

FORM FEATURES OF LAKES IN THE MOJOS PLAIN

Kanumchan Gogo^a and Susumu Ogawa^b

^aGraduate student, Faculty of Technology and Environment, Prince of Songkla University, Kathu, Phuket, 83120 Thailand; Phone: +66-76-276-100 ;Fax: 66-76-276-102

E-mail address: kanumchan@gmail.com

^bE-mail address: ogawa.susumu.phd@gmail.com

KEYWORDS: Archaeology, Fractal, Image processing, SAR, Shape factor

Abstract: In the *Mojos* Plain, Bolivia, artificial lakes distribute widely as remains of the *Mojos* Culture. The artificial lakes were estimated to function as fish cultivation and reservoirs, which related with a human life. Therefore, from its function, artificial lakes and residences were estimated to exist in a neighborhood each other. Then, this study extracted lakes and river systems from SAR images with image processing and identified the center in the distribution as the focus of the *Mojos* Culture. 700 artificial lakes and 380 natural lakes were extracted from 136 scenes of SAR images, and the shape factor distinguished between natural and artificial lakes. From the result, the survey site was examined prior to a preliminary survey of excavations. 700 artificial lakes and 380 natural lakes were extracted by judging their features from SAR images. Finally the center of artificial lake locations was obtained. The center location of artificial lakes was 60 km northwest of Trinidad, the capital of *Beni* State, at 14°25'S and 65°15'W. The shape factor for natural lakes is a logarithmic normal distribution with the average of 4.18, while the shape factor for artificial lakes is a normal distribution with the average of 2.54. The mass and edge fractal dimensions for natural lakes are 1.66 and 1.02, respectively, while the mass and edge fractal dimensions for artificial lakes are 1.71 and 1.01, respectively. The main direction of artificial lakes is northeast, while the main direction of natural lakes is north. In a dry season people have a little rainfall and small amount of discharge in the Amazon River, therefore people need also irrigation for agriculture from the lakes. Development of big artificial lakes might relate with agriculture irrigation. On the other hand, most of small artificial lakes distribute near the Mamore River.

1. INTRODUCTION

In archeology, selection of a survey site for an excavation is very important. Thus, the survey site of the excavation should be determined through a careful preliminary research. When the survey site of the excavation is determined suitably, collecting samples in the excavation is developed efficiently. Then, destruction of the remains becomes the minimum and the remains are conserved enough (Iwasaki, 1998).

The remote sensing is a possible method to select the survey site of the excavation efficiently from the wide objective area. Then, the remote sensing is very effective in the preliminary research for the objective area where research access is difficult (Sakata, 2002). Especially, synthetic aperture radar, SAR is a very powerful tool to detect water body, groundwater and archeological remains (Ohuchi, 2004).



Fig. 1 Objective area



Fig. 2 Artificial lake from the airplane.

Artificial lakes distribute as the remains of the *Mojos* Culture in the *Mojos* Plain (Denevan, 2001). The *Mojos* Plain is this study's objective area. Artificial lakes had functions as fish cultivation and reservoirs for agriculture (Erickson, 2000; Erickson, 2001). Therefore, the center of locations for the lakes would relate with the focus of the *Mojos* Culture. Then, this study extracted images of lakes and river systems from JERS-1/SAR and identified the center in the distribution for the ground survey.

2. MATERIALS AND METHOD

2.1. *Mojos* culture

The *Mojos* Plain is in the Amazonia north region of *Beni* State, Bolivia as shown in Fig. 1. Mixed forests cover over 2,000 km² of the land, and savannas and swamps extend about 90,000 km² in this plain. A third of the plain sinks under water from the flooding river in a rainy season.

The *Mojos* Culture, which prospered in the *Mojos* Plain, had advanced civil engineering and irrigation technology. The origin of this culture started thousands years ago. Most the remains of this culture include a *loma* (an artificial mound), a *terraplen* (a road), a canal, the cultivated field, and an artificial lake, which are still observable as land scape. Those remains distribute in the plain and inside the rain forest in the Amazonia. The *loma* is an artificial mound, which was constructed to protect people from flooding and also was estimated to use as grave because of discovery of human remains. The *terraplen* is an artificially raised road and connects each *loma* as networks.

