WATERSHED LAND COVER CHANGE IN GUAM

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Land cover change (LCC) has been a subject of concern for the past century, particularly the past few decades around the world. Although many of the changes have been recorded qualitatively through the use of comparative photography and historical reports, little quantitative information has been available at watershed scale. It is currently possible to detect land cover change and determine trends in ecological and hydrological condition at watershed scale using advanced geo-spatial technologies. Satellite remote sensing, spatial statistics, geographic information systems (GIS), and global positioning system (GPS) can be used to identify LCC of watersheds. These technologies provide the basis for developing landscape composition and pattern indicators as sensitive measures of environmental change and thus, may provide an effective and economical method for evaluating watershed condition related to disturbance from human and natural stresses.

Landsat observations have evolved from an experimental system in the 1970s to a feasible system to ensure our ability to explore, characterize, monitor, manage, and understand changes in the Earth's surface. Land cover has been derived from a multi-date satellite imagery database which incorporates Landsat Multi-Spectral Scanner (MSS) imagery from the early 1970s to early 1990s, Landsat Thematic Mapper (TM) imagery from early 1980s to current, Landsat Enhanced Thematic Mapper Plus (ETM +) from early 1999 to current at local and/or regional scale. Recent surveys indicate that land cover/use changes have a direct and enormous effect on water quality and environmental change. Watershed water quality and ecosystem are threatened constantly by both human impacts such as forest fires and development and also natural phenomena such as storms and droughts. Therefore, it is critical to conduct research on land cover change in watersheds. This study was mainly focused on extraction of land cover information from satellite imagery from early 1970s to 2001, and determination of LCC in watersheds of southern Guam. Remote sensing and GIS were integrated for land cover classification of satellite images.

One scene of Landsat MSS image of November 14, 1973, and one scene of Landsat TM image of March 15, 2001 were utilized to extract land cover information. Different data sources such as digital line graph (DLG), recent IKONOS and QuickBird imagery were used as auxiliary information for land cover classification. Ten (10) meter digital elevation model (DEM) data has been used to delineate the watersheds in Guam. There are 14 watersheds in Southern Guam. The study area focuses on these watersheds in Southern Guam. Land cover change in each watershed, and overall land cover change in the watersheds are presented in this report.

INTRODUCTION

Land cover change (LCC) is caused by human disturbances and/or natural events such as climate variation and flooding. LCC at different scales from local to global, especially quantitative analysis of LCC has been a main concern to scientists and researchers in the past century, particularly the past few decades around the world. Detection of land cover change at watershed scale may help to determine ecological and hydrological trends in a watershed scale using advanced geo-spatial technologies. Satellite remote sensing, geographic information systems (GIS), geo-statistics, and global positioning system (GPS) can be harnessed to identify LCC of watersheds (Kepner et al, 1999 and 2002). These technologies provide the basis for developing landscape composition and pattern indicators as sensitive measures of environmental change and thus, may provide an effective and economical method for evaluating watershed conditions related to disturbances from human and/or natural stresses (Sikdar et al, 2004).

Guam Research Advisory Council meets once every year to discuss priority research needs for Guam. Spatial and temporal modeling of changes in wetlands and badlands in southern Guam watersheds was identified as one of the highest priority research needs for Guam on the Council's meetings of November 15, 2004, October 4, 2005, and September 26, 2006. There are no records showing that any land cover change at watershed level in Guam has been done. This study is focused on the watershed land cover changes in the southern Guam, which addressed the aforementioned priority research need.

Landsat imagery and historical GIS data were applied to extract land cover information in watersheds in Guam, and then land cover information from different dates were used to determine the overall watershed land cover change and land cover change for each watershed was presented. Details about study area, data sources, data processing, and study results are discussed in the following chapters.

METHODOLOGY

This chapter discusses the study area, data sources and data processing, and methods used to extraction of land cover information.

Description of Study Area

The Mariana Islands, spanning 500 miles, is composed of fifteen populated islands that separate the Pacific Ocean from the Philippine Sea. Figure 1 illustrates the location of Guam, a tropical island in the western Pacific. Guam, the largest and southernmost of the Mariana Islands, is located at latitude 13°28' N. and longitude 144°45' E. It is an unincorporated territory of the United States. This westernmost piece of U.S. soil is 3,800 miles from Honolulu, Hawaii, 2,500 miles (4,000 km) from Beijing, China, 1,600 miles from Manila, the Philippines, and 1,560 miles from Tokyo, Japan (Figure 1). It is about 30 miles long with a width of 8.5 miles at the northern tip, a minimum width of about 4 miles at the middle, and a maximum width of 11.5 miles in the south (Figure 2). Approximately 171,000 residents live in the 19 municipalities on Guam, which has a total area of about 209 square miles or 541.3 square kilometers. The shoreline length is 116.5 miles, coral reef length is 80 miles, and area of parklands is 25,333.3 acres (Guam Bureau of Statistics and Plans, 2005).

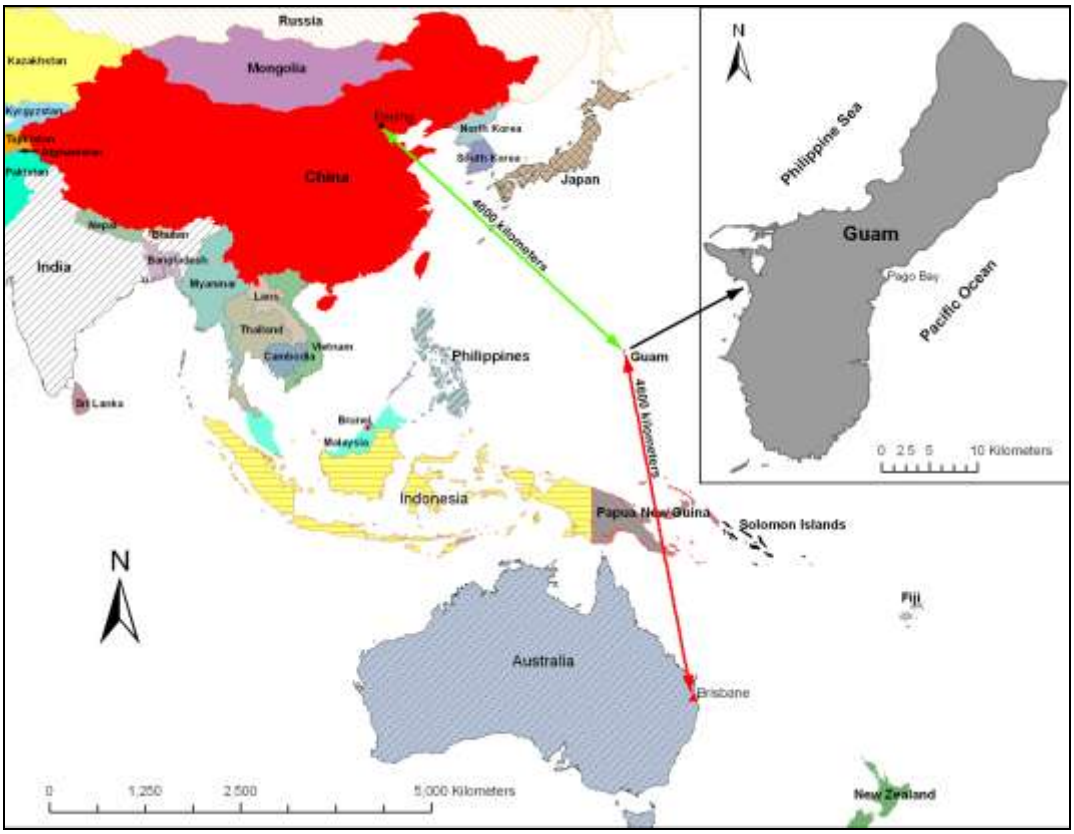

Figure 1. Location of Guam

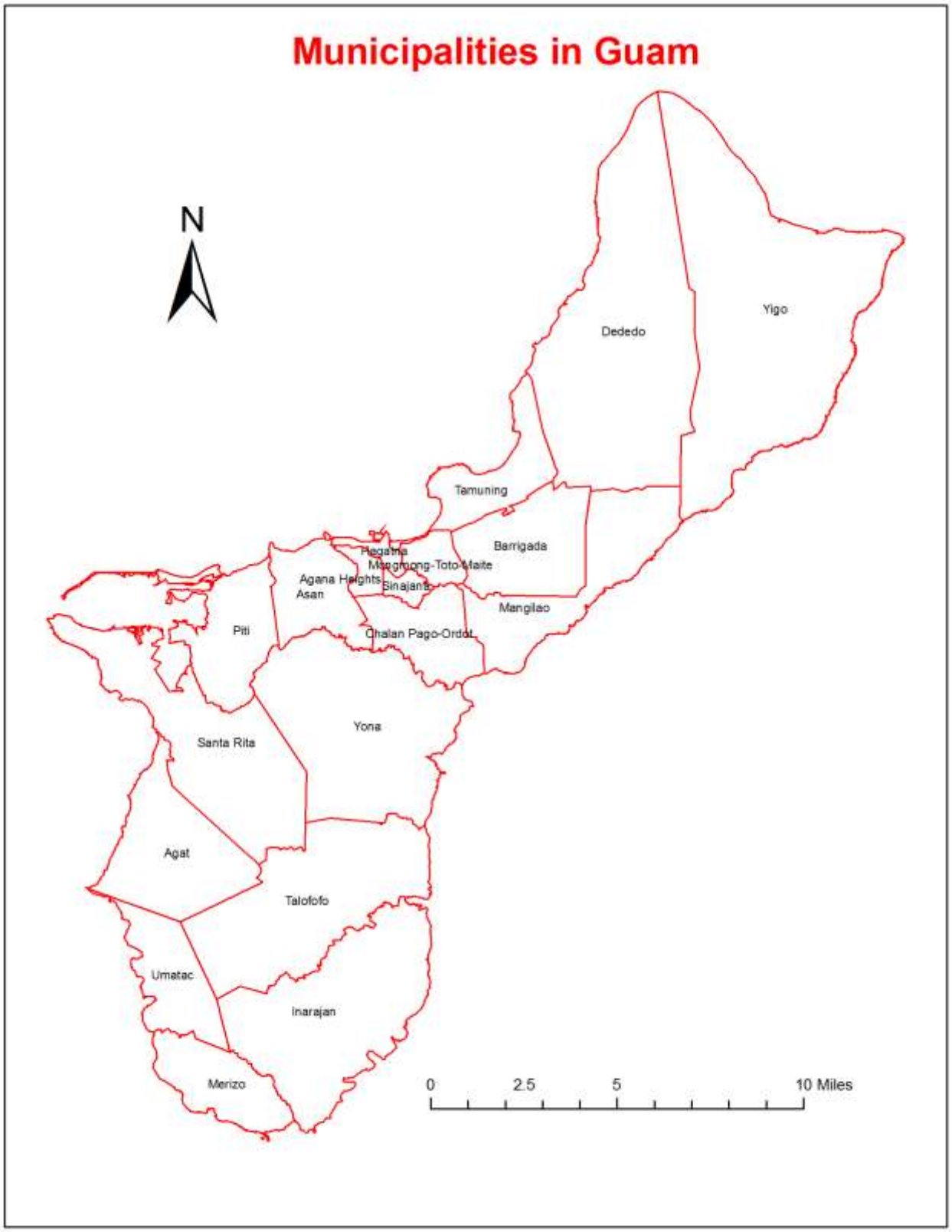

Figure 2. Municipalities in Guam

The north half of the island is a broad limestone plateau bounded by cliffs, and the south half of the island is a dissected volcanic upland fringed with limestone along the east coast (Figure 3).

