lc==luC[16],clr[16],ifelse(lc==luC[17],clr[17],ifelse(lc==luC[18],clr[18
        ],
        ifelse(lc==luC[19],clr[19],ifelse(lc==luC[20],clr[20],ifelse(lc==luC[21],clr[21
        ],
        ifelse(lc==luC[22],clr[22],ifelse(lc==luC[23],clr[23],ifelse(lc==luC[24],clr[24
        ],
        ifelse(lc==luC[25],clr[25],"purple"))))) ))))) ))))) ))))) )))))

points(lu18$x,lu18$y,pch=22,cex=0.2,col=lu18$clr)

for (i in plotIDs) {
 pi <- subset(Rxy18,Rxy18$plotID==i)
 di <- Rdata18$luCode[Rdata18$plotID==i]
 polygon(pi$x,pi$y,border="dimgrey")
}
```

```
grid(col="dimgrey")
abline(h=850+5*c(1:11),lty="13",col="dimgrey")
box()

luC18 <- ifelse(luC=="UNCLAS","unclas",luC)
sgn <- ifelse(tA$Freq.y>tA$Freq.x,"+","")

luG <- paste(luC18," (",sgn,tA$Freq.y-tA$Freq.x,")",sep="")
len1 <- nchar(luG[1])-1
luG[1] <- paste(substr(luG[1],1,len1)," ha)",sep="")
legend("bottomright",luG,ncol=1,inset=c(0.005,0.002),fill=clr,cex=1,bg="white",
        x.intersp=0.4,y.intersp=0.7)

plot(1,type="n",xlim=c(xmin,xmax),ylim=c(ymin,ymax),yaxt="n",# plot data for
        1975
        xaxs="i",yaxs="i",xlab="",ylab="",xaxt="n")
axis(side=1,cex.axis=0.9,padj=-0.4)
axis(side=1,at=xat,lab="UTM-E(km)",padj=1,cex.axis=1)

mtext(side=3,line=0.1,adj=0.5,"Phuket: 1975",cex=0.8)

plotIDs <- Rdata18$plotID
plotIDs <- plotIDs[order(Rdata18$area,decreasing=T)]

lc <- lu18$luCode

lu18$clr <- ifelse(lc==luC[1],clr[1],ifelse(lc==luC[2],clr[2],ifelse(lc==luC[3],clr[3],
        ifelse(lc==luC[4],clr[4],ifelse(lc==luC[5],clr[5],ifelse(lc==luC[6],clr[6],
        ifelse(lc==luC[7],clr[7],ifelse(lc==luC[8],clr[8],ifelse(lc==luC[9],clr[9],
        ifelse(lc==luC[10],clr[10],ifelse(lc==luC[11],clr[11],ifelse(lc==luC[12],clr[12
        ],
        ifelse(lc==luC[13],clr[13],ifelse(lc==luC[14],clr[14],ifelse(lc==luC[15],clr[15
        ],
        ifelse(lc==luC[16],clr[16],ifelse(lc==luC[17],clr[17],ifelse(lc==luC[18],clr[18
        ],
        ifelse(lc==luC[19],clr[19],ifelse(lc==luC[20],clr[20],ifelse(lc==luC[21],clr[21
        ],
        ifelse(lc==luC[22],clr[22],ifelse(lc==luC[23],clr[23],ifelse(lc==luC[24],clr[24
        ],
        ifelse(lc==luC[25],clr[25],"purple"))))) ))))) ))))) ))))) )))))

points(lu18$x,lu18$y,pch=22,cex=0.2,col=lu18$clr)
for (i in plotIDs) {
 pi <- subset(Rxy18,Rxy18$plotID==i)
 di <- Rdata18$luCode[Rdata18$plotID==i]
 polygon(pi$x,pi$y,border="dimgrey")
}
```

```
grid(col="dimgrey")
abline(h=850+5*c(1:11),lty="13",col="dimgrey")
box()

luC18 <- ifelse(luC=="UNCLAS","unclas",luC)
luG <- paste(luC18," (",tA$Freq.y,")",sep="")
len1 <- nchar(luG[1])-1
luG[1] <- paste(substr(luG[1],1,len1)," ha)",sep="")
legend("bottomright",luG,ncol=1,inset=c(0.005,0.002),fill=clr,cex=1,bg="white",
        x.intersp=0.4,y.intersp=0.7)

#------------------End of plot change from 1967 to 1975-------------------
windows(13,8)
par(mfrow=c(1,3),las=1,tcl=0,oma=c(1.8,1.3,1.8,0.5),mar=c(0.2,0.3,0,0),mgp=c(1.1,0
        .1,0))

plot(1,type="n",xlim=c(xmin,xmax),ylim=c(ymin,ymax),              # plot data for
        1975
        xaxs="i",yaxs="i",xlab="",ylab="",xaxt="n",cex.axis=0.9)
xat <- (xmin+xmax)/2
axis(side=1,cex.axis=0.9,padj=-0.4)
axis(side=1,at=xat,lab="UTM-E(km)",padj=1,cex.axis=1)
mtext(side=3,line=0.1,adj=-0.07,"UTM-N(km)",cex=0.7)

mtext(side=3,line=0.1,adj=0.5,"Phuket: 1975",cex=0.8)

plotIDs <- Rdata18$plotID
plotIDs <- plotIDs[order(Rdata18$area,decreasing=T)]
lc <- lu18$luCode

lu18$clr <- ifelse(lc==luC[1],clr[1],ifelse(lc==luC[2],clr[2],ifelse(lc==luC[3],clr[3],
        ifelse(lc==luC[4],clr[4],ifelse(lc==luC[5],clr[5],ifelse(lc==luC[6],clr[6],
        ifelse(lc==luC[7],clr[7],ifelse(lc==luC[8],clr[8],ifelse(lc==luC[9],clr[9],
        ifelse(lc==luC[10],clr[10],ifelse(lc==luC[11],clr[11],ifelse(lc==luC[12],clr[12
        ],
        ifelse(lc==luC[13],clr[13],ifelse(lc==luC[14],clr[14],ifelse(lc==luC[15],clr[15
        ],
        ifelse(lc==luC[16],clr[16],ifelse(lc==luC[17],clr[17],ifelse(lc==luC[18],clr[18
        ],
        ifelse(lc==luC[19],clr[19],ifelse(lc==luC[20],clr[20],ifelse(lc==luC[21],clr[21
        ],
        ifelse(lc==luC[22],clr[22],ifelse(lc==luC[23],clr[23],ifelse(lc==luC[24],clr[24
        ],
        ifelse(lc==luC[25],clr[25],"purple"))))) ))))) ))))) ))))) )))))

points(lu18$x,lu18$y,pch=22,cex=0.2,col=lu18$clr)
```

```
for (i in plotIDs) {
 pi <- subset(Rxy18,Rxy18$plotID==i)
 di <- Rdata18$luCode[Rdata18$plotID==i]
 polygon(pi$x,pi$y,border="dimgrey")
}

grid(col="dimgrey")
abline(h=850+5*c(1:11),lty="13",col="dimgrey")
box()

luC18 <- ifelse(luC=="UNCLAS","unclas",luC)
luG <- paste(luC18," (",tA$Freq.y,")",sep="")
len1 <- nchar(luG[1])-1
luG[1] <- paste(substr(luG[1],1,len1)," ha)",sep="")
legend("bottomright",luG,ncol=1,inset=c(0.005,0.002),fill=clr,cex=1,bg="white",
        x.intersp=0.4,y.intersp=0.7)


# plot change from 1975 to 1985----------------------------------------------------------
plot(1,type="n",xlim=c(xmin,xmax),ylim=c(ymin,ymax),yaxt="n",
        xaxs="i",yaxs="i",xlab="",ylab="",xaxt="n")
axis(side=1,cex.axis=0.9,padj=-0.4)
axis(side=1,at=xat,lab="UTM-E(km)",padj=1,cex.axis=1)

mtext(side=3,line=0.1,adj=0.5,"Land-use change: 1975-1985",cex=0.8)
plotIDs <- Rdata28$plotID
plotIDs <- plotIDs[order(Rdata28$area,decreasing=T)]

lc0 <- lu18$luCode
lc1 <- lu28$luCode
lc <- ifelse(lc1==lc0,"Z0",lc1)

lu28$clr <- ifelse(lc==luC[1],clr[1],ifelse(lc==luC[2],clr[2],ifelse(lc==luC[3],clr[3],
        ifelse(lc==luC[4],clr[4],ifelse(lc==luC[5],clr[5],ifelse(lc==luC[6],clr[6],
        ifelse(lc==luC[7],clr[7],ifelse(lc==luC[8],clr[8],ifelse(lc==luC[9],clr[9],
        ifelse(lc==luC[10],clr[10],ifelse(lc==luC[11],clr[11],ifelse(lc==luC[12],clr[12
        ],
        ifelse(lc==luC[13],clr[13],ifelse(lc==luC[14],clr[14],ifelse(lc==luC[15],clr[15
        ],
        ifelse(lc==luC[16],clr[16],ifelse(lc==luC[17],clr[17],ifelse(lc==luC[18],clr[18
        ],
        ifelse(lc==luC[19],clr[19],ifelse(lc==luC[20],clr[20],ifelse(lc==luC[21],clr[21
        ],
        ifelse(lc==luC[22],clr[22],ifelse(lc==luC[23],clr[23],ifelse(lc==luC[24],clr[24
        ],
        ifelse(lc==luC[25],clr[25],"purple"))))) ))))) ))))) ))))) )))))
```

```
points(lu28$x,lu28$y,pch=22,cex=0.2,col=lu28$clr)

for (i in plotIDs) {
 pi <- subset(Rxy28,Rxy28$plotID==i)
 di <- Rdata28$luCode[Rdata28$plotID==i]
 polygon(pi$x,pi$y,border="dimgrey")
}

grid(col="dimgrey")
abline(h=850+5*c(1:11),lty="13",col="dimgrey")
box()
luC28 <- ifelse(luC=="UNCLAS","unclas",luC)
sgn <- ifelse(tA$Freq.y>tA$Freq.z,"+","")

luG <- paste(luC28," (",sgn,tA$Freq.y-tA$Freq.z,")",sep="")
len1 <- nchar(luG[1])-1
luG[1] <- paste(substr(luG[1],1,len1)," ha)",sep="")
legend("bottomright",luG,ncol=1,inset=c(0.005,0.002),fill=clr,cex=1,bg="white",
        x.intersp=0.4,y.intersp=0.7)

plot(1,type="n",xlim=c(xmin,xmax),ylim=c(ymin,ymax),yaxt="n",# plot data for
        1985
        xaxs="i",yaxs="i",xlab="",ylab="",xaxt="n")
axis(side=1,cex.axis=0.9,padj=-0.4)
axis(side=1,at=xat,lab="UTM-E(km)",padj=1,cex.axis=1)

mtext(side=3,line=0.1,adj=0.5,"Phuket: 1985",cex=0.8)

plotIDs <- Rdata28$plotID
plotIDs <- plotIDs[order(Rdata28$area,decreasing=T)]

lc <- lu28$luCode

lu28$clr <- ifelse(lc==luC[1],clr[1],ifelse(lc==luC[2],clr[2],ifelse(lc==luC[3],clr[3],
        ifelse(lc==luC[4],clr[4],ifelse(lc==luC[5],clr[5],ifelse(lc==luC[6],clr[6],
        ifelse(lc==luC[7],clr[7],ifelse(lc==luC[8],clr[8],ifelse(lc==luC[9],clr[9],
        ifelse(lc==luC[10],clr[10],ifelse(lc==luC[11],clr[11],ifelse(lc==luC[12],clr[12
        ],
        ifelse(lc==luC[13],clr[13],ifelse(lc==luC[14],clr[14],ifelse(lc==luC[15],clr[15
        ],
        ifelse(lc==luC[16],clr[16],ifelse(lc==luC[17],clr[17],ifelse(lc==luC[18],clr[18
        ],
        ifelse(lc==luC[19],clr[19],ifelse(lc==luC[20],clr[20],ifelse(lc==luC[21],clr[21
        ],
        ifelse(lc==luC[22],clr[22],ifelse(lc==luC[23],clr[23],ifelse(lc==luC[24],clr[24
        ],
        ifelse(lc==luC[25],clr[25],"purple"))))) ))))) ))))) ))))) )))))
```

```
points(lu28$x,lu28$y,pch=22,cex=0.2,col=lu28$clr)
for (i in plotIDs) {
 pi <- subset(Rxy28,Rxy28$plotID==i)
 di <- Rdata28$luCode[Rdata28$plotID==i]
 polygon(pi$x,pi$y,border="dimgrey")
}

grid(col="dimgrey")
abline(h=850+5*c(1:11),lty="13",col="dimgrey")
box()
luC28 <- ifelse(luC=="UNCLAS","unclas",luC)
luG <- paste(luC28," (",tA$Freq.z,")",sep="")
len1 <- nchar(luG[1])-1
luG[1] <- paste(substr(luG[1],1,len1)," ha)",sep="")
legend("bottomright",luG,ncol=1,inset=c(0.005,0.002),fill=clr,cex=1,bg="white",
          x.intersp=0.4,y.intersp=0.7)

End --------------------------------------------------
```

Figure 20. Create bubble plots showing associations between outcomes and determinants

```
options(scipen=4)              # display numbers properly
read.table("Phuket.txt", h=T,as.is=T) -> p

for (j in c(3,5,7,9,11)) {
 pj <- substr(p[,j],1,1)
 pj <- toupper(pj)        # This section convert water & flat land to other
 p[,j] <- ifelse(pj %in% c("W","M","F","A"),"F",pj)
}

p$land10 <- ifelse(is.na(p[,3]),0,1)
p$land18 <- ifelse(is.na(p[,5]),0,1)
p$land28 <- ifelse(is.na(p[,7]),0,1)
p$land43 <- ifelse(is.na(p[,9]),0,1)
p$land52 <- ifelse(is.na(p[,11]),0,1)

addmargins(table(p$land10,p$land18))
addmargins(table(p$land18,p$land28))
addmargins(table(p$land28,p$land43))
addmargins(table(p$land43,p$land52))
str(p)

########## reduce the sample to land that always remained land
p1 <- subset(p,p$land10==1 & p$land18==1 & p$land28==1 &
```

```
                    p$land43==1 & p$land52==1)
##Separate location
p1$location <- ifelse(p1$y>881,"north","south")
# bar charts for predicting location of urban land at the next survey
p1$yU18 <- ifelse(p1$luCode18=="U",1,0)
p1$yU28 <- ifelse(p1$luCode28=="U",1,0)
p1$yU43 <- ifelse(p1$luCode43=="U",1,0)
p1$yU52 <- ifelse(p1$luCode52=="U",1,0)
lu <- p1$luCode10
loc <- p1$location
p1$lu10.loc <- ifelse(lu=="F" & loc=="north",1,
                    ifelse(lu=="F" & loc=="south",2,
                    ifelse(lu=="U" & loc=="north",3,
                    ifelse(lu=="U" & loc=="south",4,0))))
lu <- p1$luCode18
p1$lu18.loc <- ifelse(lu=="F" & loc=="north",1,
                    ifelse(lu=="F" & loc=="south",2,
                    ifelse(lu=="U" & loc=="north",3,
                    ifelse(lu=="U" & loc=="south",4,0))))
lu <- p1$luCode28
p1$lu28.loc <- ifelse(lu=="F" & loc=="north",1,
                    ifelse(lu=="F" & loc=="south",2,
                    ifelse(lu=="U" & loc=="north",3,
                    ifelse(lu=="U" & loc=="south",4,0))))
lu <- p1$luCode43
p1$lu43.loc <- ifelse(lu=="F" & loc=="north",1,
                    ifelse(lu=="F" & loc=="south",2,
                    ifelse(lu=="U" & loc=="north",3,
                    ifelse(lu=="U" & loc=="south",4,0))))
#-----------------------------------------------------------------------------------
rez <- addmargins(table(p1$plotID10,p1$lu10.loc,p1$yU18))
rez[,,2] -> x
rez[,,3] -> n
nPlots <- dim(n)[1]-1
nGrps <- dim(n)[2]-1
n <- n[c(1:nPlots),c(1:nGrps)]
x <- x[c(1:nPlots),c(1:nGrps)]
ph <- colSums(x)/colSums(n)

r <- n
for (i in c(1:nGrps)) {
 r[,i] <- r[,i]*ph[i]
}
r <- x-r
ssr <- colSums(r^2)
m <- ifelse(n>0,1,0)
m <- colSums(m)
```

```
n <- colSums(n)
v <- ssr*m/((m-1)*n^2)
d18 <- n*v/(ph*(1-ph))         # variance inflation factors
rez <- addmargins(table(p1$plotID18,p1$lu18.loc,p1$yU28))

rez[,,2] -> x
rez[,,3] -> n
nPlots <- dim(n)[1]-1
nGrps <- dim(n)[2]-1
n <- n[c(1:nPlots),c(1:nGrps)]
x <- x[c(1:nPlots),c(1:nGrps)]
ph <- colSums(x)/colSums(n)

r <- n
for (i in c(1:nGrps)) {
 r[,i] <- r[,i]*ph[i]
}
r <- x-r
ssr <- colSums(r^2)
m <- ifelse(n>0,1,0)
m <- colSums(m)
n <- colSums(n)
v <- ssr*m/((m-1)*n^2)

d28 <- n*v/(ph*(1-ph))                # variance inflation factors

rez <- addmargins(table(p1$plotID28,p1$lu28.loc,p1$yU43))
rez[,,2] -> x
rez[,,3] -> n
nPlots <- dim(n)[1]-1
nGrps <- dim(n)[2]-1
n <- n[c(1:nPlots),c(1:nGrps)]
x <- x[c(1:nPlots),c(1:nGrps)]
ph <- colSums(x)/colSums(n)
r <- n
for (i in c(1:nGrps)) {
 r[,i] <- r[,i]*ph[i]
}
r <- x-r
ssr <- colSums(r^2)
m <- ifelse(n>0,1,0)
m <- colSums(m)

n <- colSums(n)
v <- ssr*m/((m-1)*n^2)
d00 <- n*v/(ph*(1-ph))                # variance inflation factors
rez <- addmargins(table(p1$plotID43,p1$lu43.loc,p1$yU52)
```

```
rez[,,2] -> x
rez[,,3] -> n
nPlots <- dim(n)[1]-1
nGrps <- dim(n)[2]-1
n <- n[c(1:nPlots),c(1:nGrps)]
x <- x[c(1:nPlots),c(1:nGrps)]
ph <- colSums(x)/colSums(n)

r <- n
for (i in c(1:nGrps)) {
 r[,i] <- r[,i]*ph[i]
}
r <- x-r
ssr <- colSums(r^2)
m <- ifelse(n>0,1,0)
m <- colSums(m)

n <- colSums(n)
v <- ssr*m/((m-1)*n^2)
d09 <- n*v/(ph*(1-ph))                    # variance inflation factors

ymaxBP <- 102
xmaxBP <- 6
clr <- c("Green","orange")
colours <- rep(clr,3)
xat <- c(1.35,3.7)
xlabs <- c("Non-urban","Urban")

#-----------------------------------------------------------------------------
windows(8,4)
par(mfrow=c(1,4),las=1,oma=c(3.5,4,3.5,1),mar=c(1,0.5,0,0),tcl=0.2,mgp=c(1,0.1,0))

tab <- table(p1$lu10.loc,p1$yU18)
pcLU.loc <- 100*tab[,2]/(tab[,1]+tab[,2])
pcLU.loc <- pcLU.loc[c(1:4)]
pcMean1 <- 100*sum(tab[,2])/sum(tab)
barplot(pcLU.loc,names.arg="",ylim=c(0,ymaxBP),xlim=c(-1,xmaxBP),
                    horiz=F,col=colours,cex.axis=1.8,cex.names=0.8,xlab="",cex.lab
=0.9,xaxs="i")
abline(h=10*c(1:10),col="grey")
abline(h=pcMean1,col="red",lwd=2)
barplot(pcLU.loc,add=T,names.arg="",cex.axis=1.8,cex.names=0.8,cex.lab=0.9,col=c
olours)
text(-0.5,pcMean1+2,"mean",cex=2,adj=c(0,0))
axis(side=1,at=xat,lab=xlabs,padj=0.4,cex.axis=2,tcl=0)
axis(side=1,at=2.5,lab="Land Use in 1967",padj=1.8,tcl=0,cex.axis=1.9)
box()
```