More than 2,000 artificial lakes might exist in the plain as shown in Fig. 2. Most of the artificial lakes direct to northeast and their perimeter form is a rectangle. The depth of the lake is fixed about 2 m deep in the center of the lake. The artificial lake was estimated to be used as a reservoir and fish cultivation (Denevan, 2001; Erickson, 2000; Erickson, 2001).

2.2. Data used

The data used in this study is 136 images of JERS-1/SAR in total. As shown in Fig. 3, JERS-1/SAR is a gray-scale image with 18 m resolution. The path numbers are from 412 to 425, and row numbers are from 319 to 329. The size of the objective area is about 700 km by 1000 km (Fig.1).

2.3. Extraction of artificial lakes

First, SAR images were resized in 1/2, and then the speckle noise was reduced. Second, the binarization was performed and black pixels corresponding to lakes were extracted. A threshold for binarization was set 0.4 to 0.6 times of the mean of pixel digital values in the image.

A noise in the binary image was removed with the reduction and expansion processes. The shape factor each object in the image was obtained with a labeling process.

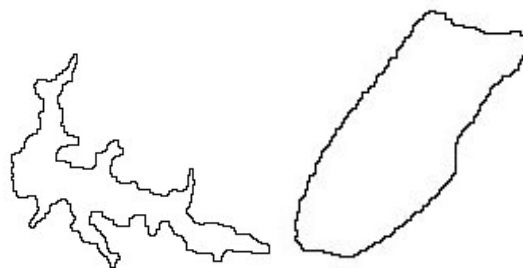
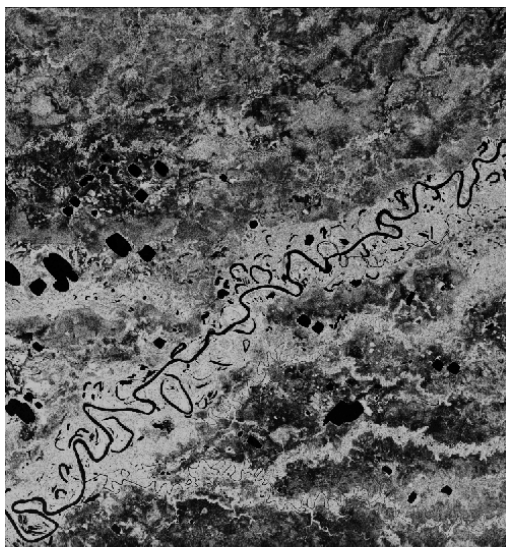


Fig. 3 SAR image for the objective area Fig. 4 Natural lake (left) and artificial lake (right)

The shapes of natural and artificial lakes are obviously different as shown in Fig. 4. Therefore, the objects with more than 1000 pixels and less than 5 of shape factor value were extracted as an artificial lake. The lakes with less than 1000 pixels are difficult to distinguish between artificial and natural lakes because of resolution in the image.

The shape factor φ is a coefficient indicating the object's irregularity and expressed by the following equation (Takagi and Shimoda, 2004).

$$\varphi = \frac{P^2}{4\pi S} \geq 1 \quad (1)$$

where the S is the area, and the P is the perimeter. If the object is a circle, φ becomes 1.

Finally, the artificial lakes were discriminated from natural lakes with their characteristic rectangle form.

2.4. Center location of the artificial lakes

After extraction of the artificial lakes, the geometric correction and mosaic process were performed with UTM values of four corners each image. Finally, the center location of artificial lakes was determined by averaging their coordinates with weights of the area.

2.5. Extraction of river

River systems were divided into the main river and tributary river systems, and extracted respectively, because the meandering features are quite different depending on the width of rivers. Then, the river systems were composed of two different types of images.

In extraction of the main river systems, first, the binarization was performed for images resized in 1/2. The threshold was 0.65 times of the mean of digital values in the image. Second, a noise in the image was removed with reduction and expansion processes. Finally, the density was calculated with labeling, and the objects with less than 0.12 of the density value were extracted as the big river systems. The density is defined by the ratio of connecting black pixels in each rectangle image surrounding the connecting black pixels.

