LAND COVER CHANGE DETECTION IN SAIPAN

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OF THE WESTERN PACIFIC
UNIVERSITY OF GUAM

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by

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ABSTRACT

Land cover change (LCC) has been a subject of concern for the past few decades. Land cover change is not only affected by anthropogenic activities, but also biophysical drivers such as droughts, flooding, earthquakes, climate change and sea level rise. Traditionally, many of the changes have been recorded qualitatively through the use of comparative photographs and historical surveys and/or reports. With advancement and development of geospatial technologies, it is possible to detect land cover change and determine impacts of human activities on environment and ecosystem in islands, particularly tropical islands where water quantity and quality is essential to sustainable development and quality of life. Satellite remote sensing, spatial statistics, geographic information systems (GIS), and global positioning system (GPS) can be utilized to identify land cover information and determine land cover changes if temporal data are applied. Considering the global warming, sea level rise and human induced activities, many island nations or regions are facing serious problems with environmental sustainability, water resources and water quality. In order to mitigate the impacts of biophysical and human factors on environment, it is important to obtain land cover information, and determine land cover change, and evaluate whether human induced activities affect environment and water quality.

This project will focus on derivation of land cover information from satellite images, and determination of land cover change in Saipan, CNMI. Landsat Multispectral Scanner (MSS) image of 1978, and Aster L1B imagery of 2009 are employed. This project mainly focuses on moderate spatial resolution data for land cover classification and land cover change detection. Higher spatial resolution data including QuickBird, GeoEye, IKONOS data, and historical aerial photos may be employed as reference data. Geospatial technologies such as GIS, spatial analysis and remote sensing are applied to complete the project. The results from the project can be applied to further address other topics such as impacts of human activities on water quality, watershed management, and island sustainable development in Saipan.

INTRODUCTION

Land cover change (LCC) has been a subject of concern for many years. Land cover change is not only affected by human-induced activities, but also by biophysical drivers such as droughts, flooding, earthquakes, climate change and sea level rise (Lo and Yang, 2002). Examples of LCC are the land clearance for housing, change of native forest into farming land and human settlement, fires that clear the lands, badland dynamics, changes in wetlands, road construction and many more. These changes can amplify soil erosion, which is the main source of non-point pollution for the streams. With advancement and development of geospatial technologies, it is possible to monitor land cover change and determine the impact of human activities on environment and ecosystem in islands, particularly tropical islands where water quantity and quality is essential to sustainable development and quality of life. Satellite remote sensing, spatial statistics, geographic information systems (GIS), and global positioning system (GPS) can be used to identify land cover information and determine land cover changes if temporal data are employed (Jensen, 2000 and 2005; Yuan et al, 2005; Hartemink, Veldkamp and Bai, 2008). Considering global warming, sea level rise and human induced activities, many island nations or regions are facing serious problems with environmental sustainability, water quantity and water quality. In order to mitigate the impact of biophysical and human factors on environment, it is important to obtain land cover information, determine land cover change, and evaluate whether human induced activities affect environment, water quantity and/or water quality.

The University of Guam Water and Environmental Research Institute coordinated Research Advisory Meeting held in Saipan, CNMI on October 16, 2012 identified the following as some of the highest priority research needs for CNMI: a). impact of historical and recent land use activities on ground and surface water quality and production; b). Streamline all agency natural resource data collections into a central repository; c). develop GIS database for soil erosion and watershed management in the CNMI; and d). Develop an updated watershed atlas for CNMI. The information of land cover and land cover change is indispensable to complete the mentioned research needs for CNMI. This project focuses on derivation of land cover information from satellite images from Landsat and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), and determination of land cover change in Saipan, CNMI from 1978 to 2009.

RELATED RESEARCH

The development of a spatial diffusion (SDIF) model for simulation of urban land cover change conducted by Dr. Yuming Wen, was part of a NASA funded project "Multiple Innovative Models in Land Cover Change Study". In this project, biophysical and socio-economic factors were incorporated to simulate and predict urban land cover change. Driving forces such as urban centers, transport networks and population, and barriers for urban development such as wetlands and lakes were used in the model (Wen, 2005).

Developing A Digital Watershed Atlas for Guam was funded by US geological Survey (USGS) through Water Institute Program, and the Guam Bureau of Statistics and Plans. The project focused on developing a digital watershed atlas including physical characteristics such as soil types, vegetation information, rivers and topography, and outreach activities such as web publishing of the digital atlas results, and providing a public education effort through workshops and by working with the local media outlets (TV and radio) to ensure that the public is aware of the availability of the watershed atlas resources (www.hydroguam.net) (Khosrowpanah, Wen, and Tabarosi, 2008).

A project recently funded by the Bureau of Statistics and Plans through the Guam Coastal Management Program Grant (NOAA) was designed to develop assessment strategies for Non-Point sources of Pollution for a Southern Guam Watershed. The objectives of this project were to gather physical and environmental data on the Ugum Watershed. The project also developed a GIS watershed management data base for Ugum Watershed that identified the spatial distribution and extent of such items as soil types; land slopes; location and extend of forest; grassland; wetland and badland areas; extend of undeveloped roads; land use areas including conservation and preserve areas; low density housing areas; urban areas; managed recreational areas such as golf courses, and areas impacted by agricultural operations; dams, wells and hydrological features; lengths and locations of streambank erosion and shoreline erosion; and areas impacted by off-road activities. Using tools available in ESRI's ArcMap and extension ArcHyrdo, areas with the highest potential to contribute pollution to the streams were identified (Khosrowpanah and Jocson, 2005).

Projects *Watershed Land Cover Change Detection in Guam* and *Land Cover Accuracy Assessment for Southern Guam* funded by USGS 104B grant aimed to derive land cover information, evaluate land cover change and conduct accuracy assessment of land cover classification for the watersheds in southern Guam. Geospatial technologies such as GIS, remote sensing and spatial analysis were applied to achieve such results (Wen, Khosrowpanah and Heitz, 2009 and 2009). A project focusing on badland dynamics in selected sites in southern Guam was completed to address how badland changed over time and in space, and how human activities and biophysical factors such as slope affected badland dynamics (Wen et al., 2010). Project *Impacts of Land Cover Change on Groundwater Quality in Guam* funded by USGS 104B grant was focused on derivation of land cover information from Landsat data, and then use of NOAA's land cover features of 2006 on Guam to determine land cover change from 1973 to 2006, and therefore impacts of land cover change on groundwater quality could be evaluated (Wen, 2011 and 2011; US NOAA, 2009).

METHODOLOGY

Description of study area

The study area for this project is the island of Saipan, the Commonwealth of the Northern Mariana Islands (CNMI). Saipan is the second largest island in the Mariana Islands archipelago, after Guam. It is located about 120 miles north of Guam. Saipan is about 12 miles long and 5.5 miles wide, with a land area of 44.6 square miles. The western coast of the island is mainly composed of sandy beaches and a large lagoon is located in the west. The eastern shore primarily consists of rocky cliffs. Saipan is close to some of Asian capital cities such as Beijing, Tokyo and Manila. The distance to Beijing, Tokyo and Manila is about 2,500 miles, 1,500 miles and 1,650 miles respectively. Mount Tapochau at 1.555 feet is the highest on the island of Saipan. It is composed of limestone. Beautiful panoramic views of Saipan can be achieved at Mount Tapochau (Figure 1). The location of Saipan is shown in Figure 2 compared to neighboring countries. Figure 3 indicates the location of Saipan in CNMI, and Figure 4 shows the study area, the island of Saipan.

Figure 1. Some views of Saipan from Mount Tapochau

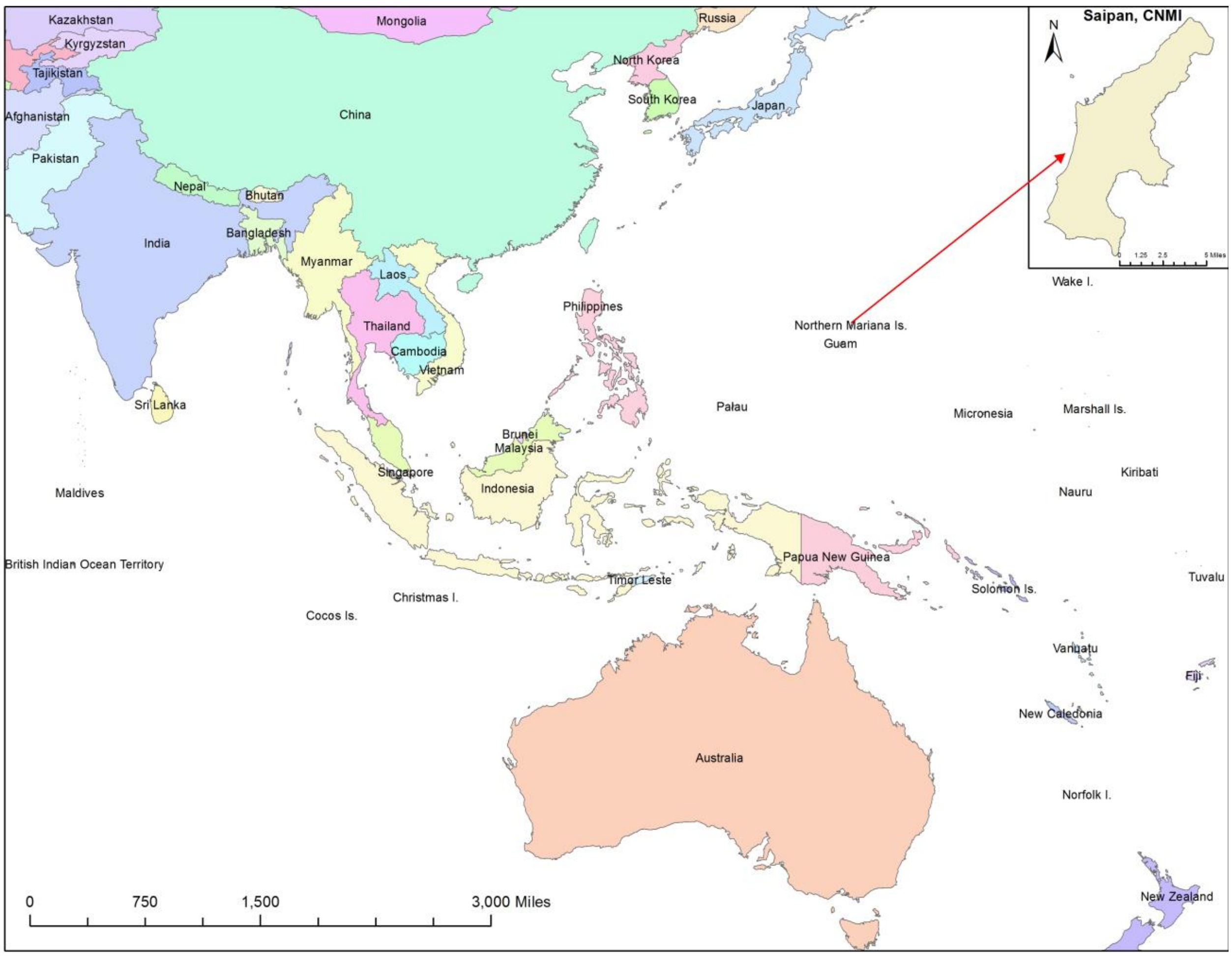

Figure 2. Location of Saipan, CNMI

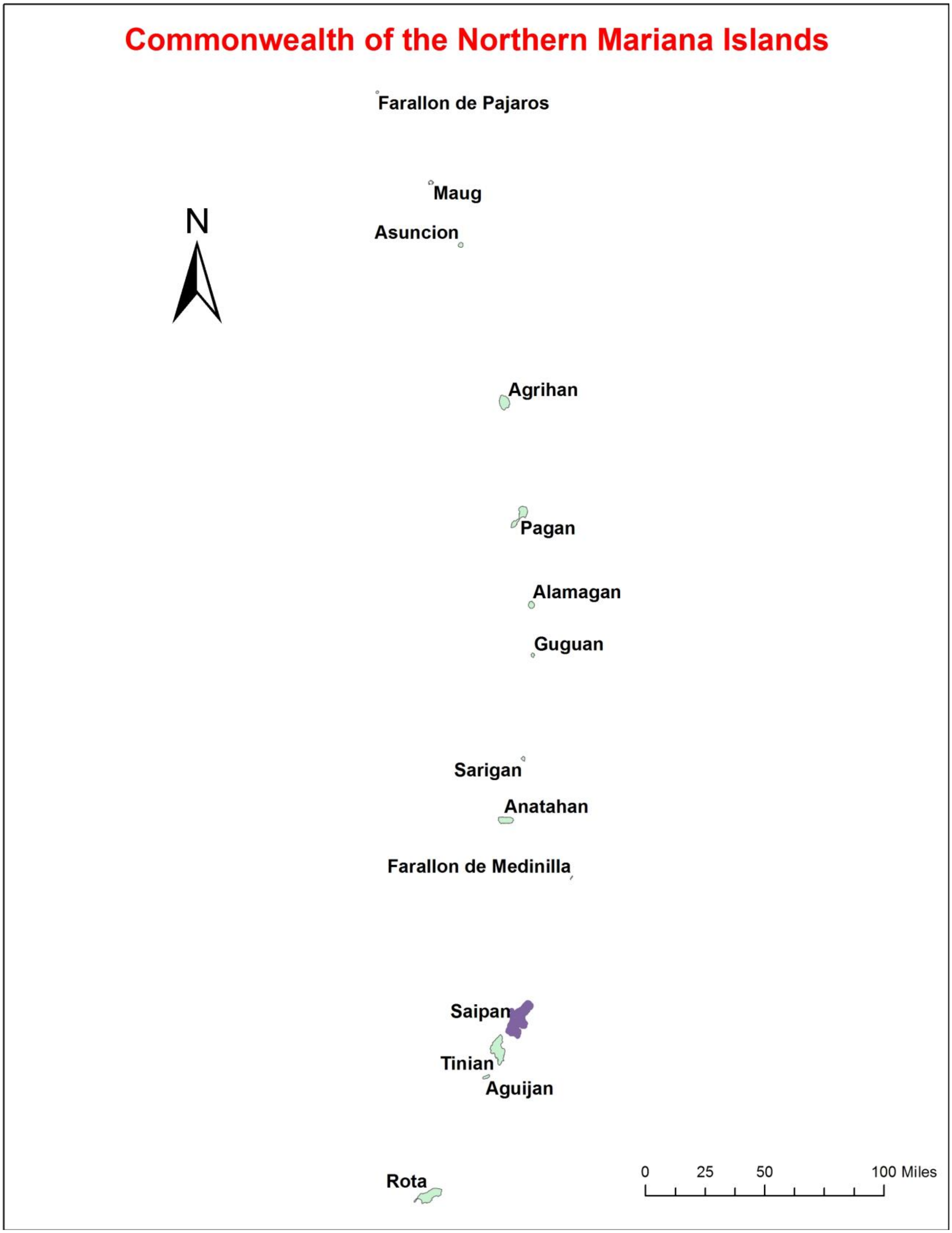

Figure 3. Location of Saipan in CNMI

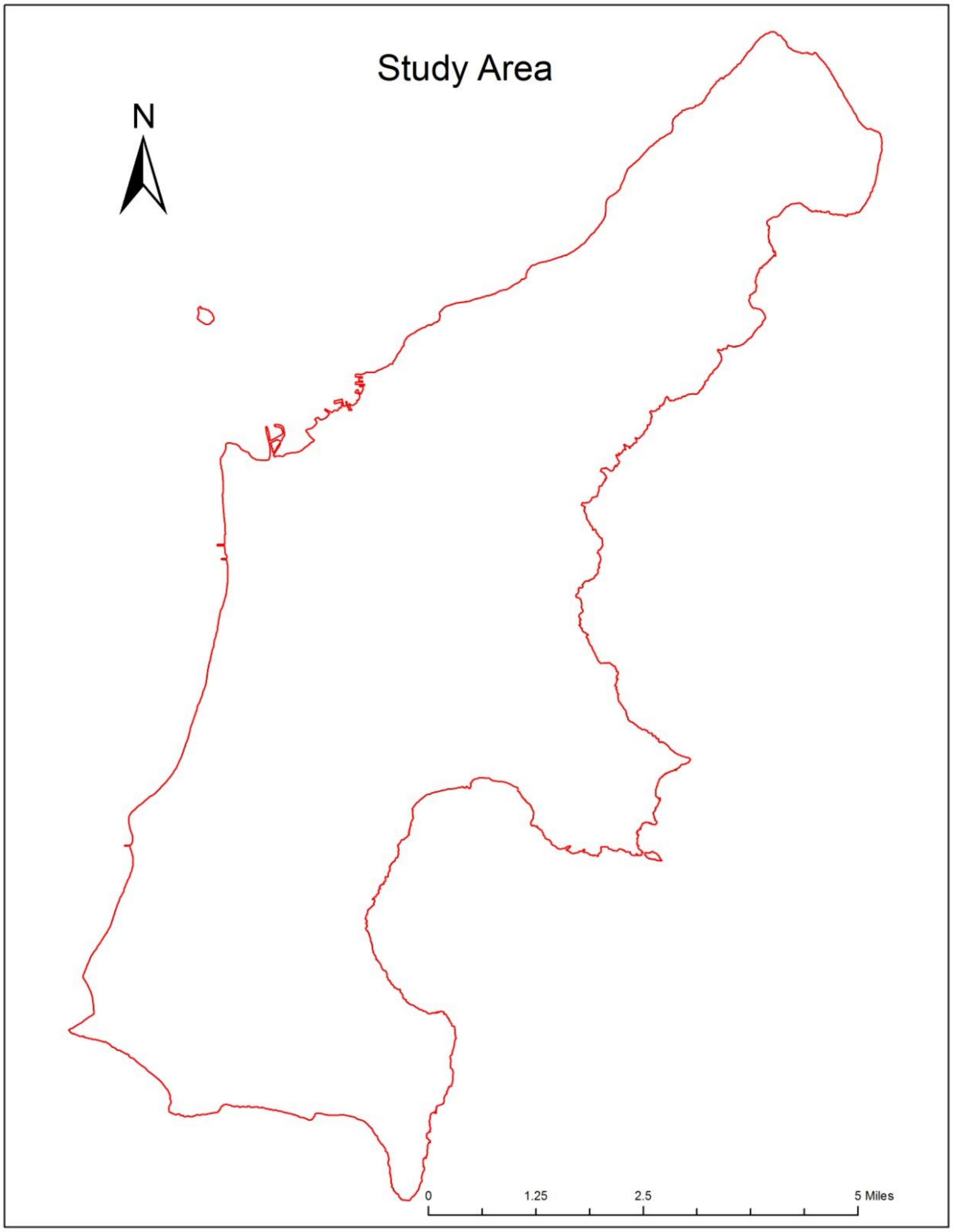

Figure 4. Study area – the Island of Saipan

Data Sources and Data Processing
Landsat Multi-Spectral Scanner (MSS) imagery of 1978 and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) L1B imagery of 2009 are available to the project. There are two scenes of Landsat MSS images for 1978, i.e, the image acquired on October 17, 1978, and the other acquired on December 10, 1978. Both of the images covered the island of Island. There are two scenes of ASTER imagers available, and both of which were acquired on March 5, 2009. One of these ASTER images was not enough to cover the whole island of Saipan. Therefore, both of the images were applied.