```
mtext(side=3,adj=1,line=0.5,"% Urban in 1975          ",cex=1.3)
#-----------------------------------------------------------------
tab <- table(p1$lu18.loc,p1$yU28)
pcLU.loc <- 100*tab[,2]/(tab[,1]+tab[,2])
pcLU.loc <- pcLU.loc[c(1:4)]
pcMean2 <- 100*sum(tab[,2])/sum(tab)
barplot(pcLU.loc,names.arg="",ylim=c(0,ymaxBP),xlim=c(-1,xmaxBP),yaxt="n",
                        horiz=F,col=colours,cex.axis=1.8,cex.names=0.8,xlab="",cex.lab
                        =0.9,xaxs="i")
abline(h=10*c(1:10),col="grey")
abline(h=pcMean2,col="red",lwd=2)
barplot(pcLU.loc,add=T,names.arg="",cex.axis=1.8,cex.names=0.8,
                        yaxt="n",cex.lab=0.9,col=colours)
axis(side=1,at=xat,lab=xlabs,padj=0.4,cex.axis=2,tcl=0)
axis(side=1,at=2.5,lab="Land Use in 1975",padj=1.8,tcl=0,cex.axis=1.9)
box()
mtext(side=3,adj=0.5,line=0.5,"in 1985",cex=1.3)
#------------------------
tab <- table(p1$lu28.loc,p1$yU43)
pcLU.loc <- 100*tab[,2]/(tab[,1]+tab[,2])
pcLU.loc <- pcLU.loc[c(1:4)]
pcMean3 <- 100*sum(tab[,2])/sum(tab)
barplot(pcLU.loc,names.arg="",ylim=c(0,ymaxBP),xlim=c(-1,xmaxBP),yaxt="n",
                        horiz=F,col=colours,cex.axis=1.8,cex.names=0.8,xlab="",cex.lab
                        =0.9,xaxs="i")
abline(h=10*c(1:10),col="grey")
abline(h=pcMean3,col="red",lwd=2)
barplot(pcLU.loc,add=T,names.arg="",cex.axis=1.8,cex.names=0.8,
                        yaxt="n",cex.lab=0.9,col=colours)
#text(-0.5,pcMean3+2,"mean",cex=2,adj=c(0,0))
axis(side=1,at=xat,lab=xlabs,padj=0.4,cex.axis=2,tcl=0)
axis(side=1,at=2.5,lab="Land Use in 1985",padj=1.8,tcl=0,cex.axis=1.9)
mtext(side=3,adj=0.5,line=0.5,"in 2000",cex=1.3)
box()
#-------------------------------------------------------------------------------------
tab <- table(p1$lu43.loc,p1$yU52)
pcLU.loc <- 100*tab[,2]/(tab[,1]+tab[,2])
pcLU.loc <- pcLU.loc[c(1:4)]
pcMean4 <- 100*sum(tab[,2])/sum(tab)
barplot(pcLU.loc,names.arg="",ylim=c(0,ymaxBP),xlim=c(-1,xmaxBP),yaxt="n",
                        horiz=F,col=colours,cex.axis=1.8,cex.names=0.8,xlab="",cex.lab
                        =0.9,xaxs="i")
abline(h=10*c(1:10),col="grey")
abline(h=pcMean4,col="red",lwd=2)
barplot(pcLU.loc,add=T,names.arg="",cex.axis=1.8,cex.names=0.8,
                        yaxt="n",cex.lab=0.9,col=colours)
#text(-0.5,pcMean4+2,"mean",cex=2,adj=c(0,0))
```

```
legend("topleft",inset=c(0.02,0.01),leg=c("north","south"),pch=22,
                    pt.bg=clr,pt.cex=3,cex=2,bg="ivory",y.intersp=0.9,x.intersp=0.7)
axis(side=1,at=xat,lab=xlabs,padj=0.4,cex.axis=2,tcl=0)
axis(side=1,at=2.5,lab="Land Use in 2000",padj=1.8,tcl=0,cex.axis=1.9)
mtext(side=3,adj=0.5,line=0.5,"in 2009",cex=1.3)
box()
#------------------------
# logistic regression models
options(contrasts=c("contr.sum","contr.poly"))

glm(data=p1,family=binomial,yU18~factor(lu10.loc)) -> mod0
p1$lu10.loc1 <- ifelse(p1$lu10.loc==1,9,p1$lu10.loc)
glm(data=p1,family=binomial,yU18~factor(lu10.loc1)) -> mod1
rez0 <- summary(mod0)
rez1 <- summary(mod1)
luCoef <- c(mod0$coef[c(2:4)],mod1$coef[4])
luSE <- c(rez0$coef[c(2:4),2],rez1$coef[4,2])

kLu18 <- -1.0519
luCILB18 <- 100/(1+exp(-(kLu18+luCoef-1.96*sqrt(d18)*luSE)))
luCIUB18 <- 100/(1+exp(-(kLu18+luCoef+1.96*sqrt(d18)*luSE)))
luEst18 <- 100/(1+exp(-(kLu18+luCoef)))
sum(luEst18*table(p1$lu10.loc)/100)
sum(p1$yU18)
#-------------------------------------------------------------------
glm(data=p1,family=binomial,yU28~factor(lu18.loc)) -> mod0
p1$lu18.loc1 <- ifelse(p1$lu18.loc==1,9,p1$lu18.loc)
glm(data=p1,family=binomial,yU28~factor(lu18.loc1)) -> mod1
rez0 <- summary(mod0)
rez1 <- summary(mod1)
luCoef <- c(mod0$coef[c(2:4)],mod1$coef[4])
luSE <- c(rez0$coef[c(2:4),2],rez1$coef[4,2])

kLu28 <- -0.3331
luCILB28 <- 100/(1+exp(-(kLu28+luCoef-1.96*sqrt(d28)*luSE)))
luCIUB28 <- 100/(1+exp(-(kLu28+luCoef+1.96*sqrt(d28)*luSE)))
luEst28 <- 100/(1+exp(-(kLu28+luCoef)))
sum(luEst28*table(p1$lu18.loc)/100)
sum(p1$yU28)
#-------------------------------------------------------------------
glm(data=p1,family=binomial,yU43~factor(lu28.loc)) -> mod0
p1$lu28.loc1 <- ifelse(p1$lu28.loc==1,9,p1$lu28.loc)
glm(data=p1,family=binomial,yU43~factor(lu28.loc1)) -> mod1
rez0 <- summary(mod0)
rez1 <- summary(mod1)
luCoef <- c(mod0$coef[c(2:4)],mod1$coef[4])
luSE <- c(rez0$coef[c(2:4),2],rez1$coef[4,2])
```

```
kLu0 <- -1.3069
luCILB0 <- 100/(1+exp(-(kLu0+luCoef-1.96*sqrt(d00)*luSE)))
luCIUB0 <- 100/(1+exp(-(kLu0+luCoef+1.96*sqrt(d00)*luSE)))
luEst0 <- 100/(1+exp(-(kLu0+luCoef)))
sum(luEst0*table(p1$lu28.loc)/100)
sum(p1$yU43)

#-------------------------------------------------------------------
glm(data=p1,family=binomial,yU52~factor(lu43.loc)) -> mod0
p1$lu43.loc1 <- ifelse(p1$lu43.loc==1,9,p1$lu43.loc)
glm(data=p1,family=binomial,yU52~factor(lu43.loc1)) -> mod1
rez0 <- summary(mod0)
rez1 <- summary(mod1)
luCoef <- c(mod0$coef[c(2:4)],mod1$coef[4])
luSE <- c(rez0$coef[c(2:4),2],rez1$coef[4,2])

kLu9 <- -0.416
luCILB9 <- 100/(1+exp(-(kLu9+luCoef-1.96*sqrt(d09)*luSE)))
luCIUB9 <- 100/(1+exp(-(kLu9+luCoef+1.96*sqrt(d09)*luSE)))
luEst9 <- 100/(1+exp(-(kLu9+luCoef)))
sum(luEst9*table(p1$lu43.loc)/100)
sum(p1$yU52)


#-------------------------------------------------------- 1967-2009 change
glm(data=p1,family=binomial,yU52~factor(lu10.loc)) -> mod0
p1$lu10.loc1 <- ifelse(p1$lu10.loc==1,9,p1$lu10.loc)
glm(data=p1,family=binomial,yU52~factor(lu10.loc1)) -> mod1
rez0 <- summary(mod0)
rez1 <- summary(mod1)
luCoef <- c(mod0$coef[c(2:4)],mod1$coef[4])
luSE <- c(rez0$coef[c(2:4),2],rez1$coef[4,2])

kLu9 <- -0.5823
luCILB9 <- 100/(1+exp(-(kLu9+luCoef-1.96*sqrt(d09)*luSE)))
luCIUB9 <- 100/(1+exp(-(kLu9+luCoef+1.96*sqrt(d09)*luSE)))
luEst9 <- 100/(1+exp(-(kLu9+luCoef)))
sum(luEst9*table(p1$lu10.loc)/100)
sum(p1$yU52)
#-----------------------------------------------------------------------------------------
xC <- c(0.72,1.89,3.07,4.34,5.44,6.72,7.87,9.16)
windows(8,4)
par(mfrow=c(1,4),las=1,oma=c(3.5,4,3.5,1),mar=c(1,0.5,0,0),tcl=0.2,mgp=c(1,0.1,0))
tab <- table(p1$lu10.loc,p1$yU18)
pcLU.loc <- 100*tab[,2]/(tab[,1]+tab[,2])
pcLU.loc <- pcLU.loc[c(1:4)]
```

```
pcMean1 <- 100*sum(tab[,2])/sum(tab)
barplot(pcLU.loc,names.arg="",ylim=c(0,ymaxBP),xlim=c(-1,xmaxBP),
                    horiz=F,col=colours,cex.axis=1.8,cex.names=0.8,xlab="",cex.lab
                    =0.9,xaxs="i")
abline(h=10*c(1:10),col="grey")
abline(h=pcMean1,col="red",lwd=2)
barplot(pcLU.loc,add=T,names.arg="",cex.axis=1.8,cex.names=0.8,cex.lab=0.9,col=c
olours)
axis(side=1,at=xat,lab=xlabs,padj=0.4,cex.axis=2,tcl=0)
axis(side=1,at=2.5,lab="Land Use in 1967",padj=1.8,tcl=0,cex.axis=1.9)
for (j in c(1:4)) {
 points(c(xC[j],xC[j]),c(luCILB18[j],luCIUB18[j]),type="l",lwd=5,col="blue")
}
box()
mtext(side=3,adj=1,line=0.5,"% Urban in 1975          ",cex=1.3)
tab <- table(p1$lu18.loc,p1$yU28)
pcLU.loc <- 100*tab[,2]/(tab[,1]+tab[,2])
pcLU.loc <- pcLU.loc[c(1:4)]
pcMean2 <- 100*sum(tab[,2])/sum(tab)
barplot(pcLU.loc,names.arg="",ylim=c(0,ymaxBP),xlim=c(-1,xmaxBP),yaxt="n",
                    horiz=F,col=colours,cex.axis=1.8,cex.names=0.8,xlab="",cex.lab
                    =0.9,xaxs="i")
abline(h=10*c(1:10),col="grey")
abline(h=pcMean2,col="red",lwd=2)
barplot(pcLU.loc,add=T,names.arg="",cex.axis=1.8,cex.names=0.8,
                    yaxt="n",cex.lab=0.9,col=colours)
axis(side=1,at=xat,lab=xlabs,padj=0.4,cex.axis=2,tcl=0)
axis(side=1,at=2.5,lab="Land Use in 1975",padj=1.8,tcl=0,cex.axis=1.9)
for (j in c(1:4)) {
 points(c(xC[j],xC[j]),c(luCILB28[j],luCIUB28[j]),type="l",lwd=5,col="blue")
}
box()
mtext(side=3,adj=0.5,line=0.5,"in 1985",cex=1.3)
#-----------------------------------------------------------------------------------------------
tab <- table(p1$lu28.loc,p1$yU43)
pcLU.loc <- 100*tab[,2]/(tab[,1]+tab[,2])
pcLU.loc <- pcLU.loc[c(1:4)]
pcMean3 <- 100*sum(tab[,2])/sum(tab)
barplot(pcLU.loc,names.arg="",ylim=c(0,ymaxBP),xlim=c(-1,xmaxBP),yaxt="n",
                    horiz=F,col=colours,cex.axis=1.8,cex.names=0.8,xlab="",cex.lab
                    =0.9,xaxs="i")
abline(h=10*c(1:10),col="grey")
abline(h=pcMean3,col="red",lwd=2)
barplot(pcLU.loc,add=T,names.arg="",cex.axis=1.8,cex.names=0.8,
                    yaxt="n",cex.lab=0.9,col=colours)
axis(side=1,at=xat,lab=xlabs,padj=0.4,cex.axis=2,tcl=0)
axis(side=1,at=2.5,lab="Land Use in 1985",padj=1.8,tcl=0,cex.axis=1.9)
```

```
mtext(side=3,adj=0.5,line=0.5,"in 2000",cex=1.3)
for (j in c(1:4)) {
 points(c(xC[j],xC[j]),c(luCILB0[j],luCIUB0[j]),type="l",lwd=5,col="blue")
}
box()
tab <- table(p1$lu43.loc,p1$yU52)
pcLU.loc <- 100*tab[,2]/(tab[,1]+tab[,2])
pcLU.loc <- pcLU.loc[c(1:4)]
pcMean4 <- 100*sum(tab[,2])/sum(tab)
barplot(pcLU.loc,names.arg="",ylim=c(0,ymaxBP),xlim=c(-1,xmaxBP),yaxt="n",
                horiz=F,col=colours,cex.axis=1.8,cex.names=0.8,xlab="",cex.lab
                =0.9,xaxs="i")
abline(h=10*c(1:10),col="grey")
abline(h=pcMean4,col="red",lwd=2)
barplot(pcLU.loc,add=T,names.arg="",cex.axis=1.8,cex.names=0.8,
yaxt="n",cex.lab=0.9,col=colours)
legend("topleft",inset=c(0.02,0.01),leg=c("north","south"),pch=22,
                pt.bg=clr,pt.cex=3,cex=2,bg="ivory",y.intersp=0.9,x.intersp=0.7)
axis(side=1,at=xat,lab=xlabs,padj=0.4,cex.axis=2,tcl=0)
axis(side=1,at=2.5,lab="Land Use in 2000",padj=1.8,tcl=0,cex.axis=1.9)
mtext(side=3,adj=0.5,line=0.5,"in 2009",cex=1.3)
for (j in c(1:4)) {
points(c(xC[j],xC[j]),c(luCILB9[j],luCIUB9[j]),type="l",lwd=5,col="blue")
}
box()
#------------------------------------------------------------------------------ end
```

Analyzing Land Use Change using Grid-Digitized Method

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Abstract

This study aims to analyse land-use change by a digitized-grid method, a simple technique that can be used for such analysis. We describe a procedure for restructuring land-use data comprising polygonal "shape files" containing successive (x, y) boundary points of plots for geographic land-use categories as grid-digitized data, and illustrate this method using data from Thailand. The new data comprise a rectangular grid of geographical coordinates with land-use codes and plot identifiers as fields in database tables indexed by the grid coordinates. Having such a database overcomes difficulties land-use researchers face when querying, analyzing and forecasting land-use change.

Key words: Land-use, Grid-Digitization, Geographical Information System.

1. Introduction

Land-use is defined as human activity carried out on land (Irwin and Geoghegan, 2001; Manonmani and Suganya, 2010, Madureira et al., 2007 and Rebelo, 2009). Land-use is influenced by economics, population, culture, politics, and policy. Land-use change is of current scientific interest due to the massive amounts of data available from remote sensing, widespread use of global positioning systems, and the availability of geographic information system (GIS) software. GIS data contain a lot of information that needs to be extracted, such as imagery, land properties, land valuation, and geography (Yang and Qiao, 2010; Strand et al., 2002 and Weng, 2001). Google Earth provides free access to current views of the whole surface of the Earth (Sadr and Rodier, 2012 and Lammeren et al., 2009). GIS software is used to develop land-use data, improve land-use planning (He-bing and Su-xia, 2010; Yang and Qiao, 2010) and to detect land-use change with image processing based on GIS data (Usha et al,. 2012). In addition, scientists study ecological systems (Gret-Regamet et al., 2008) and use GIS technology in environmental surveys (Manonmani and Suganya, 2010 and Gret-Regamey et al., 2008). Klajnsek and Zalik (2005), Bach *et al* (2006), and Mizutani (2009) used GIS data to analyze polygonal shaped land-use data. They focused on shape change and use polygon events and status to understand land-use change.

Although polygonal data structure can provide thematic maps for displaying patterns for a given year, the data are difficult to analyze because the polygons change. Hun *et al* (2011), Stehman and Wickham (2011), Frazier and Wang (2011), Bach *et al* (2006) and Guo *et al* (2011) described the use of pixels, blocks and polygons to construct accurate maps. Whiteside *et al* (2011) confirmed that pixel-based construction can accurately show land-use maps.

Using freely available software such as the R program and its special (*sp*) library, data can be restructured as points on a grid, for which land-use change is easily measured because the grid stays put while only the data change. The grid-digitized method provides a data structure that can be used directly for statistical analysis of land-use change. Data were obtained from the Thailand Department of Land Development.

2. Methodology

2.1 Grid-Digitized Method

The grid-digitized method involves converting the polygonal data to grid-point data. We illustrate this method using a simple example as shown in the maps in Figure 1 based on data structures listed in Table 1.

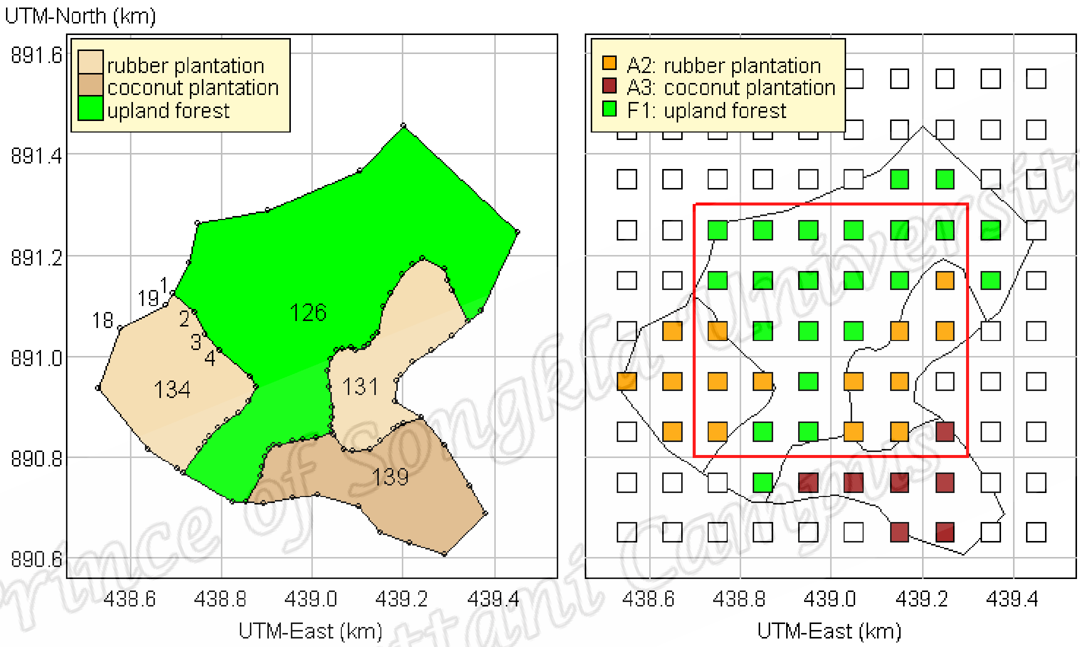

Figure 1. Conversion of polygonal representation (left panel) to digital representation (right panel) for land-use data from Naka-Yai Island in Phuket province of Thailand in 1985.

In this example, the region contains four polygonal plots indentified as 126, 131, 134 and 139, with corresponding land uses recorded as upland forest, rubber plantation or coconut plantation. The corresponding data structure is a table with the four fields plotID, pointID, x and y as indicated in the left panel of Table 1. The pointID field determines the order in which the boundary points (x,y) are connected to obtain a closed polygon for each land-use plot. For example the first four and last two values of pointID for plot 134 are indicated in the left-panel of Figure 1.

plotID	pointID	X	Y
126	1	438.69	891.12
126	2	438.73	891.18
126	3	438.75	891.26
126	4	438.90	891.29
.	.	.	.
.	.	.	.
126	56	438.74	891.09
126	57	438.69	891.12
131	1	439.34	891.07
131	2	439.31	891.04
131	3	439.26	891.01
131	4	439.22	890.99
.	.	.	.
.	.	.	.
131	39	439.31	891.13
131	40	439.34	891.07
134	1	438.69	891.12
134	2	438.74	891.09
134	3	438.76	891.04
134	4	438.80	891.01
.	.	.	.
134	18	438.58	891.05
134	19	438.68	891.10
134	20	438.69	891.12
139	1	439.05	890.85
139	2	439.05	890.84
139	3	439.07	890.81
139	4	439.09	890.81
.	.	.	.
.	.	.	.
139	30	439.01	890.84
139	31	439.05	890.85

x	y	plotID
438.75	891.25	126
438.85	891.25	126
438.95	891.25	126
439.05	891.25	126
439.15	891.25	126
439.25	891.25	126
438.75	891.15	126
438.85	891.15	126
438.95	891.15	126
439.05	891.15	126
439.15	891.15	126
439.25	891.15	131
438.75	891.05	134
438.85	891.05	126
438.95	891.05	126
439.05	891.05	126
439.15	891.05	131
439.25	891.05	131
438.75	890.95	134
438.85	890.95	134
438.95	890.95	126
439.05	890.95	131
439.15	890.95	131
439.25	890.95	0
438.75	890.85	134
438.85	890.85	126
438.95	890.85	126
439.05	890.85	131
439.15	890.85	131
439.25	890.85	139

Table 1. Data structures used to create the land use maps for Figure 1. The left panel lists polygonal data for creating the left panel of Figure 1, whereas the right panel lists grid-point data within the five rows of the rectangle in the right panel of Figure 2. Note that area outside the specified region has plotID coded as 0 (sea, with land-use code labeled Z0).

The computational method for connecting from the polygonal coordinates to those based on the grid involves determining how to assign grid points to polygons. The pseudo code for the program takes the following form.