In the tributary river systems, the binarization was performed in images resized in 1/2. In this case, the threshold was determined by subtracting the standard deviation from the average. For the purpose of removal of noises, isolated points were removed. Next, the reduction and expansion processes were performed for connection of the divided objects. The labeling was performed in the picture and the object with over 13000-pixel area and over 30 of the shape factor was extracted. Moreover, noises left finally were deleted visually. The threshold used for extraction in the main and tributary river systems was calculated from an empirical rule.

2.6. Fractal dimensions

Fractal is irregular shape figures with self-similarity, indicated by fractal dimensions (Mandelbrot, 1982). Rivers are typical fractal. In lake figures, two kinds of fractals exist, mass fractal and edge fractal. Fractal dimensions are calculated with box counting (Mandelbrot, 1982).

Relationship between the perimeter and the area for lakes is expressed as next.

$$P = aS^{D/2} \quad (2)$$

where a is an coefficient and D is a fractal dimension.

Substituting (2) into (1),

$$\varphi = \frac{a^2}{4\pi} S^{D-1} \quad (3)$$

This equation is relationship between a shape factor and a fractal dimension.

3. RESULTS

3.1. Extraction of artificial lakes and river systems

Fig. 5 shows the result of extraction for artificial lakes. From 136 images, 700 artificial lakes and 380 natural

lakes were extracted. Fig. 6 shows the result of extraction for river systems. The main river systems were extracted accurately. However, in the case of tributary river systems, pixels of intricately serpentine rivers were connected each other and then these pixels were not extracted as tributary river systems accurately. In general, the pixel intensity of tributary rivers is weaker than the main rivers.

Fig. 7 shows the extracted image of artificial lakes and river systems in the total objective area. Most of artificial lakes direct to northeast along the *Mamore* River, which flows north in the center of the *Mojos* Plain. Large artificial lakes distributed through the upper *Mamore* River and the upper *Beni* River. Artificial lakes did not distribute in the western *Beni* River or the northern *Guapore* River, Brazil.

3.2. Center location of artificial lakes

Fig. 7 shows also the center location of artificial lakes. The center location of artificial lakes was 60-km northwest of Trinidad, the capital of *Beni* State, at $14^{\circ}25'S$ and $65^{\circ}15'W$.