The data quality of ASTER L1B imagery of 2009 was very good. However, both of these two scenes of ASTER images were needed to be mosaicked to cover the island of Saipan. One image only covered a small part of Saipan in the north (Figure 5, left), and another one covered most part of Saipan but missing a small part of the north (Figure 5, right).

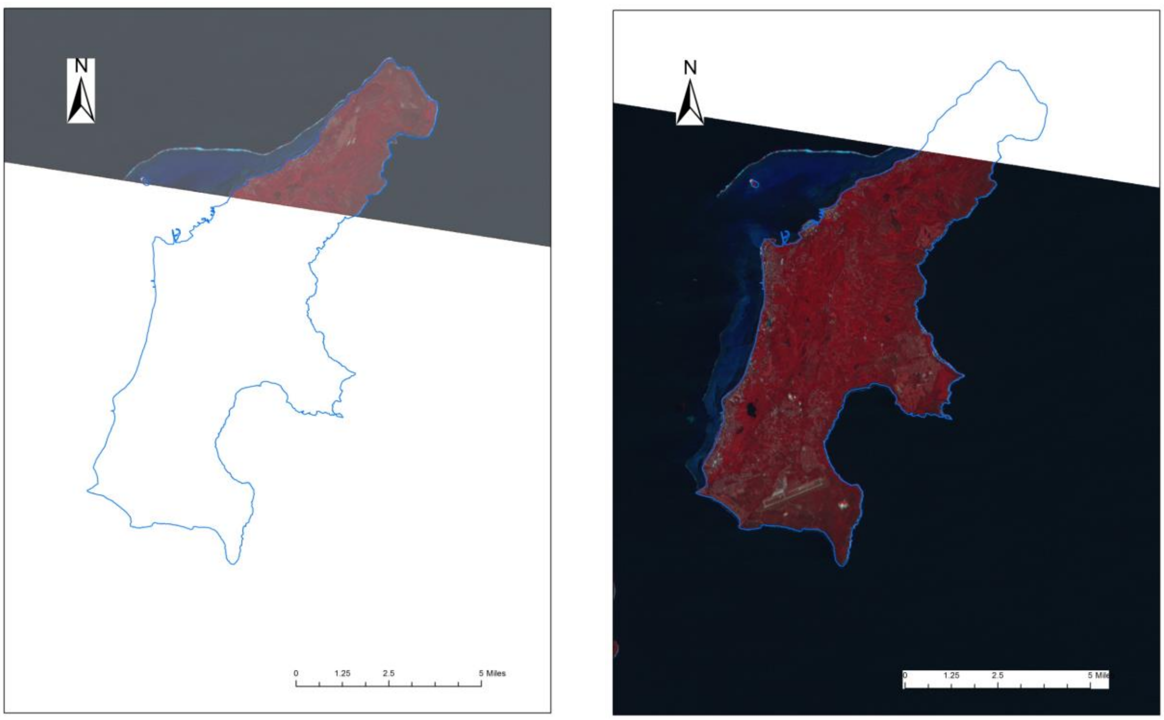

Figure 5. ASTER Images of December 10, 2009

ERDAS Imagine was utilized to mosaic the ASTER images of 2009. The overlapping of the ASTER images of 2009 indicated that they could cover the whole island of Saipan (Figure 6). The mosaicked ASTER image of March 5, 2009 is shown in Figure 7.

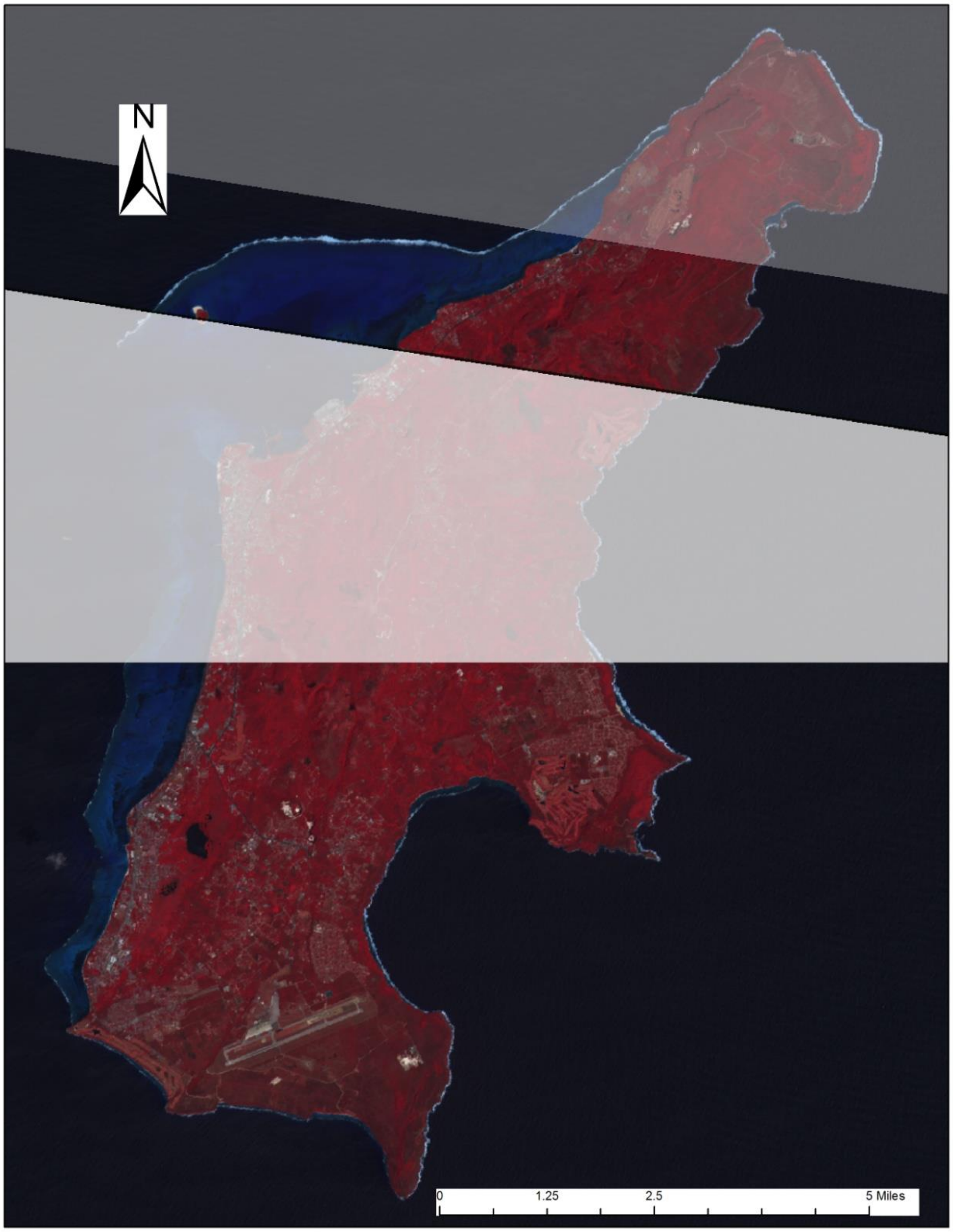

Figure 6. Overlapping of ASTER Images of 2009

Figure 7. Mosaicked ASTER Image of March 5, 2009

The Landsat MSS satellite imagery of October 17 and December 10 of 1978 had problems with data quality since they were not located in the correct positions, and were covered by a lot of clouds and shadows (Figures 8 and 9). The boundary of Saipan is shown in blue, and obviously both of the Landsat MSS images of 1978 are displaced from Saipan. The Landsat image of

December 10, 1978 got more problems. Some parts of the Landsat imagery of December 10, 1978 were displaced from their correct locations (Figure 9).

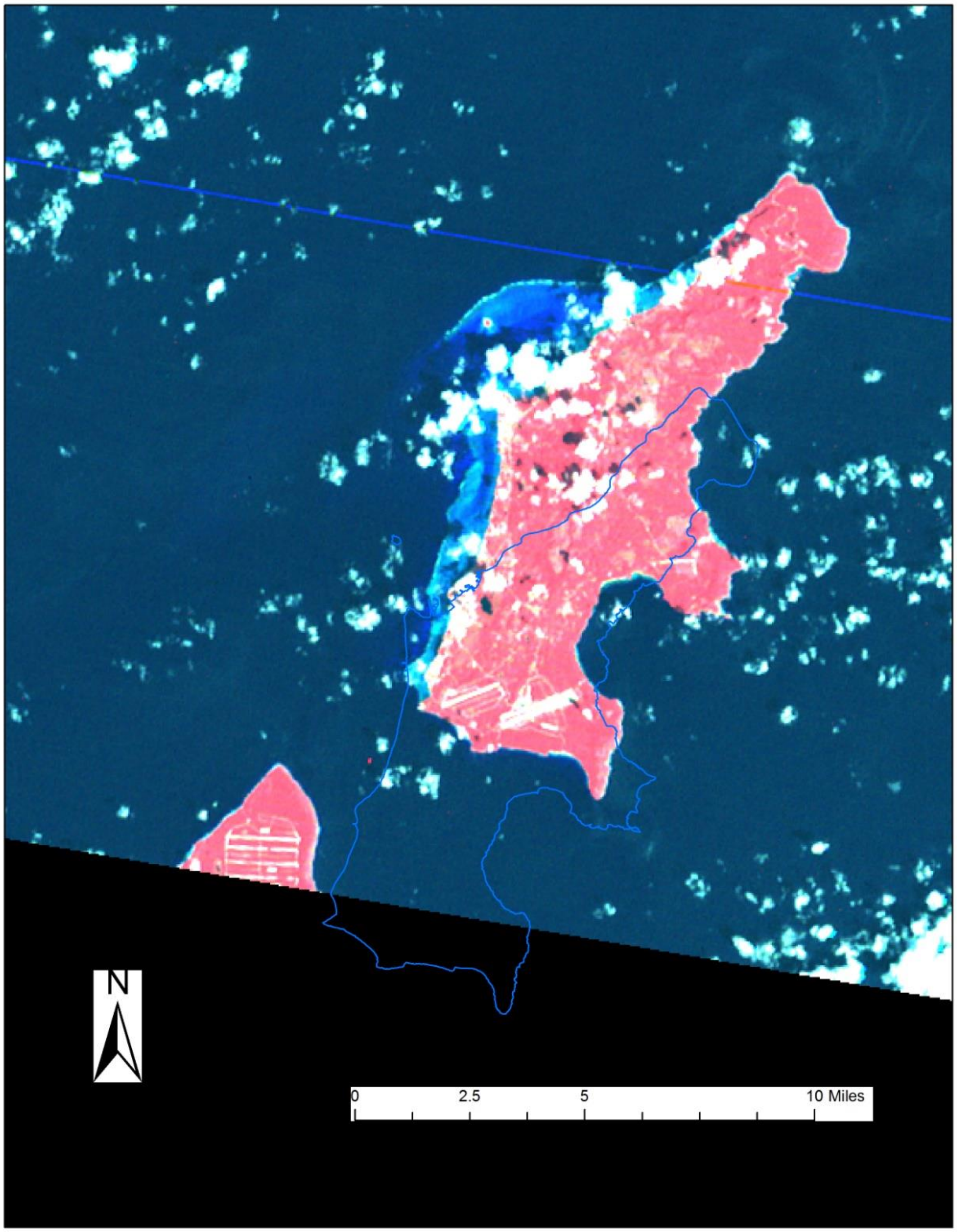

Figure 8. Landsat Multispectral Scanner (MSS) Image of October 17, 1978

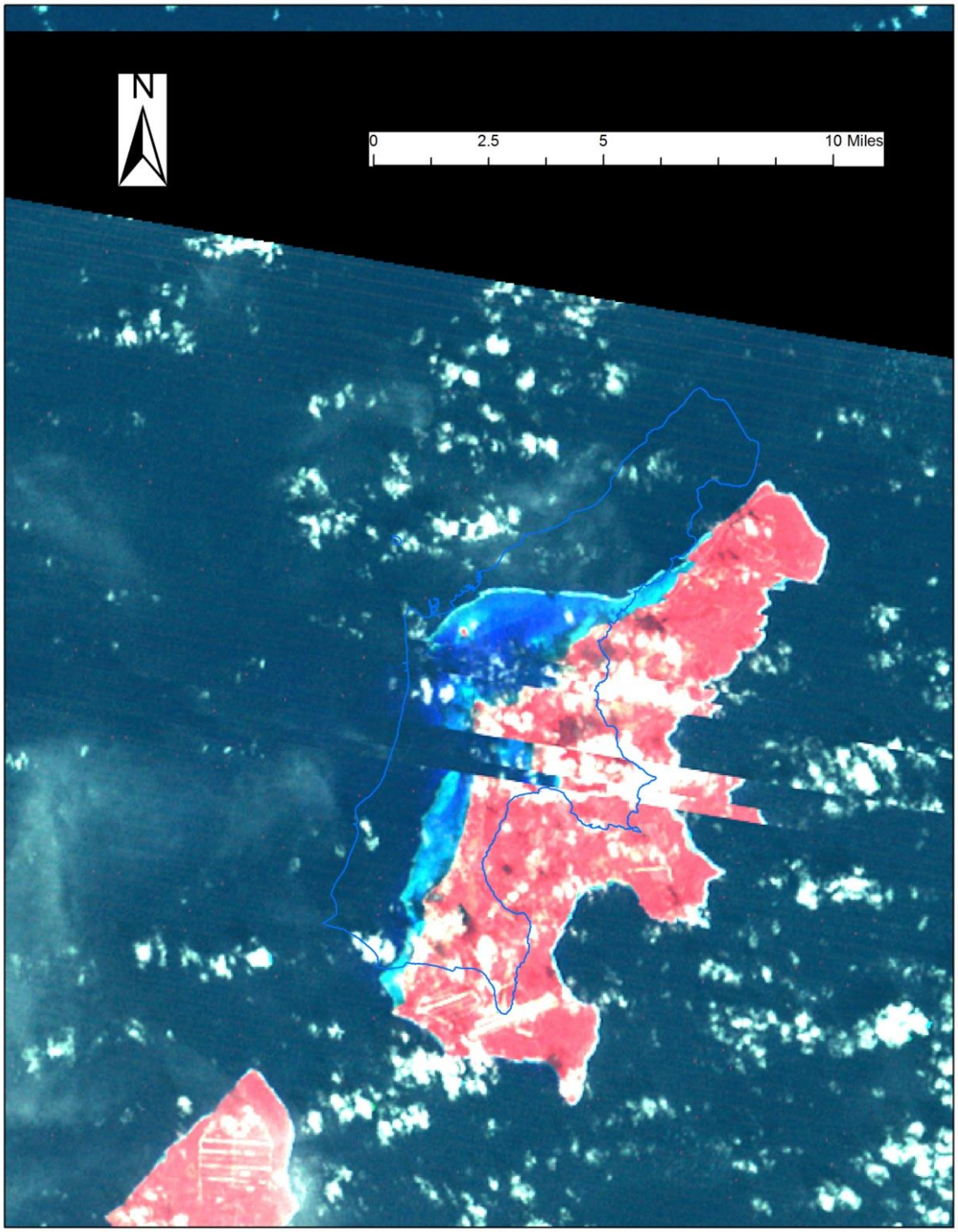

Figure 9. Landsat Multispectral Scanner (MSS) Image of December 10, 1978

In order to make the Landsat images of 1978 useful, preprocessing of the images was needed to remove clouds and shadows, and deal with the displacement of some parts of the Landsat image of December 10, 1978. First, both of the images were georeferenced using ArcGIS

Georeferencing tool. The mosaicked ASTER image of 2009 was used as reference data for georeferencing. The georeferenced Landsat MSS images were shown in Figures 10 and 11.