```
for  each polygon p_i in the specified region
         label all grid points inside p_i as i
end
```

This program can be implemented in any language that accommodates *for…end* loops, provided this language has a function that determines which elements of a specified set of points are contained within a specified polygon. We use the R program after loading its *sp* library, which contains the function *point.in.polygon* () (R Development Core Team, 2012). We use R because we are not aware of any other freely available software that can do this.

3. Land-Use Data Analysis & Findings

3.1 Land-use change

The grid-digitized method described in the preceding section facilitates measurement of land-use change. However this measurement is complicated by the fact that land-use codes themselves change. For example, the categories A2 (rubber plantation), A3 (coconut plantation), and F1 (upland forest) used in 1985 became A302 (para rubber), A405 (coconut plantation) and F101 (dense evergreen forest) respectively, in 2009. Using the 2009 land-use codes, Figure 2 shows the change in land-use for Naka-Yai Island from 1985 to 2009. Note that the four plots corresponding to the three different land-uses reported in 1985 were reduced to a single land use in 2009, and this land-use corresponds to F101 in 1985.

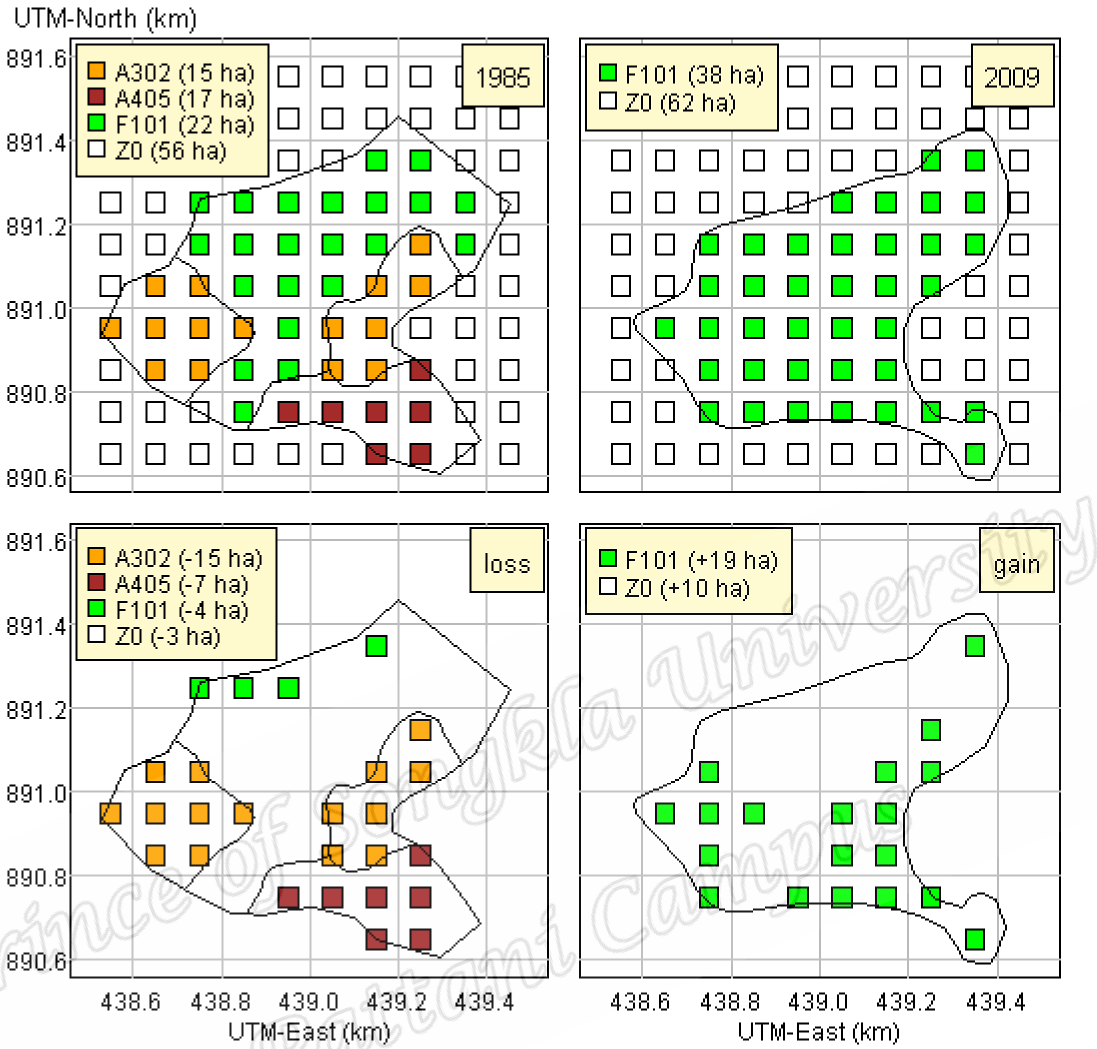

Figure 2. Land-use change in Naka-Yai Island from 1985 to 2009 with losses from 1985 (upper right panel) and gains to 2009 (lower right panel).

Note that plots 131 and 134 changed from para rubber in 1985 to other land-use in 2009, and plot 139 also changed completely. An area of plot 126 along its north coast was also lost but these losses were compensated by gains to plot 126. Note, however, that the apparent loss of the land along the north coast is not a real loss, because the area remained within the island. The explanation of this anomaly is that the coordinates shifted, as described next.

3.2 Coordinate Shifts

A complication when comparing land-use over time is that earlier records of UTM coordinates are inaccurate and require correction. Figure 4 shows polygonal maps of small areas in four corners of Phuket province using the original UTM coordinates for 1985 with maps based on corresponding 2011 Google coordinates (http://maps.google.com) superimposed.

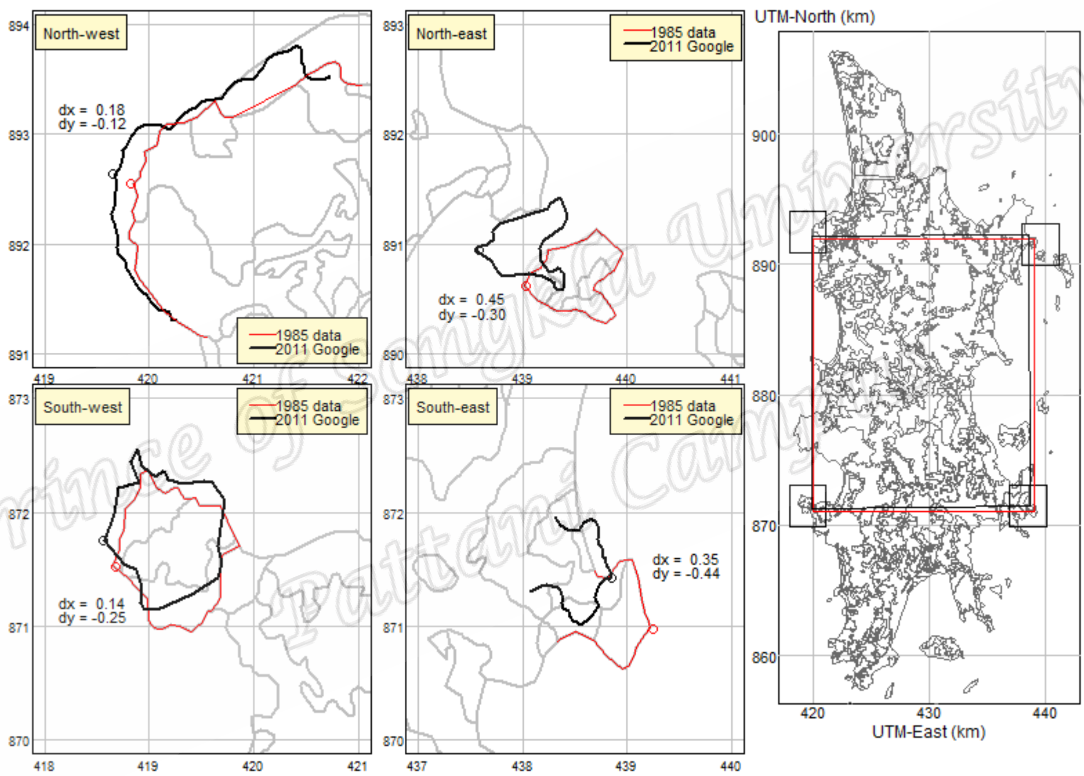

Figure 3. Horizontal (dx) and vertical (dy) shifts (in kilometers) of UTM east and north coordinates, respectively, from 2011 Google map locations in corner regions of Phuket Island, to the corresponding positions based on land-use records recorded by the Thailand Department of Land Development in 1985. Table 2 shows (x,y) coordinates of the location of the rectangle (coloured red) in the right panels, with corresponding (u,v) coordinates.

The coordinate shifts illustrated in Figure 3 are quite substantial and complicate accurate measurement of land-use change. Assuming that coordinates available from Google Earth maps are correct and that these locations have not changed substantially over recent decades, it is desirable to convert all land-use coordinates to agree with the corresponding Google Earth coordinates. Table 2 shows how the coordinates around Phuket Island shifted from 1985 (x, y) to 2009 (u, v)

Table 2. Coordinate shifts in Phuket Island based on information in Figure 3

Rectangle Corner	x, y	km	u, v
North east	439.0, 892.0	-0.45, 0.30	438.55, 892.30
North west	420.0,871.0	-0.18, 0.12	420.18, 870.89
South east	439.0, 871.0	-0.35, 0.44	438.65, 871.44
South west	420.0, 871.0	-0.14,0.25	419.86, 871.25

The method we use for this conversion is based on a bilinear transformation of the form.

$$u = a_1 + b_1x + c_1y + d_1xy \qquad (1)$$

$$v = a_2 + b_2x + c_2y + d_2xy \qquad (2)$$

The parameters ($a_1, b_1, c_1, d_1, a_2, b_2, c_2, d_2$) in equations (1) and (2) are determined by using the data for the coordinate shifts (dx, dy) at the four locations mapped in Figure 3. There equations are expressed in matrix form as

$$\boldsymbol{g} = \boldsymbol{F}\,\boldsymbol{h} \qquad (3)$$

In this formulation $\boldsymbol{g}$ is the column vector ($u_1, v_1, u_2, v_2, u_3, v_3, u_4, v_4$), $\boldsymbol{h}$ is the column vector($a_1, b_1, c_1, d_1, a_2, b_2, c_2, d_2$) and $\boldsymbol{F}$ is an 8 × 8 matrix, as follows

$$\begin{bmatrix} u_1 \\ v_1 \\ u_2 \\ v_2 \\ u_3 \\ v_3 \\ u_4 \\ v_4 \end{bmatrix} = \begin{bmatrix} 1 & x_1 & y_1 & x_1y & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & x_1 & y_1 & x_1y \\ 1 & x_2 & y_2 & x_2y & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & x_2 & y_2 & x_2y \\ 1 & x_3 & y_3 & x_3y & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & x_3 & y_3 & x_3y \\ 1 & x_4 & y_4 & x_4y & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & x_4 & y_4 & x_4y \end{bmatrix} \times \begin{bmatrix} a_1 \\ b_1 \\ c_2 \\ d_2 \\ a_3 \\ b_3 \\ c_4 \\ d_4 \end{bmatrix}.$$

3.3. Analysis Method

Using methods described in the preceding section, the grid-digitized method provides a digital map. Change in land-use is then summarized in a cross tabulation giving area (in hectares) or percentages of land-use categories from one period to the next. These numbers can be displayed as a bubble plot matrix as shown in the right panel of Figure 3, with digital maps of changes shown in the middle panels. Note that darker colours show changes and lighter colours denote no change. For example, the changes from agriculture (A) to urban (U) land-use over the period 1985-2000 was 9.9%, and from agriculture to forest (F) during the same period was 10.3%.

In summary, from 2000 to 2009, agriculture change to forest was 5.0% and agriculture change to urban was 5.8%.

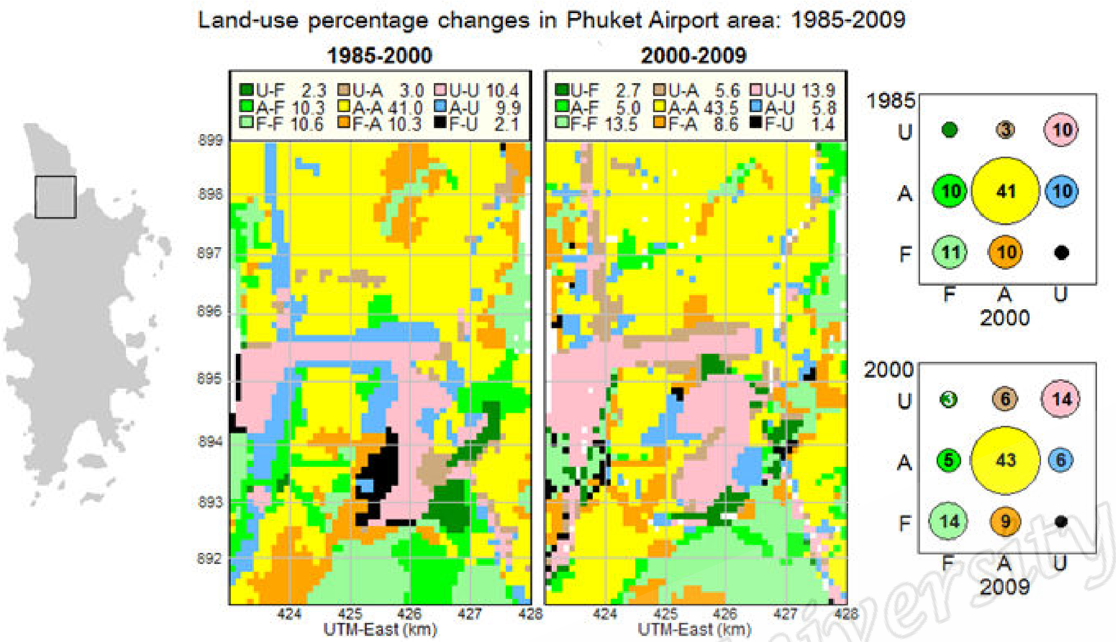

Figure 4. Land-use changes in the region surrounding Phuket airport from1985 to 2009 based on digitized data structure. The thematic maps use the same colours as these used in the bubble plots

4. Discussion and Conclusion

This paper presents a method for measuring GIS data using a grid-digitized method based on GIS data. With appropriate choice of colours, bubble plots show how land-use changes between categories, such as natural (forest, grassland, etc), farm land, and wetland areas.

The land-use database is freely available from the Thailand Department of Lands and can provide a valuable resource for seeing what happened in the past and for planning and predicting the future. Converting shape files comprising polygonal boundaries to more tractable gridded one-hectare units simplifies analysis, enabling straight forward creation of bubble plots and corresponding thematic maps that informatively show changing land-use patterns. The digital grid-based data structure also provides a simple basis for statistical analysis of land-use development over time, because it easily accommodates changes in polygonal plot boundaries and takes account of changing GPS settings.

Moreover, the basic statistical analysis can focus on the percentage of change when the outcome at each grid-point is binary. In this case data can be analyzed by logistic regression, because the specific land-use of interest is binary (urban or not, say).Various determinants, such as accessibility or proximity to roads and transport hubs, climate, and population density, may be incorporated into a model based on gridding to predict future land-use at each grid-point.

Acknowledgements

The authors thank Don McNeil for research supervision and Dr. Somporn Chuai-Aree for suggestions. The Thailand land development support of the GIS data is also gratefully acknowledged.

Reference

Bach, M., Breuer, L., Frede, H.G., Huisman, J.A., Ott, A., and Waldardt, R. 2006. Accuracy and congruency of three different digital land-use maps. Landscape and Urban Planning.78, 289-299.

Frazier, A.E. and Wang, L.2011. Characterizing spatial patterns of invasive species using sub-pixel classifications, Remote Sensing of Environment. 115, 1997-2007.

Gret-Regamey, A., Bebi, P., Bishop, I.D. and Schmid, W.A. 2008. Linking GIS-based model to value ecosystem services in an Alpine region. Journal of Environment Management. 89, 197-208.

Guo, L., Du, S., Haining, R. and Zhang, L. 2011. Global and local indicators of spatial association between points and polygons: A study of land use change.

International Journal of Applied Earth Observation and Geoinformation. 21, 384-356.

He-bing, Z. and Su-xia, Z. 2010. Development and application of land-use planning management information system based on ArcGIS, Proceedings of 2010 International Forum on Technology and Application, Kunming, China, July 16-18, 2010, 64-67.

Huh, Y., Yu, K., and Heo, J. 2011. Detecting conjugate-point pairs for map alignment between two polygon data sets. Computer Environment and Urban System. 35, 250-262.

Irwin, E.G. and Geoghegan, J. 2001. Theory, data, methods: developing spatially explicit economic models of land use change. Agriculture, Ecosystem and Environment.85, 7-23.

Klajnsek, G. and Zalik, B. 2005. Merging polygon with uncertain boundaries. Computer and Geosciences. 31, 353-359.

Lammeren, R.V., Houtkamp, J., Colijn, C., Hiferink, M. and Bouwman, A. 2009. Google Earth based visualization of Land Use scenario studies. GSDI 11 World Conference: Spatial Data Infrastructure Convergence: Building SDI Bridges to Address Global Challenges, Rotterdam, The Netherlands. Jun, 2009, 15-19.

Madureira, L., Rambonilaza, T. and Karpinski, I. 2007. Review of methods and evidence for economic valuation of agricultural on-commodity outputs and suggestions to facilitate its application to Broader decisional contexts, Agriculture, Ecosystems and Environment. 120, 5-20.

Manonmani, R. and Suganya, M.D.2010. Remote sensing and GIS application In change detection study in urban zone using multi temporal satellite. International Journal of Geomatics and Geosciences.1, 60-65.

Mizutani, C.2009. Land use transition process analysis using polygon events and polygon status: A case study of Tsukuba science city, proceedings of the 17 th International Conference of Geoinformatics, Virginia, USA, Aug 12-14, 2009, 1-6.

Rebelo, E.M. 2009. Land-economic rent computation for urban planning and fiscal purposes. Land Use Policy. 26, 521-534.

Sadr, K. and Rodier, X. 2012. Google Earth, GIS and stone-walled structures in southern Gauteng, South Africa. Journal of Archaeological Science. 39, 1034-1042.

Stehman, S.V. and Wickham, J.D. 2011. Pixels, blocks of pixels, and polygons: Choosing a spatial unit for thematic accuracy assessment. Remote Sensing of Environment. 115, 3044-3055.

Strand, G.H., Dramstad, W. and Engan, G. 2002.The effect of field experience on the accuracy of identifying land cover types in aerial photographs. International Journal of Applied Earth Observation and Geoinformation.4, 137-146.

Usha, M., Anitha, K. and Iyappan, L. 2012. Land use change detection through image processing and remote sensing approach: a case study of palladamtalukm, tamilnadu. International Journal of Engineering Research and Application. 2, 289-297.

Venables, W. N. and Smith, D. M. 2008. R Development Core Team. 2008. R: A language and environment for statistical computing. Vienna: R Foundation for Statistical Computing.

Weng, Q. 2001. Land use change analysis in the Zhujiang Delta of China using satellite remote sensing, GIS and stochastic modeling. Journal of Environmental Management.64, 273-284.

Whiteside, T.G., Boggs, G.S., and Maier, S.W. 2011. Comparing object-based and pixel-based classifications for mapping savannas. International Journal of Applied Earth Observation and Geoinformation.13, 844-893.

Yang, G. and Qiao, G. 2010. Data processing method for current land use using GIS Technology. Second International Workshop on Education Technology and Computer Science. Wuhan, China, March 6-7, 2010, 511-514.

International Journal of Computer and Electrical Engineering, Vol. 6, No. 2, April 2014

Management of LUCC and Land-Use Transition in Phuket Island, Thailand

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***Abstract*—This study examines the problem from the different land-use data set from Thailand department of land development, that caused the use of uncertain land-use change code (LUCC). The LUCC previous which was classified didn't correlate to the new LUCC, hence it couldn't be used as a historical information. We classified LUCC from geographic information system data (GIS) into land-use change mapping for Phuket island from 1967 to 2000. The LUCC were classified and displayed in thematic map format in 1:1000 and demonstrated in freely available software. The results showed that the occupation of land-use in Phuket in 4 period by the unity LUCC will help the land-use planning and land-use policy for the future.**

***Index Terms*—Land-use code/ land-use cover (LUCC), Phuket island, GIS, thematic map.**

I. Introduction

Remote sensing data contain a lot of information that needs to be extracted, such as imagery, land properties, land valuation, soil data, and geography[1]-[3]. Thailand still owes its development to an agricultural base and part to the heavy industries. The important products such as para rubber, rice, mining, and palm are the natural resources that helped power the growth of Thailand's economy including tourism services. That cause is a direct effect to land-use changes. In Thailand, Ramesh focused on the land-use in Chang Mai area by secondary classification data from aerial photographs [4]. Raine studied land-use change in Chanthaburi province which was coastal zone especially agricultural area changes to different categories [5]. They also used the differences of LUCC to classify land-use.

Land use in the Phuket Province is very important because there are many land-use types, such as communities, factories, building, institutions, commercial, service and others such as allocated land project [6].

Phuket and its surroundings have been experiencing severe environmental problems, such as land transition, and deforestation in order to promote tourism in the cities.

Mostly, land utilization around the island has expanded without planning and good management or without following the plan to development. Land use data of Phuket have stored in ordinary format which much was constrained and used with GIS software and demonstrated in analog format. The land-use data with LUCC in the past and now have different relationship.

In the past, land-use and land-cover data had been sampled from digital land-use and land-cover files obtained from the USGS organization in the USA. The development of land use and land-cover characteristics has been defined. Some of land-use categories in US didn't correspond to UNESCO vegetation (the land-use categories have been defined by UNESCO). The classification has been defined into different names of LUCC but it can be used as information because the different countries have distinct definition for the LUCC [7].

Land-use classification is one point that refers to a representative of the area. It would be to consider the land-use categories. The conception of the Los Angeles country planning commission was also suggested to classification of land-use categories and how to define colour for land-use [8].

The basic step for classifying land-use category is to provide a good information to the system or tools to analyse land-use change in the future especially in Thailand.

Although, land-use classification can be classified by tools of GIS program some of them didn't correspond to real area. The difference in LUCC caused confusion in the land-use categories. Normally, LUCC are classified within 6 classes such as in Australia [9]. Classification for LUCC is as follow; Conservation and natural environments, Production from relatively natural environments, Production from dry-land agriculture and plantations, production from irrigated agriculture and plantations, intensive uses and water [10].

In Thailand, in 1967 Thai department of land development collected LUCC into 6 classes but in 1975 the LUCC had each type in sub-class. The problem was that growth of new LUCC changed to new categories which were not unified by LUCC [11], [12].

This paper will explain and discuss the unification of LUCC and show land-use change for example area in Phuket Province, Thailand. The map will be displayed in thematic map format in 1:1000 scale by R program. This program will compute the land-use map same as the license software such as Arc GIS. Restructuring LUCC provides unity of LUCC which will be assessed in this paper.

II. Land-Used Record

A. Definition of the Study Area

The study was conducted in Phuket province in Thailand. The island is mostly mountainous with a mountain range in the west of the island and from north to south of the island. The study area covers 543 square kilometers in three districts:

Manuscript received August 23, 2013; revised November 14, 2013.
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DOI: 10.7763/IJCEE.2014.V6.817

Mueang Phuket, Kathu, and Thalang, situated along the Andaman Sea. The geographic location is between latitude 07°53'N and longitude 98°24'E (see in Fig. 1).

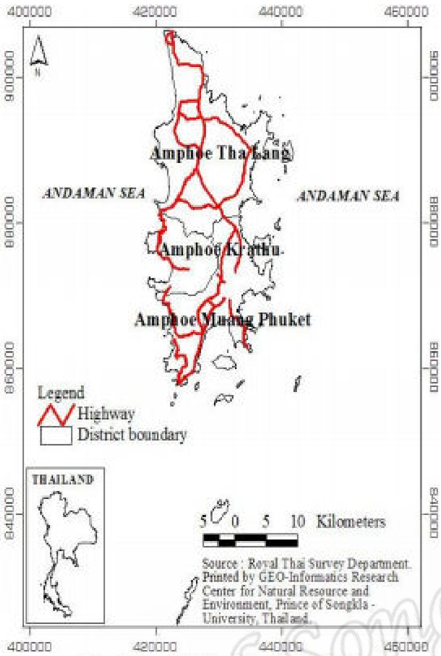

Fig. 1. Map of Phuket Island, Thailand.

B. Thailand Land-Use Record

Pattern for advantages of land-use have been increasing in Thailand since 1980 and these data contain a lot of information that needs to be extracted. The Thailand Department of Lands has recorded land-use for many specified categories, such as "transplanted paddy", "Para rubber", "rain forest", "village", "shrimp farm", "mixed orchard" in hundreds of plots within every sub-district of Thailand. The data collections of land-use have been stored in different forms where the project surveys would be of much benefit to the economy and also follow the national economic development plan. All of land-use categories in Thailand have been explained by LUCC such as in 1967 LUCC identified the infrastructure group and AXX code for agricultural group.

The problem is how to define the LUCC change since land use in 1967 has been replaced by new LUCC. Thematic map such as colour-codes of the polygonal is one problem which is a change in the outcome.The basic data sources are the remote sensing data in 1967-2000. We gauge the data from Landsat based on the topographic map at the scale of 1:1000 from shape file format. Thai department of land development has classified the LUCC into 3 level such as level 1 (explains main land use area), level 2 (contribute to type of main land use area) and level 3 (demonstrate the detail in Table I).

Land-use data stored in the data base of the Thai department of land development and thus, the GIS data from the data base requires the program to support, data that had been collected in shape file that contributed by GIS system. Shape file stored a data such as LUCC, area, point of polygon and the position. The position of land-use in data record have differences because the Department of land development survey only an important project and use the data for beneficial purpose such as project management and project that contribute to the road. When the GIS was used for the project, it did not develop a record that matched into the new data base. LUCC between 1967 till 1985 and 2000 was different, so the data structure could not have been used together at the same time. For instance, the land-use for rubber growing in 1967 (A2) and in 2009 (A302) was impossible to compare due to the differences in LUCC (Show that in Table II)

TABLE I: EXAMPLE FOR LUCC FOR 1967-1975 IN U GROUP FROM THAI DEPARTMENT OF LAND

Level 1	Level 2	Level 3
U	U1, City town	-
	U2, Village	U200, abandoned village U201, Village U202, Hill tribe village
	U3, Institutional	U300, School
	U4, Transportation	U401, Airport U402, Railway station U403, Bus station U404, Harbor

TABLE II: LAND LUCC OF 1967-1985 (1967 SERIES) AND 2000 SERIES

Descript	1967	2000	Descript	1967	2000
Abandoned paddy	-	A100	Wetland	-	M2
Transplanted paddy field	A1	A101	Abandoned mine	-	M300
Para rubber	A2	A302	Mining Area	U5	-
Teak	-	A305	Soil pit	-	M304
Coconut	A3	A405	Beach	M2	M402
Mixed orchard	A4	A401	Allocated land	-	U200