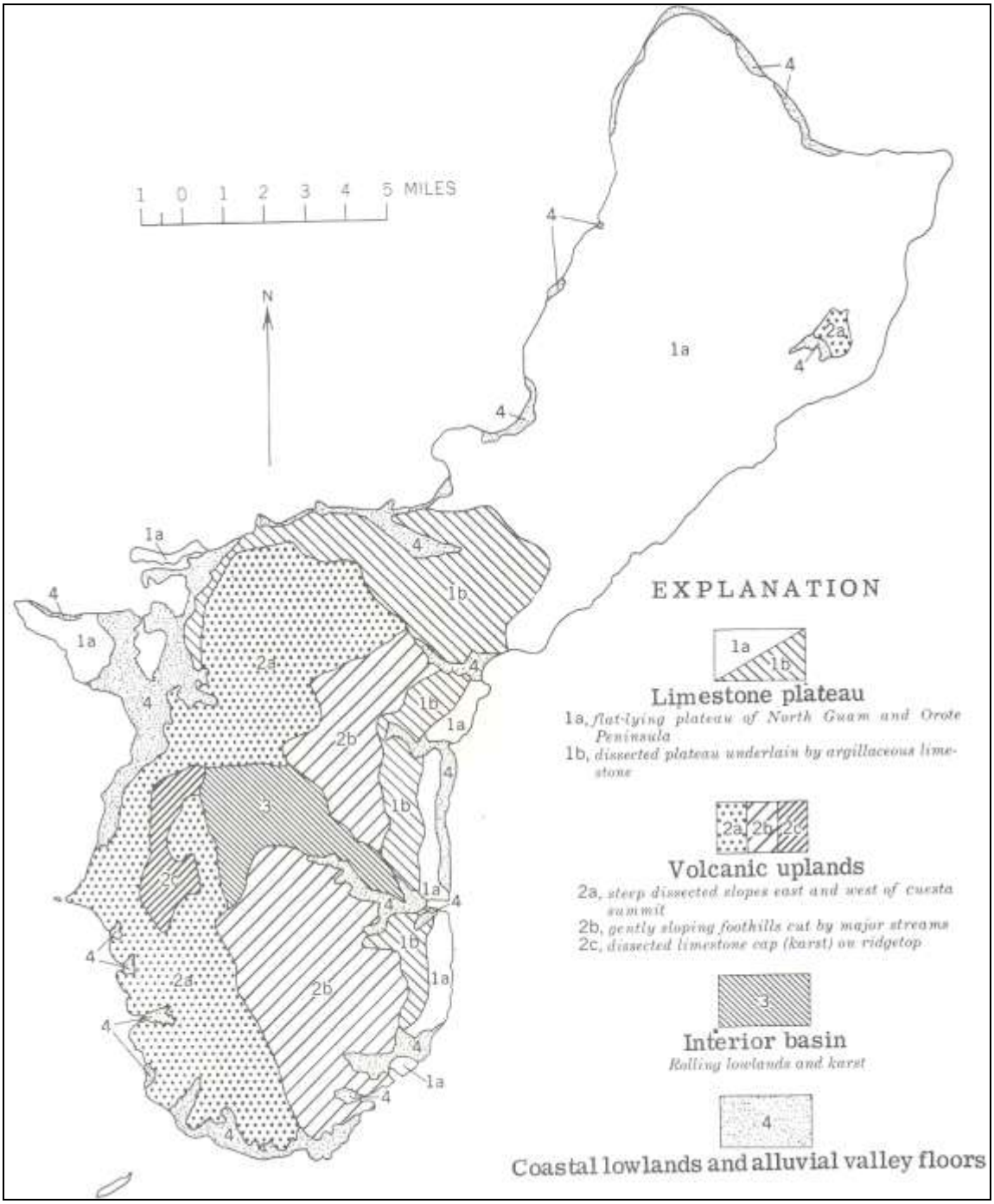

Figure 3. Physiographic divisions of Guam (Tracey et. al, 1964)

No streams flow on the north porous limestone plateau, whereas the south part of the island contains numerous streams and is mostly a surface water territory. The study area is composed of the watersheds in the southern Guam, which include villages of Merizo, Inarajan, Talofofo, Umatac, Agat, Yona, Santa Rita and Piti, and parts of Mangilao, Chalan Pago Ordot, and Asan (Figure 4).

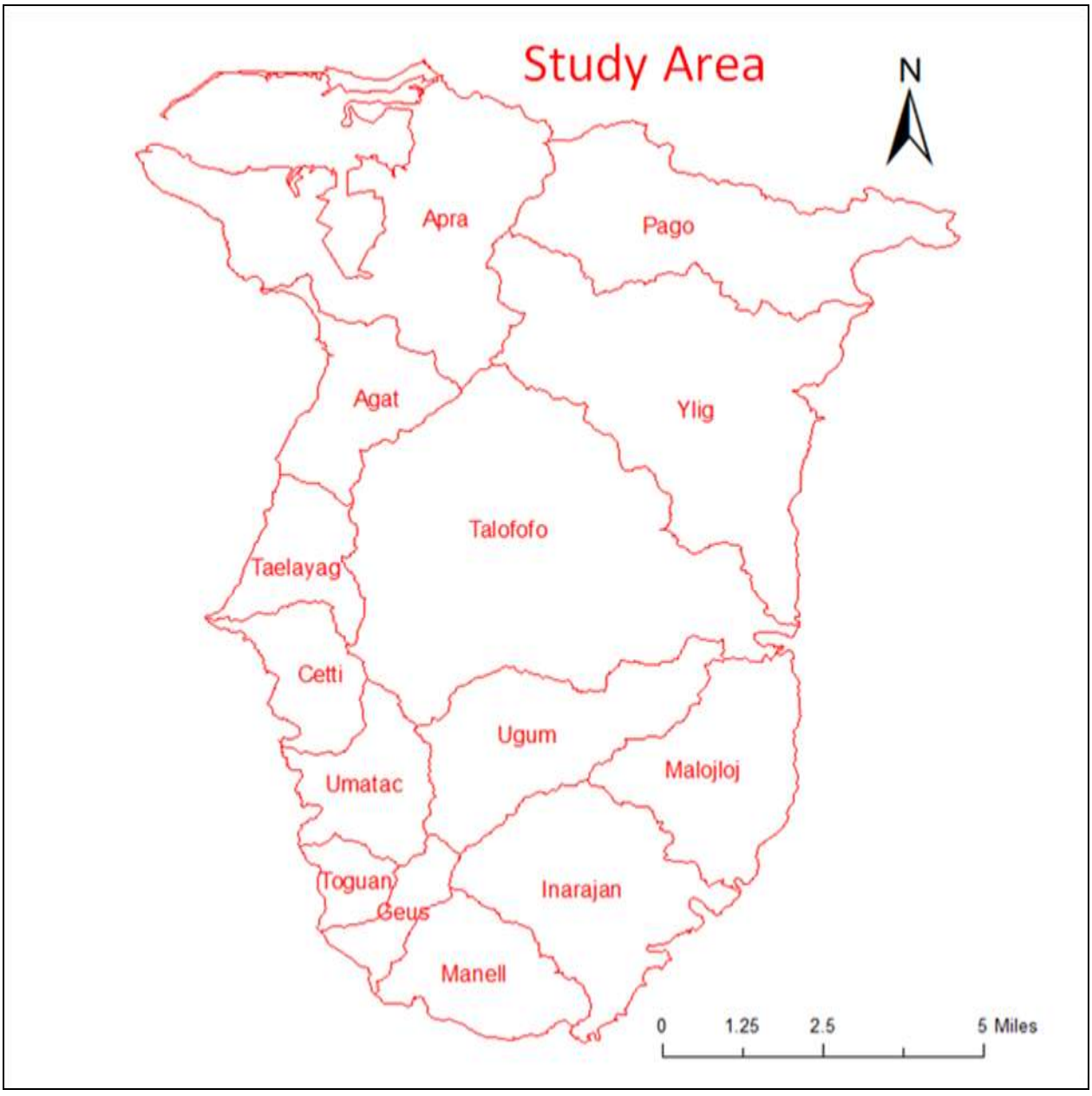

Figure 4. Watersheds in the southern Guam

Data Sources and Data Processing

Digital Elevation Model (DEM) data with spatial resolution of 10 by 10 meters from U.S. Geological Survey (USGS) was applied to delineate the watersheds in the southern Guam (Khosrowpanah, Wen and Heitz, in press). There are 14 watersheds in the southern Guam, and 13 of them are coastal watersheds. Only Ugum Watershed is an inland watershed, which is discharged to Talofofo Watershed, and then to Talofofo Bay (Figure 4). A buffer distance of 500 meters is used to buffer the study area so that more accurate land cover classification can be obtained along the boundary of the study area (Figure 5).

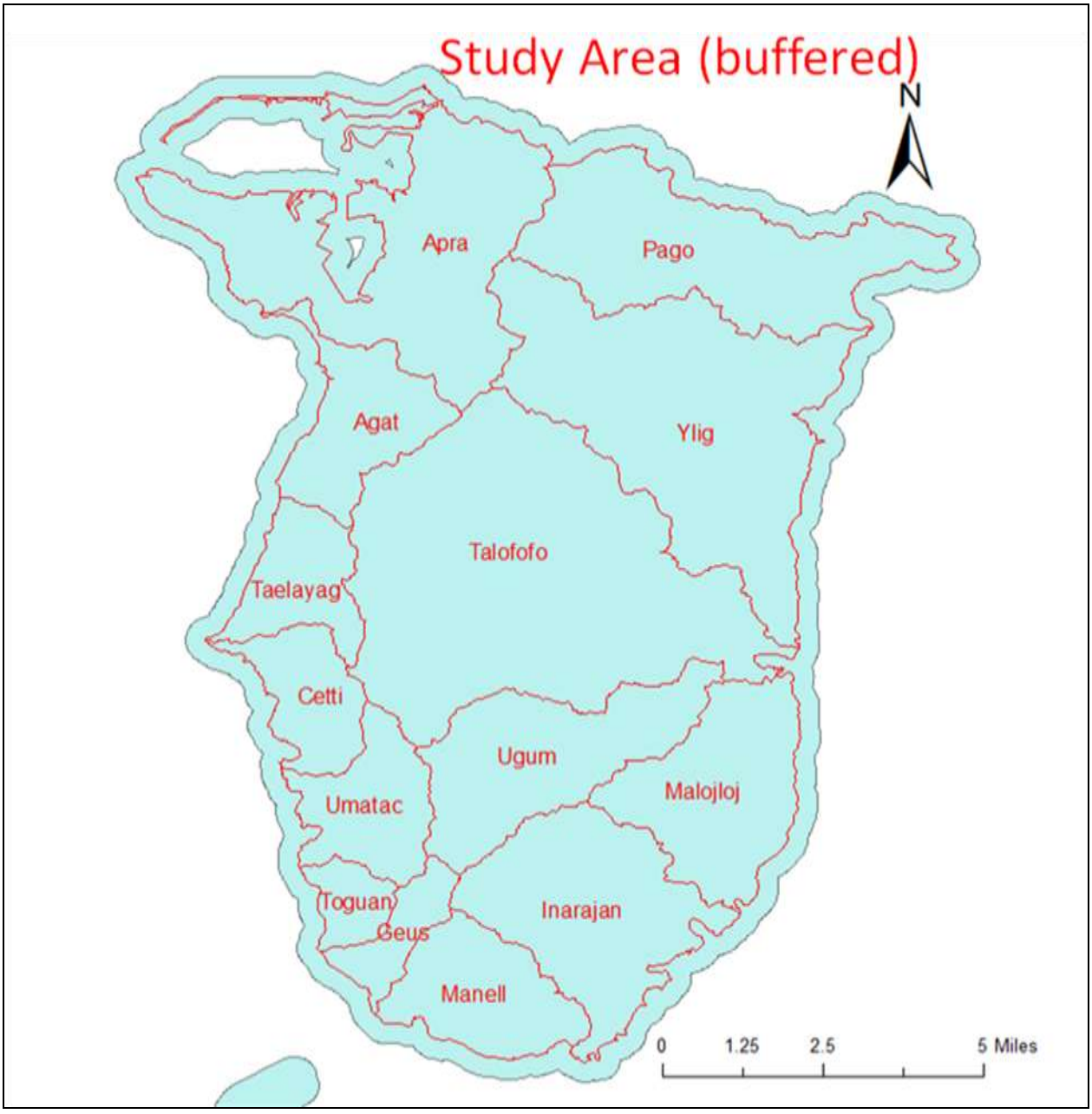

Figure 5. Buffered study area

Two temporal Landsat images, i.e., Landsat MSS image of November 14, 1973 (Figure 6) and Landsat TM image of March 15, 2001(Figure 7) have been used to extract land cover information for watersheds in Southern Guam. Since the Landsat MSS image of 1973 is not aligned with the Landsat TM image of 2001, and the 1973 Landsat MSS data needs to be georeferenced to the coordinate system used by the 2001 Landsat TM data (Figure 8).

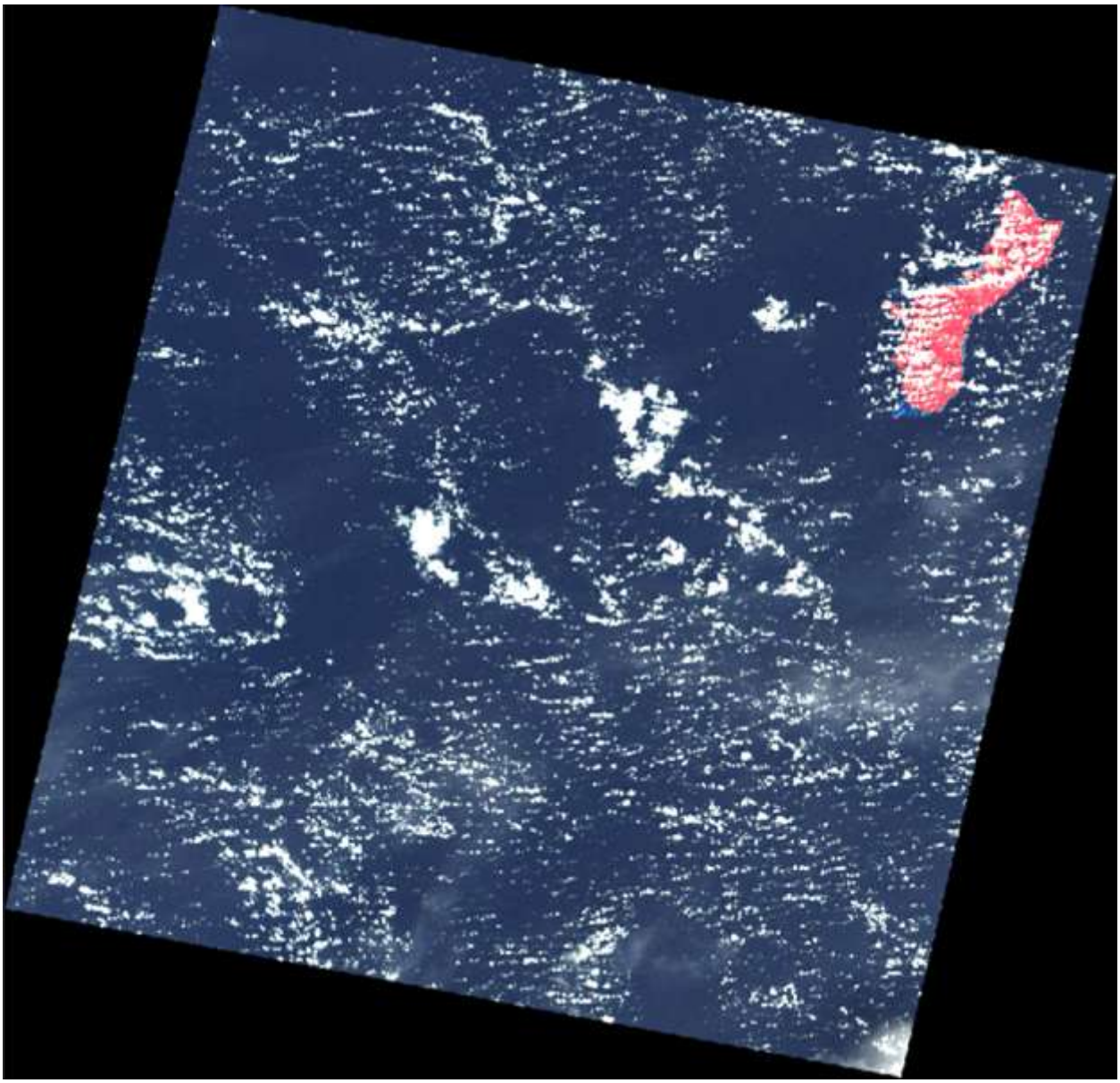

Figure 6. Landsat MSS image of November 14, 1973 with band combination of bands 4, 2 and 1