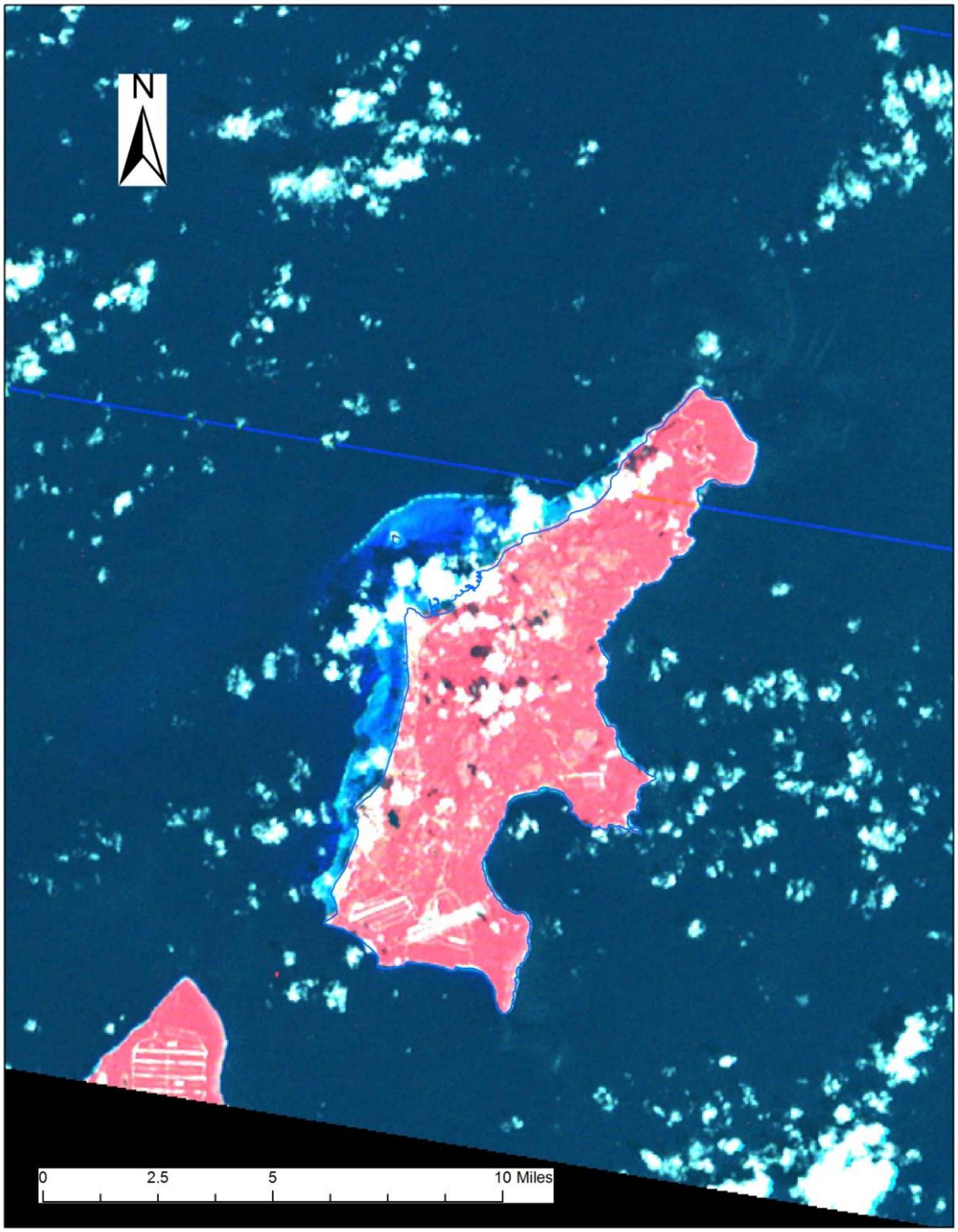

Figure 10. Georeferenced Landsat MSS Image of October 17, 1978

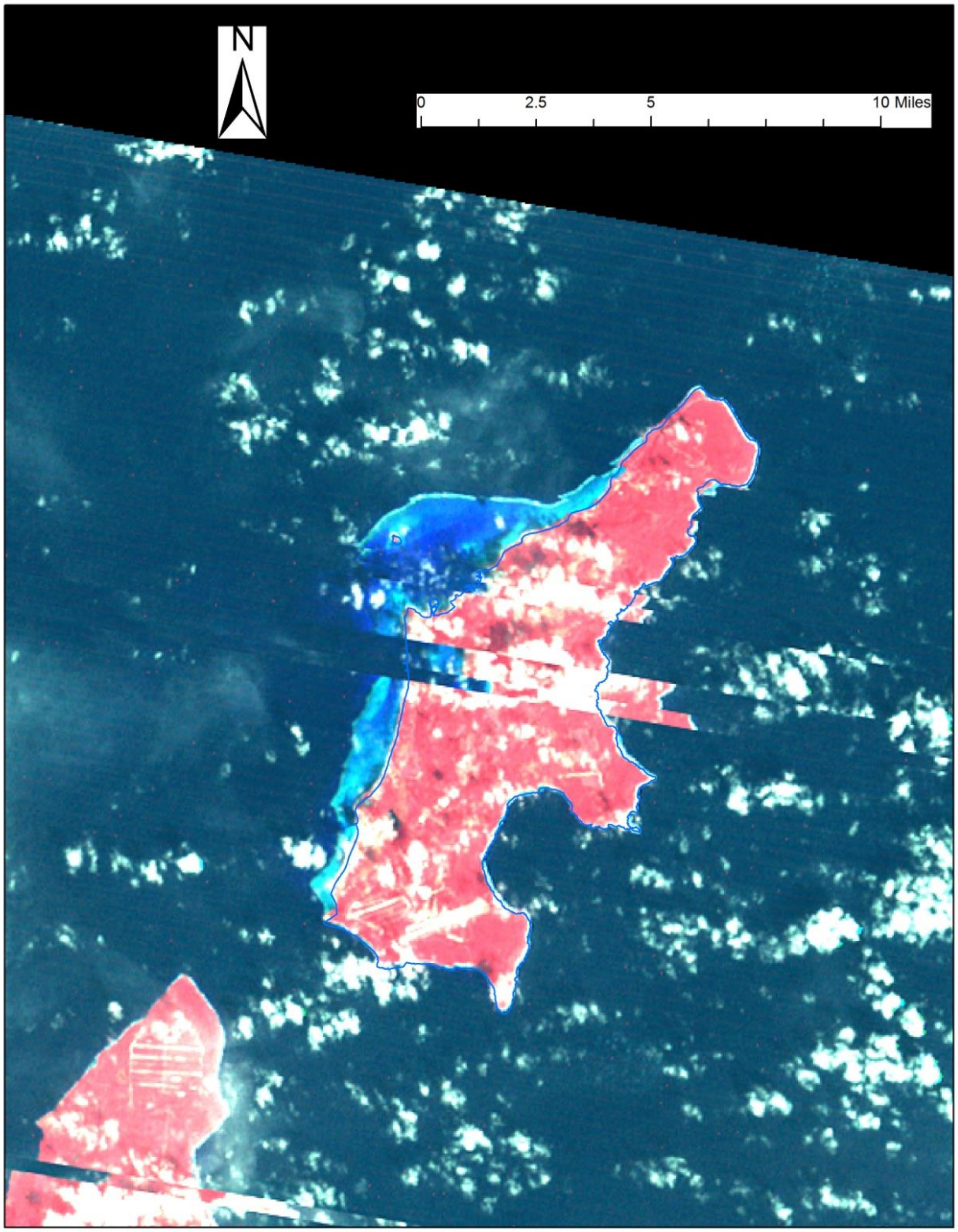

Figure 11. Georeferenced Landsat MSS Image of December 10, 1978

The original Landsat MSS images of 1978 covered the whole island of Saipan and a much larger surrounding features including the Pacific Ocean, the Philippine Sea and Tinian in the south of Saipan. Since the study area was only focused on Saipan, it was necessary to subset the images to a smaller area to cover Saipan. However, considering some parts of the Landsat MSS image of December 10, 1978 displaced from the correct locations, a subset area greater than the study area was applied. ERDAS Imagine was employed to subset the Landsat image of December 10, 1978 (Figures 12).

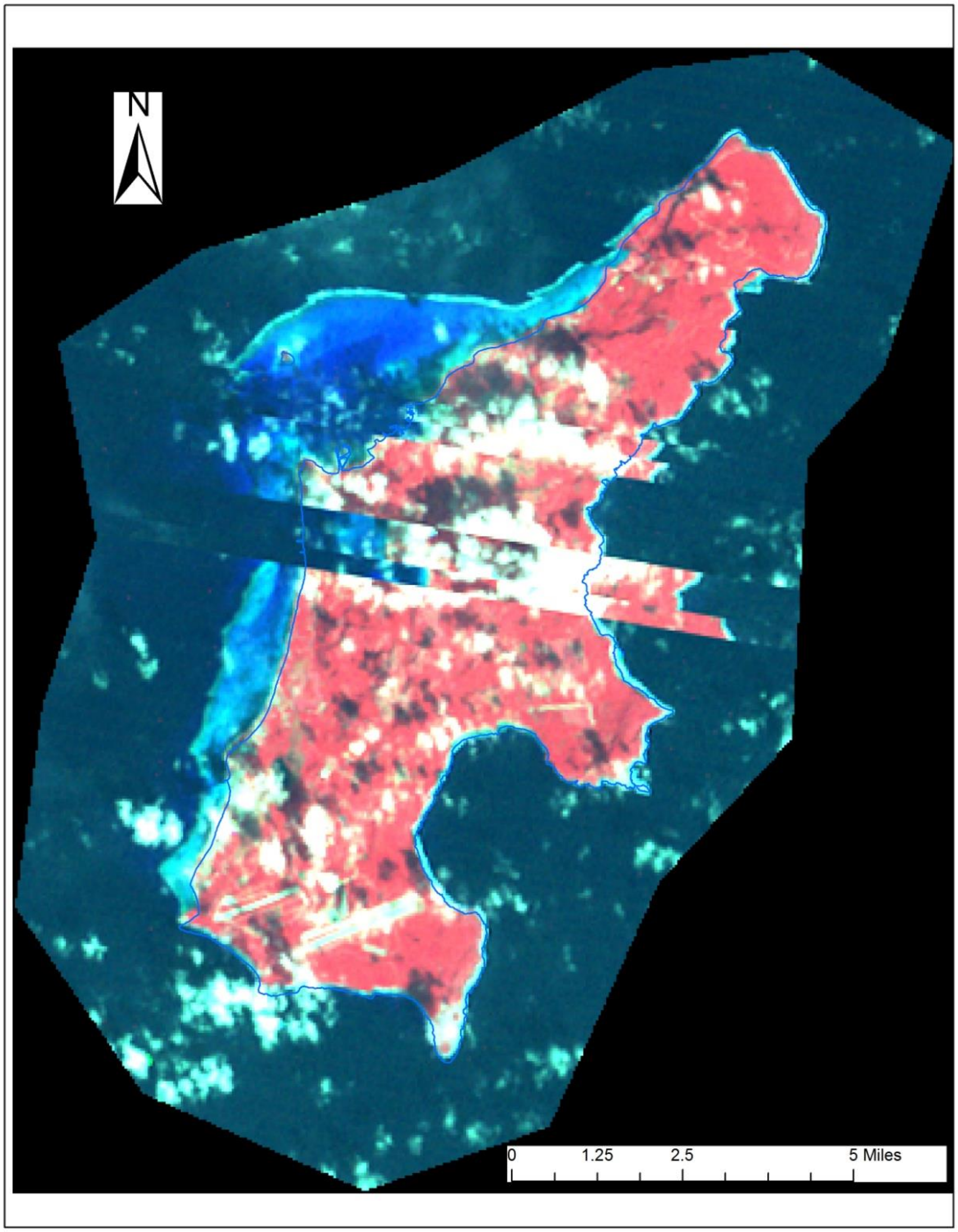

Figure 12. Subset Landsat Image of October 17, 1978

ArcGIS Desktop was used to locate the displaced parts (Figure 13), and ERDAS Imagine was used to extract the displaced parts from the original imagery of December 10, 1978 (Figure 14), and then ArcGIS Desktop was applied to georefernce the displaced parts to correct locations (Figure 15). The georeferenced parts were applied to update the original imagery of December 10, 1978 (Figure 16).

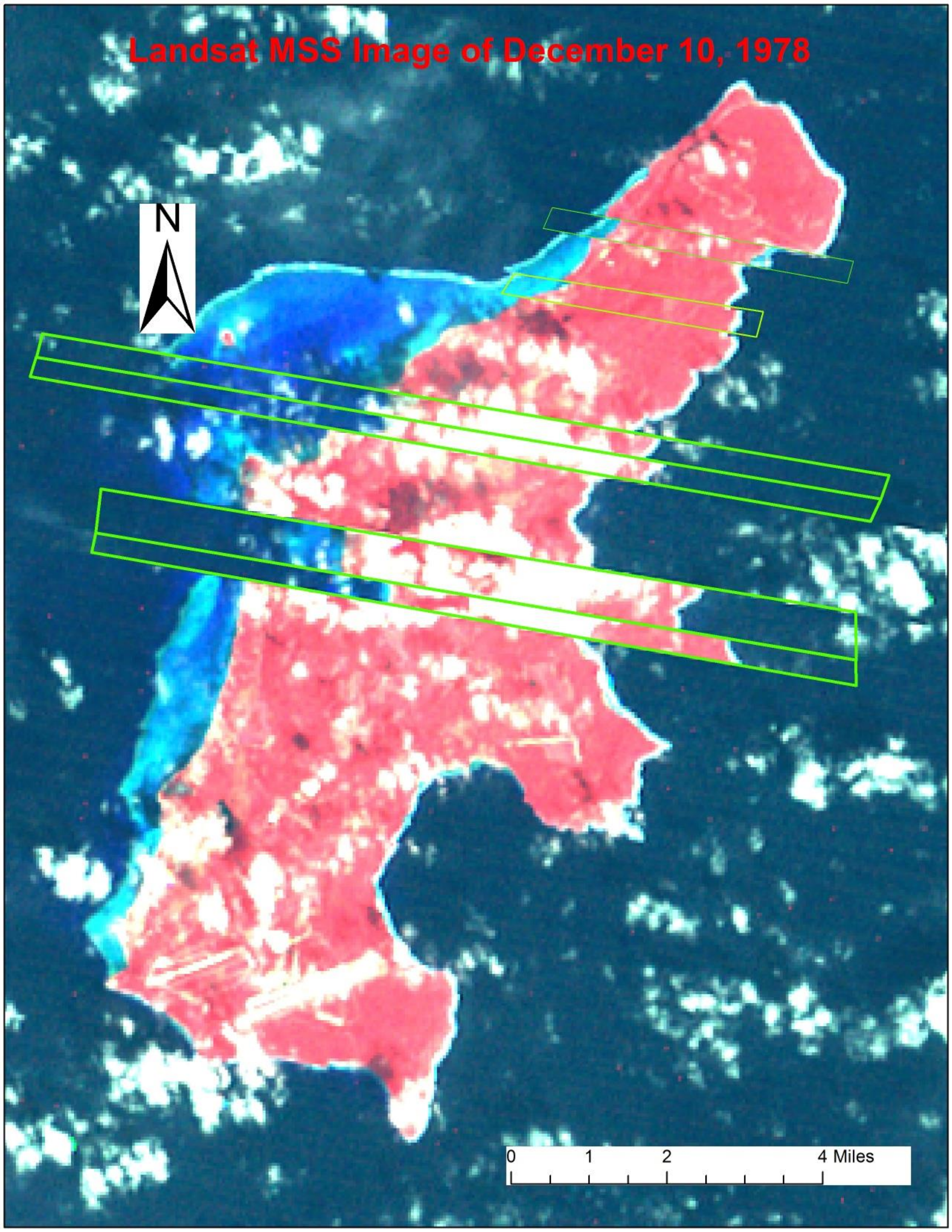

Figure 13. Locations of Displaced Parts of Landsat MSS Image of December 10, 1978

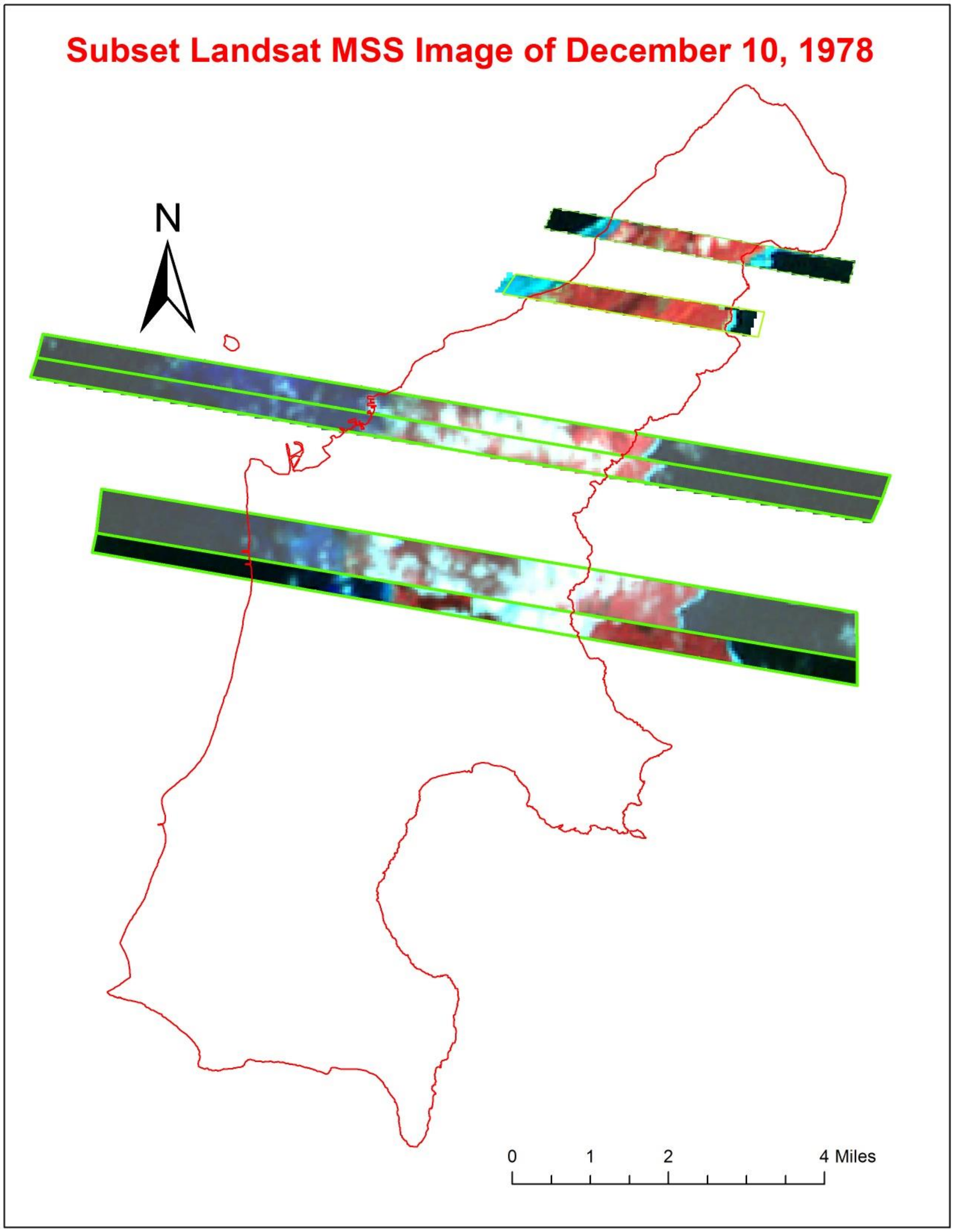

Figure 14. Subset Image of Displaced Parts from Landsat MSS Image of December 10, 1978