Truck crop	-	A502	Lowland village	-	U201
Pasture and farm house	-	A7	Urban, Commercial	U1	U1
Abandoned Aquaculture	-	A900	Village	U2	-
Shrimp farm	-	A903	Hotel	U3	U3
Upland forest	F1	-	Infrastructure	U4	-
Disturbed evergreen forest	-	F100	Airport	-	U401
Moist evergreen forest	-	F101	Harbor	-	U404
Beach forest	-	F107	Factory	-	U502
Shrub,Bush	F2	-	Recreation area	-	U601
Mangrove	F3	F106	Golf course	-	U602
Costal Woodland	F4	-	Reservoir woodland	W1	W201
Forest Plantation	F5	-	Mari culture Concession	W2	-
Marsh	M1	-	Un-classification	NA	NA

According to Table II, in 1967-1985 and 2000, the LUCC number was added, for example, LUCC in level 3 gained more detailed. In 1967, F1 was transferred into Upland Forest, but in 2000, it was replaced by F100 and transferred into Disturbed evergreen forest instead. Moreover, in the F category, there was F101, which meant moist evergreen forest. Then considering the difference between LUCC using in 1967 and 2000, it was necessary to re-organize the data structure so that LUCC had the same pattern. Hence, LU-Code in 2000

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was applied to transfer the data in 1967 for more detailed mapping and gaining high accuracy.

Another example was the infrastructure in 1967 was (U4), but in 2000, it was divided into Airport, Harbor, Factory, Recreational area, and Golf course, which mentioned that it was re-organized into more detailed specification of land-use information. Thus, it was necessary to re-organize the consistence of applying LUCC.

C. Land-Used Classification

Land-use cover or land-use category, more than 187 countries was visually checked, said Zheng *et al.* [10]. If all countries can be used in the same LUCC, it will be beneficiary to the study of land-use change.

According to the Los Angeles country planning commission, the land just to be classified was distinguished. They classified it into 10 groups starting from 000 to 999, for example 000-099 refer to unused land, 100-199 for open use, 200-299 for farming, 300-399 for residence, 400-499 for commerce, 500-599 for industry, 600-699 for utility, 700-799 for instruction, 800-899 for recreation and 900-999 for problem uses. From above, it is a good idea for separate LUCC to correspond to real world land-use. In Thailand, we modified LUCC in support of the new LUCC in sub-class. Table 2 demonstrated the LUCC of 1967 – 1985 which were re-organized in the same pattern of the LUCC in 2000.

TABLE III: RESTRUCTURE OF LUCC TO THE UNITY OF LUCC FROM 1967 TO 2000.

LUCC	Descript	LUCC	Descript
A100	Abandoned paddy- field	F101	Dense evergreen forest
A101	Rice paddy	F106	Mangrove forest
A205	Pineapple	F107	Beach forest
A205-A302	Pineapple/ Para	M102	Scrub, grass
A219	Sweet potato	M2	Wetland
A301	Mixed perennial	M300	Abandoned mine
A302	Para rubber	M304	Soil pit
A303	Oil palm	M402	Beach
A305	Teak	U100	City, Town
A401	Mixed orchard	U2	Allocated land
A401-A405	Mixed orchard/ Coconut	U201	Lowland village
A404	Rambutan	U201-A401	Lowland / Mixed
A405	Coconut	U3	Institutional
A408	Cashew	U401	Airport
A502	Truck crop	U404	Harbour
A503	Floricultural	U502	Factory
A703	Poultry farm house	U601	Recreation area
A704	Swine farm	U602	Golf course
A900	Abandoned Aquacultural	W201	Reservoir
A902	Fish farm	UN	Unclassified
A903	Shrimp farm	XX-XX	Ratio 50/50%

Although, the LUCC in the unity format can be collected in the real area, it's complicated to analyse land-use change. This is due to the fact that some of the LUCC can be collected in the same group, for example, paddy field and mixed paddy field. New classification for the investigation of land-use change used to group LUCC in Phuket Island.

In addition, Ax, Ux and Mx groups are the main classes of level 2 which still defines the old LUCC because this LUCC needs to be extended in the future when the categories have another group. Some of LUCC such as U2 has been extended to U201 for lowland village. In the future, U group need to be extended to correspond to a type of property for example U202 for a condominium, U301 for bank and U302 for hospital. For example, the real LUCC data from Thai department of land development and department of agricultural has been managed corresponding to old LUCC record. We compute the program to change the LUCC of old LUCC series in 1967 for using to 2000 (up to date). An example will demonstrate the classification for change LUCC follow in Fig. 2.

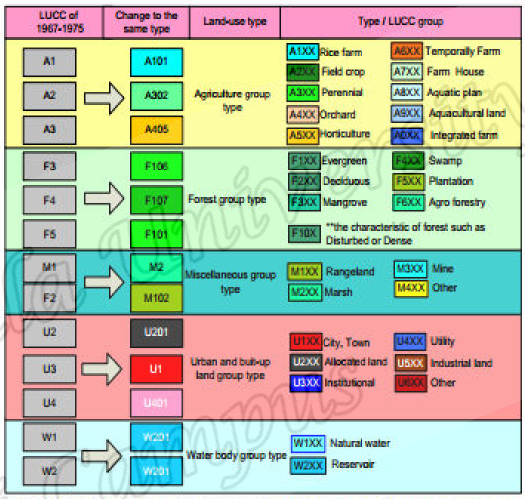

Fig. 2 Managed for LUCC data from Thai department of land development and department of agricultural. Note that some of LUCC has been changed to other type. Type /LUCC group indicated the sub type of LUCC for classification land-use form 1967-2000.

III. PHUKET LAND-USE

For example to use LUCC for Thailand, we compute the thematic map by R program. Current land-use for Phuket island since 1967-2000, four panels of mapping were conducted through digitization interpretation and the land-use categories were classified by the type of land-use.

To see occupation of land-use type of Phuket, thematic maps are useful to show the total land-use during 4 periods (show in the Fig. 1). Majority of the land-use only in 1967 and 1975 were found to be covered by forest group (FXX) and decrease in each year. An agricultural group (AXX) area increased in the following years; 1975, 1985 and decreased only in 2000. This is due to the fact that, in 1985-2000 majority of agricultural areas were mining areas, while some areas were been converted to abandoned mining areas. Other land-use categories, such as A4XX of LUCC were small in number every year. The urban area (UXX) was increased since 1967 to 1985 and increased again in 2000.

This caused agricultural categories to change to urban groups by property investment. Note that Z0 was a sea area around Phuket Island in the thematic map. Number of occupation of land-use types of Phuket will be shown next to LUCC label in hectare unit converter. See in Fig. 3(a)-(d).

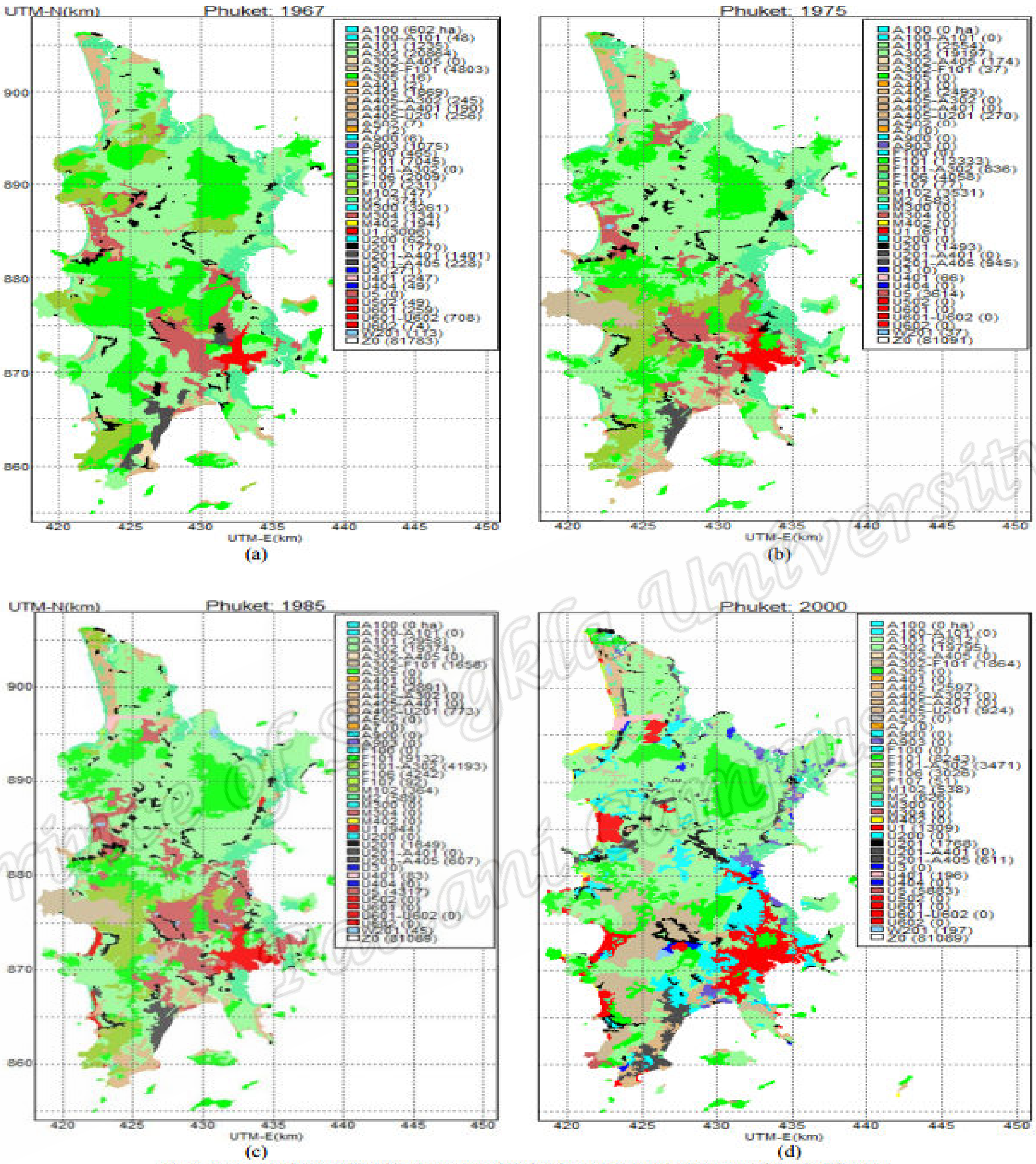

Fig. 3. Summary of occupation of land-use type of Phuket from1967-2000 in 41 groups of the classification.

IV. Conclusion

This article expands the problem for LUCC of Thai land-use data from 1967 to 2000 it's classified the LUCC for unity of Thai land-use data.

In our study, we classified the LUCC of Phuket Island to correspond to the new LUCC. The result showed land-use occupation very clearly by thematic map using freely available software; R program. This study, gives more idea for the management of LUCC in the clouded area in the big city of Phuket. Suitable data management can be further researched into Thus:

1) Change of LUCC to unity code would be extended to cover all the land-use type corresponding to real area.
2) Land-use data would be analysed by comparison and show land-use loss and gain.

What we have to do next, we will develop program to compute land-use data from polygonal shape to raster format which can analyze land-use change by a high statistical analysis especially third country in the world.

Acknowledgment

The authors would like to thank the Thailand land department of development for provision of the GIS data.
We are also very grateful to GIS center Prince of Songkla University for supporting the land-use with information.
The authors want to express our gratitude to Prof. Don

McNeil for guidance and land-use research term.

REFERENCES

[1] G. Yang and G. Qiao, "Data processing method for current land use using GIS Technology," in *Proc. Second International Workshop on Education Technology and Computer Science*, Wuhan, China, 2010, pp 511-514.

[2] G. H. Strand, W. Dramstad, and G. Engan, "The effect of field experience on the accuracy of identifying land cover types in aerial photographs," *International Journal of Applied Earth Observation and Geoinformation*, vol. 4, pp. 137-146, 2002.

[3] Q. Weng, "Land use change analysis in the Zhujiang Delta of China using satellite remote sensing, GIS and stochastic modeling," *Journal of Environmental Management*, vol. 64, pp. 273- 284. 2001.

[4] B. Ramesh, "Urban land use change detection using sequential aerial photographs and spot image case study: Chiang Mai Thailand," *Journal of the Indian society of remote sensing*, vol. 17, pp. 101-108. 1989.

[5] R. M. Raine, "Current land use and changes in land use over time in the coastal zone of Chantaburi province Thailand," *Biological Conservation*, vol. 67, pp. 201-204. 1994.

[6] D. Phantumvanita and S. Sathirathai, "Degradation and Development in a Resource-Rich Land, Environment," *Science and Policy for Sustainable Development*, vol. 30, pp. 11-15, 1988.

[7] The Los Angeles county planning commission, "Land Use Classification," *Journal of the American Institute of Planners*, vol. 7, no. 3, pp. 26-27, 1941.

[8] T. R. Loveland, J. W. Merchant, D. O. Ohlen, and J. F. Brown, "Development of a Land-Cover Characteristics Database for the Conterminous U.S.," *Photogrammetric Engineering and Remote Sensing*, vol. 57, pp. 1454-1463, 1991.

[9] M. M. Barson, L. A. Randall, and V. Bordas, *Land Cover Change in Australia: Results of the collaborative Bureau of Rural Sciences - State agencies Project on Remote Sensing of Land Cover Change. Bureau of Rural Sciences,* 1st ed. Canberra, Australia: Bureau of Rural Science, 2000. ch. 3, pp. 28-36.

[10] Z. Zheng, W. Yang, H. Zhou, and Z. Wang. "Analysis of land use and land cover change in sichuan province, China," *Journal of applied remote sensing*, vol. 6, 2012.

[11] J. Kongwongjan, C. Suwanprasit, and P. Thongchumnum, "Effect of Land-Use Change on Coastal Erosion in Phuket, Thailand," in *Proc. the 12th Graduate Research Conference, Khon Kaen University*, Thailand, 2013, pp. 270-277.

[12] M. Omakup and S. Maneerat "Land use survey data from satellites," *Journal of the Thailand Department of Land Development*, vol. 31, pp.11-18.1994.

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Detection of Land-Use Change Using the R Program A Case Study of Phuket Island, Thailand

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Abstract

Urban growth is an important topic that developers around the world need to assess because of expansion of the city which directly affects adjacent areas. After land reform was initiated in 1987, by remote sensing data (RS), developers became aware of the study of land planning and land policy. Although geographic information system (GIS) software can be used in detecting land-use change, there is the need to pay the license cost. Nowadays, geographers have been able develop GIS programs such as Map Windows GIS and Quantum GIS for detecting land-use change. However some techniques are not available with the free software. The main purpose for investigating land-use change was to show loss and gain in areas and also to show the basic statistics. This study examines the use of GIS in land-use change mapping for Phuket Island from 1967 to 2009. Secondary data from the Thai Department of Land Development was appropriate for analyzing land-use change. We used the data from supervised classifications to classify the RS data. For the analysis of land-use categories change, the digitization approach was used. The computation was based on the actual number of observations for land-use data on Phuket by free software, the R. program. Three categories of land-use change were investigated: forest, agriculture and urban; quantitative analysis changed using a bubble-plot matrix. The study illustrated the increasing trend of urban growth in tourist areas which directly affect the forest area on Phuket Island. Land-use changes from one category to another have been clearly represented by map format, using a scale of 1:1000.

Key words**:** Land-use, Phuket Island, urban, agricultural, forest, GIS freely available software, R program.

1. Introduction

Land-use change has been investigated in many countries by geographers. In the past, researchers argued about how to best monitor land-use change—whether to use the survey or remote sensing system (Hill, 1984). When the remote sensing data provided high accuracy, land-use change was investigated (Yang and Qiao 2010, Strand *et al* 2002, Weng 2001, Sadr and Rodier 2012, and Lammeren *et al* 2009). After land reform was initiated in 1987, by RS, land-use change was investigated, by use of high technology (Chang and Masser, 2003). The majority of the researchers used the remote sensing data to investigate land-use changes.

Several researchers studied land-use changes and the causes that affected the quality of human life. For example, the changes to urban land-use represent a particular land-use intensification, because the change affected the good life of the population especially in the increasing urban area. The disorder from globalization has used up a lot of resources especially the land. That has directly affected the natural resources, such as the growth of urban area in Shenzhen which has disturbed the ecology system (Li *et al* 2008). In the northeast of China, interference of natural resources, especially in the forest area by deforestation, has affected the biodiversity of the tourist industry (Zhao *et al*, 2011). We also need to know where to allocate the recourses to achieve the highest benefits and plan accordingly to fit the problem of the environment. The pattern of change from forest area to urban was also studied by Jim and Liu (2001). They investigated whether the association between land-use and trees (forest) was related to the culture, history, biodiversity and pattern of change in Guangzhou city, China. Moreover, they found an important characteristic: the land-use scale showed that the old districts conserved the forest area more than new districts. Hascic and Wu (2006) studied how forest land-use change affected drinking water, where water from catchment areas with a large portion of forests is of higher quality. Kurt (2013) studied the land-use change of Black Sea coastal regions in Istanbul. Agricultural and forest areas have changed to urban areas, and the particular urban area has increased to 122%. Recently, Muma *et al*. (2011) studied the effects of the change from forest to agricultural area in Canada. The agricultural land-use has resulted in an inversion of hydrological effects and a decrease in forest cover.

In Thailand, land-use has changed rapidly since 1980. The Thai Department of Lands has been regularly surveying and recording land-use in hundreds of small plots in every province since 1967. These data contain a lot of valuable information about Thai history and culture development that is not available elsewhere and tends to be forgotten and lost. Such information is also valuable to planners and developers. Some of the researchers, Bamesh (1989), focused on the land-use in Chang Mai area by secondary classification data from aerial photographs. Nine groups of land-use have been classified, the result showed that, urban area has increased to other land-use categories and maximum agriculture has been converted to urban land-use over a 12 year period. In the west of Thailand, Raine (1994) studied land-use change in Chanthaburi province, which is a coastal zone, especially the agricultural area changes in each category. It was estimated that deforestation decreased from 1975 to 1989.

Now, Thailand still owes its development to an agricultural base and some to the heavy industry. The important products such as rubber, rice, minerals, and palm trees are the natural resources that helped power the growth of Thailand's economy, including tourism, especially in the southern part. However, that has had a direct effect on land-use. We investigated this on Phuket Island, which is one of the provinces of Thailand that has grown faster than other regions. Since the opening of tourist areas and many projects around Phuket city, Phuket has developed; the most active zone of economic development is the city of Phuket, which is adjacent to forest area.

This paper presents land-use change of Phuket Island, and especially focuses on the R program. Land-use was classified broadly as natural (forest and grassland), farm (agriculture and fish farming) and urban (village, city and other developed land including mines) based on GIS of Phuket Island. The majority of researchers used license software, such as AreGIS, AreView, MapInfo, Intergraph, IDRISI, SAGA GIS etc. The essence of detecting land-use change involves detecting the change and showing it on graphic or thematic map. Licensed software can detect land-use change but it is costly. Nowadays, geographers have been able to develop GIS programs such as MapWindows GIS and Quantum GIS but the limitation is that some techniques are not available for free. So, analysis was made possible by the R. program (R

Development core term, 2012), which is free-to-use software. The program used the secondary data and transformed it to digital data (Grid-point) by digitization. The program can display the thematic map the same as licensed software which illustrated the loss and gain corresponding to statistical display. We will show land-use changes with a bubble plot matrix, it's easy to understand the changes in such a manner. Moreover, the result will provide qualitative statistics. Land-use change can provide valuable resources for analyzing what happened in the past and for planning and forecasting for the future.

2. Materials and Methods

The study used the remote sensing data as the basic data. The data in shape-file in analog format from remote sensing was based on a thematic map. In this paper, the steps for the study of land-use change will be shown in Figure 1.

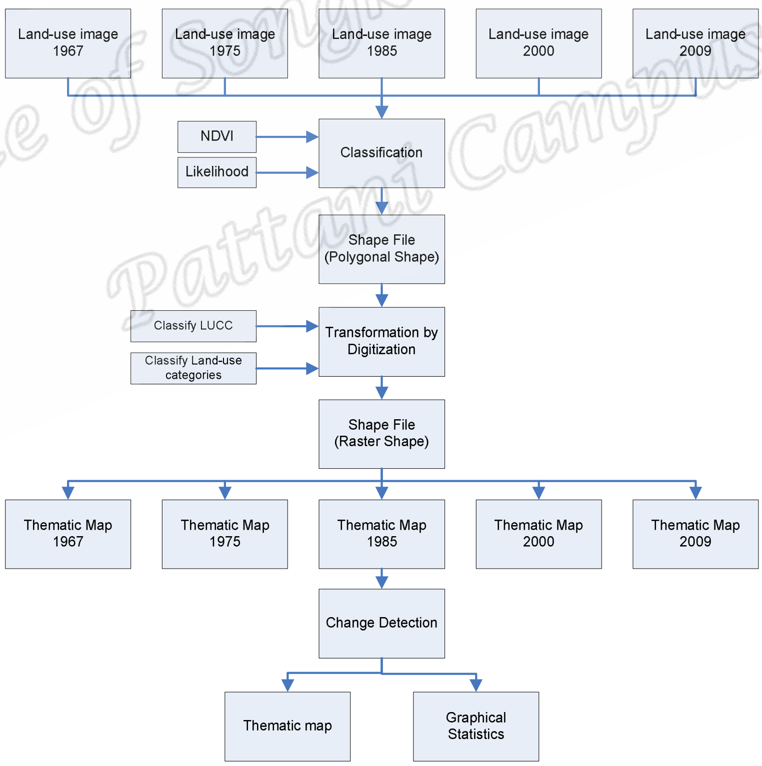


Figure1: Conceptual framework of research

The Area of Study

Phuket Island is located between latitude 7° 53N, and longitude 98° 24E**.** Neighboring provinces are Phang Nga and Krabi, and since Phuket is an island, it has no land boundaries. It is situated off the west coast of Thailand near the Andaman Sea.

In 2009, land-use categories in the study area covered forest, urban, agriculture farm, rubber and mine. The total area of Phuket Island is 576 square kilometers. In 1967, accounted forest area was 41.13%, whereas urban area was 12.66 % and agriculture area was 46.21%. Agriculture areas, especially rubber, play an important role in the economy of Phuket Island, including mining for export products.

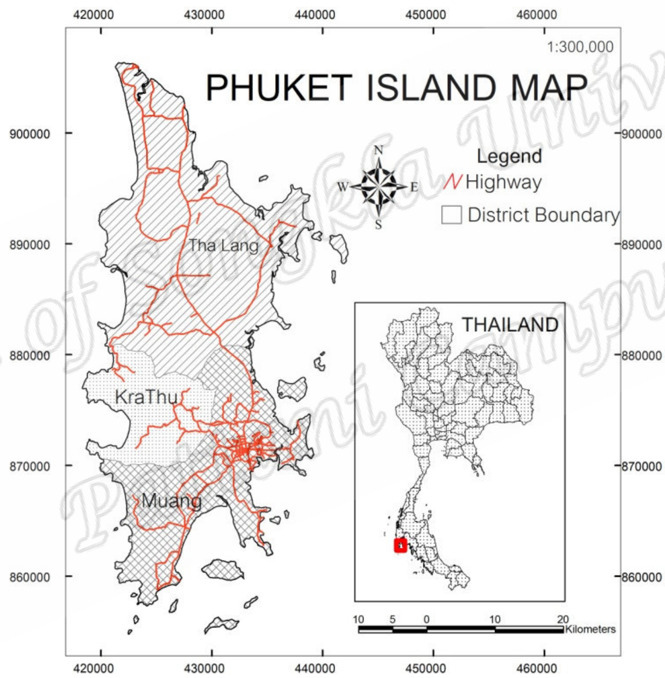


Figure2: Phuket Island map body.

Geometric Correction (coordinate shift)

Geometric Correction is the process of digitally manipulating image data such that the image's projection precisely matches a specific projection surface or shape. We need to project the thematic map to the same position as land-use data from 1967 to 2009. The thematic data from the Landsat image were geo-referenced to a digital map using a bilinear transformation.

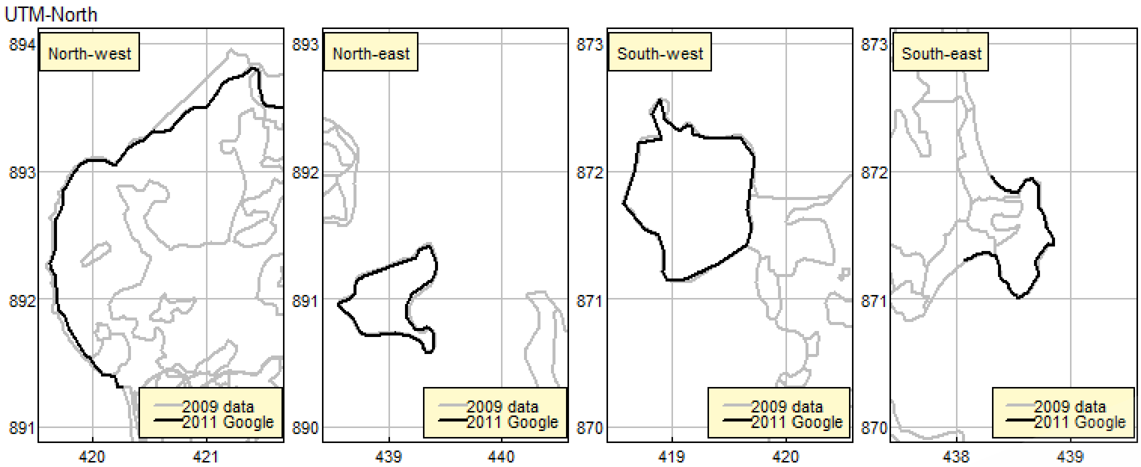


Figure3: Geometric correction shows the coordinates around Phuket Island which comparison land-use data between 2009 and 2011 (Google Earth).

Detection land-use by digitalization

The analysis of land-use changes, raster and polygonal shapes are the majority that geographers used to study. Although a polygonal shape can provide thematic maps a display of patterns for a given year, the data is difficult to analyze because the polygons change. Digital (raster) can provide clear land-use change and is more suitable to analyze change detection. Thinnukool *et al* (2013)[A] extracted the classification data and reformed digital data by the digitalization concept. The concept was an idea for the representation of a point on land-use map. We used the concept to convert the polygonal data by grid-point data to digital data. The computation from digitization, for connecting from the polygonal coordinates to those based on the grid, involves assigning grid points to polygons.

1) The image transformation from polygonal data to digital data by digitization is a command used to convert meters to kilometers. P_{43} is land-use data (polygonal form) including field plotID, x, y, DESEng, and LUcode, which are recorded in txt. file. This program takes the form:

Program Command : Convert to km^3