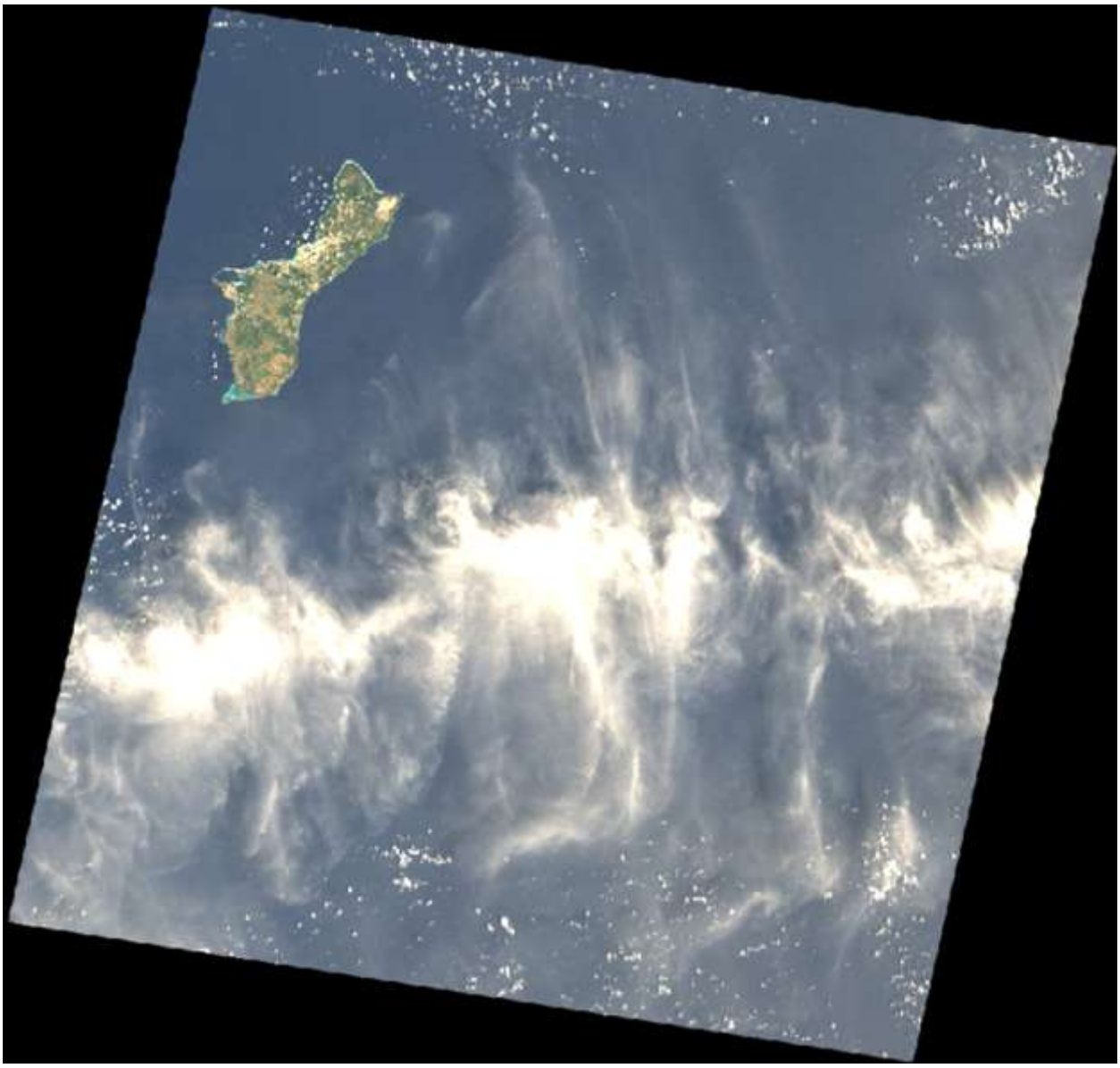

Figure 7. Landsat TM image of March 15, 2001 with band combination of bands 3, 2 and 1

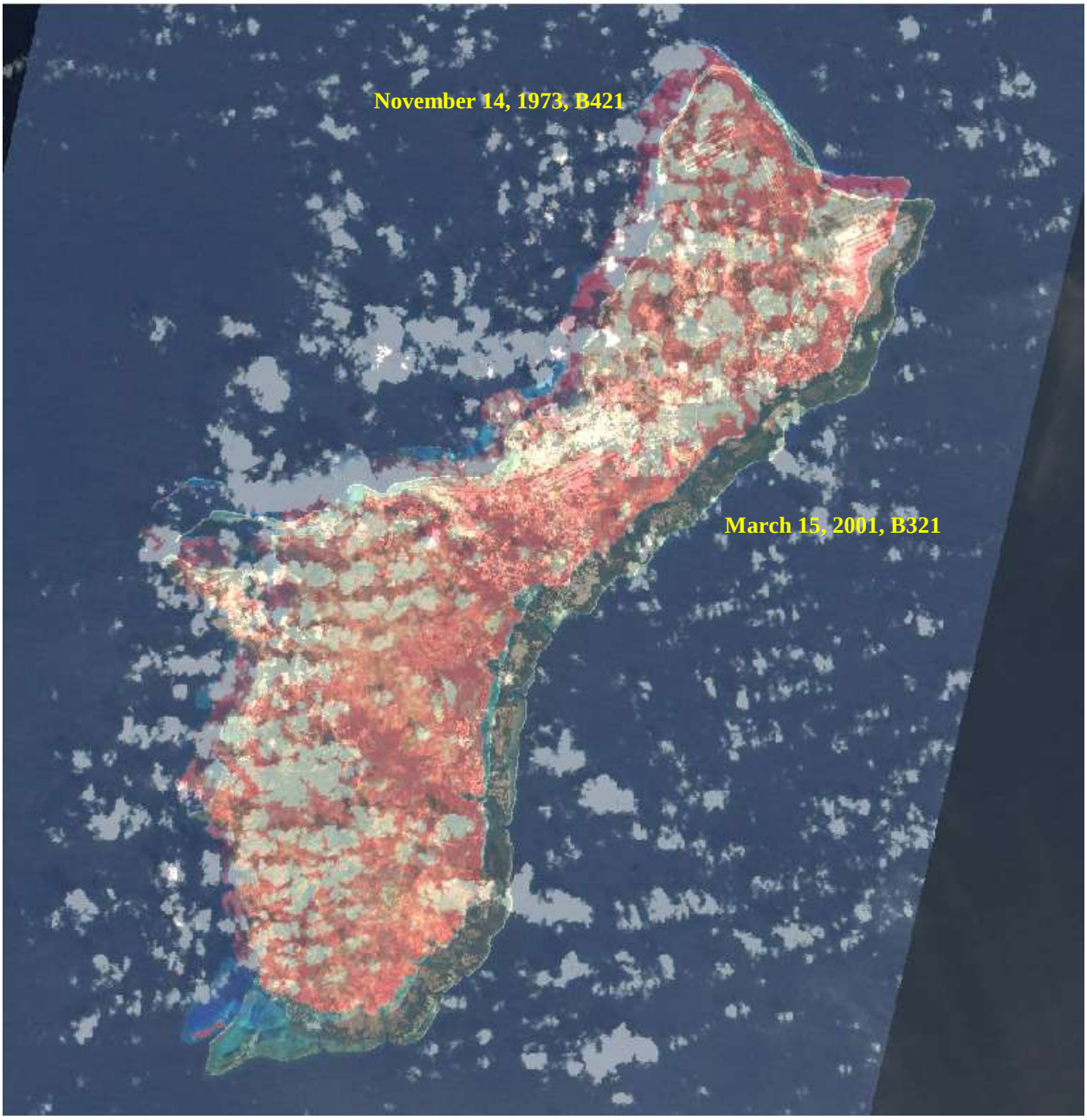

Figure 8. The shoreline from Landsat MSS image of 1973 does not match that from Landsat TM image of 2001.

Georeferencing tool from ESRI ArcInfo Desktop is used to geo-reference the Landsat MSS image of 1973. Georeferencing method with 1st order polynomial transformation is applied. Four obvious locations from the Landsat MSS image are selected to be linked to the corresponding locations on the referenced Landsat image of 2001. The link table information is listed in Figure 9. Sometimes the georeferencing is a time-consuming procedure. If some points have residual values greater than expected, they will be deleted, and some new points or ground objects will be selected for georeferencing until the residual values for all selected points or objects are within

required limits, and the total root mean square (RMS) error is small enough for the georeferencing purpose. Figure 10 shows the original Landsat image of 1973 and the georeferenced one. It indicates that how the image changes after the georeferencing procedure. Figure 11 shows that the boundary of the georeferenced Landsat MSS image of 1973 matches that of the Landsat TM image of 2001. After the Landsat MSS image is georeferenced using Landsat TM iamge of 2001 as reference data, these two satellite images can be utilized for extraction of land cover information, and then for determination of land cover change in watersheds in Guam.