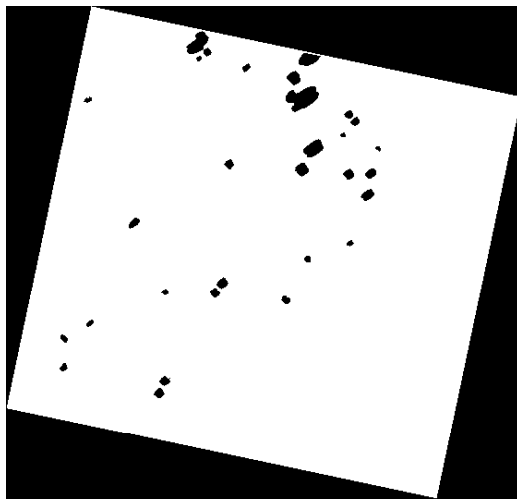


Fig. 5 Extraction image of artificial lakes



Fig. 6 Extraction image of river systems

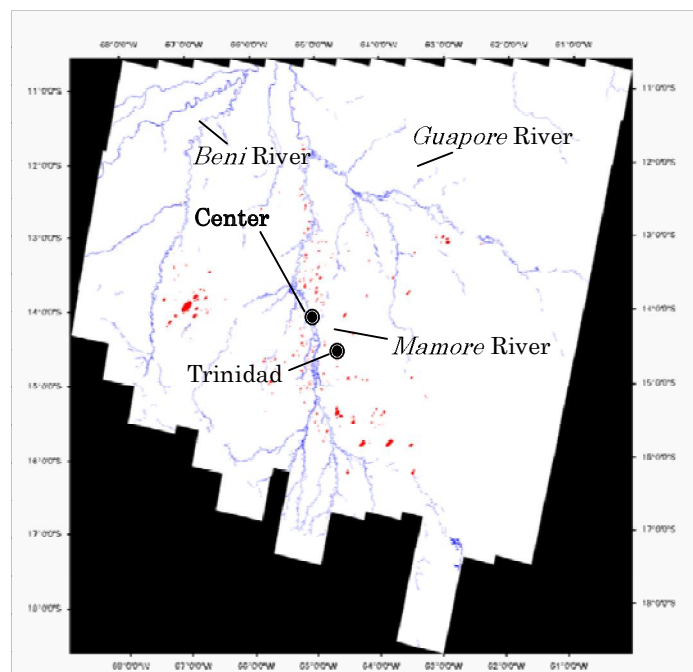


Fig. 7 Center location of the artificial lakes. It was 60 km northwest of Trinidad, the capital of *Beni* State, at $14^{\circ}25'S$ and $65^{\circ}15'W$.

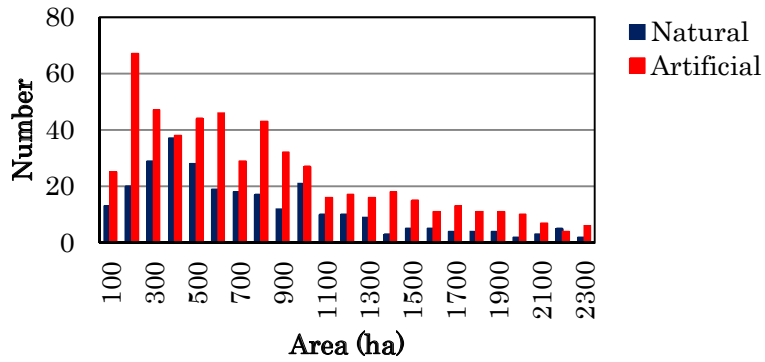


Fig. 8 Histogram of natural and artificial lake area (ha)

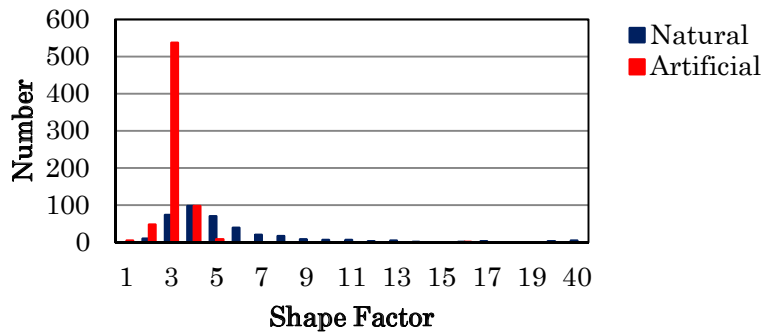


Fig. 9 Histogram of shape factors for artificial and natural lakes.

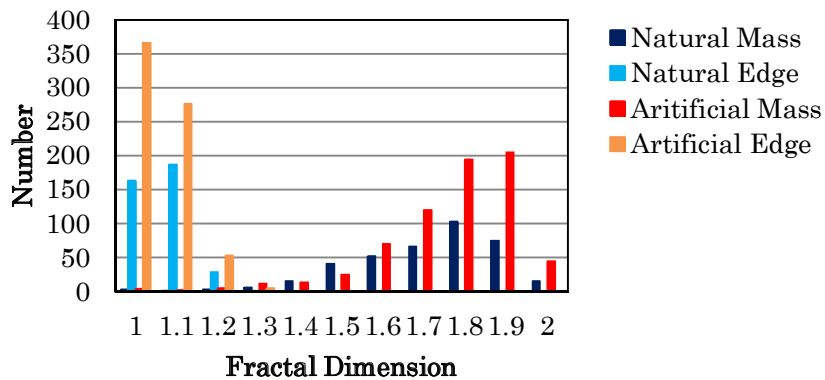


Fig. 10 Histogram of fractal dimensions for artificial and natural lakes.

Table 1 Means and the standard deviations of shape factor

Natural lakes	Artificial lakes
4.18 (1.21)*	2.54 (0.54)

* The mean of shape factors for natural lakes is in a logarithmic normal distribution. Values in the parentheses indicate the standard deviations.

Table 2 Fractal dimensions

Natural lakes		Artificial lakes	
Mass	Edge	Mass	Edge
1.66 (0.18)	1.02 (0.06)	1.71 (0.17)	1.01 (0.07)

*Values in the parentheses indicate the standard deviations.