```
Require: Read txt. land-use data (polygonal form)
1:  p43data$x <- p43data$x/1000
2:  p43data$y <- p43data$y/1000
3:  p43xy$x <- p43xy$x/1000
4:  p43xy$y <- p43xy$y/1000
```

2) Geometric correction: this proposed process is used for the p43 to fix the mistake of positioning in the thematic map.

Program Command : Geometric correction

Require: Read txt. land-use data (polygonal form) (**constant value 0.31 and 0.24)

```
p43xy$x <- p43xy$x-0.31
p43xy$y <- p43xy$y+0.24
p43data$x <- p43data$x-0.31
p43data$y <- p43data$y+0.24
```

3) Remove holes plot: this is proposed to remove some plots in the thematic map which provides only one type of occupation in one polygon.

Program Command : Remove holes plot

Require: Read txt. land-use data (polygonal form)

```
p43data$hole <- 0*p43data$plotID
rxya <- NA+p43xy[1,]
(j in p43data$plotID) {rxyj <- subset(p43xy,p43xy$plotID==j)
 rxyjNA <- subset(rxyj,is.na(rxyj$x))
 (dim(rxyjNA)[1]>0) ptID1 <- min(rxyjNA$pointID)
 rxyj <- subset(rxyj,rxyj$pointID<ptID1)
 p43data$hole[p43data$plotID==j] <- 1
 rxya <- rbind(rxya,rxyj)
 p43xy <- rxya[-1,]
```

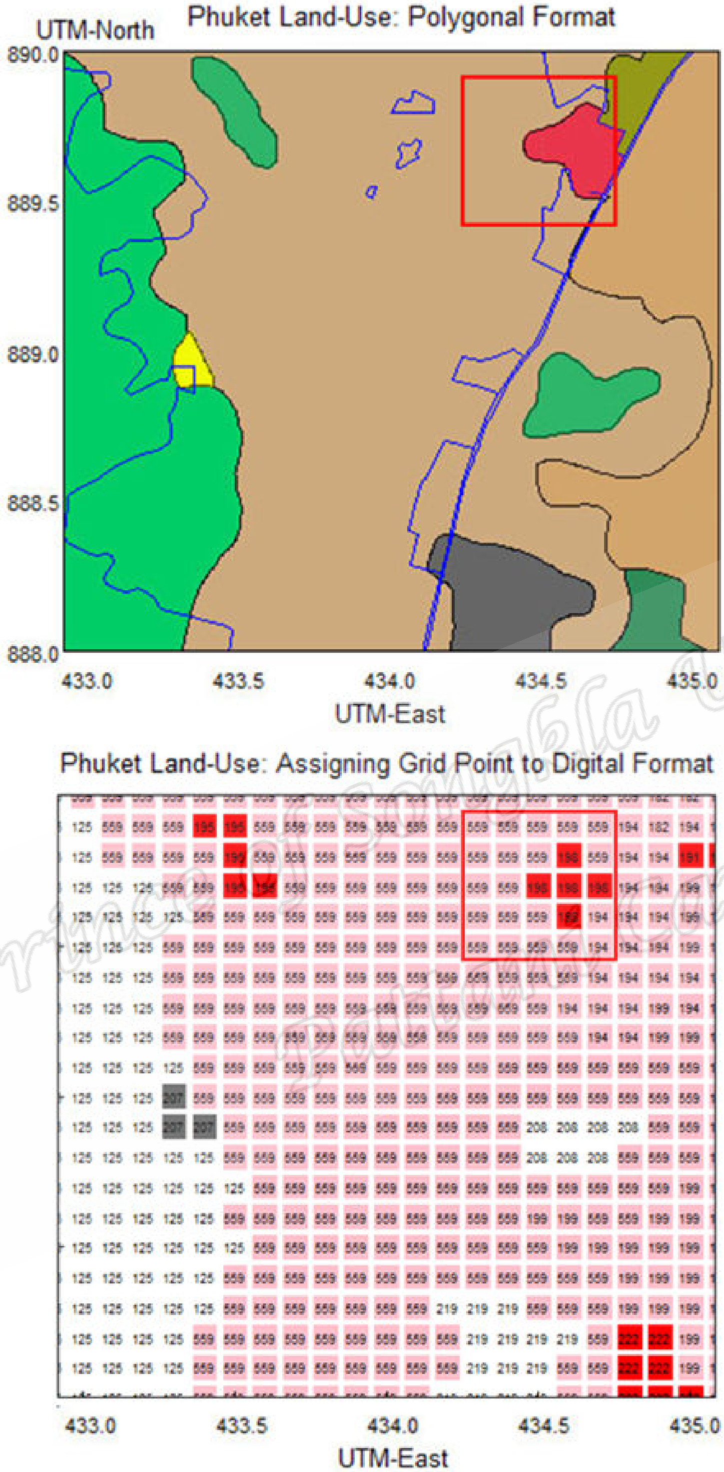
4) Assign Gird point: The computational method for connecting from the polygonal coordinates to those based on grid point, this program takes the command line.

Program Command : Assign gird point

Require: Read txt. land-use data (polygonal form)