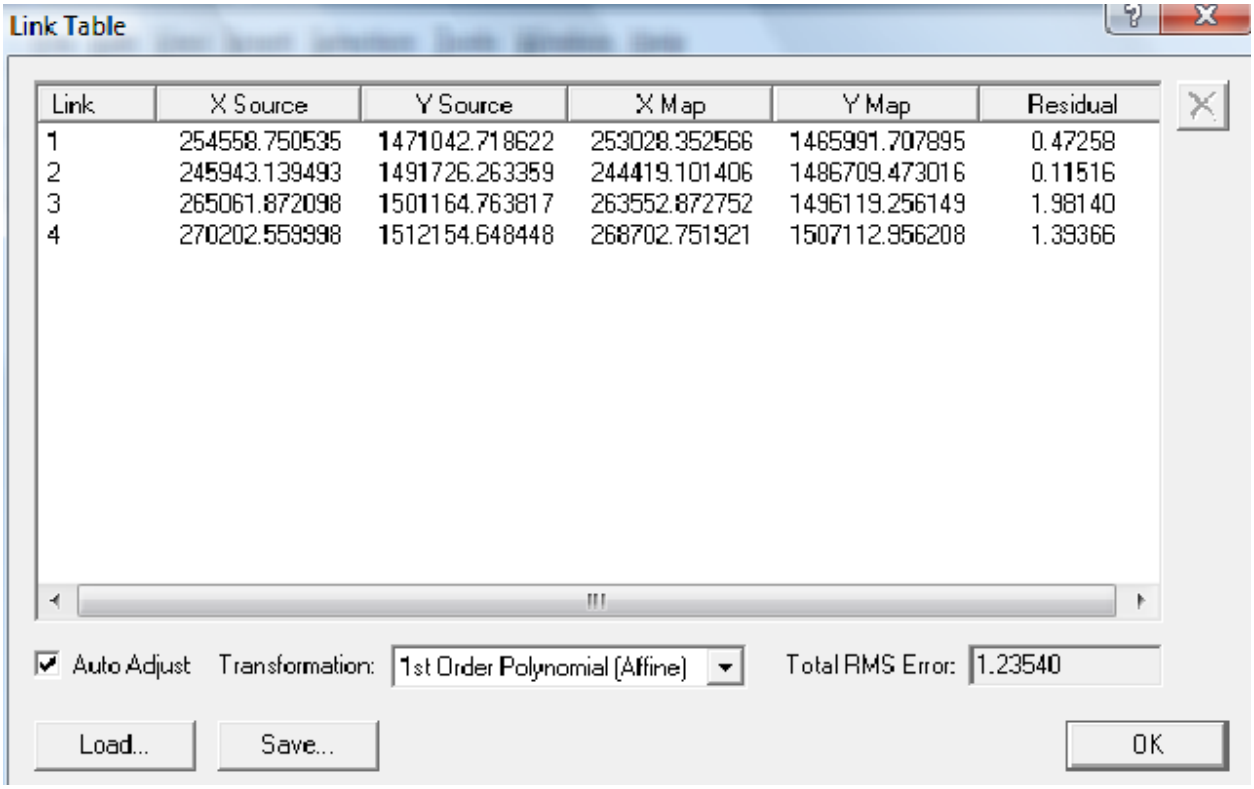

Figure 9. Link table for georeferencing the Landsat MSS image of 1973

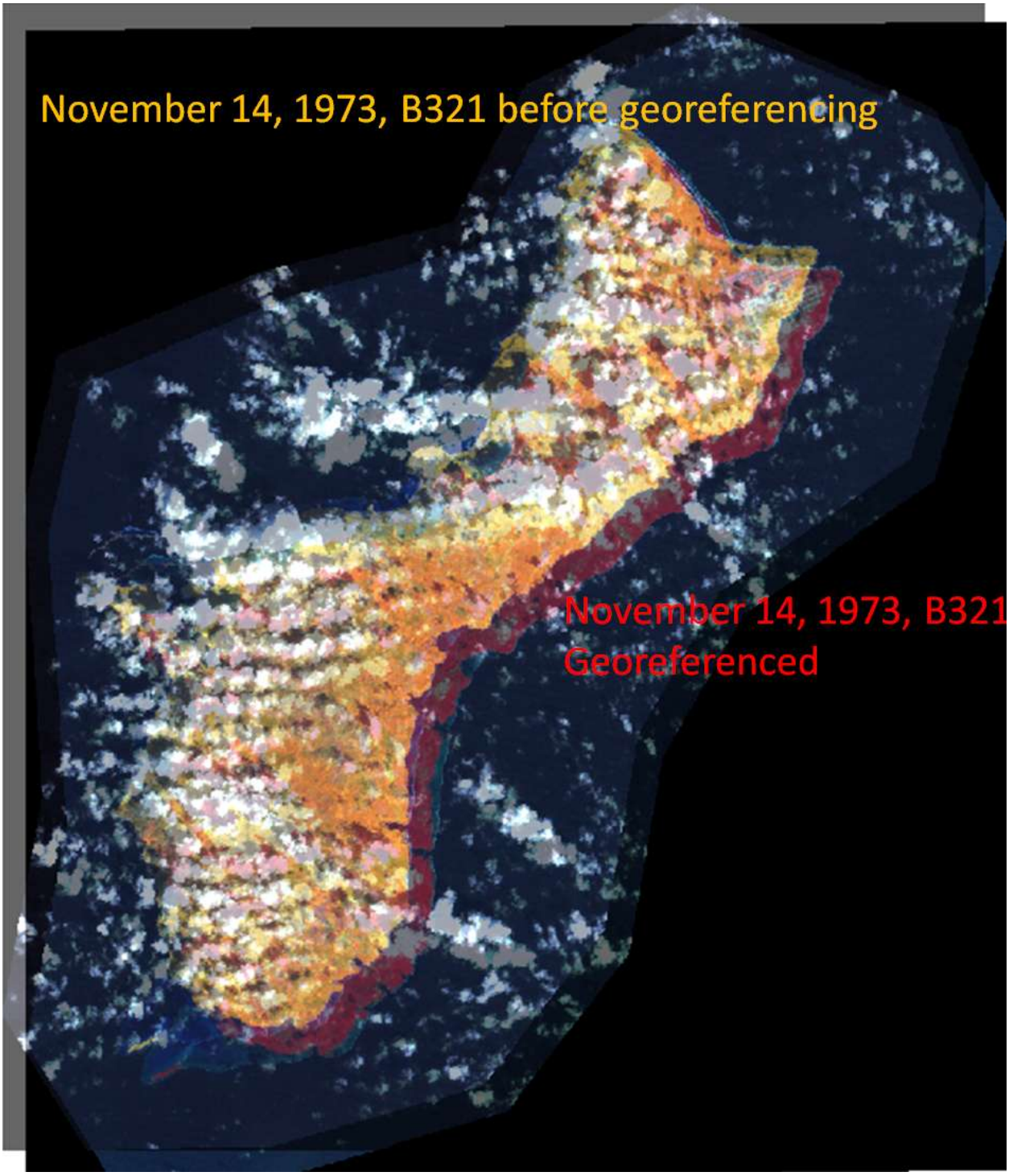

Figure 10. The original Landsat MSS image of 1973 and the georeferenced one shown together

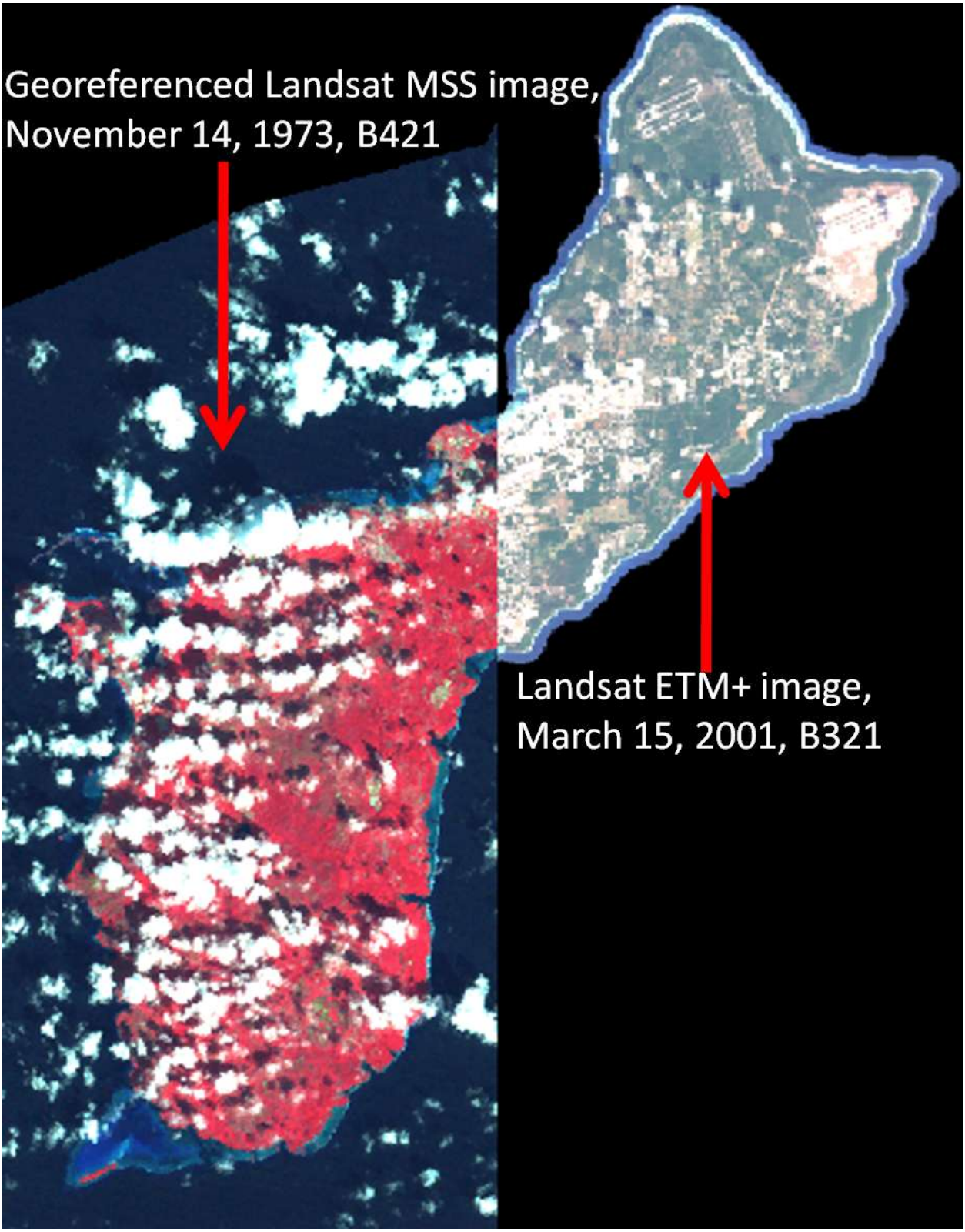

Figure 11. The georeferenced Landsat MSS image of 1973 and the Landsat TM image of 2001

Methods

In order to detect land cover changes of the watersheds in southern Guam, two scenes of Landsat images from different dates, i.e., November 14, 1973 and March 15, 2001 have been collected. Integration of remote sensing and GIS is the primary method applied to obtain land cover information from the satellite images. Map algebra is utilized to measure the land cover changes in the watersheds of southern Guam.

The original Landsat images cover the whole island of Guam and a vast surrounding oceanic area including the Pacific Ocean and the Philippine Sea. However, the study area is only focused on the southern part of the island, actually the spatial extent of the fourteen watersheds in the southern Guam. Therefore, the boundary of study area is used to subset the Landsat imagery for the purpose of watershed land cover change detection in Guam. ESRI ArcInfo software is applied to buffer the study area for a bigger area to subset the Landsat imagery so that the land cover classification accuracy along shoreline or watershed boundaries can be improved (Figure 5). Image subsetting is completed in ERDAS IMAGINE. The subset images for Landsat MSS image of 1973 and Landsat TM image of 2001 are shown in Figure 12.

When the subset images are available, a classification method will be considered to extract land cover information for the watersheds in the southern Guam. The researchers know the study area well and can recognize pixels that represent the specific classes in the watersheds, and just a few classes will be used for watershed land cover change detection, therefore supervised classification is chosen for this study. In supervised training, a set of desired classes should be determined, and appropriate signatures should be created from the data (Leica Geosystems Geospatial Imaging, LLC, 2005).

For this research, the supervised classification method with parametric rule of maximum likelihood is introduced. However, the subset Landsat MSS image of 1973 is covered by a lot of clouds. In order to reduce the impacts of clouds on classification, clouds and shadows are removed from the Landsat MSS image first, and then supervised classification just works on the rest part of the image. The cloud and shadow covered areas are replaced with USGS digital line graph (DLG) data and topographical map information. As for the Landsat TM image of 2001, since there are only a few small patches of clouds on it, supervised classification is applied directly to obtain watershed land cover information. More details about the classification results of Landsat images of 1973 and 2001are discussed in the next section.

A signature file is created for supervised classification for Landsat MSS image and Landsat TM image respectively. USGS digital raster graphic (DRG) topographic map of 1978, DLG data of 1975, and aerial photos of 1975 for Guam are used as reference data to create a training sample for a signature file used for watershed land cover classification derived from Landsat MSS image of 1973. The IKONOS imagery acquired in late 2000 and early 2001, and QuickBird image of 2006 are available as reference data to create a training sample for a signature file used for watershed land cover classification derived from Landsat TM image of 2001. However, there are five classes used to classify the Landsat MSS image of 1973, while seven classes are applied to classify the Landsat TM image of 2001.

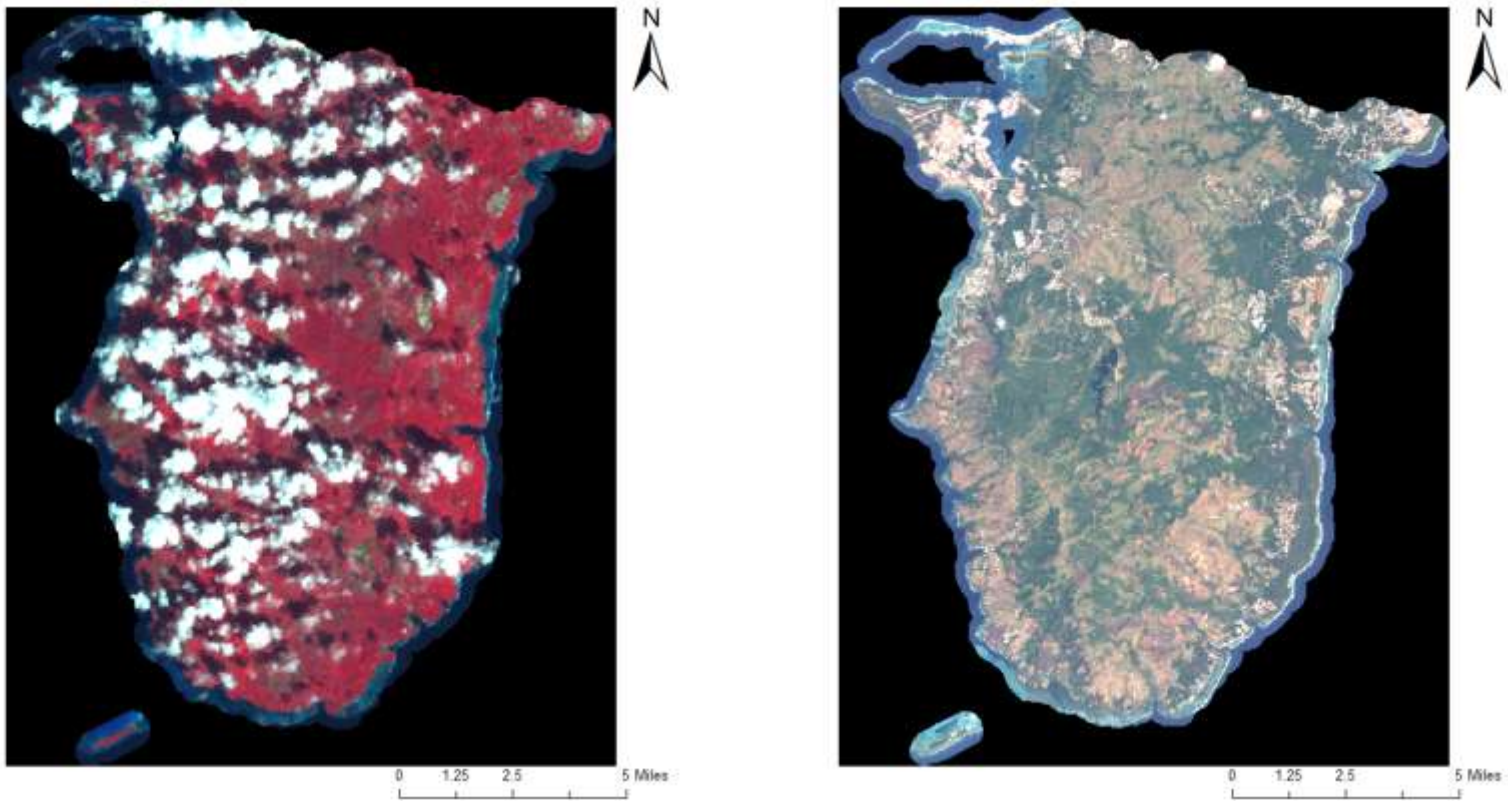

Figure 12. Subset Landsat images (Left: subset Landsat MSS image of 1973; Right: subset Landsat TM image of 2001)