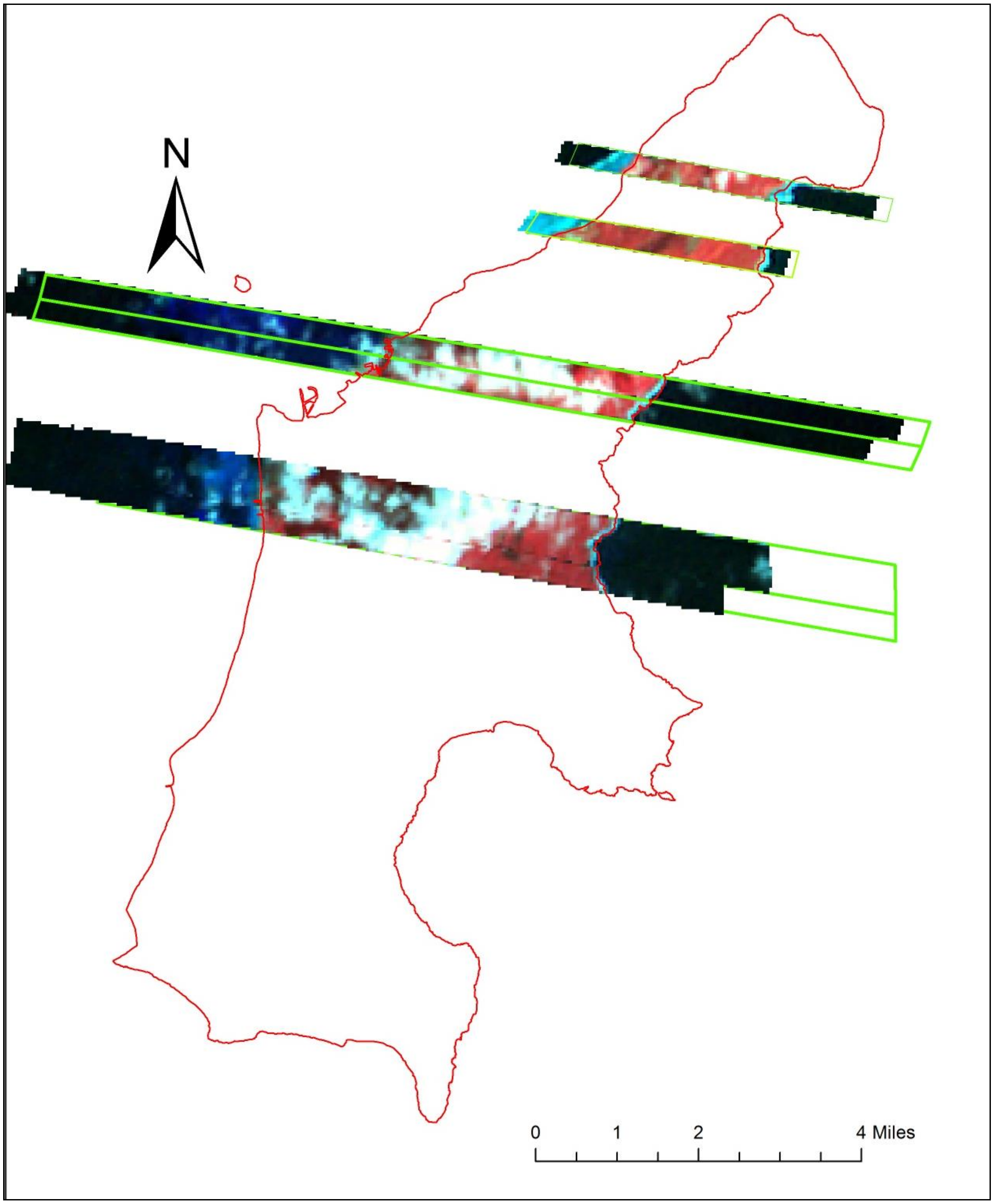

Figure 15. Georeferenced Subset Image of Displaced Parts from Image of December 10, 1978

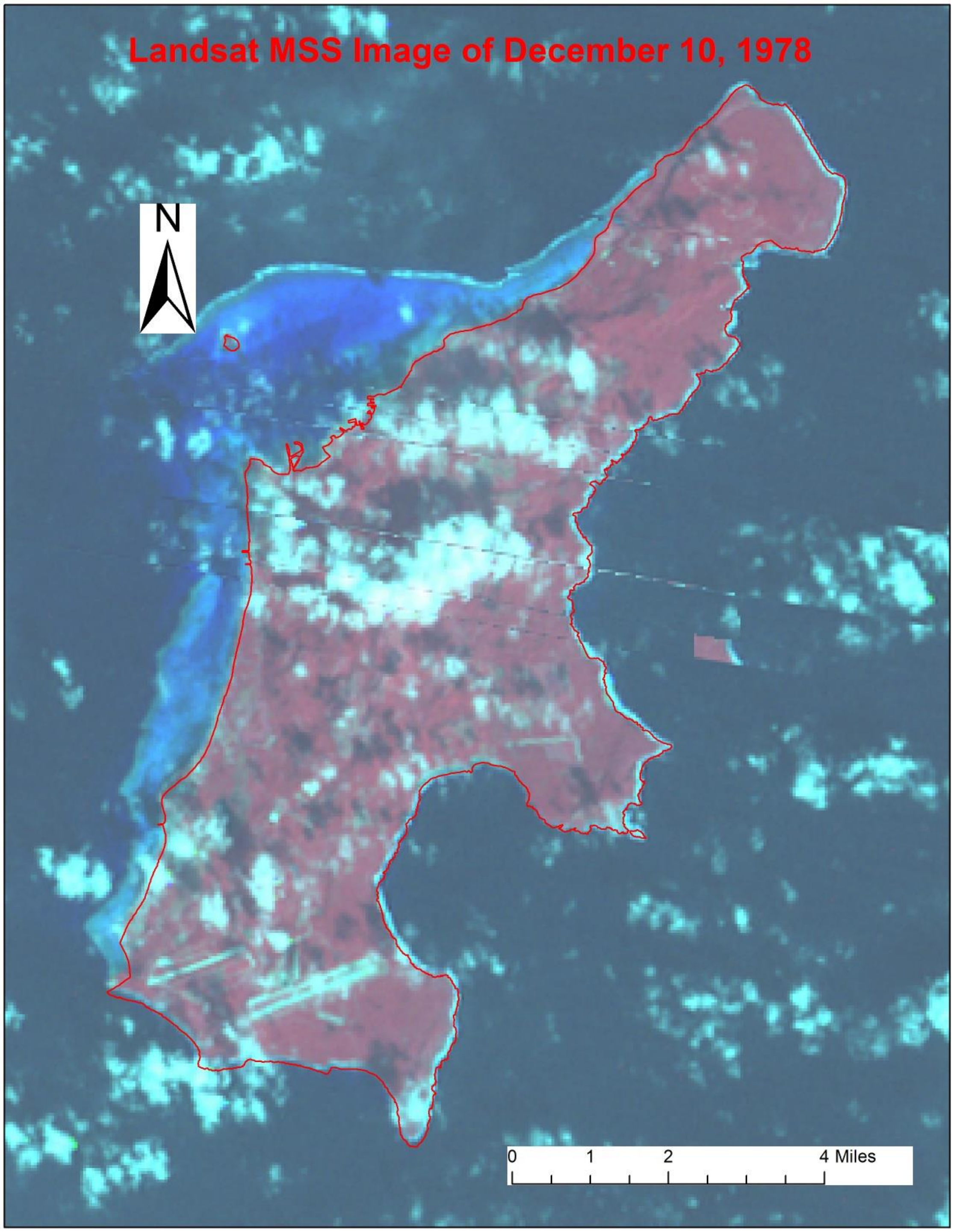

Figure 16. Georeferenced Image of December 10, 1978 with Displaced Parts Corrected

In order to improve the quality of the Landsat MSS imagery of 1978 and therefore increase the accuracy of land cover classification of the Landsat MSS imagery of 1978, both of the images of October 17 and December 10 of 1978 were used to remove some clouds and shadows.

Since the original satellite images used in the project covered a much bigger area. In order to process the data more efficiently, the boundary of study area (Figure 4) was used to subset the imagery for the purpose of land cover change detection in Saipan. ESRI ArcGIS Desktop was applied to buffer the study area for a bigger area to subset the satellite images so that the land cover classification accuracy along shoreline could be improved (Figure 17). Image subsetting was completed in ERDAS Imagine. The subset images for Landsat MSS images of October 17 and December 10, 1978, and ASTER image of 2009 are shown in Figures 18, 19 and 20 respectively.