```
plotIDs <- 0*pt.x
(j in c(1:571))
pol <- subset(p43xy,p43xy$plotID==j)
pol.x <- pol$x
pol.y <- pol$y
point.in.polygon(pt.x,pt.y,pol.x,pol.y) -> grid
plotIDs <- ifelse(grid==1,j,plotIDs)
```

Apparently, following the command was used to compute the polygonal form to digital form, Figure 4 illustrated the thematic map by grid point and showed the new data structure (Right panel).



X	Y	plotID
434.30	890.90	559
434.40	890.90	559
434.50	890.90	559
434.60	890.90	559
434.70	890.90	559
434.30	890.80	559
434.30	890.80	559
434.40	890.80	559
434.50	890.80	198
434.60	890.80	559
434.30	890.70	559
434.30	890.70	559
434.40	890.70	198
434.50	890.70	198
434.60	890.70	198
434.30	890.60	559
434.30	890.60	559
434.40	890.60	559
434.50	890.60	198
434.60	890.60	559
434.30	890.50	559
434.30	890.50	559
434.40	890.50	559
434.50	890.50	559
434.60	890.50	559

Figure4: The digitization involves converting the polygonal data in analog form (polygonal format) to digital form by grid-point.

The conversion of polygonal representation to digital data in Figure 4, right panel was a data structure of an example of 5x5 grip-points that indicated in the rectangle of middle panel.

Our research has contributed a digital thematic map (raster) of preliminary studies of land-use change. In order to detect and assess land-use change with digitization, follow Figure 5 to show land-use loss and gain in the sample area. An important thing in land-use change is the land-use code/land-cover (LUCC), which is a description of land-use categories.

Thinnukool *et al* (2013)[B] managed LUCC in Thailand and explained the problem to define the LUCC change since land use in 1967 has been replaced by new LUCC. The modification of LUCC is supported by the new LUCC in sub-class, Table 1 demonstrated the LUCC of 1967-1985, which were re-organized in the same pattern as the LUCC in 2000.

Table 1: Land-use code and land-cover

LUCC	Descript	LUCC	Descript	LUCC	Descript
A100	Abandoned paddy-field	A502	Truck crop	M402	Beach
A101	Rice paddy	A503	Floricultural	U100	City, Town, Commercial
A205	Pineapple	A703	Poultry farm house	U200	Allocated land project
A205-A302	Pineapple/ Para rubber	A704	Swine farm	U201	Lowland village
A219	Sweet potato	A900	Abandoned Aqua-cultural land	U201-A401	Lowland village/ Mixed orchard
A301	Mixed perennial	A902	Fish farm	U300	Institutional
A302	Para rubber	A903	Shrimp farm	U401	Airport
A303	Oil palm	F101	Dense evergreen forest	U404	Harbor
A305	Teak	F106	Mangrove forest	U502	Factory
A401	Mixed orchard	F107	Beach forest	U601	Recreation area
A401-A405	Mixed orchard/ Coconut	M102	Scrub, grass and scrub	U602	Golf course
A404	Rambutan	M200	Wetland	W201	Reservoir
A405	Coconut	M300	Abandoned mine	UN	unclassified
A408	Cashew	M304	Soil pit	XX-XX	Ratio 50/50%

An experimental test was been used, for an example area in north-west of Phuket. Note that Figure 5 show loss and gain is area from 1985 to 2000, A302 (539 ha in 1985) rubber gained remained at 262 ha and A101 remained at 61 ha and urban area gained 16 ha in 1985 to 2000. While in 2000, A302 had a loss from 1985 to 2000 which was 53 ha and urban areas had a loss which was 106 ha. However, the loss of the land was not a real loss, because the area remained within the island and the land changed to other types.

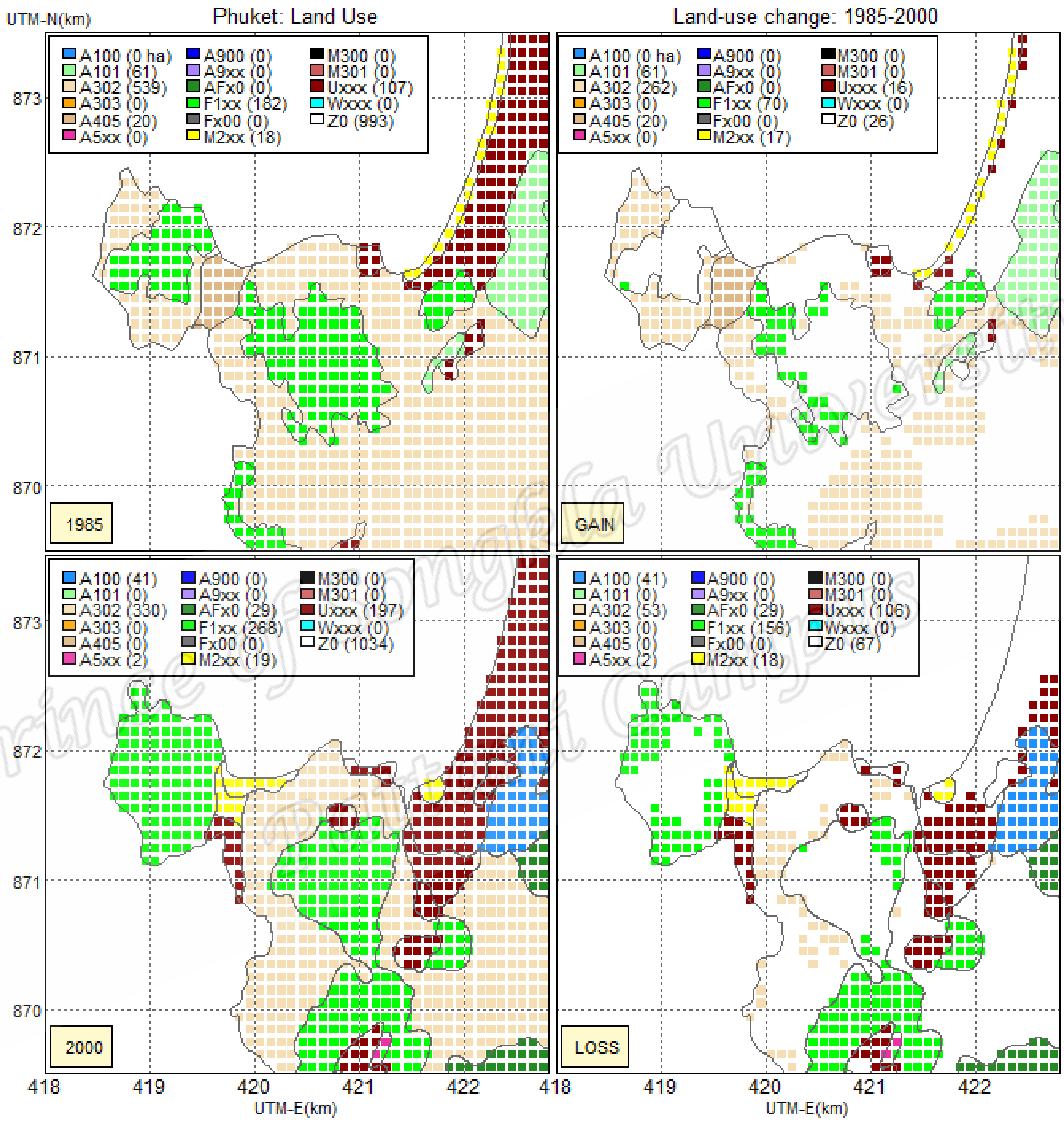


Figure 5: The thematic map was useful to illustrate land loss and gain of land-use change detection. Note that the first row of panels demonstrated land-use occupancy of land-use type. The top right panel showed land-use gained from 1985-2000 and bottom right show the land-use loss in 1985 (compare with 2000).

3. Results and Discussion

Land-use for Phuket Island, since 1967-2009, is depicted by five panels of mapping which were constructed through digitization interpretation. Land-use categories were classified by the type of land-use. Therefore land-use types in Phuket Island are more than the three types which have been managed for detecting important areas, especially forest areas, because they have direct effect on biodiversity, daily life, and natural balance. We classify thematic land-use map in three categories such as natural (F) (mainly forest, grassland and beach), farm (A) (including agricultural and fish farming), and development (U) (including the city, villages, institutional and recreational land & mines).

The majority of land, in 1967, was found to be covered by forest and decreased in the successive years. The agricultural areas increased in the following years: 1975, 1985, 2000 and only in 2009 the agricultural area decreased because in 1985-2000 the majority of agricultural areas started changing to mining areas, while some mining areas were also converted to abandoned mining areas. Other land-use categories, such as urban areas, were small in number in every year. In order to see occupation of land-use type of Phuket thematic map, it is useful to show the total land-use during 5 periods. Urban areas decreased from 1967 to 1985 but had a slight increase in 2009. This was caused by the change from agricultural area to urban area by property investment. To see where land-use changes occurred from one type to another type see figure 6.

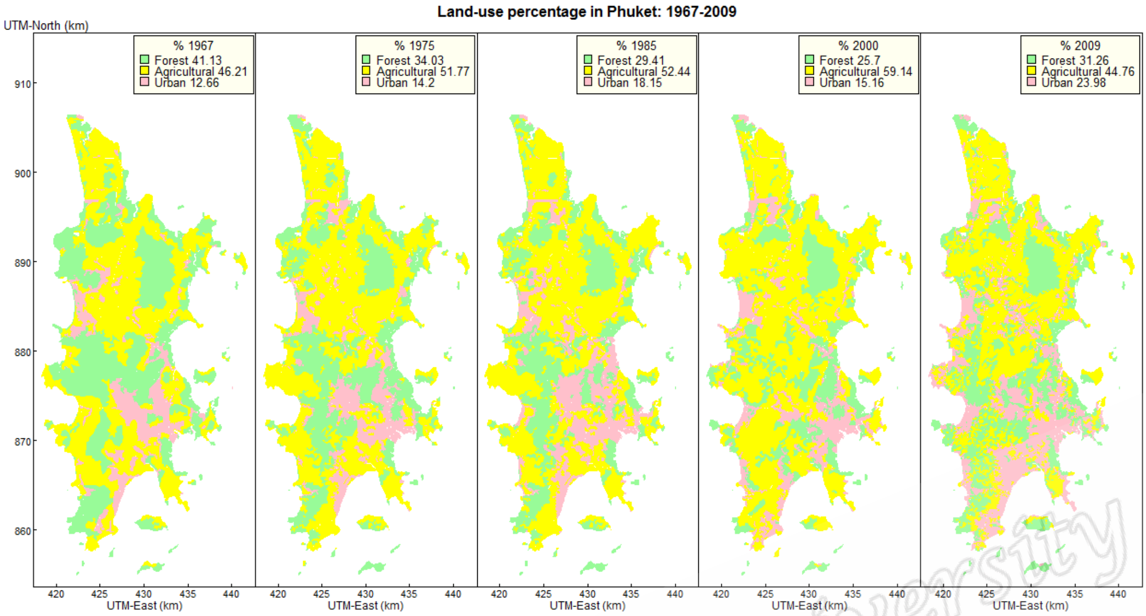


Figure6: Summary of occupation of land-use type of Phuket from 1967 to 2009 in the three types of groups.

Change in land-use is effectively summarized in a cross-tabulation giving area (in hectares) or percentages of land-use categories from one period to the next. These numbers can be displayed as a bubble plot matrix; (note that darker colors show changes and lighter colors denote no change). We used bubble plots to show variation of the land use change for each of three categories: natural (mainly forest, grassland and beach), farm (including agricultural and fish farming), and development (including the city, villages, institutional and recreational land & mines). Converting shape files comprising polygonal boundaries to more tractable gridded one-hectare sub-plots simplifies analysis, enabling straightforward creation of bubble plot matrices and corresponding thematic plots to highlight changes in land-use patterns. For example, we found that in the park area, north of Phuket city changes from surveys in 1967,1975,1985, 2000 and 2009 had similar patterns, except for the period when land devoted to urban use increased from 1975-1985 but substantially decreased in 1985-2000. This occurred because almost all the mining industry ceased and returned to natural and farm land.

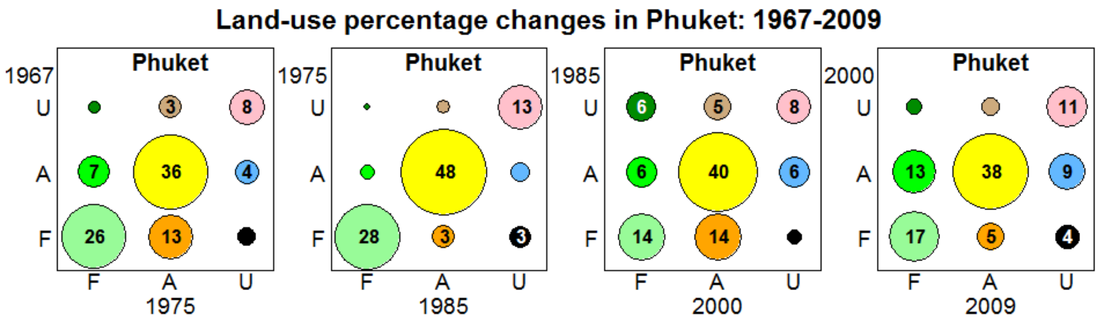


Figure 7: Change in land-use is effectively summarized in a cross tabulation giving area (in hectares) or percentages of land-use categories from one period to the next. These numbers can be displayed as a bubble-plot matrix as above (Note that darker colors show changes and lighter colors denote no change.)

In Figure 7, it can be found that the area of forest land continued to reduce, especially the south of Phuket. Forest occupied a large area of land, especially in 1975 to 1985, but tends to decrease in time. Regarding the total urban areas from 1967 to 1975—the number of the urban areas did not change, (28%), and increased in next period, from 1985 to 2000,(14%).There was an increase again from 2000 to 2009 of 17%. The coverage of agricultural and fish farming (A) areas in four periods were large in number, but the trend of change to urban decreased. In the first period, 1967 until 1975, the agricultural area changed to urban area (4%), then from 1975 to 1985 (2.5%), after that, from 1985 to 2000 (6%), and lastly, from 2000 to 2009 (9%). Focusing on the number of forest areas from first period, (1967-1975), to the fourth, (2000-2009), to see where changes occurred, thematic maps were useful. Figure 8 showed how land-use changed during those four periods. Panel one showed the land-use change from 1967 to 1975 whereas panel 2, 3 and 4 showed land-use change in 1975 to 1985, 1985 to 2000 and 2000 to 2009 respectively.

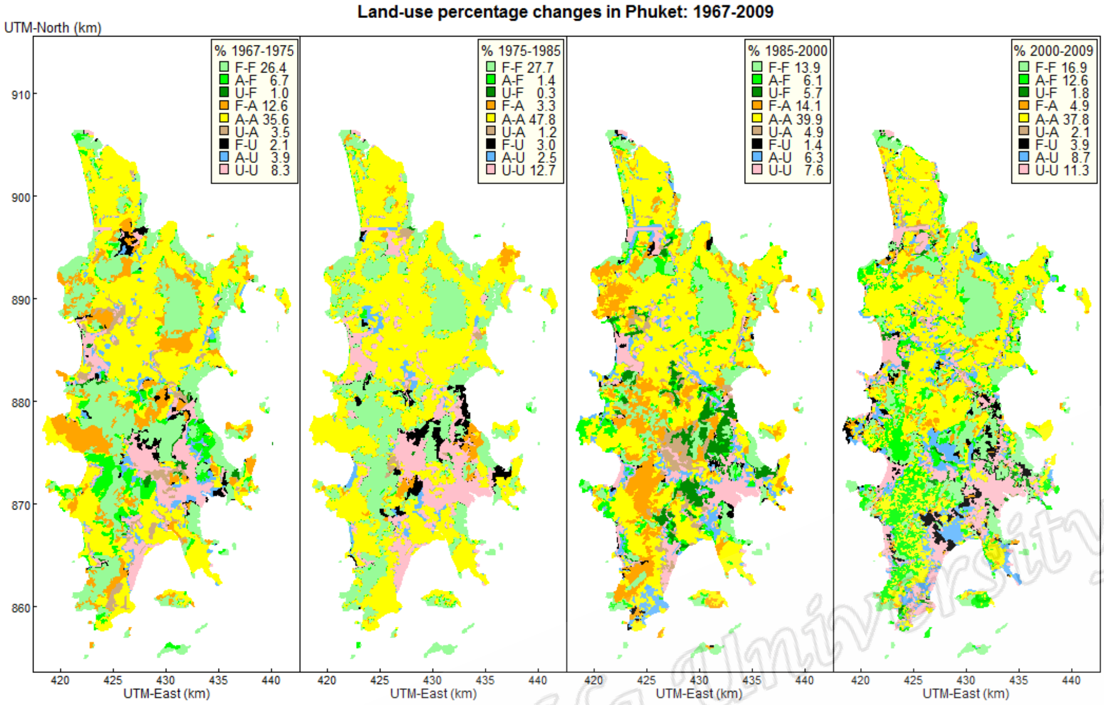


Figure8: To see where changes occur, thematic maps are useful. The map below uses the same colors as in the bubbleplot matrix. Note that, the number of land-use changes in 4 panels corresponds with bubbleplot matrix

The reduction in forest area was less in the period of years from 1985 to 2000, the forest area was mainly converted into agriculture area. In the 2000 to 2009 period, the land use type has the largest number of urban land during all 4 periods. The dominant area is Patong beach, an important area in Phuket Island, which is 20 km^3 of the island. The area has been constructed into infrastructure, commercial area, hotels, etc. To see land-use change, figure 9 and 10 will explain the type of land-use change during the past 42 years.

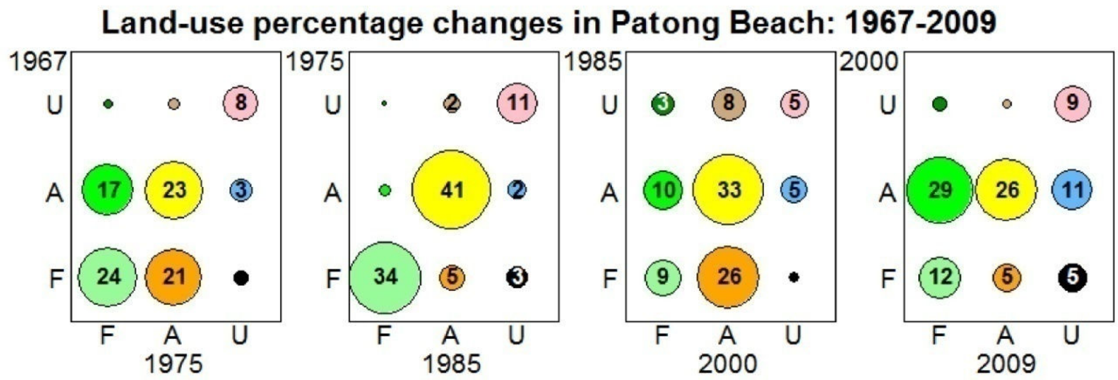


Figure 9: Land-use change surrounding Patong beach displayed as a bubble-plot matrix as follows in four periods which corresponds to figure 10.

Figure 10 shows the land-use change over the 42 year study period; 20 km^3 around Patong beach. 21.0 % of this study area during 1967-1975 was changed from forest to agriculture with greater changes in 1985-2000 periods. An important point to consider is the change from urban reclaimed to forest from 1985-2000. Tin mining has been a major source of income for the island since 1980, when the mining activity ceased, the area changed from abundant mining to forest area. Along Patong beach there was a change to urban and a small area change from forest to urban in the 2000-2009 period.

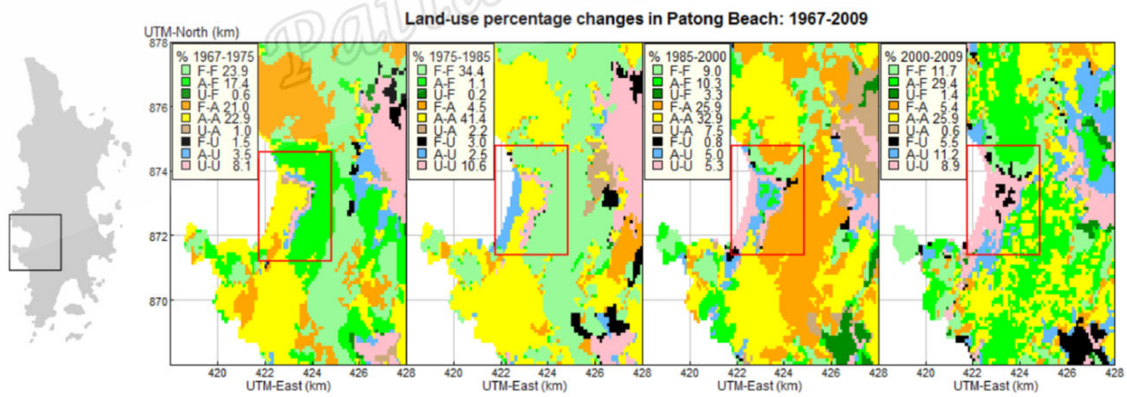


Figure10: The map on the extreme left of Phuket Island, with the rectangular box, indicates the thematic map for Patong beach. Thematic maps for land-use change surrounding Patong beach are 20 km^3 In area.

The increasing demand from tourists has brought about substantial changes in the coastal areas of Phuket. According to the report of Wang (1998), upland resort development has resulted and will continue to have negative impacts on the coastal environment in Southeast Asia. Moreover, in 2009, the Tourism Authority of Thailand (TAT) reported that numbers of hotels in the southern part of Thailand are 25% more than the rest of the regions. The demand of construction of new hotels and resorts has grown and that is a direct cause which affects land-use on Phuket in the tourist areas.

4. Conclusion

This paper presents the results of land-use changes for measuring GIS data with respect to digitization based on GIS data which was computed by freely available software with no license fees. This computation is based on the actual number of observations for digitizing to compute land-use data of Phuket from 1967 to 2009. We used bubble plots to show variation of the land use change for each of three categories corresponding with a thematic map. The results show the proportion for land-use change from year to year whereas the bubble plots show the simple statistics where the developer, planner, and geographer can understand the result.

Land-use is quite important for Phuket Island due to the constantly increasing urban area. Agricultural areas and forests are quite important for a crowded city, however, human encroachment and commercial projects have impacted locally, mostly because of the construction in the tourist areas. Based on this paper, it can be concluded that future study is needed to monitor land-use change in the long term, and high statistical analysis is needed to predict the land-use change.

Acknowledgements

The authors thank Prof. Dr. Don McNeil (Emeritus Professor in statistics Macquarie University) for research supervision, Dr. Somporn Chuai-Aree, and Assistant Prof. Thakerng Wongsirichot for the suggestions. The Thailand land development for the support of the GIS data is also gratefully acknowledged.

Reference

Abildtrup, J., Garcia, G., and Stenger, A. 2013. The effect of forest land use on the cost of drinking water supply: A spatial econometric analysis. Ecological Economics. vol. 92, 126-136.

Annual Report 2009 [homepage on Internet], Tourism Authority of Thailand (TAT). [cited 2013 Sep 3]. Available from: http://www.tourismthailand.org/About-TAT/annual-report.