RESULTS AND DISCUSSION

There are fourteen watersheds in the southern Guam (Khosrowpanah, Wen and Heitz, in press). This study aims to measure the overall land cover change of the watersheds in the southern Guam, and detect land cover change in each watershed. Watershed land cover classification of 1973 makes use of many data sources such as Landsat MSS image, aerial photos, DLG and USGS DRG topographical map. Only use of Landsat MSS image of November 14, 1973 may not produce an acceptable land cover classification result because the image is covered by many clouds and shadows. Supervised classification is used to derive land cover information from Landsat MSS image of November 14, 1973 after clouds and shadows have been removed. Aerial photos of 1975, DLG and DRG data are utilized as reference data for training samples. The land cover map of 1973 is shown in Figure 13. The overall accuracy of 1973 watershed land cover is 82.74%, and the overall Kappa statistics is 0.7658. Considering the relatively low spatial resolution and few bands available from Landsat MSS, the land cover classification result is very satisfactory. There are five general land cover classes for the watersheds in the southern Guam, i.e., forest, grassland, barren land, urban area and water.

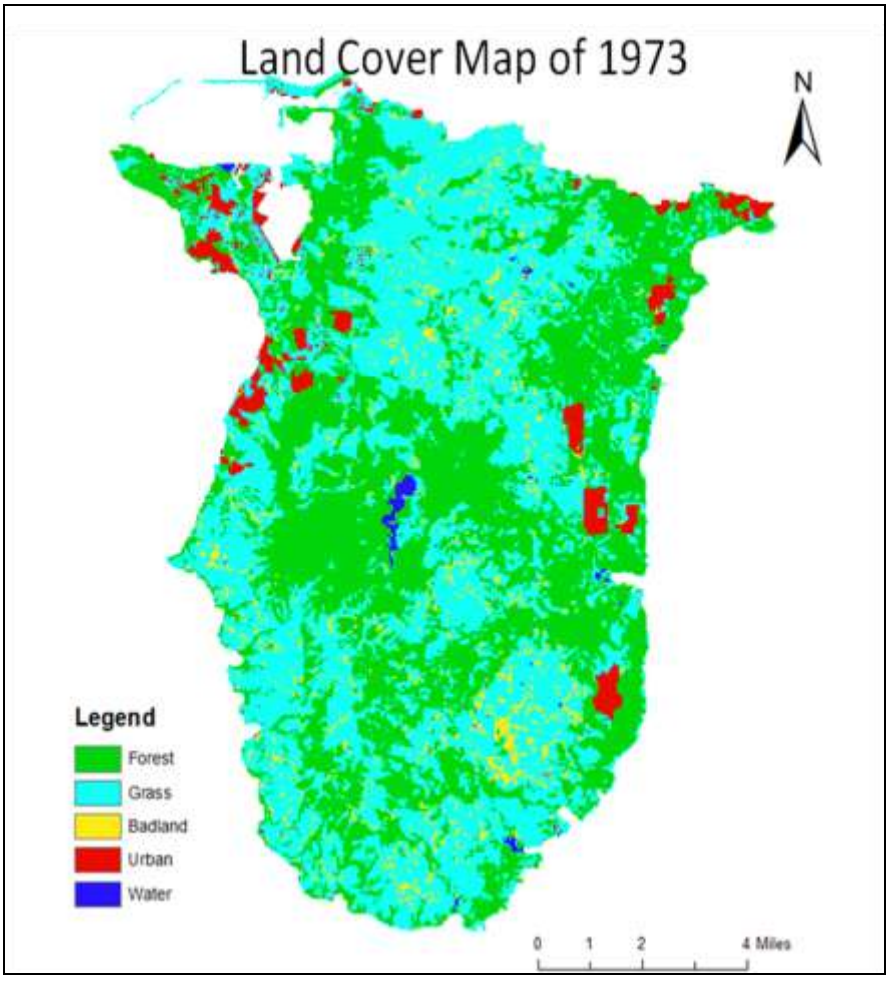

Figure 13. Land cover derived from Landsat MSS image of November 14, 1973

The image quality of Landsat TM data of March 15, 2001 is pretty high. Only small areas are covered by clouds. The supervised classification with parametric rule of maximum likelihood is applied to extract land cover information. IKONOS imagery with acquisition dates of November 30, 2000 and February 23, 2001, and QuickBird satellite image of 2006 are applied to create a signature file for a training sample for the supervised classification. There are seven general classes, i.e., forest, grassland, barren land, urban area, burned area, water and cloud (Figure 14). The overall accuracy is 90.42%, and the overall Kappa statistics is 0.8802. When a comparison is made between the watershed land cover of 1973 and that of 2001, it is obvious that there are lots of burned areas in the land cover of 2001. Since the Landsat TM image was acquired on March 15, 2001, when was very dry. There is a tradition that local people like setting wildfires for hunting deer and wild pigs in dry seasons. That may be why a lot of burned areas could be found at that time.

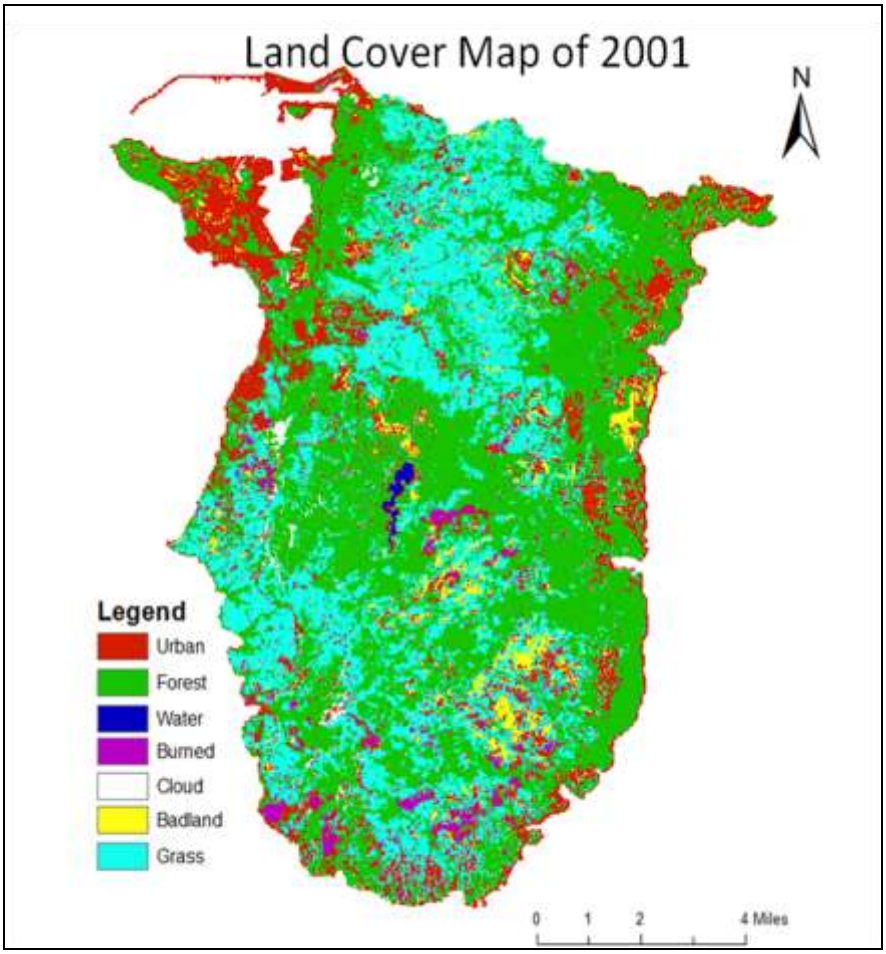

Figure 14. Land cover derived from Landsat TM image of March 15, 2001

Details of land cover change in watersheds are discussed in the following. For each table, there are two parts. The columns are referred to as land cover information derived from Landsat TM image of 2001, while the rows stand for land cover information derived from Landsat MSS image of 1973. There are two parts for each table. The values in the top part are presented in number of pixels for each class, and the values in the bottom part are illustrated in percentage for each class of 1973 changed to other categories in 2001.

Overall watershed land cover change

	Urban	Forest	Water	Burned	Cloud	Barren	Grassland	Total
Forest	2416	31053	3	27	501	117	3110	37227
Grassland	8556	7808	0	970	149	2318	21310	41111
Barren	673	517	1	82	19	541	1996	3829
Urban	2438	320	0	3	5	67	102	2935
Water	153	13	175	8	0	2	15	366
Total	14236	39711	179	1090	674	3045	26533	85468

	Urban	Forest	Water	Burned	Cloud	Barren	Grassland	Total
Forest	6.49%	83.42%	0.01%	0.07%	1.35%	0.31%	8.35%	43.56%
Grassland	20.81%	18.99%	0.00%	2.36%	0.36%	5.64%	51.84%	48.10%
Barren	17.58%	13.50%	0.03%	2.14%	0.50%	14.13%	52.13%	4.48%
Urban	83.07%	10.90%	0.00%	0.10%	0.17%	2.28%	3.48%	3.43%
Water	41.80%	3.55%	47.81%	2.19%	0.00%	0.55%	4.10%	0.43%
Total	16.66%	46.46%	0.21%	1.28%	0.79%	3.56%	31.04%	100.00%

Table 1. Overall watershed land cover change in the southern Guam from 1973 to 2001

From the above table, the following findings can be achieved. The area of forest in 1973 was 43.56% of the whole study area, and the forest area increased to 46.46% in 2001. The grassland area in 1973 was about 48% of the whole study area, but it decreased to about 31% in 2001. The urban area in 1973 was 3.43% of the whole study area, and it increased to 16.66% in 2001. The barren land area was 4.48% of the study area, and it decreased a little bit to 3.56% in 2001. Water area in 1973 was about 0.43% of the study area, and it changed to about 0.21% of the study area.

About 6.49% and 8.35% of forest in 1973 were converted to urban area and grassland respectively in 2001. About 1.35% of forest in 1973 could not be decided to be converted to which land cover categories in 2001 because it was covered by cloud and/or shadows. About 21% and 18% of grassland in 1973 were changed to urban area and forest respectively in 2001. About 17.6%, 13.5% and 52% of barren land were changed to urban area, forest and grassland respectively in 2001. About 10.9% and 3.5% of urban area were converted to forest and grassland respectively in 2001. About 42%, 3.6% and 4% of water body were converted to urban area, forest and grassland respectively in 2001. In general, the urban area changed dramatically from 1973 to 2001.

Apra watershed land cover change

	Urban	Forest	Water	Burned	Cloud	Barren	Grassland	Total
Forest	798	3115	0	4	81	35	208	4241
Grassland	2014	1034	1	23	13	212	2060	5357
Barren	92	68	0	1	1	11	142	315
Urban	790	26	0	1	0	16	14	847
Water	24	0	0	0	0	2	1	27
Total	3718	4243	1	29	95	276	2425	10787

	Urban	Forest	Water	Burned	Cloud	Barren	Grassland	Total
Forest	18.82%	73.45%	0.00%	0.09%	1.91%	0.83%	4.90%	39.32%
Grassland	37.60%	19.30%	0.02%	0.43%	0.24%	3.96%	38.45%	49.66%
Barren	29.21%	21.59%	0.00%	0.32%	0.32%	3.49%	45.08%	2.92%
Urban	93.27%	3.07%	0.00%	0.12%	0.00%	1.89%	1.65%	7.85%
Water	88.89%	0.00%	0.00%	0.00%	0.00%	7.41%	3.70%	0.25%
Total	34.47%	39.33%	0.01%	0.27%	0.88%	2.56%	22.48%	100.00%

Table 2. Land cover change from 1973 to 2001 in Apra Watershed

From the above table, the following findings can be achieved for Apra Watershed. The area of forest in 1973 covered 39.26% of Apra Watershed, and the forest area almost did not change from 1973 to 2001. The grassland area in 1973 covered about 49.7% of the watershed, but it decreased to about 22.5% in 2001. The urban area in 1973 covered 7.85% of the watershed, and it increased to 34.47% in 2001. The barren land covered 2.92% of the watershed, and it decreased a little bit to 2.56% in 2001. Water area in 1973 covered about 0.25% of the watershed, and the open water area only covered about 0.01% of the watershed in 2001.