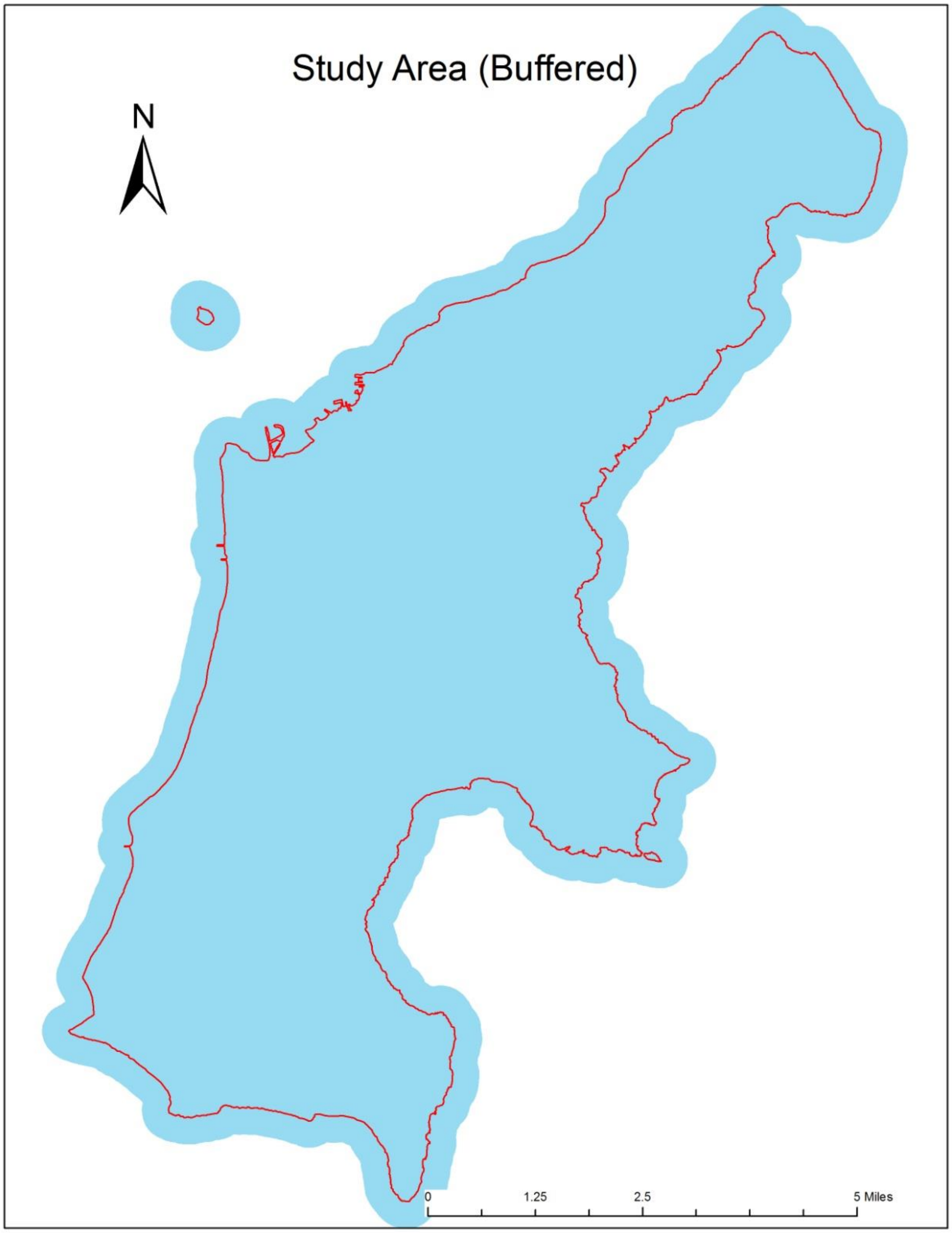

Figure 17. Buffered Study Area

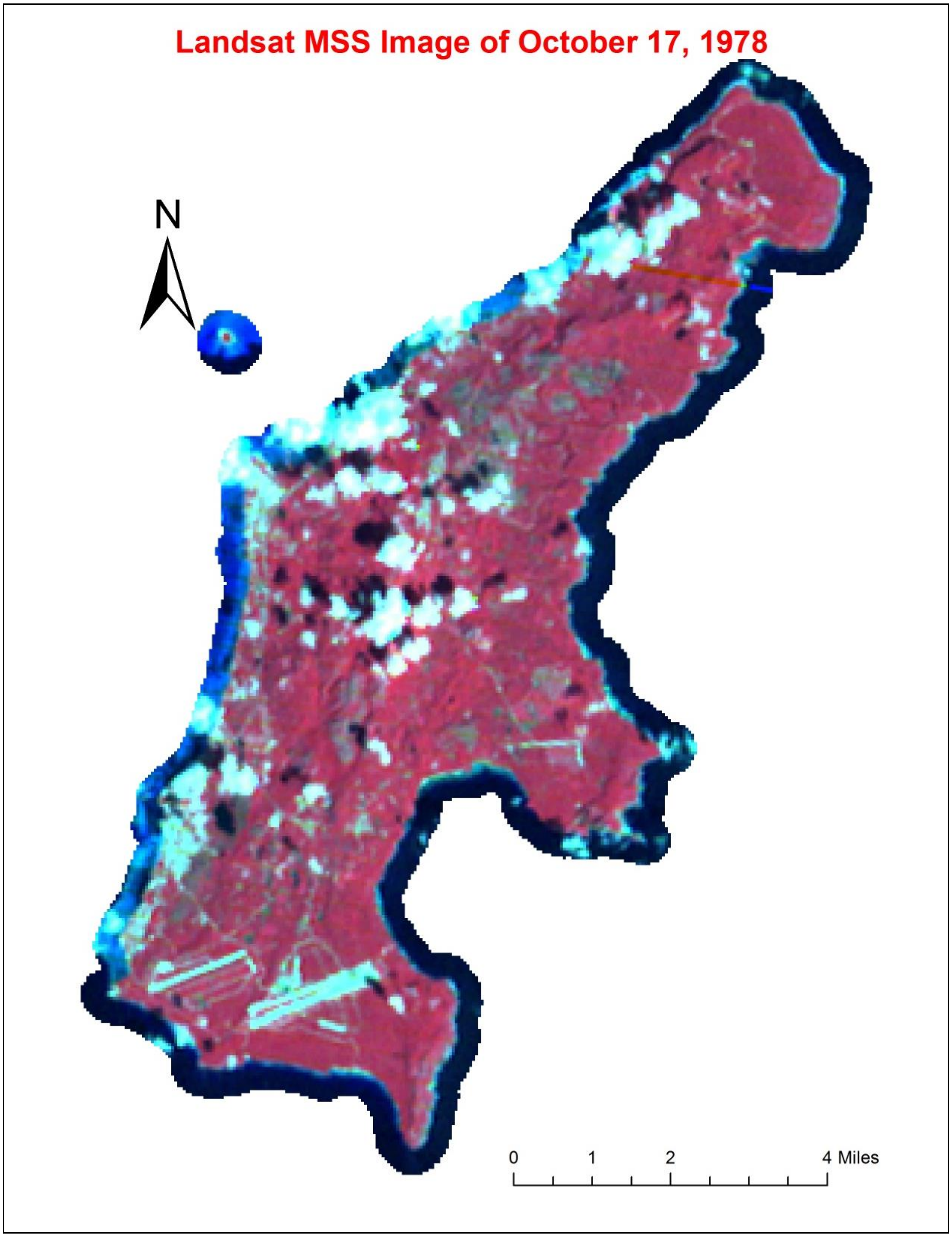

Figure 18. Subset Landsat MSS Image of October 17, 1978

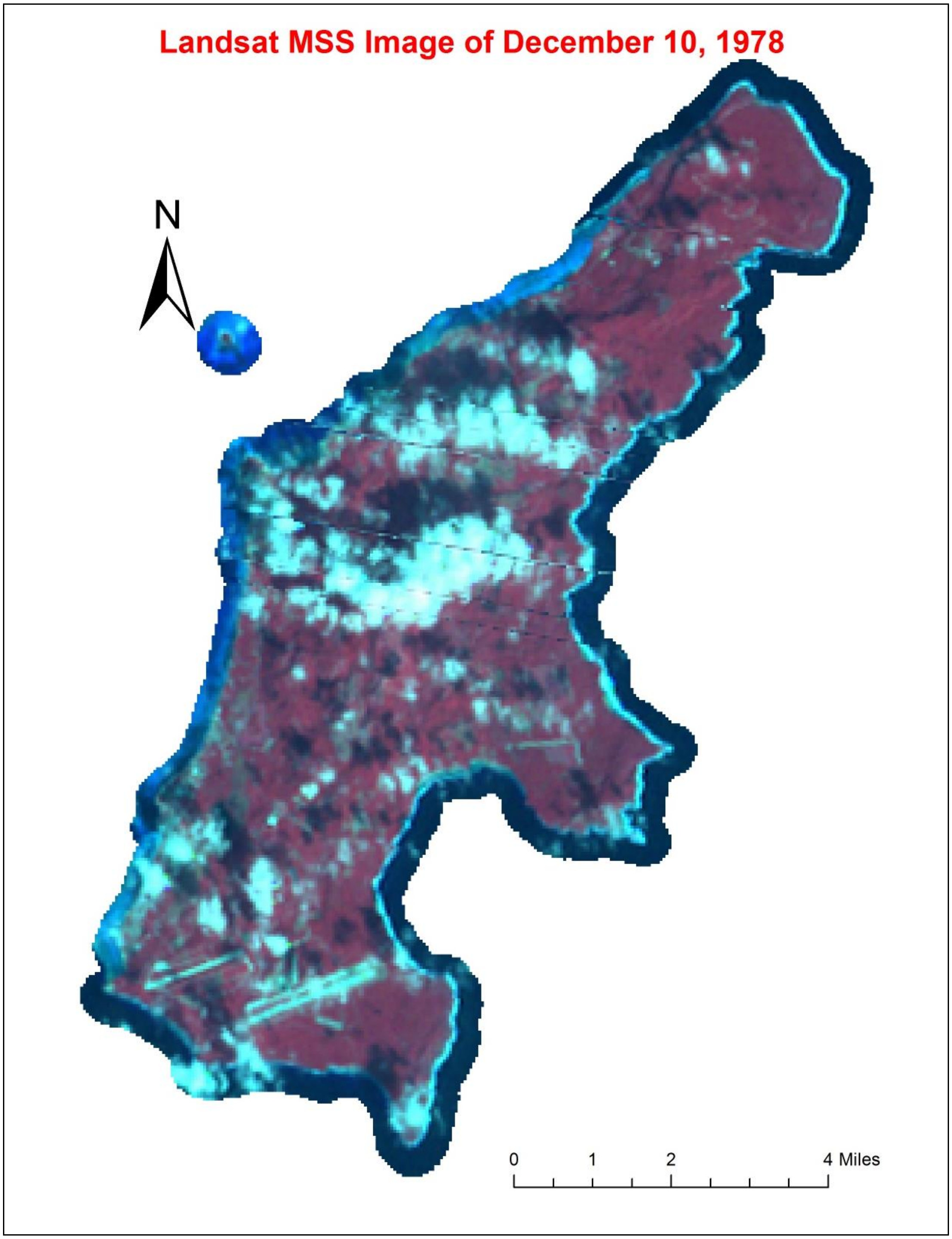

Figure 19. Subset Landsat MSS Image of December 10, 1978

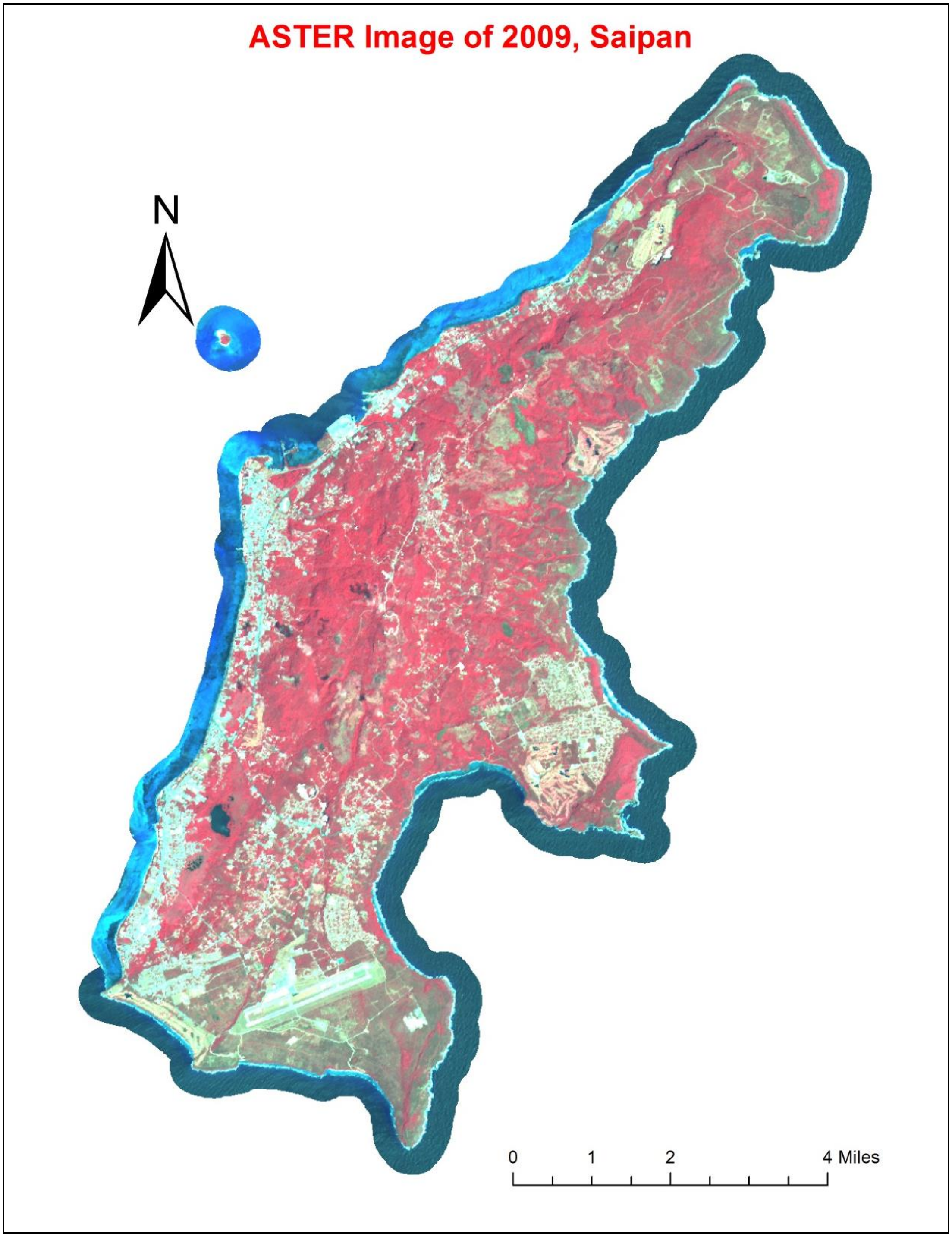

Figure 20. Subset ASTER Image of March 5, 2009

Figures 18 and 19 indicated that there were lots of clouds and shadows in the Landsat MSS images of 1978. In order to improve the accuracy of the land cover information derived from the Landsat MSS images, it was necessary to remove as many clouds and shadows as possible from the images. Since it was very difficult to differentiate between water and shadows, water was also removed in the beginning. The Landsat MSS images of 1978 indicated that the data quality of Landsat MSS image of October 17, 1978 was better than that of Landsat MSS image of December 10, 1978 because there were much more coverages of clouds and shadows in the latter image. The coverages of clouds, shadow and water from Landsat images of October 17, and December 10, 1978 were demonstrated in Figures 21 and 22 respectively. Such information was applied to remove clouds and shadows from Landsat MSS images of 1978 (Figures 23 and 24). Then the Landsat MSS image of October 17, 1978 was updated with the Landsat MSS image of December 10, 1978 with clouds and shadows removed (Figure 25), and the Landsat MSS image of December 10, 1978 was complemented with the Landsat MSS image of October 17, 1978 with clouds and shadows removed (Figure 26). The next step was to merge the Landsat MSS images of October 17 and December 10, 1978 with more clouds and shadows removed from the processed images listed in Figures 25 and 26, and the final Landsat MSS image of 1978 for land cover classification was achieved with much fewer clouds and shadows (Figure 27). So far, the Landsat MSS image of 1978 processed from Landsat MSS images of October 17 and December 10, 1978 with clouds and shadows removed and the mosaicked ASTER image of 2009 could be applied to extract land cover information. The images of Landsat MSS and ASTER are listed in Figure 28 side by side.