Hascic, I., and Wu, J.J., 2006. Land use and watershed health in the United States. Land Economics. vol. 82, 214-239.

Hill, R.D. 1984. Land use change. Geoforum. vol. 15, 457- 461.

Jim, C.Y. and Liu, H.T. 2001. Pattern and dynamics of urban forests in relation to land use and development history in Guangzhou City, China. The Geographical Journal, vol.167, 358-375.

Kurt, S. 2013. Land use changes in Istanbul's Black Sea coastal regions between 1987 and 2007. Journal of Geographic Sci. vol. 23, 271-279.

Lammeren, R.V., Houtkamp, J., Colijn, C., Hiferink, M. and Bouwman, A. Google Earth based visualization of Land Use scenario studies. GSDI 11 World Conference: Spatial Data Infrastructure Convergence: Building SDI Bridges to Address Global Challenges, Rotterdam, The Netherlands. Jun, 2009, 15-19.

Qingwei, Z. 2009. A new method for information of urban. Land Use Urban Remote Sensing Joint Event.

Raine, R.M. 1994. Current land use and changes in land use over time in the coastal zone of Chantaburi province Thailand. Biological Conservation. vol. 67, 201-204.

Ramesh, B. 1989. Urban land use change detection using sequential aerial photographs and spot image case study: ChiangMai Thailand. Journal of the Indian Society of Remote Sensing. vol.17, 101-108.

R Development Core Team. 2012. R: A language and environment for statistical computing. Vienna: R Foundation for Statistical Computing.

Sadr, K. and Rodier, X. 2012. Google Earth, GIS and stone-walled structures in southern Gauteng, South Africa. Journal of Archaeological Science. vol. 39, 1034-1042.

Strand, G.H., Dramstad, W. and Engan, G. 2002.The effect of field experience on the accuracy of identifying land cover types in aerial photographs. International Journal of Applied Earth Observation and Geoinformation. vol. 4, 137-146.

Thinnukool[A], O., Chuangchang, P., and Kongkraphan, K. 2013. Analyzing land-use change using grid-digitized method. Songklanakarin Journal of Science and Technology. vol.30, (In process)

Thinnukool[B], O., Kongchouy, N. and Appianing, C.B. 2013. Management of LUCC and Land-Use Transition in Phuket Island, Thailand. 6th International Conference on Computer Science and Information Technology. Paris, France, December 20-21.

Weng, Q. 2001. Land use change analysis in the Zhujiang Delta of China using satellite remote sensing, GIS and stochastic modeling. Journal of Environmental Management. vol. 64, 273-284.

Wong, P.P. 1998. Coastal tourism development in Southeast Asia: relevance and lessons for coastal zone management. Ocean and Coastal Management. vol. 38, 89-109.

York, A.M. and Munroc, D.K. 2010. Urban encroachment, forest regrowth and land-use institution: does zoning matter. Land Use Policy. 471- 479.

Yang, G. and Qiao, G. 2010. Data processing method for current land use using GIS Technology. Second International Workshop on Education Technology and Computer Science. Wuhan, China, March 6-7,511-514.

Urbanization of Tourism Areas in Phuket Island, Thailand A Case Study of Patong, Kammala and Karon

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Abstract

The factors influencing the urbanization growth of tourism industry have been debated and discussed by developers, about tourism literature and the issue continues to be one of the most popular topics for research.Using Phuket tourism areas as our target population, we assessed areas such as Patong, Kamala and Karon. This study aims to review available approaches to model land-use change and thus identify priorities for future urbanization growth. A logistic regression model was fitted separately to predict these outcomes since 1975 to 2009 with those locations and the land-use 8 years earlier as determinants. The results of this study, therefore do not only provide sufficient information on the urban growth in three places of Phuket tourism areas from 1967 to 2009 but they also provides quantitative information about urban change by simple geographical from freely available software R program. For the areas that had much than each locations, we found substantial changes in Patong, Kamala and Karon, with 24.2 %, 13.0 % and 19.5 % of other land-use type, respectively, becoming urbanized while 93% of urban land did not change whereas the estimated urban growth of the Island on the East coast was higher than West coast.

Key words: Grid-digitized, predictions, land-use, logistic regression, Phuket Island.

1. Introduction

Recently, tourism industry in the world conducted economic growth, the report of Research note from 1990 to 1995 was annual growth of 8.2 % whereas growth in the world tourist increased at a rate 4.7 % (Research note, 1988). Corresponding to the study of Wong, upland resort development will continue to have negative impacts on the coastal environment in Southeast Asia (Wong, 1998). Although, the tourism industry could provide increasing economic growth, the results of the management for supporting the tourist industry changed urbanization. The impacts of urbanization gains are well known and observed. Currently, in Southeast Asia there have been many buildings such as the five-star hotel, resorts, and floating bungalows (Lee, 2010). The contribution of travel and tourism to GDP (in 2009) from the studies of Wong was 11.0 % in ASEN community (Wong, 2008). The direct effect of growth for tourism industry was changed of land-use. In Malaysia the reported of Lee said, the increased in coastal resort is mainly due to decreasing forest, agriculture, and beach. The coastal tourism growth in Malaysia, East coast area was relatively new to coast resort development whereas the information on aquaculture and habitat (mangroves) loss from 1970 to 1988 was 0.3-4% per year. In Pattaya (Thailand), the increasing of most intensely developed urban has been strongly effected to the environment, traffic, and land-plan (Wong, 1988).

Without tourism industry, over 45% the world's population live in urban or city or commercial areas and the annual population growth rate is around 2.4% in a year in urban areas compared to around 1.7% in a year in non-urban areas (United Nations, 1997, Wu and Murray, 2003). Increasing of urbanization is a major problem and a form of environmental change that impacts directly on the quality lives of human. Estimating, urban growth in Tokyo 40 years ahead, urban or new built-up density decreased in the metropolitan inner core as the city center experienced depopulation whereas urban growth out site the city increased [(Bagan and Yamagata, 2012). In Beijing, the prediction of urban growth from 2020 to 2049 increased and hence urbanization will disturb other land-use (Ying *et al*, 2009). In London studied the limitation of urban growth in London's street network which effected to the urban growth up corresponding to the street, the results showed that the trend of urban area was increased (Masucci *et al*., 2013). Moreover, Liao and Wei predicted urban growth in Dongguan, China which the outcome was found that the urban area increased by 1,181 % in 1988 to 2006 (Liao and Wei, 2012). Focusing on Southeast Asia, especially in the popular of tourism area such as Phuket, Bali, Hanoi, Langkawi, etc. there are places which have been disturbed by urbanization urbanization (Martin and Assenov, 2008). Following the topic of the City in 2050 of Brown, the effect from gain of the city was been constructed from rural to urban which needed to plan and manage the recourses such as infrastructure, transportation, and regional planning to support the gain (Brown, 2013).

Our current research focused on the Southern part of Thailand, which has the highest percentage of the urbanization in particular Phuket Island, which is one of the provinces in Thailand that has fast grown by tourism industry more than the other regions. The objective of this study is to predict future urbanization by logistic regression analysis with Remote Sensing (RS) data. Based on grid-digitized method the computed RS data outcome is binary, these data can be analyzed by logistic regression as either the specific land-use of interest (urban land, for example) or not. Finally, the thematic map and geographical display by freely available software R program are implemented to simulate spatial distribution of urbanization from 1967 to 2009; three locations of tourism areas such as Patong, Kamala and Karon are assessed.

2. Materials and Methods

2.1 Study Area

The Phuket Island is located between latitude 7° 53N, and longitude 98° 24E**.** Phuket Island is divided by mountain ranges that extend the entire length of the western coast, all fronted by wide sandy beaches. The balance of the island is somewhat flat with green hills and valleys and a rich, tropical feel. Neighboring provinces are Phang Nga and Krabi, since Phuket is an island it has no land boundaries. It is situated off the west coast of Thailand near the Andaman Sea.

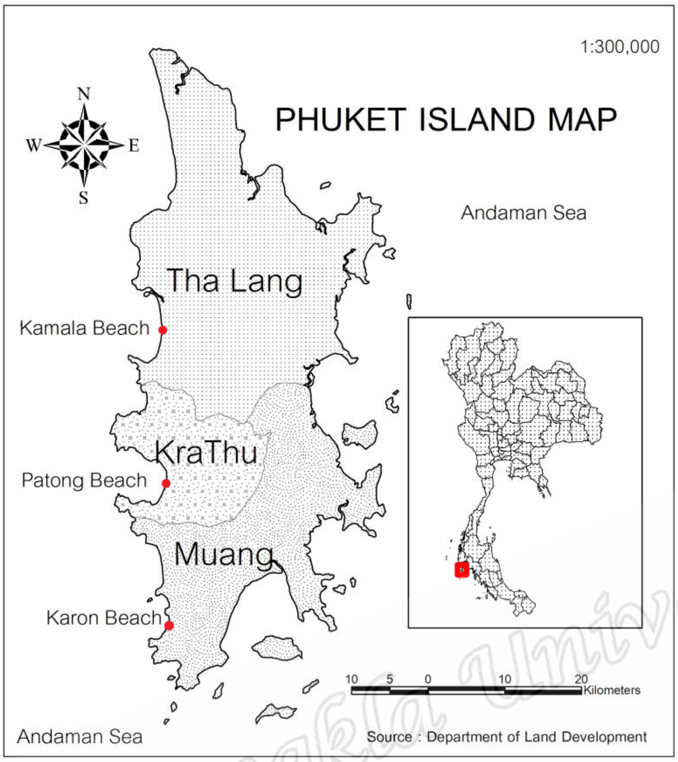

Figure1, Phuket Island map body.

The population density of Phuket Island has been reported by National Statistical Office which was more than 239 people per 1 m^3 whereas population is growing at a constant rate of 2.99 % per year from 1990 to 2000 (National statistical office, 2000). This population density has placed considerable pressure on the city's infrastructure and is the point driving force of urbanization for the support of tourism industry. The current trends in urban development are currently most apparent in the suburbs of the tourism area particularly at Patong, Kamala and Karon where numerous new resorts, hotels, and tourism zones are located. The population density in that place increased drastically at the beginning of the 1990s due to rapid tourism industry. Consequently, the direct effect of growing of tourism industry such as traffic jams, flooding are becoming serious problems for Phuket's province government.

2.2 Management Data

For this study, the steps for data management and use of data for analysis are summarized in Fig 2.

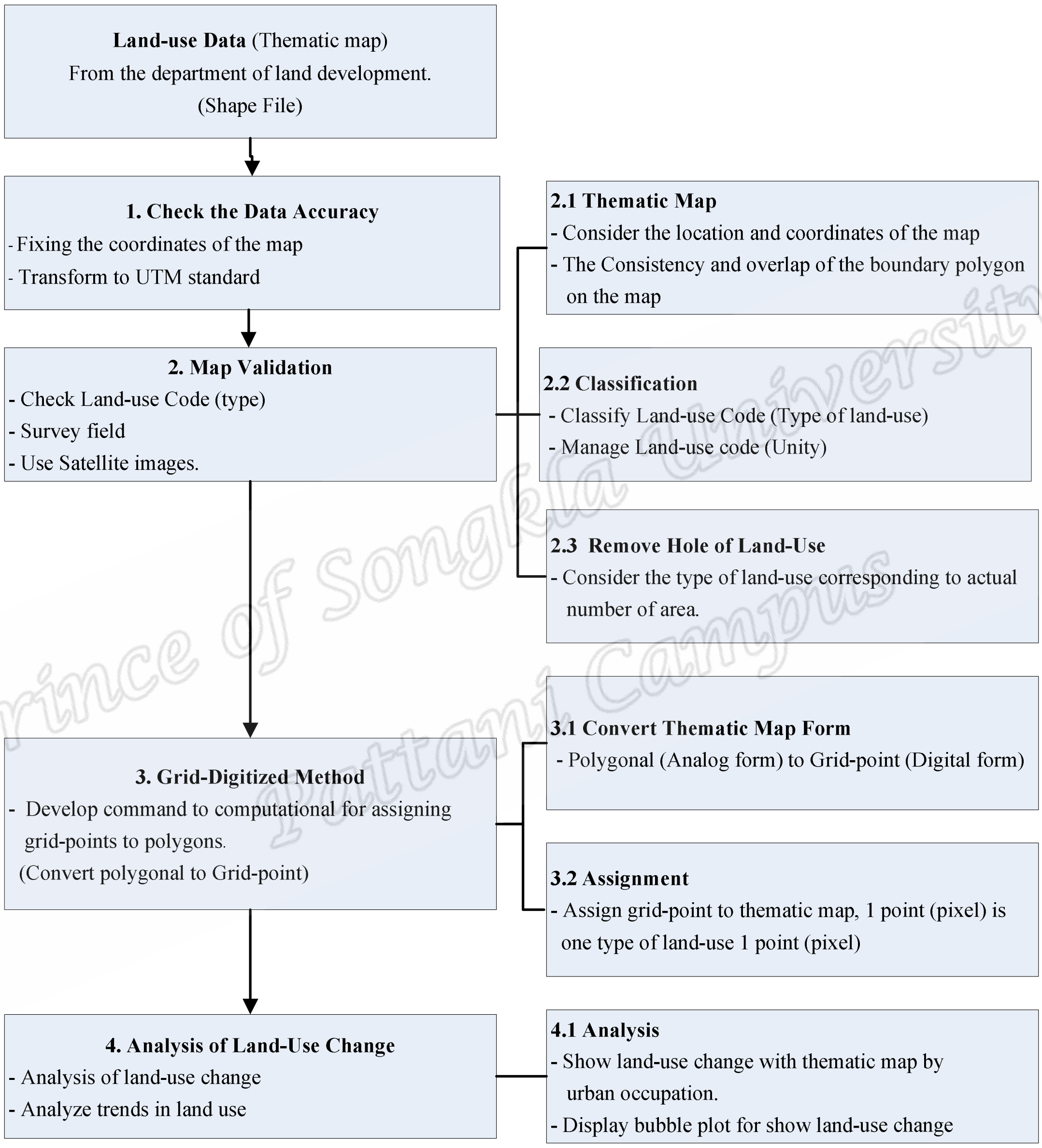

Figure 2, Step used for data management and data analysis

Data for this study were derived from RS data conducted by the Thai Department of Land Development. Data were collected through grid-digitized method which involves converting the polygonal data (RS data) to grid-point data (Thinnukool *at el*., 2013). The researchers such as Hun *et al* (2011), Stehman and Wickham (2011), Frazier and Wang (2011), Bach *et al* (2006), Guo *et al* (2011) and Whiteside *et al* (2011) studied and described the use of pixels, blocks and polygons to construct accurate maps . They also confirmed that pixel-based construction can accurately show land-use and the pixel can be accepted for representative of land-use data. The concept of this method was connected from the polygonal coordinates to those based on the gridding in which one point is the area 10×10 meters. R program was used to compute RS data after loading its *sp* library, which contains the function *point.in.polygon* () (R Development Core Team, 2012). Examples of grid-digitized outcome illustrated in Fig 3, there are quite substantial and accepted accurate measurement of land-use which is provided to analyze land-use.

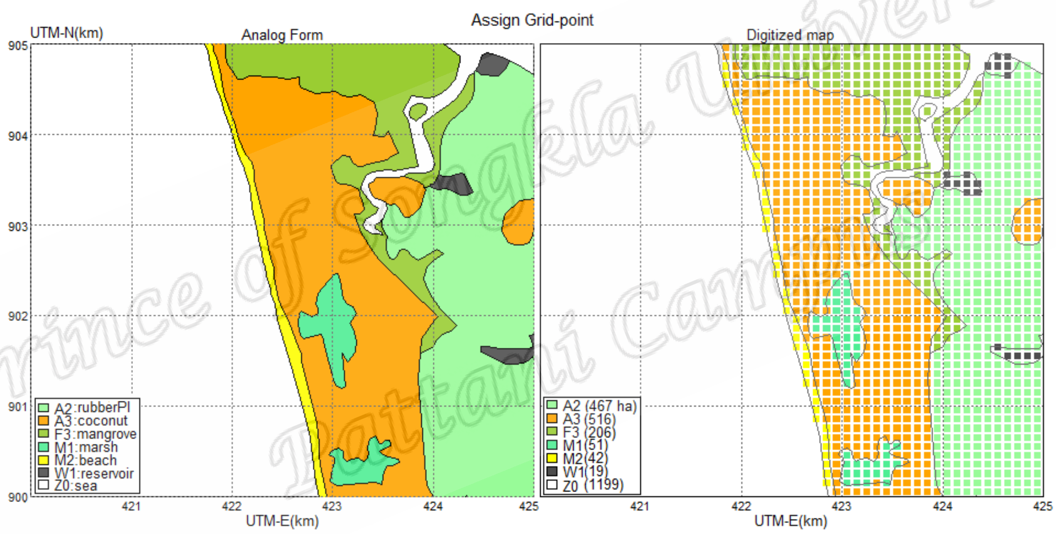

Figure 3, An example to shows the conversion of polygonal representation (left panel) to digital representation (right panel) in digital form by digitized land-use data from North of Phuket Island in 1967.

To detect urban change in Phuket Island, data classified by the Thailand Department of Land Development were used in this study. After the data in polygon form had been transformed to grid-point (digital data), the data were managed considering the land-use categories (urban, non-urban). Thailand land-use type had 48 categories in which that data have been change into 2 type of land-use, Fig 4 describe how to classify land-use type.

Land-use Group Type	Type / Land-use Code	Define Land-use
Agriculture	A1XX Rice farm A2XX Field crop A3XX Perennial A4XX Orchard A5XX Horticulture A6XX Temporally Farm A7XX Farm House A8XX Aquatic plan A9XX Aquacultural land A0XX Integrated farm	Non-Urban