18.82% and 4.9% of forest in 1973 were converted to urban area and grassland respectively in 2001. About 1.91% of forest in 1973 could not be decided to be converted to which land cover categories in 2001 because it was covered by clouds and/or shadows. 37.6%, 19.3% and 3.96% of grassland in 1973 were changed to urban area, forest and barren land respectively in 2001. 29.21%, 21.59% and 45.08% of barren land were changed to urban area, forest and grassland respectively in 2001. 3.07%, 1.89% and 1.65% of urban area were converted to forest, barren land and grassland respectively in 2001. 88.89% and 3.7% of water body were converted to urban area and grassland respectively in 2001.

Agat watershed land cover change

	Urban	Forest	Burned	Cloud	Barren	Grassland	Total
Forest	182	1038	1	96	3	126	1446
Grassland	508	285	17	17	17	478	1322
Barren	33	14	2	4	1	29	83
Urban	514	85	0	1	1	14	615
Total	1237	1422	20	118	22	647	3466

	Urban	Forest	Burned	Cloud	Barren	Grassland	Total
Forest	12.59%	71.78%	0.07%	6.64%	0.21%	8.71%	41.72%
Grassland	38.43%	21.56%	1.29%	1.29%	1.29%	36.16%	38.14%
Barren	39.76%	16.87%	2.41%	4.82%	1.20%	34.94%	2.39%
Urban	83.58%	13.82%	0.00%	0.16%	0.16%	2.28%	17.74%
Total	35.69%	41.03%	0.58%	3.40%	0.63%	18.67%	100.00%

Table 3. Land cover change from 1973 to 2001 in Agat Watershed

From the above table, the following findings can be achieved for Agat Watershed. The area of forest in 1973 covered 41.72% of Apra Watershed, and the forest area did not change much from 1973 to 2001. The grassland area in 1973 covered 38.14% of the watershed, but it decreased to 18.675% in 2001. The urban area in 1973 covered 17.74% of the watershed, and it increased to 35.69% in 2001. The barren land covered 2.39% of the watershed, and it decreased a lot to 0.63% in 2001. There was no open water body in 1973 and 2001.

12.59% and 8.71% of forest in 1973 were converted to urban area and grassland respectively in 2001. 38.43%, 21.56% and 1.29% of grassland in 1973 were changed to urban area, forest and barren land respectively in 2001. 39.76%, 16.87% and 34.94% of barren land were changed to urban area, forest and grassland respectively in 2001. 13.82% and 2.82% of urban area were converted to forest and grassland respectively in 2001. 3.40% of land cover in this watershed in 1973 could not be decided to be converted to which land cover categories in 2001 because it was covered by clouds and/or shadows.

Taelayag watershed land cover change

	Urban	Forest	Water	Burned	Cloud	Barren	Grassland	Total
Forest	89	620	0	3	98	2	145	957
Grassland	292	260	0	72	21	32	759	1436
Barren	19	15	0	1	0	5	80	120
Urban	55	7	0	0	0	0	1	63
Total	455	902	0	76	119	39	985	2576

	Urban	Forest	Water	Burned	Cloud	Barren	Grassland	Total
Forest	9.30%	64.79%	0.00%	0.31%	10.24%	0.21%	15.15%	37.15%
Grassland	20.33%	18.11%	0.00%	5.01%	1.46%	2.23%	52.86%	55.75%
Barren	15.83%	12.50%	0.00%	0.83%	0.00%	4.17%	66.67%	4.66%
Urban	87.30%	11.11%	0.00%	0.00%	0.00%	0.00%	1.59%	2.45%
Total	17.66%	35.02%	0.00%	2.95%	4.62%	1.51%	38.24%	100.00%

Table 4. Land cover change from 1973 to 2001 in Taelayag Watershed

From the above table, the following findings can be achieved for Taelayag Watershed. The area of forest in 1973 covered 37.15% of this watershed, and the forest area decreased to 35.02% in 2001. The grassland area in 1973 covered 55.76% of the watershed, but it decreased to 38.24% in 2001. The urban area in 1973 covered 2.45% of the watershed, and it increased to 17.66% in 2001. The barren land covered 4.66% of the watershed, and it decreased to 2.95% in 2001. There was no open water body in 1973 and 2001.

9.3% and 15.15% of forest in 1973 were converted to urban area and grassland respectively in 2001. 12.24% of forest in 1973 could not be decided to be converted to which land cover categories in 2001 because it was covered by cloud and/or shadows. 20.33%, 18.11% and 2.23% of grassland in 1973 were changed to urban area, forest and barren land respectively in 2001. There was about 5% burned area in 2001, which was covered by grassland in 1973. Although land cover classes could not be determined for the burned area, they probably were forest and/or grassland in 2001. 15.83%, 12.5% and 52.86% of barren land were changed to urban area, forest and grassland respectively in 2001. 3.07%, 1.89% and 1.65% of urban area were converted to forest, barren land and grassland respectively in 2001. 4.62% of land cover in this watershed in 1973 could not be decided to be converted to which land cover categories in 2001 because it was covered by clouds and/or shadows.

Cetti watershed land cover change

	Urban	Forest	Burned	Cloud	Barren	Grassland	Total
Forest	27	348	0	34	0	108	517
Grassland	111	248	1	3	22	1367	1752
Barren	13	15	0	1	20	126	175
Urban	1	0	0	0	0	0	1
Total	152	611	1	38	42	1601	2445

	Urban	Forest	Burned	Cloud	Barren	Grassland	Total
Forest	5.22%	67.31%	0.00%	6.58%	0.00%	20.89%	21.15%
Grassland	6.34%	14.16%	0.06%	0.17%	1.26%	78.03%	71.66%
Barren	7.43%	8.57%	0.00%	0.57%	11.43%	72.00%	7.16%
Urban	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.04%
Total	6.22%	24.99%	0.04%	1.55%	1.72%	65.48%	100.00%

Table 5. Land cover change from 1973 to 2001 in Cetti Watershed

From the above table, the following findings can be achieved for Cetti Watershed. The area of forest in 1973 covered 21.15% of this watershed, and the forest area increased to about 25% in 2001. The grassland area in 1973 covered 71.66% of the watershed, but it decreased to 65.48% in 2001. The urban area in 1973 covered only 0.04% of the watershed, and it increased to 6.22% in 2001. The barren land covered 7.16% of the watershed, and it decreased to 1.72% in 2001. There was no open water body in 1973 and 2001.

5.22% and 20.89% of forest in 1973 were converted to urban area and grassland respectively in 2001. 6.58% of forest in 1973 could not be decided to be converted to which land cover categories in 2001 because it was covered by cloud and/or shadows. 6.34%, 14.16% and 1.26% of grassland in 1973 were changed to urban area, forest and barren land respectively in 2001. 7.43%, 8.57% and 72% of barren land were changed to urban area, forest and grassland respectively in 2001. 1.55% of land cover in this watershed in 1973 could not be decided to be converted to which land cover categories in 2001 because it was covered by clouds and/or shadows.

Umatac watershed land cover change

	Urban	Forest	Water	Burned	Cloud	Barren	Grassland	Total
Forest	40	738	0	0	13	0	89	880
Grassland	345	495	0	35	75	32	1051	2033
Barren	22	34	0	1	10	2	66	135
Urban	2	0	0	0	0	0	0	2
Total	409	1267	0	36	98	34	1206	3050

	Urban	Forest	Water	Burned	Cloud	Barren	Grassland	Total
Forest	4.55%	83.86%	0.00%	0.00%	1.48%	0.00%	10.11%	28.85%
Grassland	16.97%	24.35%	0.00%	1.72%	3.69%	1.57%	51.70%	66.66%
Barren	16.30%	25.19%	0.00%	0.74%	7.41%	1.48%	48.89%	4.43%
Urban	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.07%
Total	13.41%	41.54%	0.00%	1.18%	3.21%	1.11%	39.54%	100.00%

Table 6. Land cover change from 1973 to 2001 in Umatac Watershed

From the above table, the following findings can be achieved for Umatac Watershed. The area of forest in 1973 covered 28.85% of this watershed, and the forest area increased to 41.54% in 2001. The grassland area in 1973 covered about 66.66% of the watershed, but it decreased to 39.54% in 2001. The urban area in 1973 covered 0.07% of the watershed, but it increased to 13.41% in 2001. The barren land covered 4.43% of the watershed, and it decreased to 1.11% in 2001. There was no open water body in 1973 and 2001.

4.55% and 10.11% of forest in 1973 were converted to urban area and grassland respectively in 2001. 16.97%, 24.35% and 1.57% of grassland in 1973 were changed to urban area, forest and barren land respectively in 2001. 16.30%, 25.19% and 48.89% of barren land were changed to urban area, forest and grassland respectively in 2001. Urban area in 1973 did not change to other land cover categories in 2001. 3.21% of land cover in this watershed in 1973 could not be decided to be converted to which land cover categories in 2001 because it was covered by clouds and/or shadows.

Toguan watershed land cover change

	Urban	Forest	Water	Burned	Cloud	Barren	Grassland	Total
Forest	36	146	0	2	14	3	36	237
Grassland	115	92	0	50	2	32	494	785
Barren	12	9	0	1	1	4	62	89
Urban	2	0	0	0	0	0	0	2
Water	0	0	0	0	0	0	1	1
Total	165	247	0	53	17	39	593	1114

	Urban	Forest	Water	Burned	Cloud	Barren	Grassland	Total
Forest	15.19%	61.60%	0.00%	0.84%	5.91%	1.27%	15.19%	21.27%
Grassland	14.65%	11.72%	0.00%	6.37%	0.25%	4.08%	62.93%	70.47%
Barren	13.48%	10.11%	0.00%	1.12%	1.12%	4.49%	69.66%	7.99%
Urban	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.18%
Water	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%	0.09%
Total	14.81%	22.17%	0.00%	4.76%	1.53%	3.50%	53.23%	100.00%

Table 7. Land cover change from 1973 to 2001 in Toguan Watershed

From the above table, the following findings can be achieved for Toguan Watershed. The area of forest in 1973 covered 21.27% of the watershed, and the forest area increased a little bit to 22.17% in 2001. The grassland area in 1973 covered about 70.47% of the watershed, but it decreased to 53.23% in 2001. The urban area in 1973 covered 0.18% of the watershed, and it increased to 14.81% in 2001. The barren land covered about 8% of the watershed, and it decreased to 3.5% in 2001. Water area in 1973 covered about 0.09% of the watershed, and there was no open water area found from the land cover of 2001.

15.19% and 15.19% of forest in 1973 were converted to urban area and grassland respectively in 2001. 5.91% of forest in 1973 could not be decided to be converted to which land cover categories in 2001 because it was covered by clouds and/or shadows. 14.65%, 11.72% and 4.08% of grassland in 1973 were changed to urban area, forest and barren land respectively in 2001. There was about 6.37% burned area in 2001, which was covered by grassland in 1973. Although land cover classes could not be determined for the burned area, they probably were forest and/or grassland in 2001. 13.48%, 10.11% and 69.66% of barren land were changed to urban area, forest and grassland respectively in 2001. Urban area in 1973 did not change to other categories in 2001. The water body in 1973 was converted to grassland in 2001.

Geus watershed land cover change

	Urban	Forest	Burned	Cloud	Barren	Grassland	Total
Forest	82	461	3	26	0	54	626
Grassland	207	160	110	7	7	198	689
Barren	13	10	11	1	1	32	68
Urban	2	0	0	0	0	0	2
Total	304	631	124	34	8	284	1385

	Urban	Forest	Burned	Cloud	Barren	Grassland	Total
Forest	13.10%	73.64%	0.48%	4.15%	0.00%	8.63%	45.20%
Grassland	30.04%	23.22%	15.97%	1.02%	1.02%	28.74%	49.75%
Barren	19.12%	14.71%	16.18%	1.47%	1.47%	47.06%	4.91%
Urban	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.14%
Total	21.95%	45.56%	8.95%	2.45%	0.58%	20.51%	100.00%

Table 8. Land cover change from 1973 to 2001 in Geus Watershed

From the above table, the following findings can be achieved for Geus Watershed. The area of forest in 1973 covered 45.2% of the watershed, and the forest area increased a little bit to 45.56% in 2001. The grassland area in 1973 covered 49.75% of the watershed, but it decreased a lot to 20.51% in 2001. The urban area in 1973 covered 0.14% of the watershed, and it increased to 21.95% in 2001. The barren land covered 4.91% of the watershed, and it decreased to 0.58% in 2001. There was no open water body in 1973and 2001.