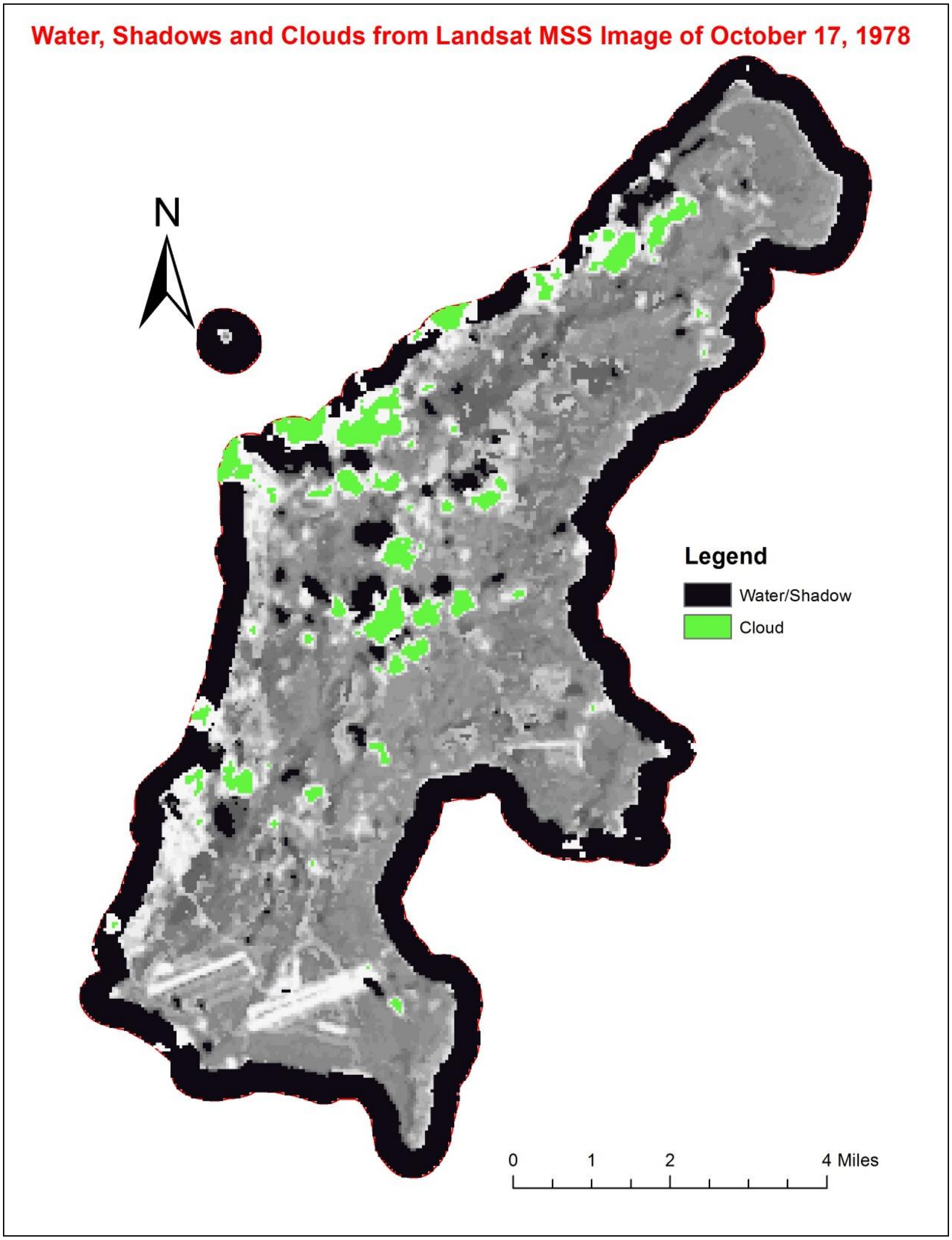

Figure 21. Water, Shadows and Clouds from Landsat Image of October 17, 1978

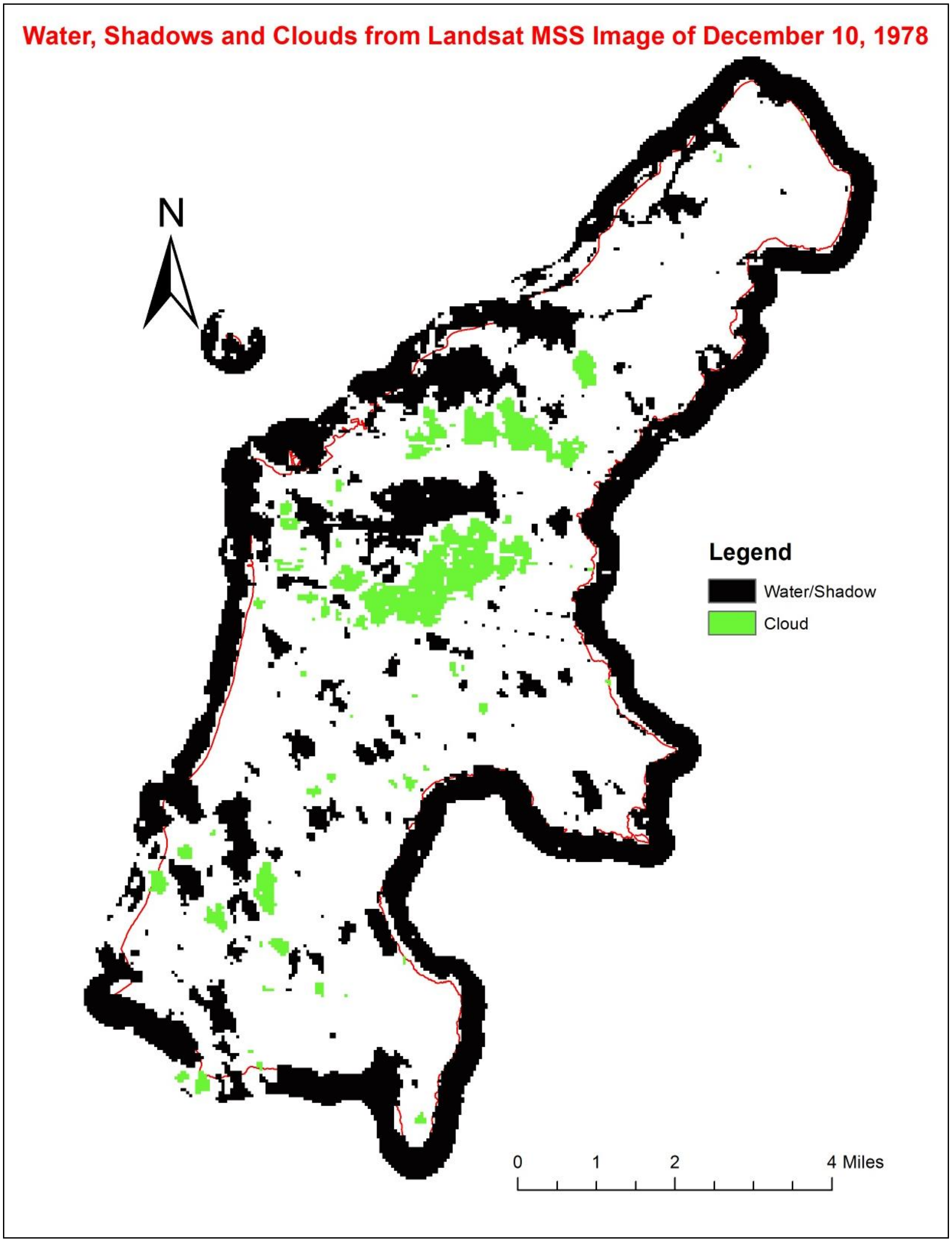

Figure 22. Water, Shadows and Clouds from Landsat Image of December 10, 1978

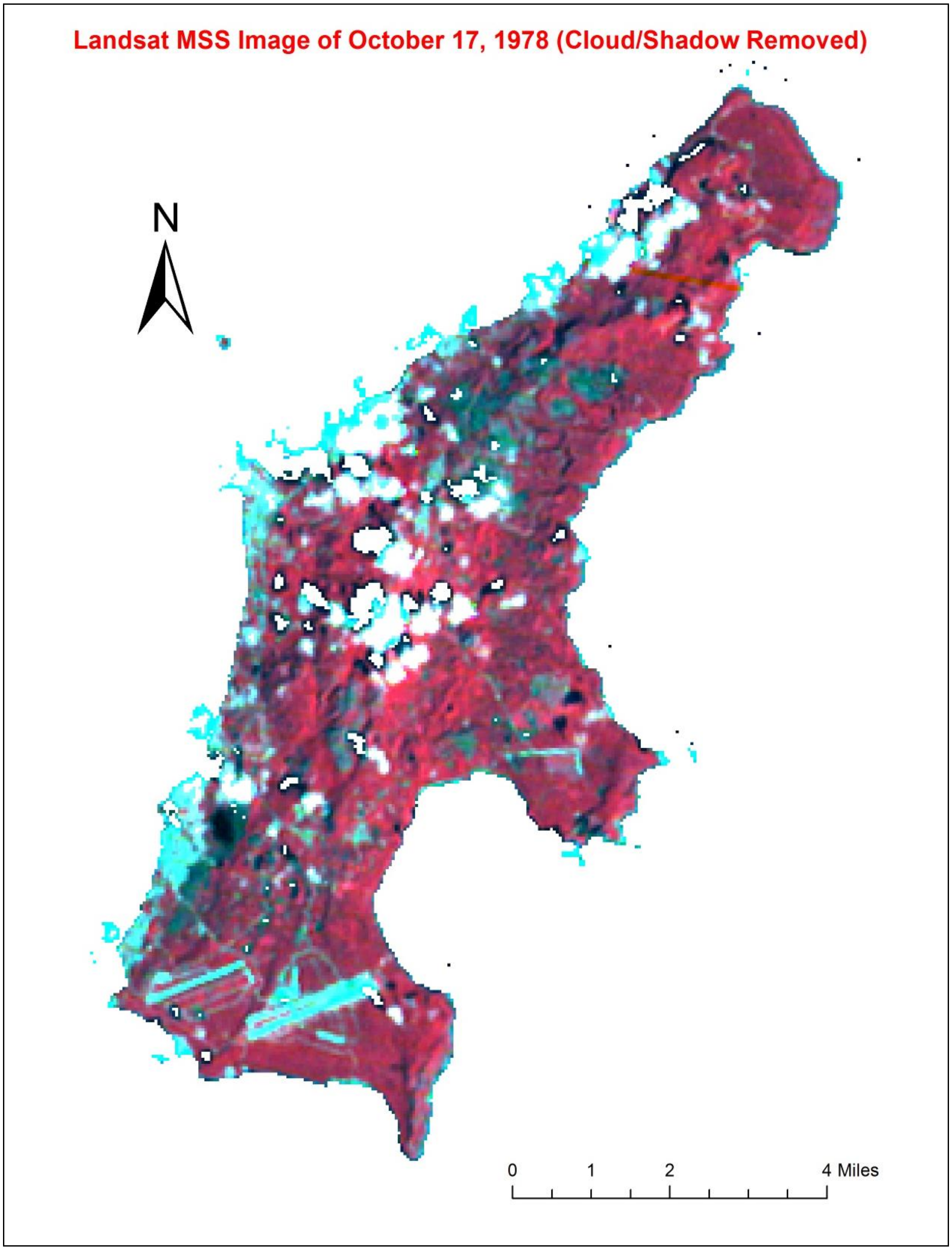

Figure 23. Landsat Image of October 17, 1978 with Water, Shadows and Clouds Removed

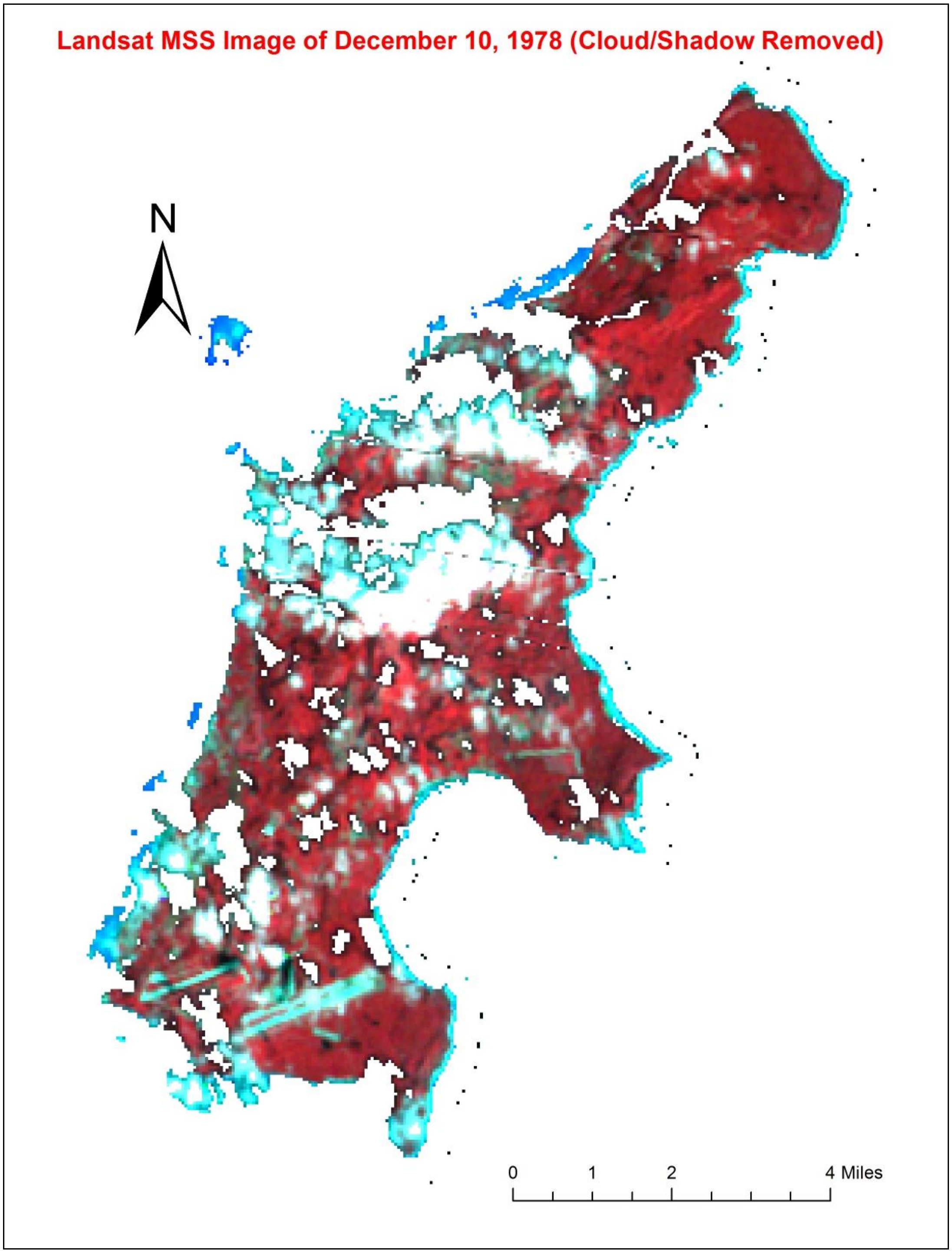

Figure 24. Landsat Image of December 10, 1978 with Water, Shadows and Clouds Removed

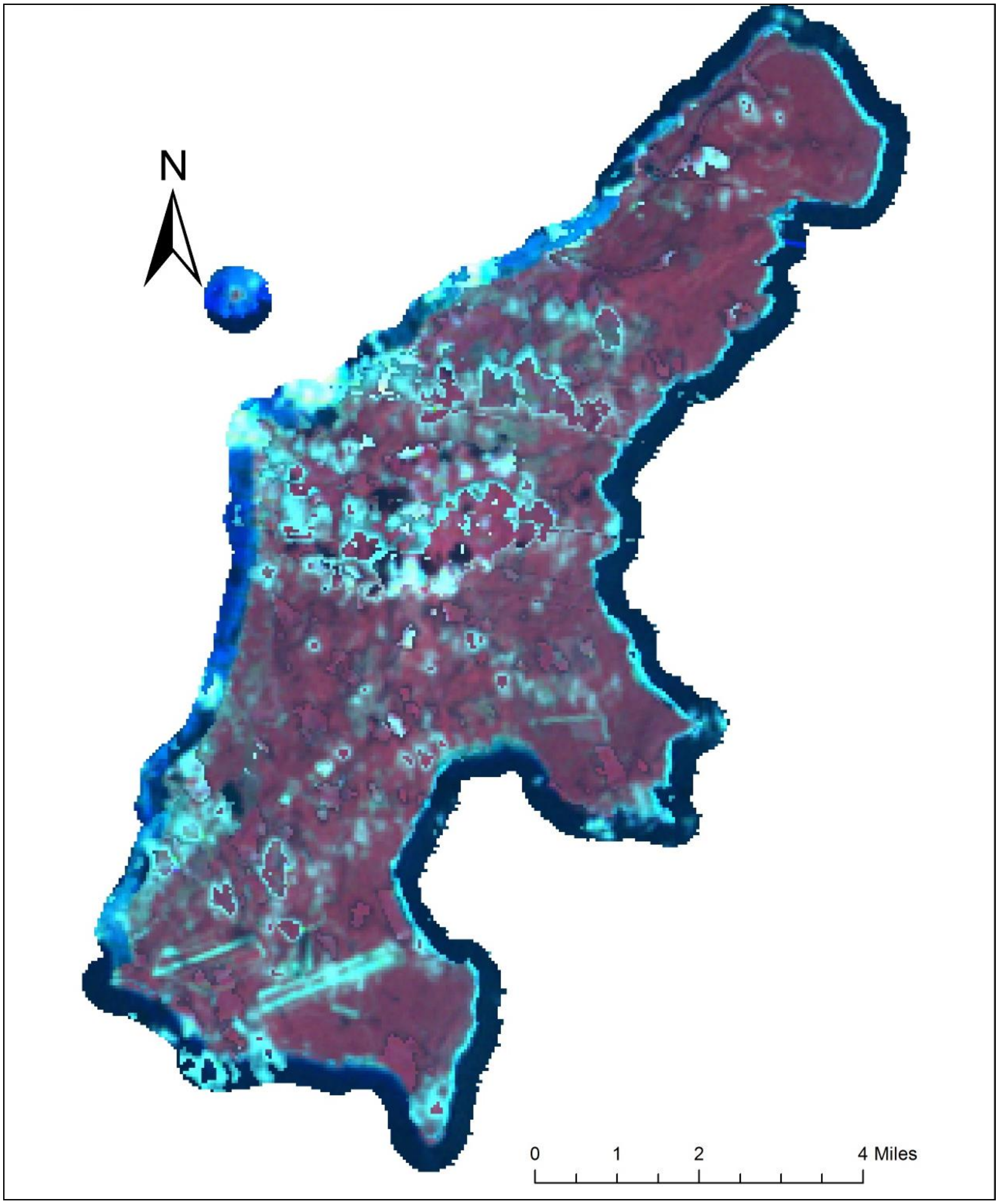

Figure 25. Landsat MSS image of October 17, 1978 was updated with Landsat MSS image of December 10, 1978 with clouds and shadows removed

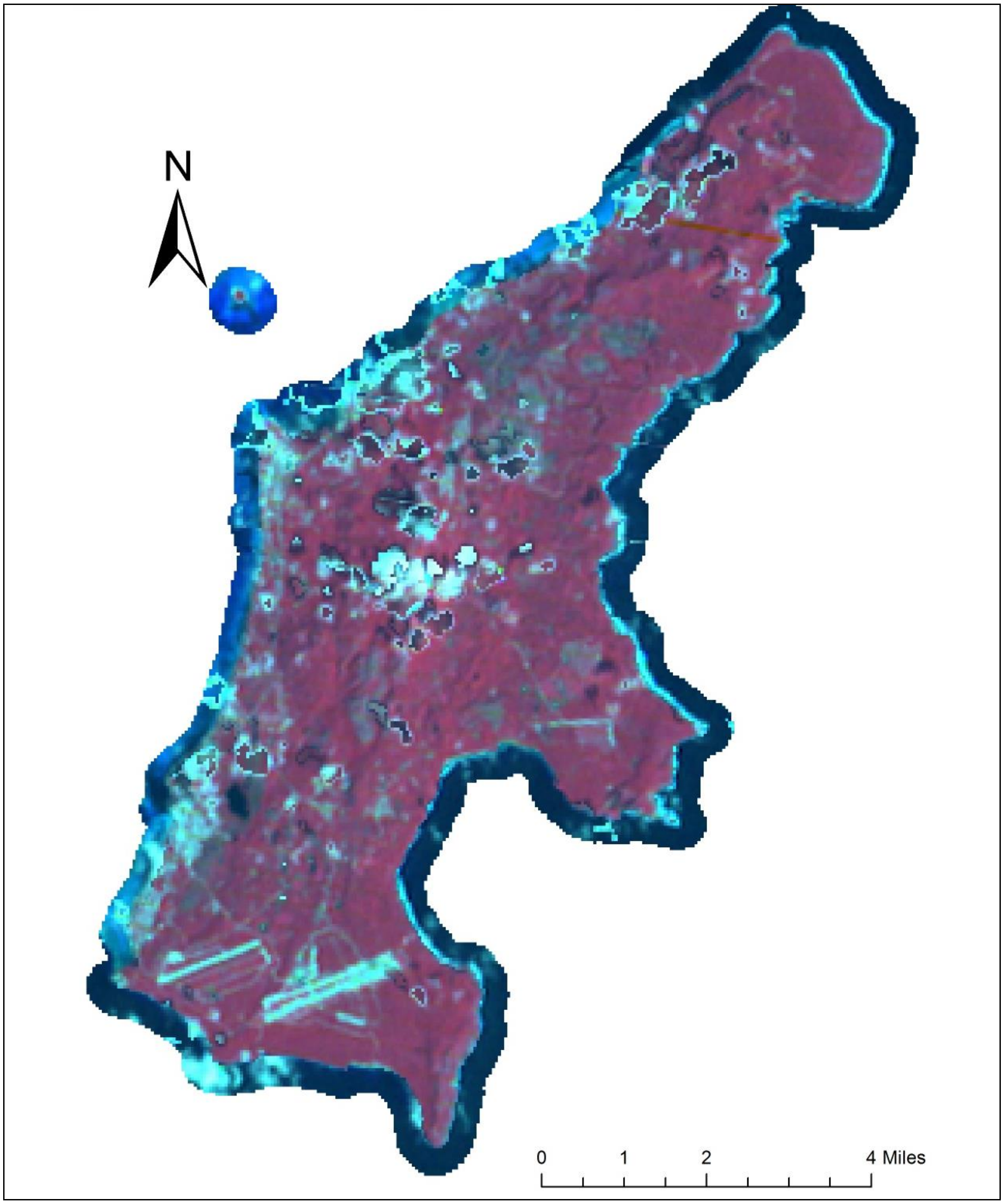

Figure 26. Landsat MSS image of December 10, 1978 was complemented with the Landsat MSS image of October 17, 1978 with clouds and shadows removed

