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# Impact assessment of road development on forest cover in the Upper Marikina Watershed, Philippines

**Tricia Joy E. Castañeda[1*], Diomedes A. Racelis[1]**

[1]*College of Forestry and Natural Resources, University of the Philippines Los Baños, College, Laguna, Philippines*

**ABSTRACT.** Most watersheds in the Philippines are already in critical condition. One of which is the Upper Marikina Watershed (UMW), where forest cover has dwindled significantly due to land conversion as well as land use and land cover change. Road networks are being developed as a means of access and transportation to land-converted areas. However, roads are a major driver of deforestation and degradation. Therefore, this study assessed the impacts of road development on forest cover in the UMW. Specifically, it determined the extent of the road network in the watershed; described the extent of forest cover in the watershed in 2005, 2010, 2015, and 2020; analyzed changes in the forest cover of the watershed through time; and established the relationship between road network development and the changes in forest cover in the watershed. Shapefiles from the National Mapping and Resource Information Authority (NAMRIA) and 2020 Landsat 8 satellite images were used to generate 2005, 2010, and 2015 land cover maps to detect changes over time. The Landsat 8 satellite image was processed for image pre-processing, cloud masking, sub-setting, image classification, and accuracy assessment through remote sensing using the QGIS software and the Semi-Automatic Classification Plugin. The data on the forest cover of the site through 2005, 2010, 2015, and 2020 were analyzed through Change Detection Analysis. This analysis was used in correlation with the existing road network within the watershed. The findings revealed a significant decrease in forest cover in the UMW between 2005 and 2020. All these changes in forest cover due to further land conversion in the area create opportunities for road network development and expansion, which are inversely correlated with forest changes.

**Keywords:** GIS, image classification, landsat satellite image, remote sensing, semi-automatic classification plugin

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*Email: tecastaneda@up.edu.ph

## INTRODUCTION

A watershed is a land area drained by a stream or fixed body of water and its tributaries having a common outlet for surface run-off (DENR, 2017). It is a functional and integrated system that provides goods and services, such as food, water, medicine, fibers, timber, and non-timber products, vital to the welfare and security of local communities.

Watersheds of various sizes are estimated to cover at least 70% of the total land area of the Philippines. Watersheds with an area of at least 100,000 ha, known as river basins, account for more than 10 M ha of the watershed area. Watershed reserves have been designated for various purposes, such as domestic water supply, irrigation, hydroelectric power generation, and multiple uses. Watersheds are valuable not only for their water resources but also for the forests and other natural resources. Watershed management is thus critical in promoting the sustainability of all-natural resources in the watersheds (DENR, 2015). Most watersheds in the Philippines are already in critical condition. Degraded forests, soil erosion, erratic streamflow, declining groundwater resource, loss of biodiversity, microclimate deterioration, and declining land productivity characterize many of the country's watersheds. Deforestation contributes significantly to the degradation of nearly 2.6 M ha of the country's identified critical watershed areas (Paragas *et al*., n.d.).

Moreover, most watersheds in the Philippines are under threat due to increasing economic activities associated with the growing population. Destructive activities such as land conversion, agricultural expansion, and road development lead to deforestation and forest degradation in the upstream portion of the watershed, which causes water pollution, mudslides, landslides, soil erosion, and flooding in the downstream areas.

Forest cover in the Philippines has drastically decreased over the past decades. About 1.2 M ha of tree cover with a 30% threshold was lost from 2001 to 2020, or an annual loss of 79,534 ha. According to the 2020 Philippine Forestry Statistics, about 15 M ha or 52.68% of the country's total land area is classified as forestland.

The Upper Marikina River Basin Protected Landscape (UMRBPL) is a protected area in the Philippines that constitute the UMW and was established in 2001 by Presidential Proclamation 296 and covers a total land area of 26,126 ha. Antipolo City, Baras, General Nakar, Rodriguez, San Mateo, and Tanay are among the six local government units that benefit from the natural resources in this area. Antipolo (Artocarpus blancoi), Red Lauan (Shorea negrosensis), Yakal (Shorea astylosa, Luzon Bleeding Heart (Gallicolumba luzonica), Rufous Hornbill (Buceros hydrocorax), and Northern Luzon Cloud Rat (Phloeomys pallidus) are all found in this watershed, which is an important front line for biodiversity conservation (DENR, 2015).