13.1% and 8.63% of forest in 1973 were converted to urban area and grassland respectively in 2001. 4.15% of forest in 1973 could not be decided to be converted to which land cover categories in 2001 because it was covered by clouds and/or shadows. 30.04%, 23.22% and 1.02% of grassland in 1973 were changed to urban area, forest and barren land respectively in 2001. There was 15.97% burned area in 2001, which was covered by grassland in 1973. Although land cover classes could not be determined for the burned area, they probably were forest and/or grassland in 2001. 19.12%, 14.71% and 47.06% of barren land were changed to urban area, forest and grassland respectively in 2001. Urban area in 1973 did not change to other categories in 2001.

Manell watershed land cover change

	Urban	Forest	Water	Burned	Cloud	Barren	Grassland	Total
Forest	97	774	0	3	22	0	136	1032
Grassland	657	406	0	128	9	18	1113	2331
Barren	85	23	0	22	0	10	111	251
Urban	0	1	0	0	0	0	0	1
Water	9	0	0	0	0	0	2	11
Total	848	1204	0	153	31	28	1362	3626

	Urban	Forest	Water	Burned	Cloud	Barren	Grassland	Total
Forest	9.40%	75.00%	0.00%	0.29%	2.13%	0.00%	13.18%	28.46%
Grassland	28.19%	17.42%	0.00%	5.49%	0.39%	0.77%	47.75%	64.29%
Barren	33.86%	9.16%	0.00%	8.76%	0.00%	3.98%	44.22%	6.92%
Urban	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.03%
Water	81.82%	0.00%	0.00%	0.00%	0.00%	0.00%	18.18%	0.30%
Total	23.39%	33.20%	0.00%	4.22%	0.85%	0.77%	37.56%	100.00%

Table 9. Land cover change from 1973 to 2001 in Manell Watershed

From the above table, the following findings can be achieved for Manell Watershed. The area of forest in 1973 covered 28.46% of the watershed, and the forest area decreased to 33.2% in 2001. The grassland area in 1973 covered 64.29% of the watershed, but it decreased to 37.56% in 2001. The urban area in 1973 covered only 0.03% of the watershed, but it increased to 23.39% in 2001. The barren land covered 6.92% of the watershed, and it decreased to 0.77% in 2001. Water area in 1973 covered only 0.3% of the watershed, and there was no water body in 2001.

9.4% and 13.18% of forest in 1973 were converted to urban area and grassland respectively in 2001. 2.13% of forest in 1973 could not be decided to be converted to which land cover categories in 2001 because it was covered by clouds and/or shadows. 28.19% and 17.42% of grassland in 1973 were changed to urban area and forest respectively in 2001. There was 5.49% burned area in 2001, which was covered by grassland in 1973. Although land cover classes could not be determined for the burned area, they probably were forest and/or grassland in 2001. 33.86%, 9.16% and 44.22% of barren land were changed to urban area, forest and grassland respectively in 2001. There was 8.76% of barren land in 1973, and was converted to vegetated area, but was burned in 2001. A small patch of urban land in 1973 was changed to forest in 2001. 81.82% and 18.18% of water body were converted to urban area and grassland respectively in 2001.

Inarajan watershed land cover change

	Urban	Forest	Water	Burned	Cloud	Barren	Grassland	Total
Forest	153	1678	0	9	21	4	234	2099
Grassland	931	613	0	271	6	254	1978	4053
Barren	106	32	0	26	1	211	201	577
Urban	7	0	0	0	0	0	0	7
Water	23	6	0	8	0	1	5	43
Total	1220	2329	0	314	28	470	2418	6779

	Urban	Forest	Water	Burned	Cloud	Barren	Grassland	Total
Forest	7.29%	79.94%	0.00%	0.43%	1.00%	0.19%	11.15%	30.96%
Grassland	22.97%	15.12%	0.00%	6.69%	0.15%	6.27%	48.80%	59.79%
Barren	18.37%	5.55%	0.00%	4.51%	0.17%	36.57%	34.84%	8.51%
Urban	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.10%
Water	53.49%	13.95%	0.00%	18.60%	0.00%	2.33%	11.63%	0.63%
Total	18.00%	34.36%	0.00%	4.63%	0.41%	6.93%	35.67%	100.00%

Table 10. Land cover change from 1973 to 2001 in Inarajan Watershed

From the above table, the following findings can be achieved for Inarajan Watershed. The area of forest in 1973 covered 30.96% of the watershed, and the forest area increased to 34.36% in 2001. The grassland area in 1973 covered about 59.79% of the watershed, but it decreased to 35.67% in 2001. The urban area in 1973 covered 0.1% of the watershed, and it increased to 18% in 2001. The barren land covered 8.51% of the watershed, and it decreased to 6.93% in 2001. Water area in 1973 covered 0.63% of the watershed, and there was no open water area in 2001.

7.29% and 11.15% of forest in 1973 were converted to urban area and grassland respectively in 2001. 22.97%, 15.12% and 6.27% of grassland in 1973 were changed to urban area, forest and barren land respectively in 2001. 18.37%, 5.55% and 34.84% of barren land were changed to urban area, forest and grassland respectively in 2001. There was 4.51% of barren land in 1973, and was converted to vegetated area, but was burned in 2001. The urban area in 1973 did not change to other land cover categories in 2001. 53.49%, 13.95% and 11.63% of water body were converted to urban area, forest and grassland respectively in 2001. 18.6% of water area changed to burned area, which might be forest or grassland in 2001.

Malojloj watershed land cover change

	Urban	Forest	Burned	Cloud	Barren	Grassland	Total
Forest	61	2223	2	2	3	99	2390
Grassland	563	618	36	0	305	909	2431
Barren	75	53	4	0	87	132	351
Urban	171	52	0	0	15	39	277
Water	2	2	0	0	0	1	5
Total	872	2948	42	2	410	1180	5454

	Urban	Forest	Burned	Cloud	Barren	Grassland	Total
Forest	2.55%	93.01%	0.08%	0.08%	0.13%	4.14%	43.82%
Grassland	23.16%	25.42%	1.48%	0.00%	12.55%	37.39%	44.57%
Barren	21.37%	15.10%	1.14%	0.00%	24.79%	37.61%	6.44%
Urban	61.73%	18.77%	0.00%	0.00%	5.42%	14.08%	5.08%
Water	40.00%	40.00%	0.00%	0.00%	0.00%	20.00%	0.09%
Total	15.99%	54.05%	0.77%	0.04%	7.52%	21.64%	100.00%

Table 11. Land cover change from 1973 to 2001 in Malojloj Watershed

From the above table, the following findings can be achieved for Malojloj Watershed. The area of forest in 1973 covered 43.82% of the watershed, and the forest area increased to 54.05% in 2001. The grassland area in 1973 covered 44.57% of the watershed, but it decreased to 21.64% in 2001. The urban area in 1973 covered 5.08% of the watershed, and it increased to about 16% in 2001. The barren land covered 6.44% of the watershed, and it decreased to 7.52% in 2001. Water area in 1973 covered 0.09% of the watershed, and there was no open water area in 2001.

2.55% and 4.14% of forest in 1973 were converted to urban area and grassland respectively in 2001. 23.16%, 25.42% and 12.55% of grassland in 1973 were changed to urban area, forest and barren land respectively in 2001. 21.37%, 15.1% and 37.61% of barren land were changed to urban area, forest and grassland respectively in 2001. 18.77%, 5.42% and 14.08% of urban area were converted to forest, barren land and grassland respectively in 2001. 40%, 40% and 20% of water body in 1973 were converted to urban area, forest and grassland respectively in 2001.

Talofofo watershed land cover change

	Urban	Forest	Water	Burned	Cloud	Barren	Grassland	Total
Forest	382	9058	3	14	42	37	1122	10658
Grassland	870	1303	2	179	1	457	3351	6163
Barren	98	96	0	8	0	68	278	548
Urban	146	33	0	0	0	6	22	207
Water	63	9	173	0	0	2	6	253
Total	1559	10499	178	201	43	570	4779	17829

	Urban	Forest	Water	Burned	Cloud	Barren	Grassland	Total
Forest	3.58%	84.99%	0.03%	0.13%	0.39%	0.35%	10.53%	59.78%
Grassland	14.12%	21.14%	0.03%	2.90%	0.02%	7.42%	54.37%	34.57%
Barren	17.88%	17.52%	0.00%	1.46%	0.00%	12.41%	50.73%	3.07%
Urban	70.53%	15.94%	0.00%	0.00%	0.00%	2.90%	10.63%	1.16%
Water	24.90%	3.56%	68.38%	0.00%	0.00%	0.79%	2.37%	1.42%
Total	8.74%	58.89%	1.00%	1.13%	0.24%	3.20%	26.80%	100.00%

Table 12. Land cover change from 1973 to 2001 in Talofofo Watershed

From the above table, the following findings can be achieved for Talofofof Watershed. The area of forest in 1973 covered 59.78% of the watershed, and the forest area decrease a little bit to 58.89% in 2001. The grassland area in 1973 covered 34.57% of the watershed, but it decreased to 26.8% in 2001. The urban area in 1973 covered only 1.16% of the watershed, and it increased to 8.74% in 2001. The barren land covered 3.07% of the watershed, and it decreased a little bit to 3.2% in 2001. Water area in 1973 covered 1.42% of the watershed, and the open water area covered 1.0% of the watershed in 2001.

3.58% and 10.53% of forest in 1973 were converted to urban area and grassland respectively in 2001. 14.12%, 21.14% and 7.42% of grassland in 1973 were changed to urban area, forest and barren land respectively in 2001. 17.88%, 17.52% and 50.73% of barren land were changed to urban area, forest and grassland respectively in 2001. 15.94%, 2.9% and 10.63% of urban area were converted to forest, barren land and grassland respectively in 2001. 24.9%, 3.56% and 2.37% of water body were converted to urban area, forest and grassland respectively in 2001. 1.13% of land cover in 1973 could not be decided to be converted to which land cover categories in 2001 because it was covered by clouds and/or shadows.

Ylig watershed land cover change

	Urban	Forest	Water	Burned	Cloud	Barren	Grassland	Total
Forest	407	4448	0	1	1	40	323	5220
Grassland	1035	1418	0	13	0	555	3381	6402
Barren	91	96	0	1	0	44	329	561
Urban	394	89	0	0	0	14	32	529
Water	18	2	0	0	0	1	0	21
Total	1945	6053	0	15	1	654	4065	12733

	Urban	Forest	Water	Burned	Cloud	Barren	Grassland	Total
Forest	7.80%	85.21%	0.00%	0.02%	0.02%	0.77%	6.19%	41.00%
Grassland	16.17%	22.15%	0.00%	0.20%	0.00%	8.67%	52.81%	50.28%
Barren	16.22%	17.11%	0.00%	0.18%	0.00%	7.84%	58.65%	4.41%
Urban	74.48%	16.82%	0.00%	0.00%	0.00%	2.65%	6.05%	4.15%
Water	85.71%	9.52%	0.00%	0.00%	0.00%	4.76%	0.00%	0.16%
Total	15.28%	47.54%	0.00%	0.12%	0.01%	5.14%	31.92%	100.00%

Table 13. Land cover change from 1973 to 2001 in Ylig Watershed

From the above table, the following findings can be achieved for Ylig Watershed. The area of forest in 1973 covered 41% of the watershed, and the forest area increased to 47.54% in 2001. The grassland area in 1973 covered 50.28% of the watershed, but it decreased to 31.92% in 2001. The urban area in 1973 covered 4.15% of the watershed, and it increased to 15.28% in 2001. The barren land covered 4.41% of the watershed, and it increased to 5.14% in 2001. Water area in 1973 covered 0.16% of the watershed, and there was no open water area in 2001.

7.8% and 6.19% of forest in 1973 were converted to urban area and grassland respectively in 2001. 16.17%, 22.15% and 8.67% of grassland in 1973 were changed to urban area, forest and barren land respectively in 2001. 16.22%, 17.11% and 58.65% of barren land were changed to urban area, forest and grassland respectively in 2001. 16.82%, 2.65% and 6.05% of urban area were converted to forest, barren land and grassland respectively in 2001. 85.71%, 9.52% and 4.76% of water body were converted to urban area, forest and barren land respectively in 2001.

Pago watershed land cover change

	Urban	Forest	Cloud	Barren	Grassland	Total
Forest	283	2885	9	25	226	3428
Grassland	432	970	9	159	2553	4123
Barren	25	74	0	8	214	321
Urban	268	38	0	17	13	336
Water	1	2	0	1	0	4
Total	1009	3969	18	210	3006	8212

	Urban	Forest	Cloud	Barren	Grassland	Total
Forest	8.26%	84.16%	0.26%	0.73%	6.59%	41.74%
Grassland	10.48%	23.53%	0.22%	3.86%	61.92%	50.21%
Barren	7.79%	23.05%	0.00%	2.49%	66.67%	3.91%
Urban	79.76%	11.31%	0.00%	5.06%	3.87%	4.09%
Water	25.00%	50.00%	0.00%	25.00%	0.00%	0.05%
Total	12.29%	48.33%	0.22%	2.56%	36.60%	100.00%

Table 14. Land cover change from 1973 to 2001 in Pago Watershed

From the above table, the following findings can be achieved for Pago Watershed. The area of forest in 1973 covered 41.74% of the watershed, and the forest area increased to 48.33% in 2001. The grassland area in 1973 covered 50.21% of the watershed, but it decreased to 36.6% in 2001. The urban area in 1973 covered 4.09% of the watershed, and it increased to 12.29% in 2001. The barren land covered 3.91% of the watershed, and it decreased to 2.56% in 2001. Water area in 1973 covered about 0.05% of the watershed, and there was no open water area in 2001.