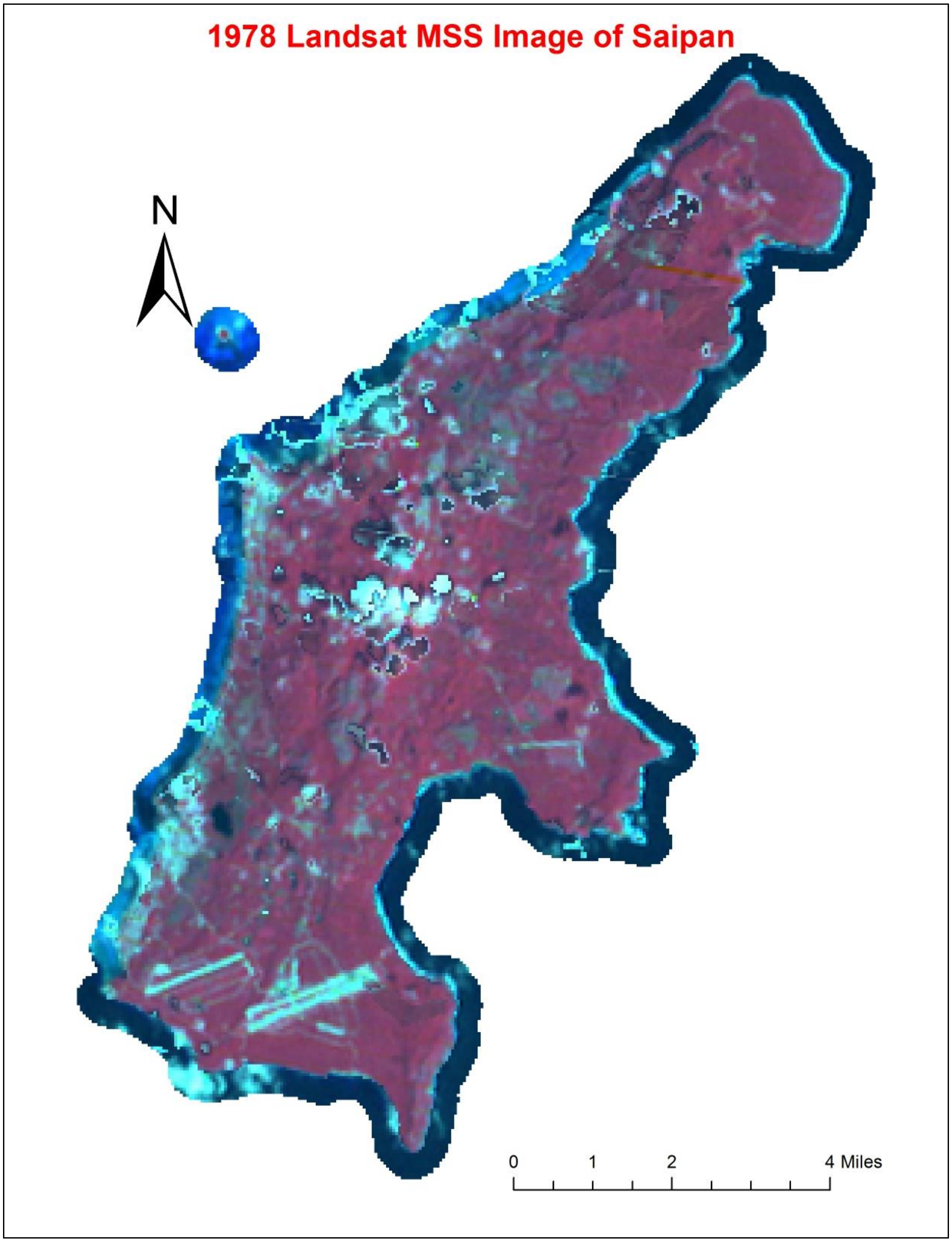

Figure 27. Landsat MSS Image of 1978

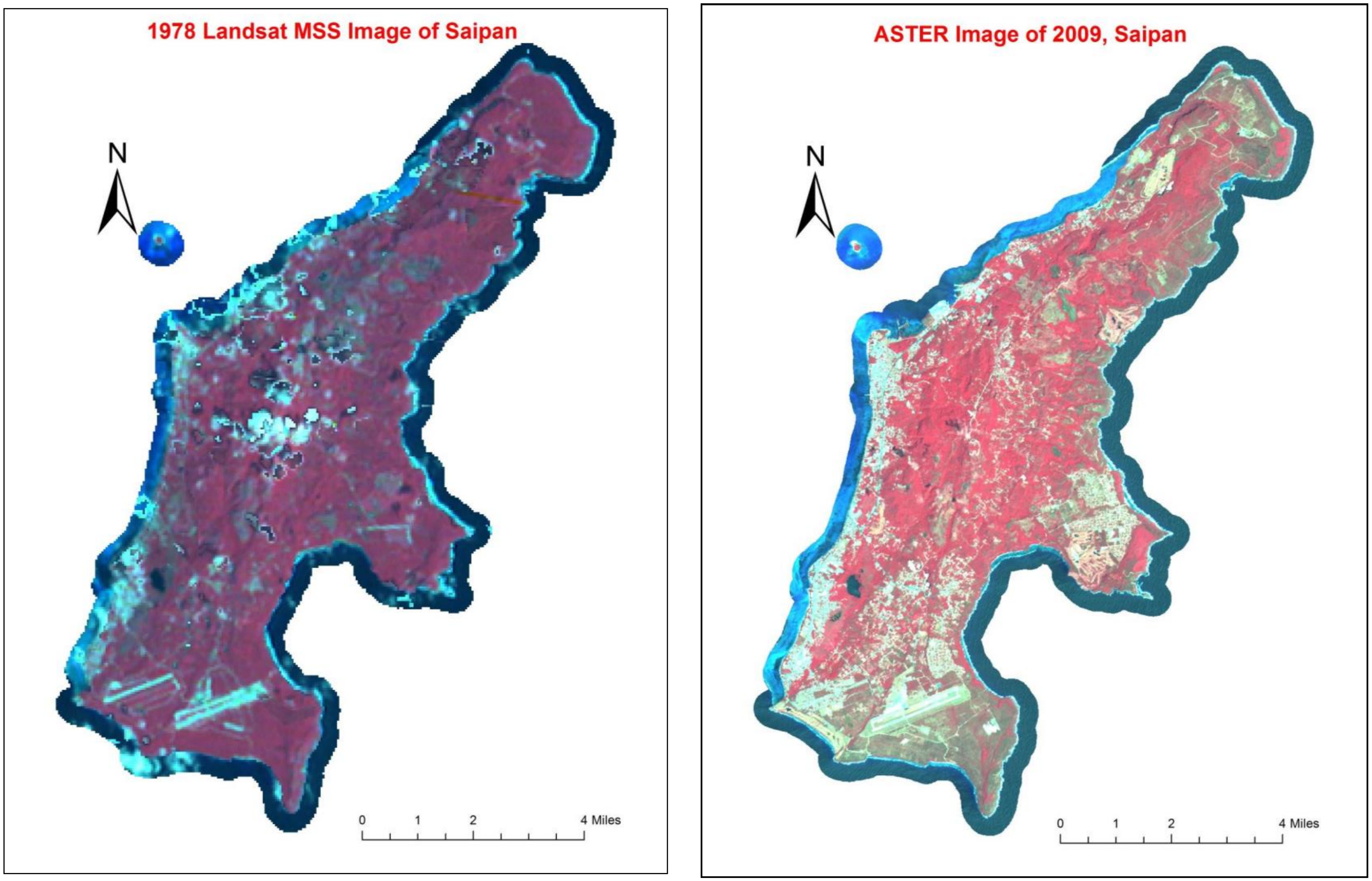

Figure 28. Landsat MSS Image of 1978 and ASTER Image of 2009

Methods

The GIS, remote sensing, and spatial analysis were utilized to obtain land cover information, and detect land cover changes. The GIS Lab at the Water and Environmental Research Institute (WERI), University of Guam is equipped with the state of the art workstations, a big size plotter, ERDAS Imagine and ArcGIS Desktop with extensions such as Spatial Analyst and Geostatistical Analyst. ArcGIS Desktop and ERDAS Imagine were the main tools used to process satellite images, and both of the software were applied to conduct land cover classification. When land cover information was derived from Landsat MSS image of 1978 and ASTER image of 2009, land cover change could be determined, and change patterns could be evaluated.

In order to determine land cover change in Saipan, two scenes of Landsat MSS images from different dates, i.e., October 17, 1978 and December 10, 1978 were applied to derive land cover information of 1978. Processing of the Landsat MSS images of 1978 was discussed in details in the previous section, Data Sources and Data Processing. Two scenes of ASTER satellite images of March 5, 2009 were obtained to extract land cover information of 2009. Integration of remote sensing, GIS and spatial analysis was the primary method applied to obtain land cover information from the satellite images of Landsat MSS and ASTER in the project. ArcGIS Desktop, particularly map algebra was utilized to measure the land cover changes in Saipan.

For this research, unsupervised and supervised classification methods were applied to derive land cover information for the available satellite images. It was very time consuming and difficult to extract land cover information from the Landsat MSS image of 1978 because of relatively low data quality, and coarse spatial resolution. This project focused on five general land cover classes, i.e., urban area, forest, water, grassland and cloud. Unsupervised classification method in ERDAS Imagine was employed to generate classes based on features on the Landsat MSS image. Based on the results from unsupervised classification, five general land cover classes were generated based on supervised classification based on the patterns, shapes, textures, tones and colors from the mosaicked Landsat MSS image of 1978. However, there were some errors found from the land cover information obtained from unsupervised and supervised classifications. The airstrip located in Kagman was missing. On-screen digitization in ArcGIS Desktop was used to delineate the airstrip in Kagman. Some parts of Saipan International Airport were misclassified. A subset image was created to cover the area of Saipan International Airport, and developed area in the airport was extracted based on a supervised classification of an unsupervised classification result. Then a further supervised classification was conducted to correct some misclassified classed from the results of unsupervised classification of Landsat MSS image of 1978. Since the land cover information was focused on the buffered study area, the boundary of the study area needed to be used to clip the classified land cover to the extent of the study area. The final land cover information of 1978 is shown in Figure 29.

The data quality of ASTER image of 2009 was very good. Five general land cover categories including forest, urban area, grassland, water and badland were used to extract land cover information from ASTER image of 2009. Unsupervised classification method in ERDAS

Imagine was used to derive land cover information from ASTER image of 2009. Then supervised classification was utilized to obtain five general land cover categories of forest, urban area, grassland, water and badland based on patterns, shapes, tones and textures of the image. The final step to achieve the land cover information of 2009 in Saipan was to clip the land cover information using the boundary of the study area (Figure 30).

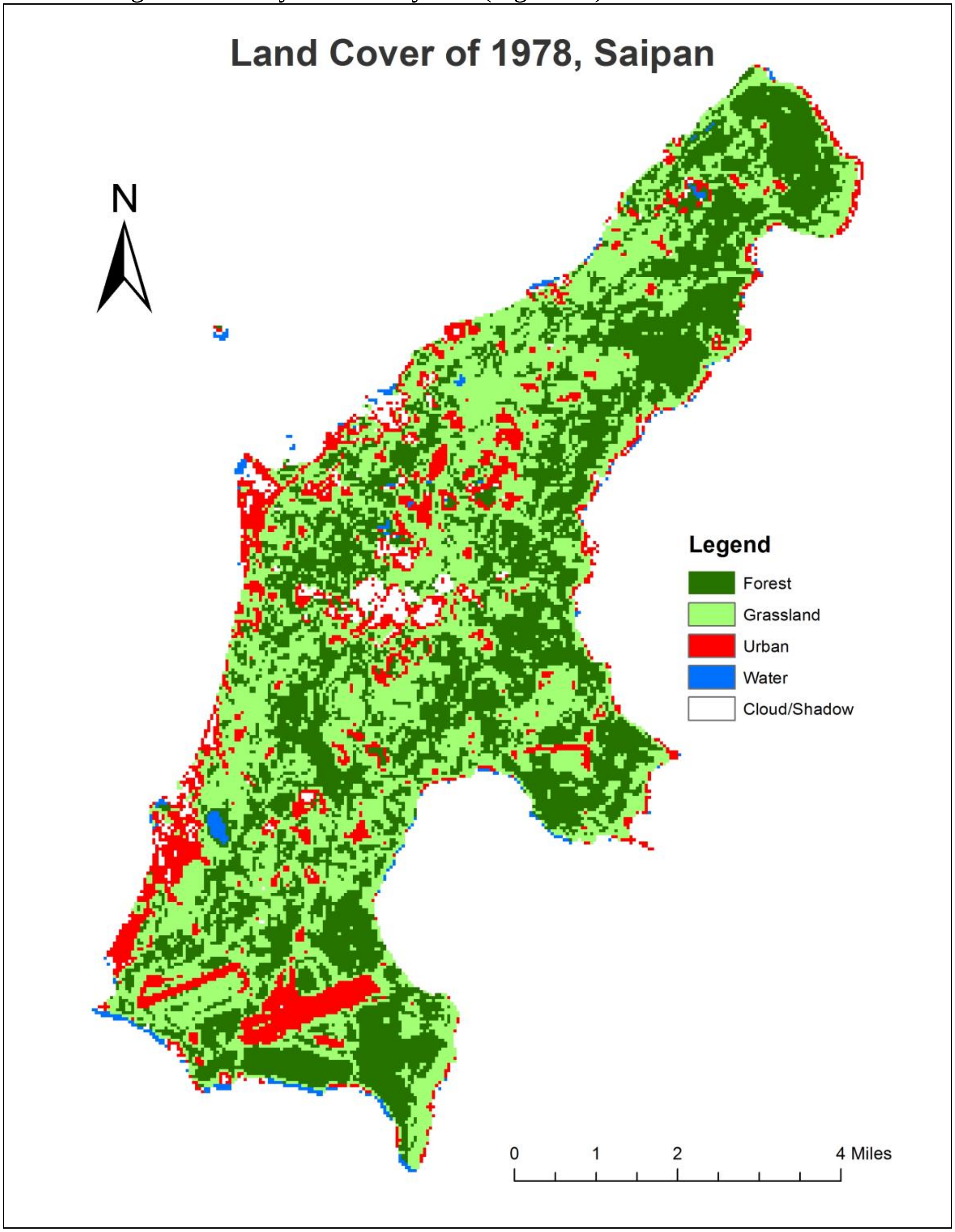

Figure 29. Land Cover Map of 1978

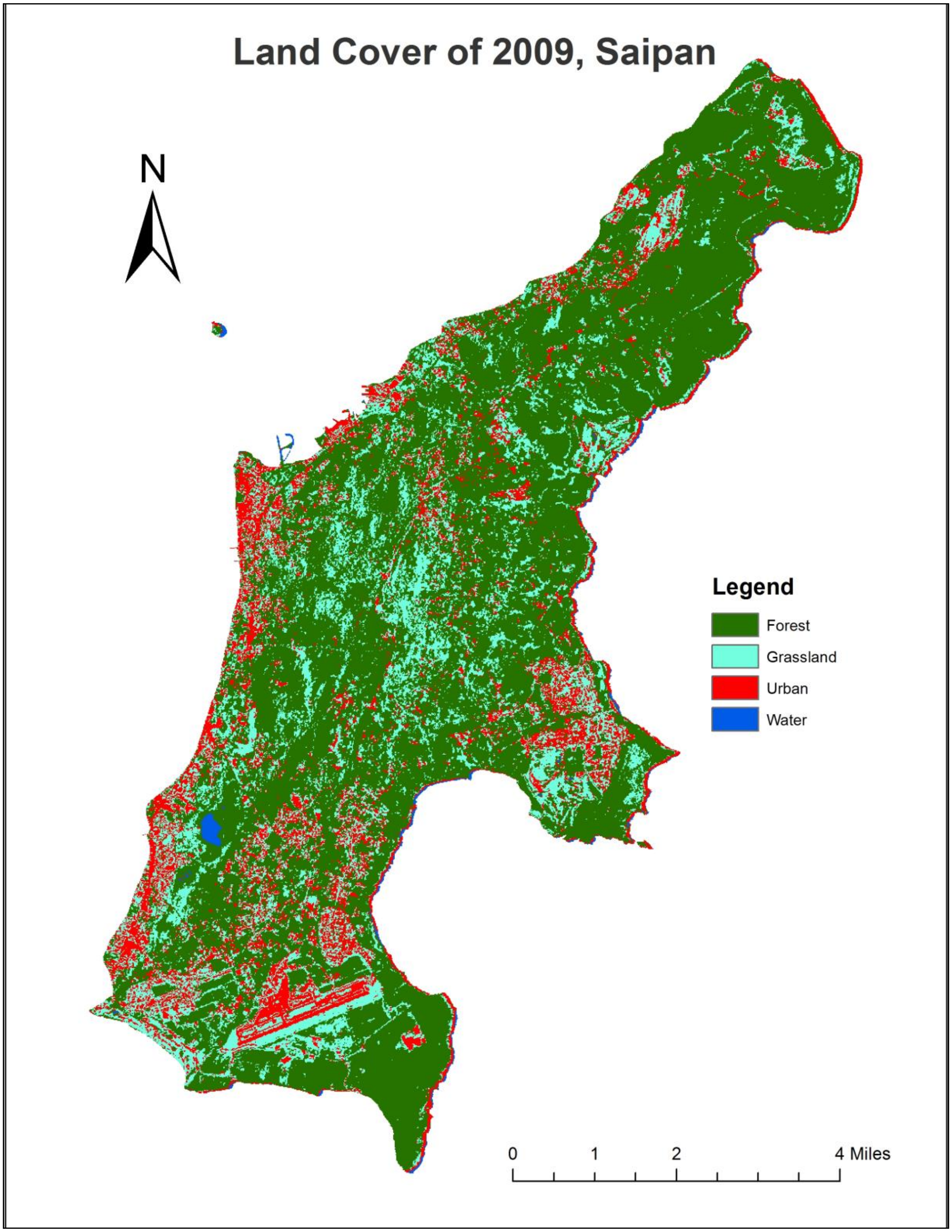

Figure 30. Land Cover Map of 2009

RESULTS and DISCUSSIONS

Landsat MSS images of October 17, 1978 and December 10, 1978 were used to derive land cover information of 1978 for Saipan. Two ASTER images of March 5, 2009 were applied to cover the whole island of Saipan, and employed to extract land cover information of 2009 for Saipan. The Landsat images, especially the Landsat MSS image of December 10, 1978 were covered by a lot of clouds and shadows. What's more, there were some displaced areas in the Landsat image of December 10, 1978. These Landsat images were also not aligned with the study area. Therefore, efforts needed to be invested to georeference the Landsat images, remove clouds and shadows, and deal with the displacement of some parts from the Landsat image of December 10, 1978. The ASTER image of 2009 did not have quality problems. However, they needed to be mosaicked to cover the island of Saipan.

The land cover information of 1978 for Saipan was derived from the Landsat MSS imagery of October 17 and December 10 of 1978. The land cover information of 2009 was derived from the ASTER L1B imagery of March 5 of 2009. Land cover maps of 1978 and 2009 in Saipan are listed in Figure 31 side by side for visual comparison. By comparison of the land cover data between 1978 and 2009, the following conclusions are made (Tables 1 and 2). Saipan was mainly covered by forest and grassland both in 1978 and 2009. The area of forest increased by about 2,923.4 hectares, or 60.88% from 1978 to 2009, and the area of grassland decreased by about 2,672.64 hectares or about 52.1% between 1978 and 2009. The built-up/urban area increased by about 165.6 hectares or 11.6% from 1978 to 2009, and most of the increased urban areas occurred in forest and grassland. Forest change from 1978 to 2009 is shown in Figure 32.

Information about land cover and land cover change in Saipan can be applied to determine land cover change in watersheds in Saipan. There are 11 watersheds in Saipan (Figure 33), and land cover maps of 1978 and 2009 in Kagman Watershed in the Southeastern Saipan are listed in Figure 34. The land cover change information indicated that many development activities occurred from 1978 to 2009 in Kagman Watershed (Tables 3 and 4). The urban area increased by about 106.9 hectares or more than doubles from 1978 to 2009, forest area increased by about 133.2 hectares or about 17.6%, and grassland decreased by about 233.3 hectares or about 38.2%.

Some pictures about the significant features of the Saipan environment were taken by a GPS camera. The geotagged pictures can be used as references to verify land cover information derived from satellite imagery (Figure 35). The land cover information can also be used to evaluate environmental concerns such as soil erosion, water quality and non-point source pollution. It can also be utilized to evaluate whether there is relationship between landscape change and climate change, and how land cover change affects watersheds, water quality and ecosystems in watersheds of Saipan. The findings and approaches from this research may be utilized to conduct research on land cover change detection in other islands affected by anthropogenic activities, and impacts of human induced activities, and/or land cover and land use change on environmental and landscape change in such islands.