Illegal tree cutting, slash-and-burn farming, unsustainable fuel-wood collection, residential and commercial expansion, and forest fires contribute to the UMW's forest and habitat degradation (DENR, 2015). The forest cover in the Marikina Watershed has also dwindled significantly due to land conversion, land use, and land cover change (Abino *et al.*, 2015).

Forest roads are built to improve access to forest areas to support forest management, resource extraction and travel, firefighting, material transit, tourism, national defense, and building renewable energy installations in distant places. However, forest roads are acknowledged to alter the hydrologic response of watersheds (Kastridis, 2020).

The study of Forman & Alexander (1998) and Leonard & Hochuli (2017) found that roads have a wide range of ecological impacts, including habitat destruction, changes in animal behavior, and higher wildlife mortality, and that the result of the rapid proliferation of roads and other infrastructure as mentioned in the study of Laurance *et al.* (2017) was in Africa's tropical forests undergoing unprecedented changes. Furthermore, Poor *et al.* (2019) found that improved forest access along the forest boundary in an endemic ecosystem in Sumatra, Indonesia was attributed to roads, which are a major driver of deforestation and degradation. Unofficial roads go unreported and unrecorded in many tropical areas, leading to inaccurate estimations of wooded areas. The findings of this study indicate that roads and their consequences pose a significant threat to the endemic ecosystem in Sumatra, Indonesia.

Due to the significant decrease of forest cover in UMW, communities in the lowland areas of the watershed are experiencing the negative impacts of forest cover loss as caused by the unregulated exploitation, change of land use, and land conversion in the forests of these watersheds. The increasing population in this area is one factor in the continuous land conversion of these forested areas erasing 47,000 ha of forests yearly

(Yan, 2020). Population growth affects land-use change and patterns (NRC, 1993). Conversion of lands and changing land use addresses the rising demand of an increasing population by establishing industries and infrastructure, *e.g.*, transportation and road development systems, to meet the population's needs.

Due to continued land use change and land conversions in the UMW, road networks have been developed to increase access and facilitate transportation to the area. As a result, the road networks have expanded in tandem with further land conversion within the watershed.

Therefore, this study assessed the impact of road development on forest cover in the UMW by determining the extent of the road network in the watershed in 2005 and 2020, determining the forest cover in the watershed in 2005, 2010, 2015, and 2020, analyzing the changes in the forest cover of the watershed through time, and establishing the relationship between road network development and the changes in forest cover in the UMW.

Addressing one of the existing environmental problems in the country will require determining its causes and impacts. Knowing the causes of forest cover decrease and its impact on the environment and community will help determine how to manage and address this problem properly. The establishment of the relationship between road network development and forest cover will help as a guide in addressing the decreasing forest cover problems in the country. Describing the impacts of the road network developments and establishing their relationship to the forest cover will aid in providing the best solution for managing the watershed in terms of crafting policies on land-use change and conversion, proper utilization of forest resources, and strengthening existing policies.

## METHODOLOGY

This study focused on establishing the relationship between road development and forest cover in the UMW by generating road network and land cover maps of the watershed in different years (2005, 2010, 2015, and 2020).

### Study site

The UMW covers 27,952 ha through the municipalities of Antipolo, Baras, Rodriguez, San Mateo, and Tanay (Olchondra, 2012) (**Figure 1**). The Marikina River is dammed in Rodriguez by Wawa Dam, a structure built in the early 1900s to provide water for Manila. It flows approximately 11 km through the center of the province. It has several tributaries in creeks and rivers, draining four municipalities and one city in the province of Rizal, as well as three cities in the National Capital Region (NCR), the largest of which is upstream in the more mountainous areas of Rodriguez. The Tayabasan and Montalban, the Boso Boso River, and the Wawa Rivers, which meet the Marikina River just upstream of Wawa Dam, are included. The Puray and Manga Rivers are located downstream of the dam but within Rodriguez (David & Pellejera, 2011).

The UMRBPL is a protected area in the Rizal Province that encompasses the UMW. "Marikina Watershed" is sometimes used to refer to this protected area. However, it also refers to the river's entire drainage basin, stretching from Rizal Province's Sierra Madre Mountains to Pasig's Napindan area, emptying into the Pasig River. The Marikina Watershed Reservation was the name of the UMRBPL until November 2011, when President Benigno S. Aquino III upgraded its status from "reservation" to "protected landscape."