3.3. Shape factor and fractal dimensions

Fig. 8 shows a histogram of the area for natural and artificial lakes. Natural lake areas are a logarithmic normal distribution with the mean of 250 ha in a logarithmic normal distribution, while artificial lake areas are also a logarithmic normal distribution with the mean of 215 ha in a logarithmic normal distribution. Table 1 shows the results of shape factor for natural and artificial lakes and Fig. 9 shows a histogram of the shape factor. The shape factor for natural lakes is a logarithmic normal distribution with the mean of 4.18 in a logarithmic normal distribution, while the shape factor for artificial lakes is a normal distribution with the average of 2.54. Table 2 shows fractal dimensions calculated for natural and artificial lakes and Fig. 10 shows a histogram of the fractal dimensions. The mass and edge fractal dimensions for natural lakes are 1.66 and 1.02, respectively, while the mass and edge fractal dimensions for artificial lakes are 1.71 and 1.01, respectively. They are very near each other.

4. DISCUSSION

The center of the artificial lakes is near Trinidad where many people live at present. The Amazon brings flooding every year. However, in the dry season people have a little rainfall and small amount of discharge in the Amazon River, therefore people need also irrigation for agriculture from the lakes in a dry season. Development of big artificial lakes might relate with agriculture irrigation. No artificial lake area is the flooding area and few people live there still today. On the other hand, most of small artificial lakes distribute near the Mamore River. Obviously the function of these small lakes is different from the big lakes. Probably they were used for fishing and aquaculture. If the lake size is less than 1000 pixels with 18 m, these lakes also disappear in the binary image. In total, among about 2000 lakes, 1080 lakes were extracted. Disappearing lakes size should be less than 324000 m², which could function for fishing, aquaculture and the daily life, out of big scale water control.

5. CONCLUSIONS

This paper describes that the preliminary research by remote sensing should be carried out to determine the optimum remains among many remains distributing widely at most efficiently. Our conclusions are the next.

1. 700 artificial lakes and 380 natural lakes were extracted by judging their features from SAR images. Finally the center of artificial lake locations was obtained. The center location of artificial lakes was 60 km northwest of Trinidad, the capital of *Beni* State, at 14°25'S and 65°15'W.
2. The shape factor for natural lakes is a logarithmic normal distribution with the average of 4.18, while the shape factor for artificial lakes is a normal distribution with the average of 2.54. The mass and edge fractal dimensions for natural lakes are 1.66 and 1.02, respectively, while the mass and edge fractal dimensions for artificial lakes are 1.71 and 1.01, respectively.
3. In a dry season people have a little rainfall and small amount of discharge in the Amazon River, therefore people need also irrigation for agriculture from the lakes. Development of big artificial lakes might relate with agriculture irrigation. On the other hand, most of small artificial lakes distribute near the Mamore River. Obviously the function of these small lakes is different from the big lakes. Probably they were used for fishing and aquaculture in a small scale. But most of the lakes are in a small size.

REFERENCES

- Denevan, W.M. (2001) *Cultivated Landscapes of Native Amazonia and the Andes*, Oxford University Press.
- Erickson, C. (2000) An Artificial Landscape-scale Fishery in the Bolivian Amazon, *Nature*, **408**, pp. 190-193.
- Erickson, C. (2001) Precolumbian Fish Farming in the Amazon. *Expedition* **43**(1) pp. 7-8.
- Iwasaki, T. et al., (1998) *Archeology Investigation and Research Handbook*, Yuzankaku.
- Ohuchi, K. (2004) *Fundamentals of SAR for Remote Sensing*, Tokyo Denki University Press.
- Sakata T. (2002) *Space Archeology: Remains and ancient environment researched by satellites*, pp. 31-35, Maruzen Publishing Co.
- Seki Y. and Aoyama K. (2005) *America Continent Ancient Civilization Encyclopedia*. pp. 154-158, Iwanami Shoten.
- Takagi, M. and Shimoda, H. (2004) *New Image Processing Handbook*, University of Tokyo Press.
- Mandelbrot, B. (1982) *The Fractal Geometry of Nature*, W. H. Freeman.