8.26% and 6.59% of forest in 1973 were converted to urban area and grassland respectively in 2001. 10.48%, 23.53% and 3.86% of grassland in 1973 were changed to urban area, forest and barren land respectively in 2001. 7.79%, 23.05% and 66.67% of barren land were changed to urban area, forest and grassland respectively in 2001. 11.31%, 5.06% and 3.87% of urban area were converted to forest, barren land and grassland respectively in 2001. 25%, 50% and 25% of water body were converted to urban area, forest and barren land respectively in 2001.

Ugum watershed land cover change

	Urban	Forest	Burned	Cloud	Barren	Grassland	Total
Forest	78	2857	4	1	11	513	3464
Grassland	214	329	27	0	213	1343	2126
Barren	26	25	5	0	31	140	227
Total	318	3211	36	1	255	1996	5817

	Urban	Forest	Burned	Cloud	Barren	Grassland	Total
Forest	2.25%	82.48%	0.12%	0.03%	0.32%	14.81%	59.55%
Grassland	10.07%	15.48%	1.27%	0.00%	10.02%	63.17%	36.55%
Barren	11.45%	11.01%	2.20%	0.00%	13.66%	61.67%	3.90%
Total	5.47%	55.20%	0.62%	0.02%	4.38%	34.31%	100.00%

Table 15. Land cover change from 1973 to 2001 in Ugum Watershed

From the above table, the following findings can be achieved for Ugum Watershed. The area of forest in 1973 covered 59.55% of the watershed, and the forest area decreased to 55.2% in 2001. The grassland area in 1973 covered 36.55% of the watershed, but it decreased to 34.31% in 2001. The barren land covered 3.9% of the watershed, and it increased to 4.38% in 2001.

2.25% and 14.81% of forest in 1973 were converted to urban area and grassland respectively in 2001. 10.07%, 15.48% and 10.02% of grassland in 1973 were changed to urban area, forest and barren land respectively in 2001. 11.45%, 11.01% and 61.67of barren land were changed to urban area, forest and grassland respectively in 2001.

CONCLUSIONS AND RECOMMENDATIONS

In order to determine the land cover changes in watersheds in southern Guam, time series data are needed. Since the study area is covered by lots of mountains in the southern Guam, it is hard to conduct field work to survey land cover for the whole study area. What's more, historical land cover information for the study area is not available or not complete. Considering the advantage of satellite imagery, it is chosen to be applied to derive land cover information.

This study is focused on land cover change from 1973 to 2001. Landsat MSS image of November 14, 1973, and Landsat TM iamge of March 15, 2001 are available for this study. However, the Landsat MSS iamge is covered by a lot of clouds and shadows. In order to improve the land cover classification results, historical GIS data such as DLG, DRG and air photos are used to assistant land cover classification.

There is no doubt that land cover classification result is affected by the quality and resolution of source data. That's why the land cover classification accuracy for 1973 is not as good as that of 2001. From Table 1, the following conclusions can be made.

- The watersheds in southern Guam were mainly covered by forest and grassland in both years of 1973 and 2001.
- The area of forest increased by about 3% from 1973 to 2001, but the area of grassland decreased by over 17% between 1973 and 2001.
- The built-up/urban area increased by over 3 times from 1973 to 2001, and most of the increased urban areas occurred in forest and grassland.
- There were some burned areas identified from the Landsat TM image of March 15, 2001. The early time in 2001 was very dry, which might make some grassland and forest areas very vulnerable to wildfires. The burned areas were probably caused by wildfires set by local people for hunting deer and wild pigs. Local people have such a tradition for hunting.
- The urban area will continue to increase in the following few years. Figure 15 shows a subset QuickBird image of 2006, which focuses on the UOG campus. The WERI and Marine Lab buildings are located at the lower bottom of this image. Figure 16 indicates that the highlighted forest area has been cleared for new residential buildings. The U.S. Department of Defense is planning a major expansion of its facilities and personnel on Guam. About 40,400 active military personnel and dependents will be relocated in Guam by 2014 (ICF International, 2009). The military build-up activities will be a potential driving force for stimulating the local economy and a major cause for more non-urban areas lost to military build-up activities on Guam in the following years.

Land cover change in each watershed in southern Guam is discussed in the following. The land cover changes of coastal watersheds are listed in Tables 2 – 15. The grassland area decreased in each coastal watershed, while forest area increased in most watersheds except for Umatac Watershed and Ugum Watershed. Most of grassland was lost to human activities such as buildings and transportation. However, the area of the combined vegetation of forest and grassland in every single watershed decreased, while urban area increased in each watershed.

That means impervious surface increased over the study period. Loss of vegetation and increase of impervious surface will cause environmental problems, and may deteriorate water quality in the watersheds of southern Guam, where about 20% drinking water is supplied to residents and tourists.

From the watershed land cover maps of 1973 and 2001, it is easy to find out that most people are living near the shoreline in the southern Guam. The house locations in the southern Guam manifest that people prefer to live near the shoreline for ocean view and marine aqua activities (Figure 17). The map of transportation also demonstrates that there is positive relationship between density of transportation and human-induced activities (Figure 18). Human activities may cause dramatic changes to landscapes and even coastal line change. Information about land cover including human activities may help watershed managers and policy makers take some measures to protect watersheds for a better place for living and biodiversity. Considering current buildup activities in Guam, the results from this research may be utilized to conduct environmental impact assessment, to locate potential soil erosion areas, and to further research on human-environment interaction, etc.

Figure 15. Subset QuickBird image of 2006 which shows the UOG campus. The highlighted area by a red rectangle was covered by trees in 2006. The area has been cleared for new houses.

Figure 16. The forest area was cleared for building houses.

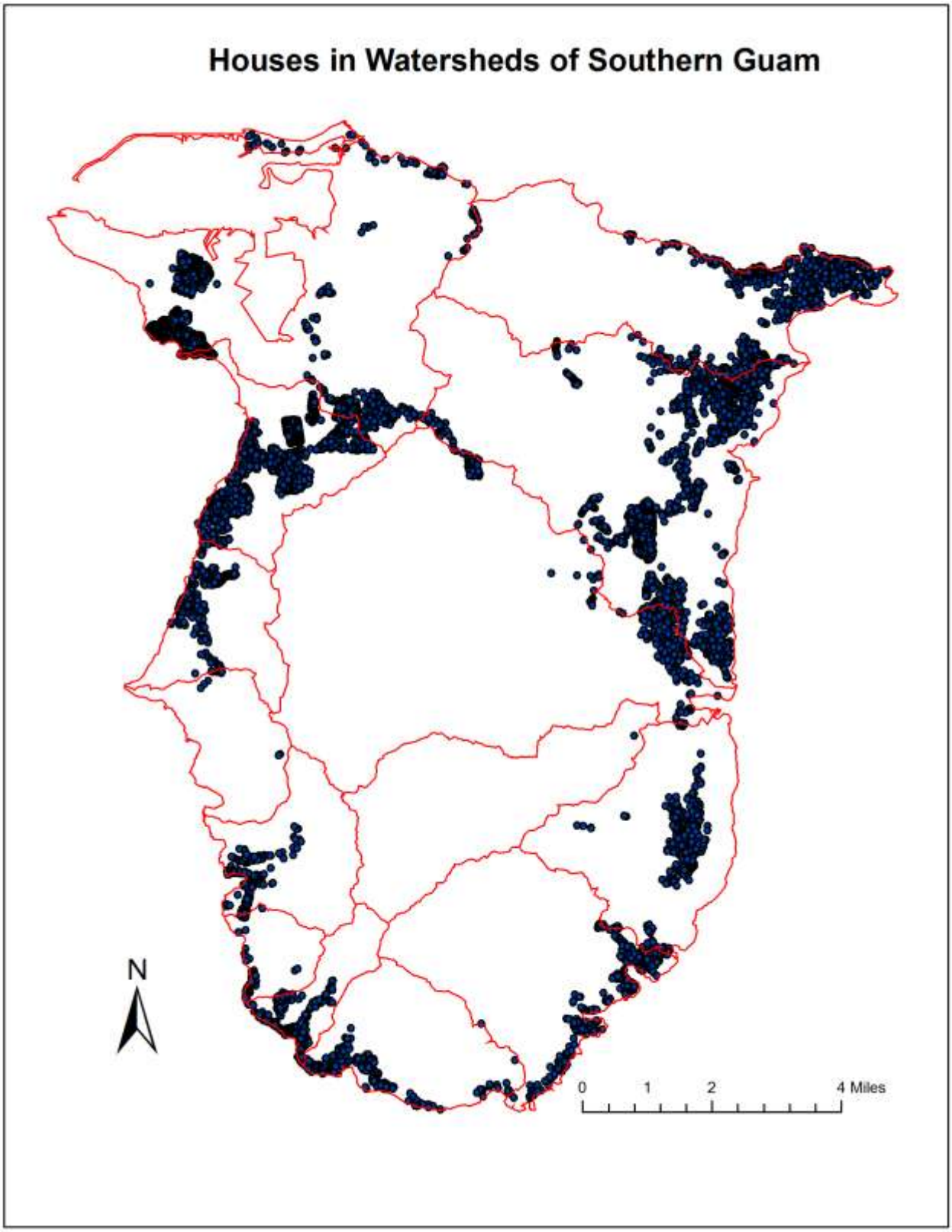

Figure 17. The clustered dots are houses located in the watersheds of southern Guam

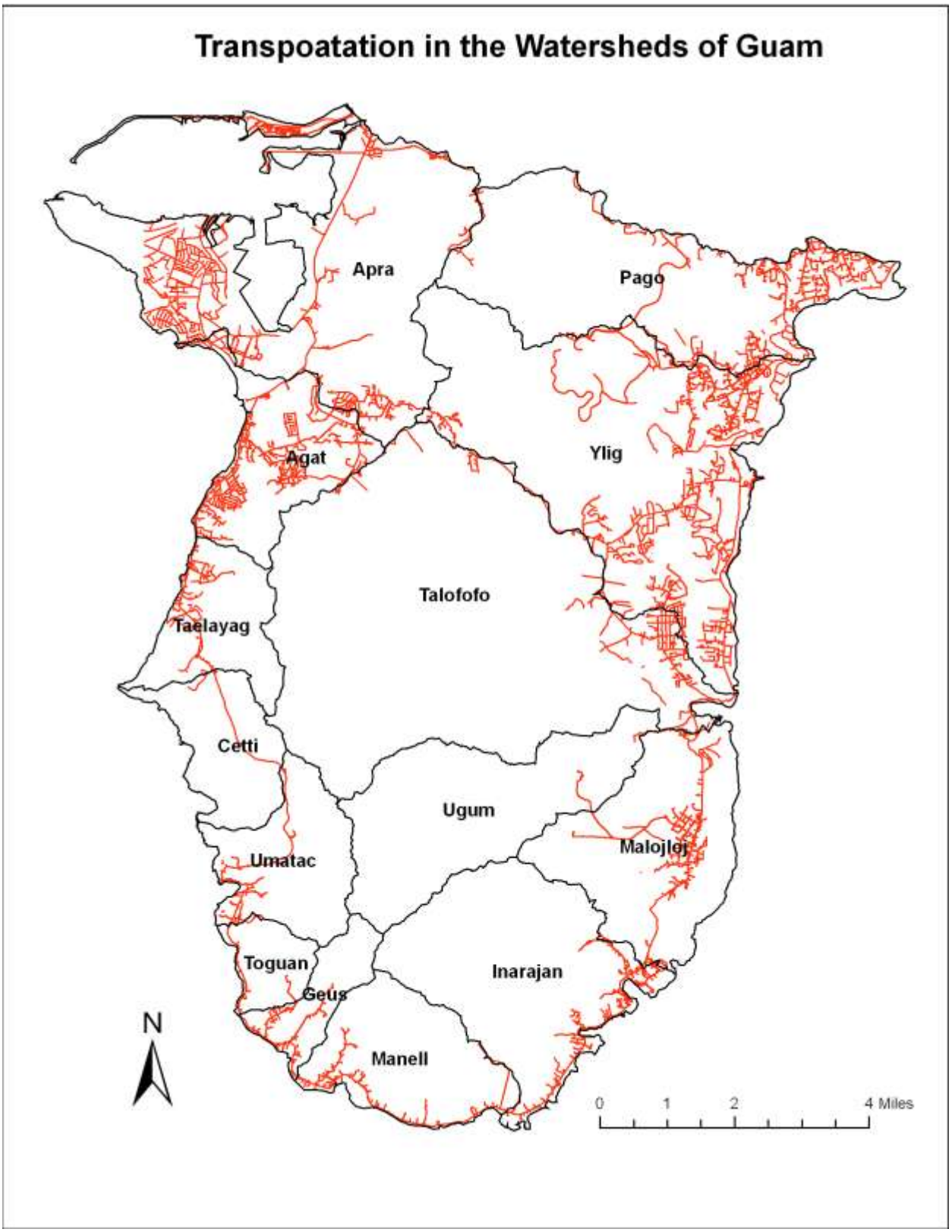

Figure 18. Transportation in the watersheds of southern Guam

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