### Data collection

This study utilized the shapefiles provided by the National Mapping and Resource Information Authority (NAMRIA) and the satellite image from the United States Geological Survey (USGS). The shapefile obtained from NAMRIA including the road centerline shapefile was used to define the extent of road network development within the study site, along with the varying land cover classes of the study site in 2003, 2010, and 2015, as well as the satellite image extracted from the Earth Explorer USGS for 2020. Furthermore, this study used the 2004 road network data from the Department of Environment and Natural

Resources (DENR) as the benchmark for 2005 and the 2018 road network data from the NAMRIA as the benchmark for 2020 in determining the trend of forest cover change over time. The 2003 land cover shape file was the benchmark for 2005 to establish a 5-year gap within periods.

### Data processing

The shapefiles from NAMRIA and DENR were processed in QGIS version 3.16.15 to generate the land cover map for 2005, 2010, and 2015 and the road network map for 2005 and 2020. The extent of each class per year was identified and compiled for documentation. The 2020 satellite image acquired was processed and classified through remote sensing using the QGIS software and the Semi-Automatic Classification Plugin (SCP).

### Image pre-processing

The satellite image was calibrated using radiometric correction techniques from the SCP plugin in QGIS. The satellite image that was remotely sensed was delivered as calibrated Digital Numbers (D.N.), and the conversion to Top of Atmosphere (TOA) reflectance and brightness temperature was performed. The natural color was the band combination used for the Landsat 8 satellite image. It was generated by matching the corresponding wavelength of the bands to the colors of band rendering – red, green, and blue to bands 4, bands 3, and bands 2, respectively.

### Cloud masking and sub-setting

Cloud masking was done to remove the existence of clouds in the satellite image scene through the SCP plugin. The image was reclassified to determine and extract the clouds. Stitching the clouded areas on the satellite image was done using the same pre-processed Landsat image classification dated January 2020. Because the