Forest	F1XX Evergreen F2XX Deciduous F3XX Mangrove F4XX Swamp F5XX Plantation F6XX Agro forestry F10X **the characteristic of forest such as Disturbed or Dense	Non-Urban
Miscellaneous	M1XX Rangeland M2XX Marsh M3XX Mine M4XX Other	Non-Urban
Urban	U1XX City, Town U2XX Allocated land U3XX Institutional U4XX Utility U5XX Industrial land U6XX Other	Urban
Water body	W1XX Natural water W2XX Reservoir	Non-Urban

Figure 4, Define type of land-use code for Phuket Island, urban and non-urban are assessed

2.3 Analysis Urbanization

Statistical modeling and forecasting of land-use are complicated by changing boundaries of polygonal land-use plots. Land-use in polygonal form can be improved by gridding. The polygons that vary in shape and size are replaced by a regular and unchanging set of grid points on which the land-use is defined.

These data can be analyzed by logistic regression, because the outcome at each grid-point is binary: it is either the specific land-use of interest (urban-land, for example) or not. The handle the substantial spatial correlation that exists between data from grid-points within the same land-use plot, we use a method based on covariates inflation factors (Rao and Scott, 1992). This method computes effective sample sizes for each land-use plot based on their sample variances, from which standard errors are applied to fitted values from the logistic model to compute confidence intervals. In the simple situation where no covariates are considered the binary dependent variable Y represents the land-use for each grid-point in a specified year and X is the corresponding land-use for a preceding year, the model is formulated as

$$P(Y = 1|X = \frac{1}{1+e^{-(a+bx)}} . \quad (1)$$

From equation (1), $P\ (Y=1|\ X)$ is the probability of the specified land-use at a grid-point given its value is X at the previous survey. This method can be extended to situations using covariates such as location. Analysis is performed using the R program (R Development core term, 2012).

3. Result

This study takes Phuket Island as the research area, and as convert its map to square kilometer with 1:1000 scale. Land-use classification was formed in which it was grouped into 48 categories and two groups (urban, non-urban). Fig 5 demonstrates a thematic map for Phuket Island from 1967 to 2009 with land-use type urban and non-urban (other land-use type). There are three places in rectangles were important tourism areas and urban percentages have been shown in the bobble plot matrix in Fig 6.

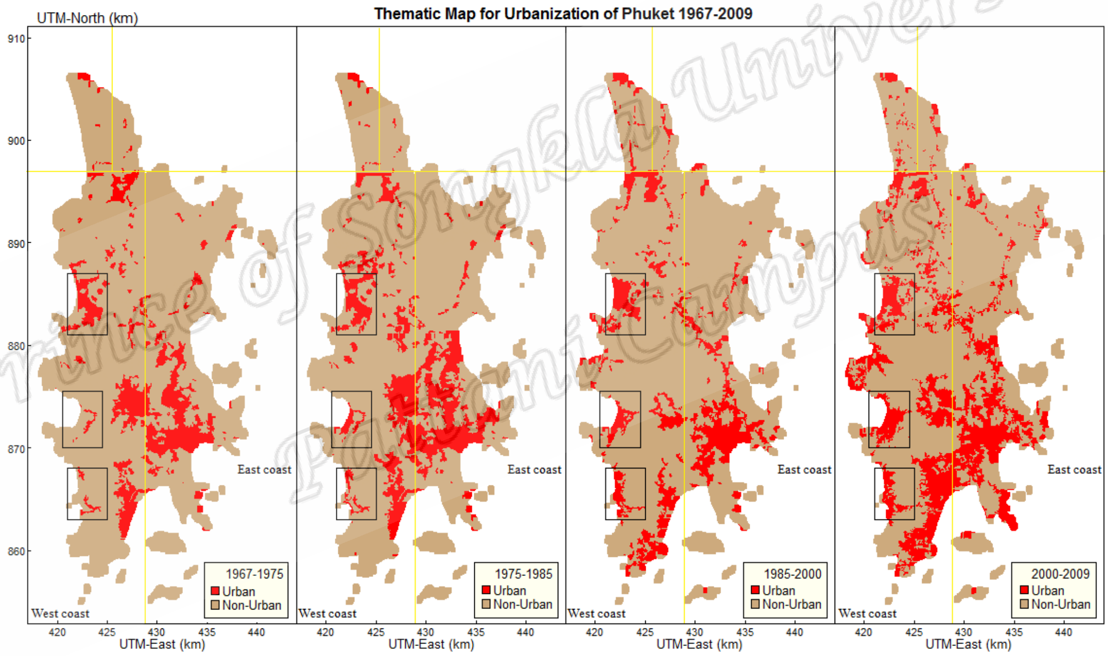

Figure 5, Thematic map was used; illustrate urbanization in three places in Phuket Island (top rectangle was showed Kamala tourism area, whereas middle rectangle showed Patong tourism area and bottom down rectangle show Karon tourism area.

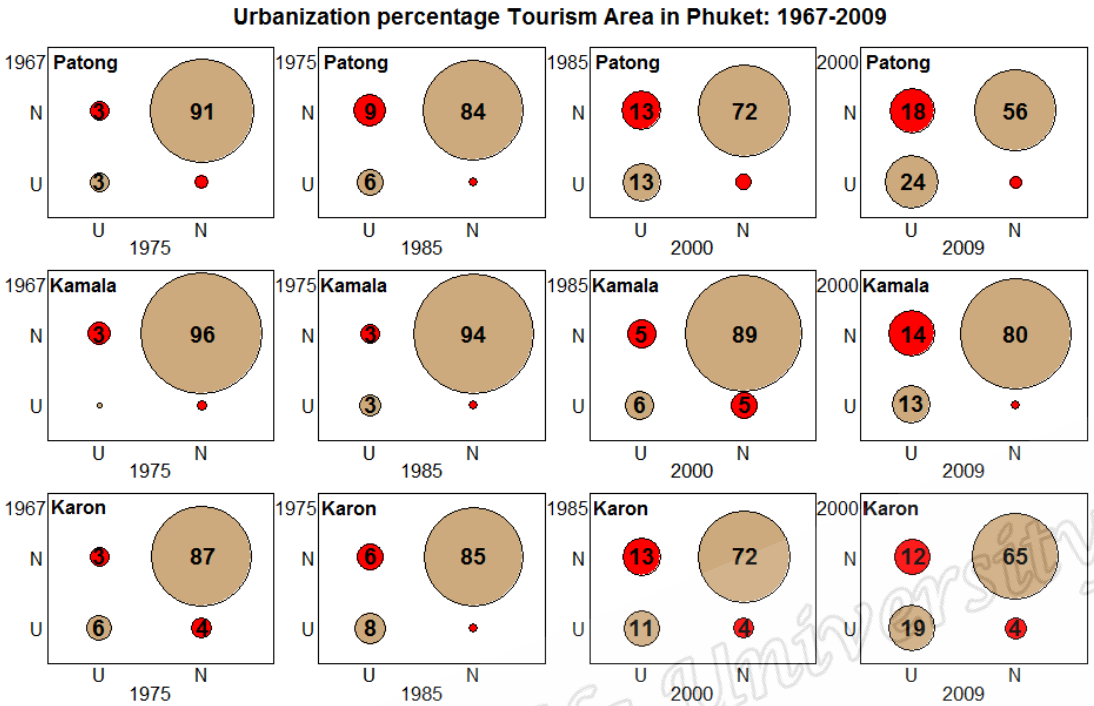

Figure 6, Summary of urbanization in 3 places in Phuket Island, 4 periods are assessed.

To understand and focus on the area of this study, Fig 7 shows the thematic map of Phuket's tourism areas which heighten on the shape and show the percentage change from non-urban (N) to urban-land (U).

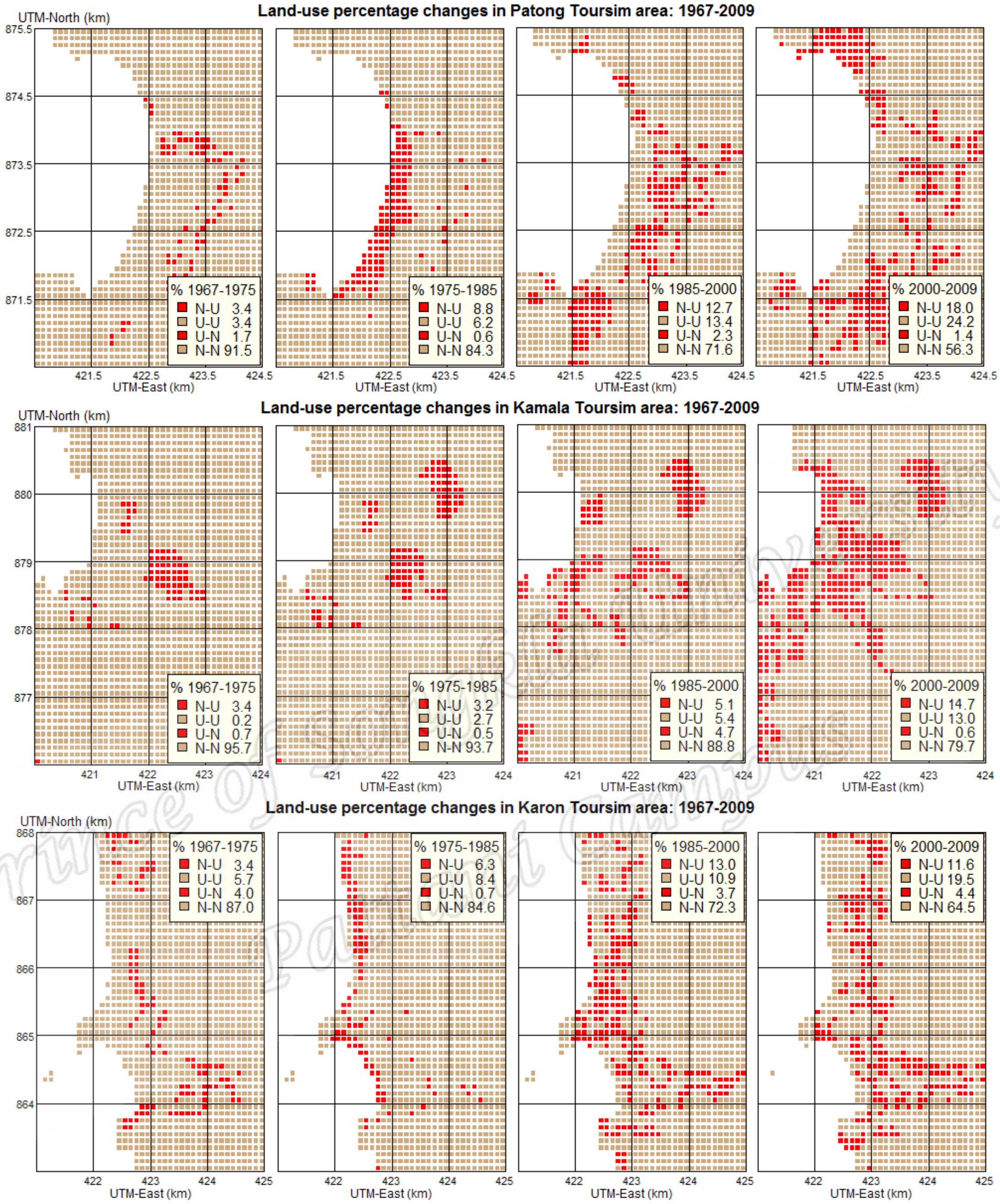

Figure 7, Thematic map illustrates land-use change with urbanization in three places in Phuket Island in 4 periods.

3.1 Land-Use Data Analysis

Urbanization of tourism area in Phuket Island, the bar chart shows percentages of urbanization in three locations 8 years earlier. In 1967, total of areas Urban in 1975 were 48, 14 and 78 hectare whereas non-urban were 90, 96 and 1186 hectares of three places. This pattern was not repeated in the period from 1967 to 2009 when over 15 %

of urban of three tourism areas remained urban, and the other land-use type also became urbanized. The blue vertical line segments denote 95% confidence intervals which are much wider than those for independent error. Following Fig 8, greater urbanization occurred in Patong tourism area, and the percentage of other land-use that became urbanized in the following 4 periods.

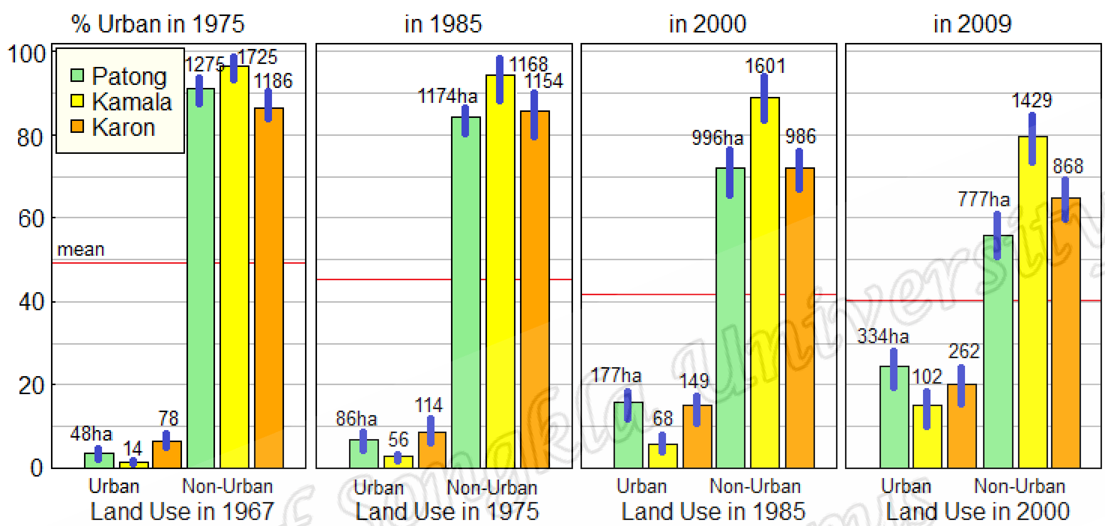

Figure 8, The bar chart shows percentages of urban land which denote 95% confident interval from logistic regression model using Rao-Scott variance inflation method to account for correlation within land-use plots.

Estimation of urbanization for Phuket tourism areas, Fig 8 shows percentages of urban land which denote 95% confident interval. The results of urban growth were 0.87, 0.18 and 0.21 for three places for Phuket tourism areas from 1967 to 1975. From 1975 to 1985, urban growths were 0.20, 0.14 and 0.23 Next period from 1985 to 2000, urban growths were 0.49, 0.22 and 0.14 whereas 2000 to 2009 were 0.41, 1.32, and 0.27 times.

Although, urbanization growth in Phuket especially the tourism areas, are located at West-coast, in the East-coast of Phuket, urbanization has occupied the entire city (CBD). We have considered the urban growth and compared the trend of growth, Fig 9 show percentages of urban land between West-coast and East-coast.

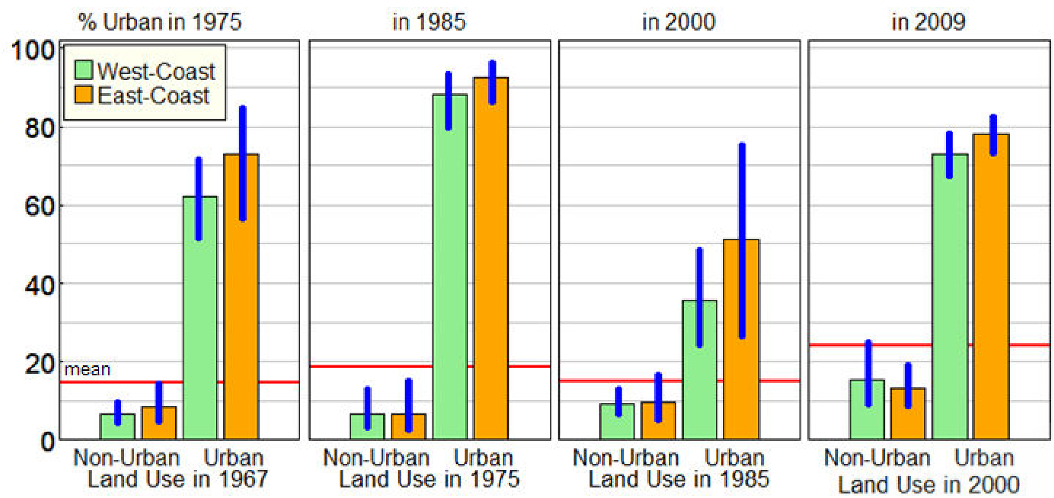

Figure 9, The bar chart shows percentages of urban land which denote 95% confident interval from logistic regression model, the prediction of urban growth of West and East coast for Phuket Island.

According to the results of Fig 9, the urban growth in West coast had an estimate of 3.93 times for 1967 to 1975 and East-coast was 6.48 times. In second period (1975-1985) urban growth were 8.84 and 14.87 times because during this period Thailand open the tourism area and the government support the tourism industry. After that in 1985 to 2000 the growth of urban decreased, they were 1.95 and 3.70 for West-coast and East-coast. In 2009, the estimated urban growth on the West Coast was 3.4 times higher than in 2000, whereas the estimate of the growth on the East Coast was 4.95 times higher/larger.

4. Discussion and Conclusion

In this study we used graphical thematic map by grid-digitized and statistical method by logistic regression to estimate urbanization of Phuket tourism areas which it fit a model for predicting the percentage of future urbanization. Consideration between West coast and East coast, proportion of urban growth West coast had been occupied by urban especially three places of Phuket tourism areas and East coast occupied by urban at CBD.

Focusing on the tourism areas, we found the urbanization growth in Patong, Kamala and Karon in which the used methodology allowed us to clearly show the patterns of urbanization in Phuket tourism areas over the past 42 years. In 1967, Phuket Island was relatively naturally abundant with few developed areas. By 1967 to 1975, Patong, Kamala and Karon, areas had been occupied by a few urban-lands whereas 10 years later, Patong and Karon have urban growth more than Kamala.

In 2000, the following period of rapid urban land expansion occurred through the conversion of other land such as agriculture, forest, grassland and farm areas (non-urban group) to tourism developed areas. Increasing of urbanization in Patong, Kamala and karon due to the expansion of the tourism industry was closely correlated with the increase in the number of tourists, corresponding to the report of Tourism Authority of Thailand which numbers hotels in Southern part to be more than the rest of the regions 25% (Annual report, 2009).

The results of this study therefore not only provide sufficient information on the urban growth in three places of Phuket tourism areas since 1967 to 2009 but also provide quantitative information about urban change by simple geographical from freely available software R program. For example, the analysis revealed urbanization associated with the urban development of Phuket Island. The rapid development of tourism industry resulted in increase in other land-use areas by becoming urban areas located mainly to the coast and up-land area of the tourism areas of Phuket Island. Applied geographical of remote sensing by grid-digitized is a valuable method for studying urbanization. However, the limitation of our methodology was derived based on comparisons of thematic maps only land-use data from shape-files was used. Future studies need to focus on using other land-use data such as characteristic of soil or the land-use price which information is also valuable to planners and developer.

Acknowledgements

The authors thank Prof. Dr. Don McNeil for research supervision. The Thailand land development support of the GIS data is also gratefully acknowledged.

Reference

Bach, M., Breuer, L., Frede, H.G., Huisman, J.A., Ott, A., and Waldardt, R., 2006. Accuracy and congruency of three different digital land-use maps. Landscape and Urban Planning., 78: 289-299.

Bagan, H., and Yamagata, Y., 2012. Landsat analysis of urban growth: How Tokyo became the world's largest megacity during the last 40 years. Remote Sensing of Environment., 127: 210-222.

Brown, L.A., 2013. The city in 2050: A kaleidoscopic perspective. Applied Geography., 1-8.

Frazier, A.E. and Wang, L., 2011. Characterizing spatial patterns of invasive species using sub-pixel classifications, Remote Sensing of Environment., 115: 1997-2007.

Guo, L., Du, S., Haining, R. and Zhang, L., 2011. Global and local indicators of spatial association between points and polygons: A study of land use change. International Journal of Applied Earth Observation and Geoinformation., 21: 384-356.

Huh, Y., Yu, K., and Heo, J., 2011. Detecting conjugate-point pairs for map alignment between two polygon data sets. Computer Environment and Urban System., 35: 250-262.

Lee, O.A., 2011. Coastal resort development in Malaysia: A review of policy use in the pre-construction and post-construction phase. Ocean and Coastal Management., 53: 439-446.

Liao, F.H.F., and Wei, Y.H.D., 2012. Modeling determinants of urban growth in Dongguan, China: a spatial logistic approach. Stochastic Environmental Research Risk Assessment Journal., 1-10.

Masucci1, A.P., Stanilov, K., and Batty, M., 2013. Limited Urban Growth: London's Street Network Dynamics since the 18th Century. Pole One., 8(1): 1-10.

Martin, S. A., and Assenov, I., 2011. Beach and Coastal Survey of Thailand: What Future for Surf Tourism. Steven Andrew Martin., 3(1): 77-87.

National statistical office. 2000. Population and housing census 2000. Bangkok: National statistical office. National statistical office. Population and housing census 2010. Advanced report.

Rao, J.N.K. and Scott, A.J., 1992. A simple method for the analysis of clustered data. Biometrics., 48: 557-585.

R Development Core Team, 2012. R: A language and environment for statistical computing. Vienna: R Foundation for Statistical Computing.

Research Note, 1988. Changing trends in Asia-Pacific tourism. Tourism Management, 19(4): 381-382.

Stehman, S.V. and Wickham, J.D., 2011. Pixels, blocks of pixels, and polygons: Choosing a spatial unit for thematic accuracy assessment. Remote Sensing of Environment., 115: 3044-3055.

Thinnukool, O., Chuangchang, P., and Kongkraphan, K., 2013. Analyzing land-use change using grid-digitized method. Songklanakarin Journal of Science and Technology., 36(2): (In process).

Tourism Authority of Thailand, 2009. Annual report 2009: Tourism Authority of Thailand. Bangkok: Tourism Authority Publishing.

United Nations, 1997. Urban and Rural Areas: 1996. ST/ESA/ SER.A/166, Sales No. E.97.XIII.3, United Nations.

Wong, P.P., 1998. Coastal tourism development in Southeast Asia: relevance and lessons for coastal zone management. Ocean and Coastal Management., 38(1): 89-109.

Wong, E.P.Y., 2008. A model of ASEAN collaboration in tourism. Annals of Tourism Research., 38 (3): 882-899.

Wu, C., and Murray, A.T., 2003. Estimating impervious surface distribution by spectral mixture analysis. Remote Sensing Environment., 84: 493-505.

Whiteside, T.G., Boggs, G.S., and Maier, S.W., 2011. Comparing object-based and pixel-based classifications for mapping savannas. International Journal of Applied Earth Observation and Geoinformation.,13: 844-893.

Ying, L., Qizhi, M., and Anrong, D., 2009. Beijing urban development model: urban growth analysis and simulation. Tsinghua Science and Technology., 16: 782-794.