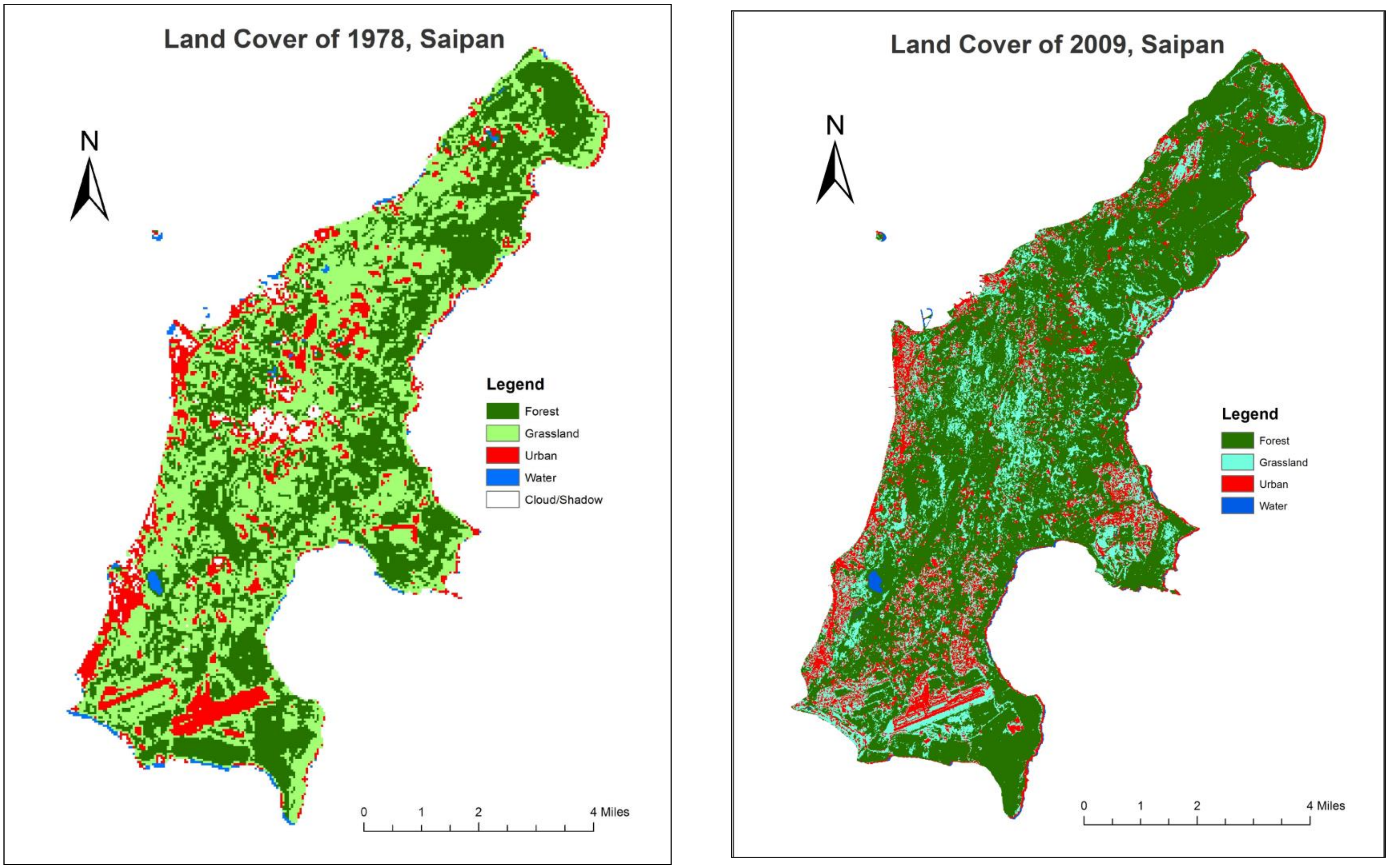

Figure 31. Land cover information of 1978 and 2009

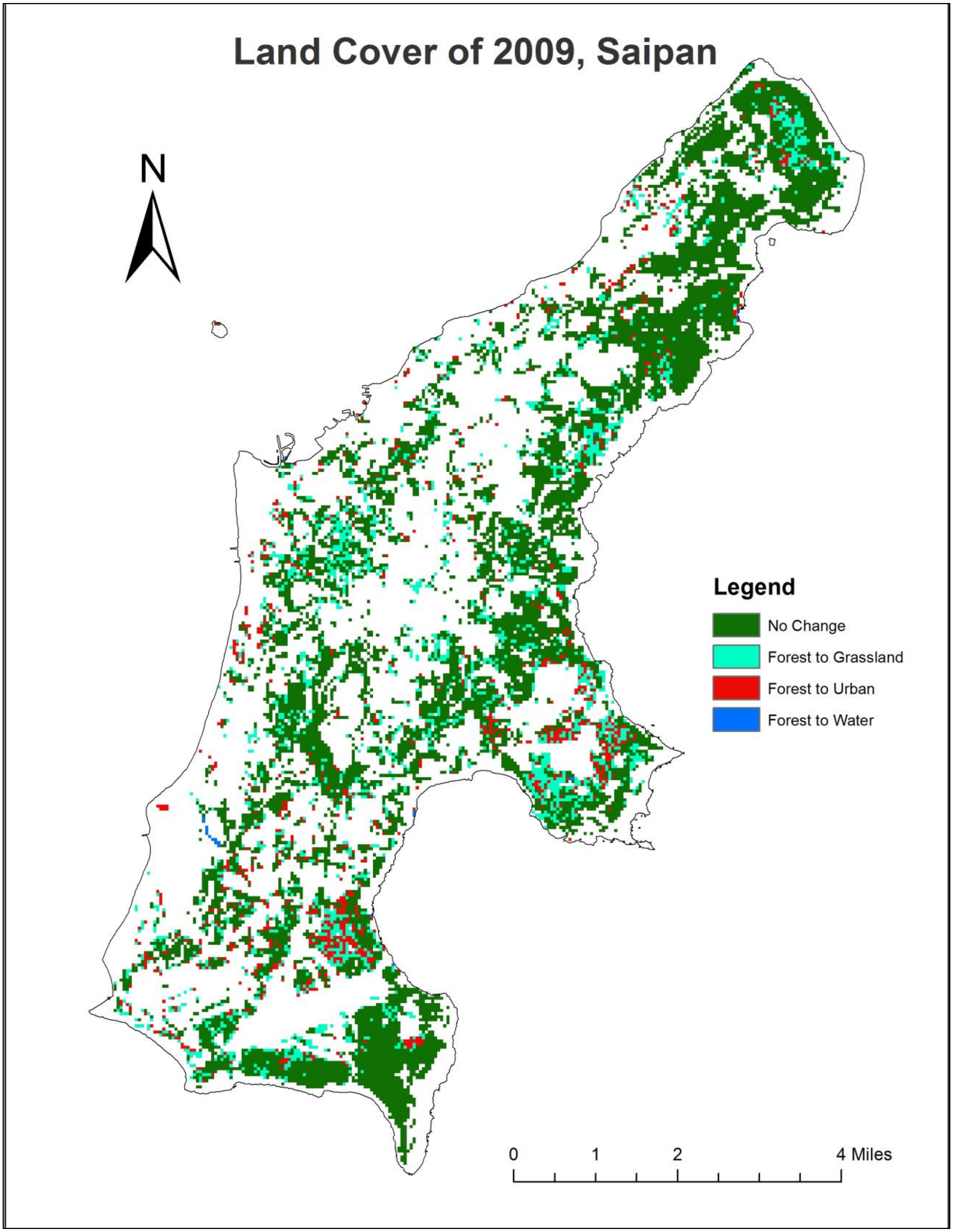

Figure 32. Forest change from 1978 to 2009 in Saipan

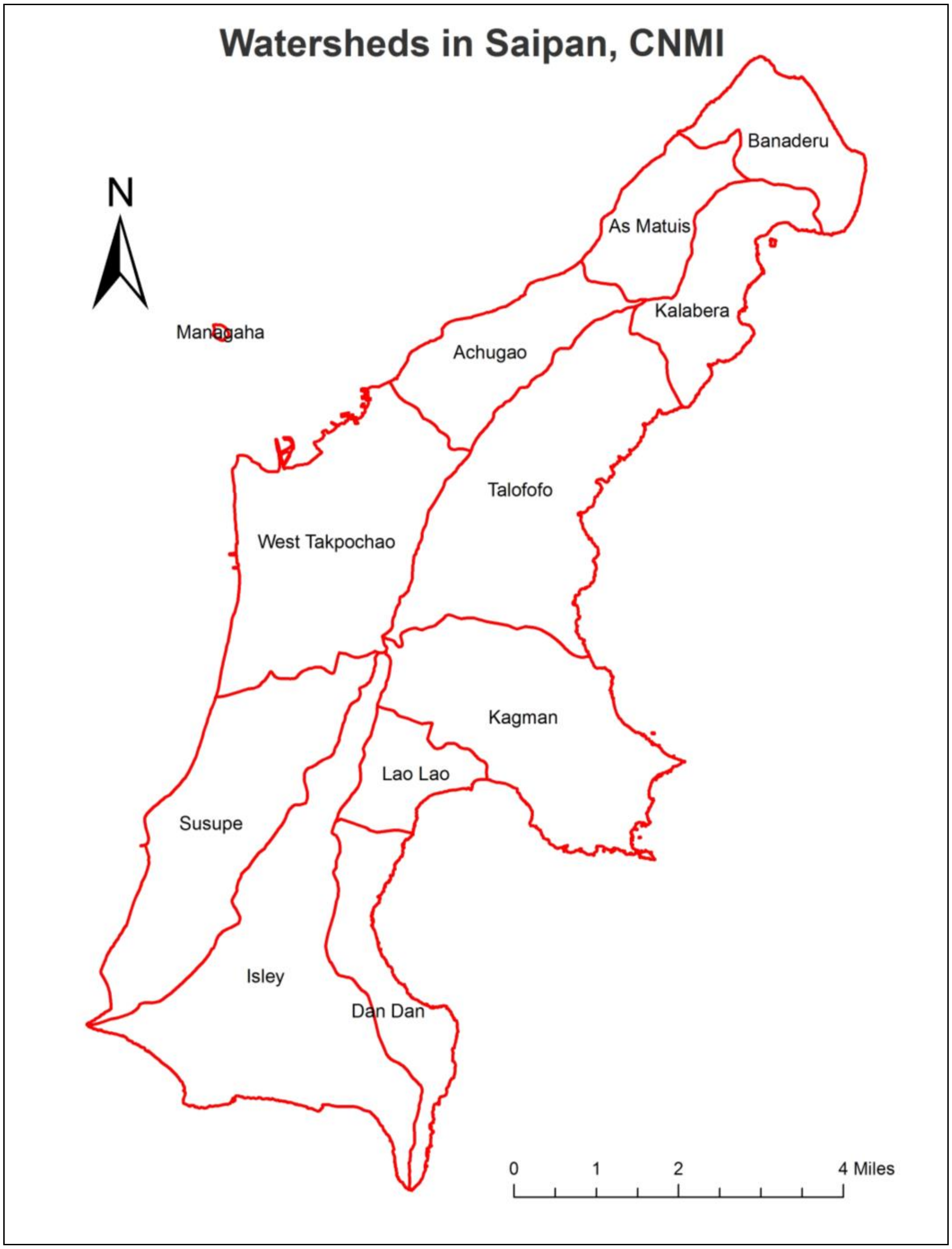

Figure 33. Watersheds in Saipan

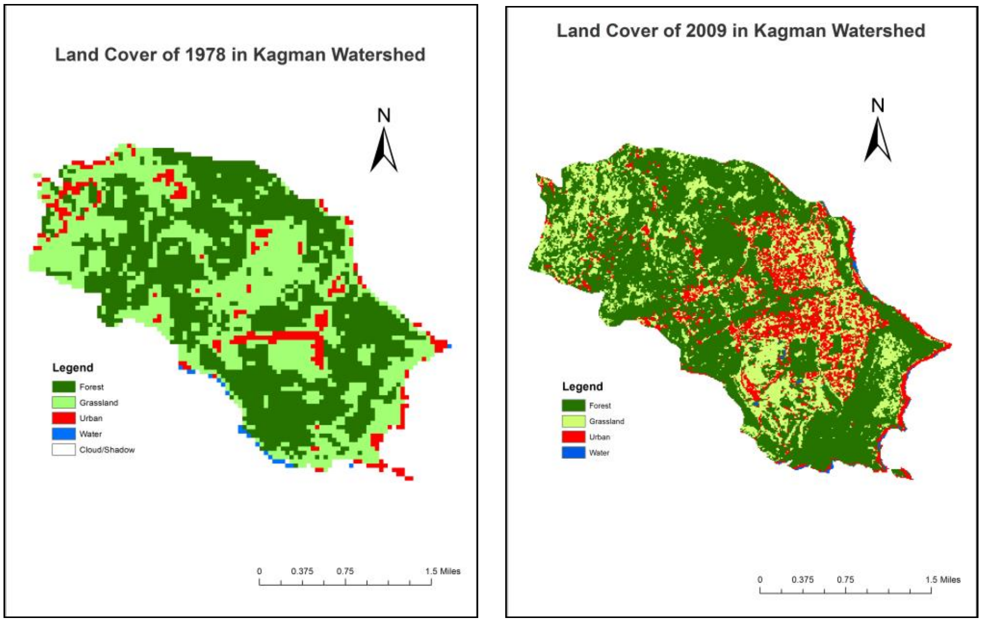

Figure 34. Land cover information of 1978 and 2009 in Kagman Watershed, Saipan

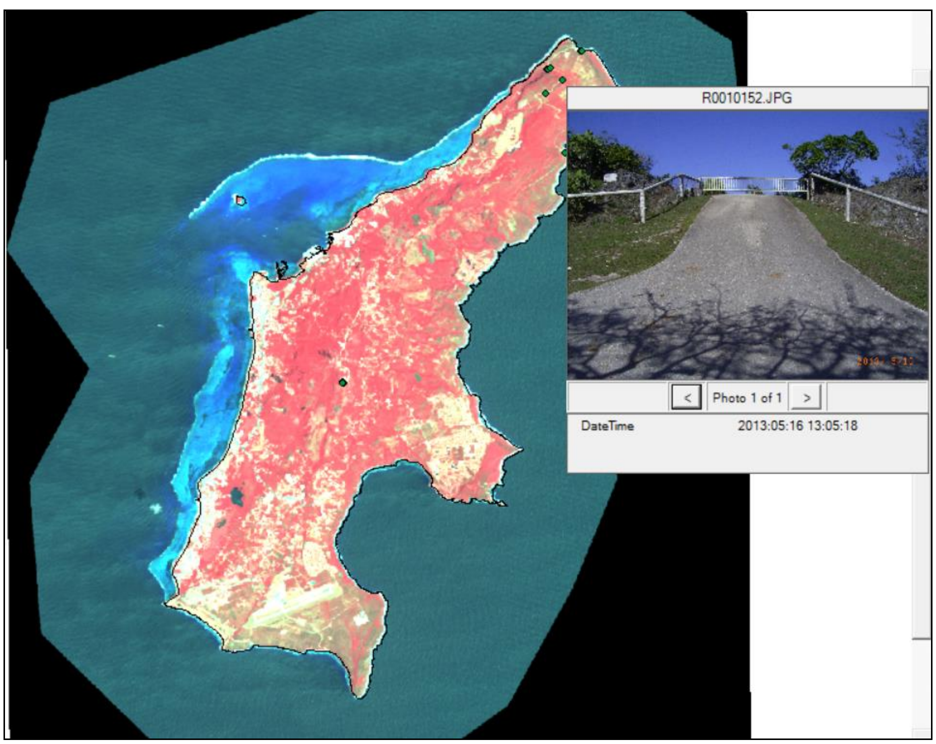

Figure 35. Geotagged picture showing features in the study area.

Table 1. Overall land cover change from 1978 to 2009 (Unit: Hectare)

1978 \ 2009	Forest	Grassland	Urban	Water	Total
Forest	3584.88	844.92	390.60	7.56	4827.96
Grassland	3412.80	1051.92	648.36	14.04	5127.12
Urban	554.40	423.00	433.80	13.68	1424.88
Water	52.20	20.16	25.92	25.20	123.48
Cloud	163.08	114.48	91.80	8.64	378.00
Total	7767.36	2454.48	1590.48	69.12	11881.44

Table 2. Overall land cover percentage change from 1978 to 2009 (Unit: %)

1978 \ 2009	Forest	Grassland	Urban	Water	Total
Forest	74.25	17.50	8.09	0.16	40.63
Grassland	66.56	20.52	12.65	0.27	43.15
Urban	38.91	29.69	30.44	0.96	11.99
Water	42.27	16.33	20.99	20.41	1.04
Cloud	43.14	30.29	24.29	2.29	3.18
Total	65.37	20.66	13.39	0.58	100.00

Table 3. Land cover change from 1978 to 2009 in Kagman Watershed (Unit: Hectare)

1978 \ 2009	Forest	Grassland	Urban	Water	Total
Forest	467.28	194.76	93.60	0	755.64
Grassland	370.44	155.88	84.60	0	610.92
Urban	46.08	26.28	23.04	0.36	95.76
Water	2.16	0.36	0.36	1.44	4.32
Cloud	2.88	0.36	1.08	0	4.32
Total	888.84	377.64	202.68	1.80	1,470.96

Table 4. Land cover percentage change from 1978 to 2009 in Kagman Watershed (Unit:%)

1978 \ 2009	Forest	Grassland	Urban	Water	Total
Forest	61.84	25.77	12.39	0	51.37
Grassland	60.64	25.52	13.85	0	41.53
Urban	48.12	27.44	24.06	0.38	6.51
Water	50.00	8.33	8.33	33.33	0.29
Cloud	66.67	8.33	25.00	0	0.29
Total	60.43	25.67	13.78	0.12	100.00

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