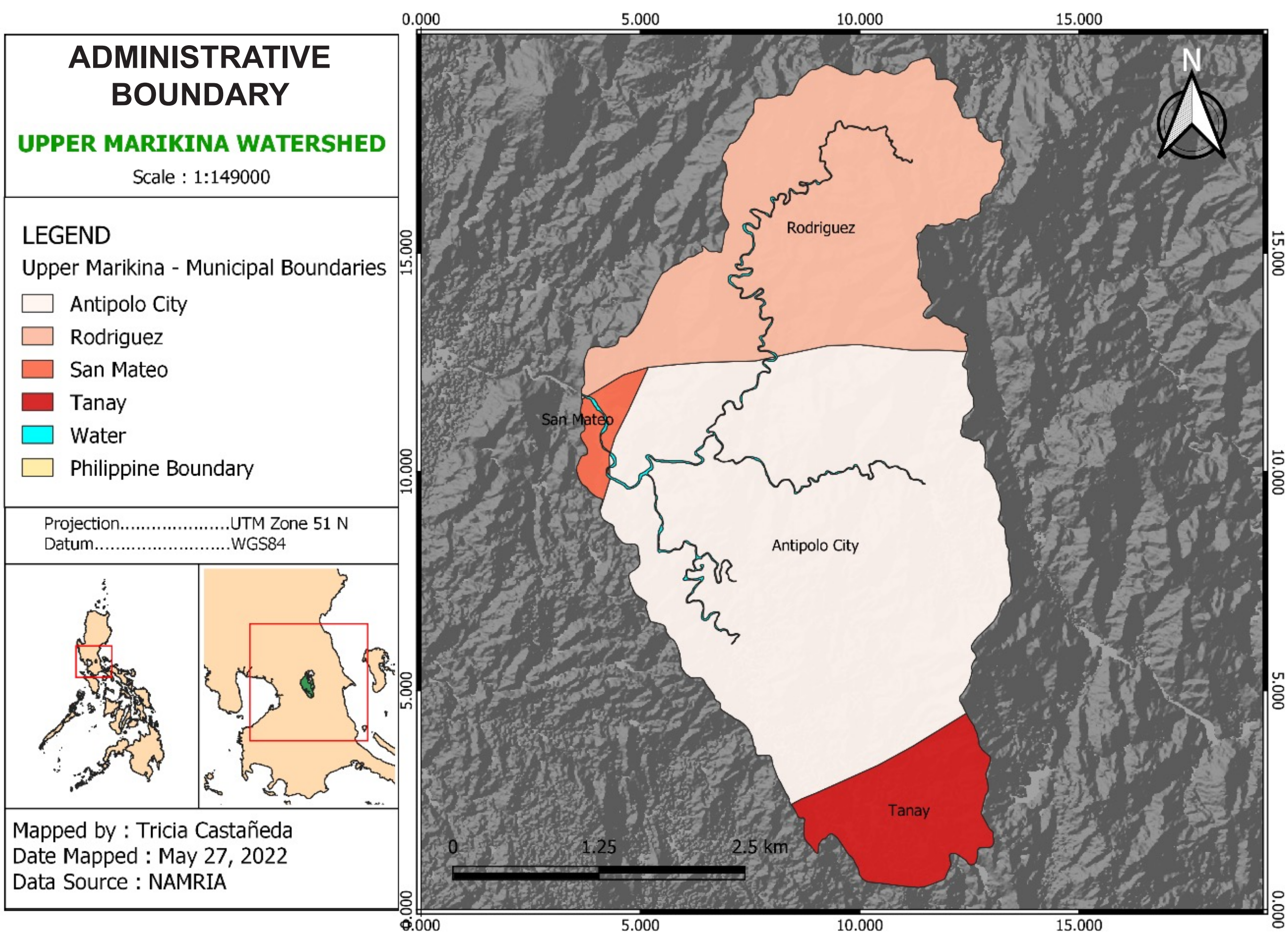


**Figure 1.** Administrative boundary map of Upper Marikina Watershed.

Landsat scenes are much larger than the study area, the images were cropped or subset to include only the area of interest, the UMW. The clip multiple raster tool of the SCP plugin was used in clipping the site's boundary on the pre-processed satellite image scene. As a result, unrelated data was removed, and processing was sped up due to the smaller data. Spectral indices using the individual pre-processed bands of the Landsat 8 satellite image were generated using the band calculator. The Normalized Difference Vegetation Index (NDVI) was generated to highlight the greenness of the area.

### Image classificatio

Image classification was performed to locate homogeneous pixel data in the remotely sensed image. These pixels were classified according to their land cover/land use. The supervised classification method of image classification was used in this study. The pre-processed image was supervised and classified to produce the various land cover categories in the study area. The band combination of the pre-processed satellite image was set to its natural color. Color composites helped identify features in creating Region of Interests (ROI) representing the classified land cover type. Training inputs were generated for sample pixels to represent the land cover class. This study used five training sets, including at least 20 ROIs in each set, as shown in **Table 2**. Supervised classification was used to group pixels in a dataset into classes corresponding to user-defined training classes based on common characteristics. After generating the training inputs, the minimum distance classification algorithm was used for the image classification process. For this algorithm, no threshold was used. This algorithm was used as it generated a better result than the maximum likelihood and spectral angle algorithm.

### Accuracy assessment

Any classification project must include an accuracy assessment. It compares the classified image to data from another source considered accurate or ground truth (ESRI, 2021). The most common method for determining a classified map's accuracy is to generate a set of random points from the ground truth data and compare them to the classified data in a confusion matrix. The creation of a confusion matrix for the classified image was done for this study to demonstrate the accuracy of classification by comparing the results to the ground. Using ground truth ROIs, the confusion matrix was calculated using the SCP plugin. Overall accuracy and kappa coefficient values were reported.

Thirty-nine points or locations in the bounds of the study area in ESRI were identified that served as the ground truth or the reference data matched on the classified satellite image to create the confusion matrix. These ground points were generated as 30% representative of the total ROIs used to classify the satellite image.

**Table 2.** Number of the region of interests (ROIs) or training inputs used per land cover class.

| Land cover | No. of training input |
|---|---|
| Forests | 45 |
| Built-up areas | 25 |
| Croplands | 25 |
| Water | 10 |
| Grassland | 20 |
| Total | 125 |

**Table 3.** Number of ground points used per class.

| Land cover | No. of ground points |
|---|---|
| Forests | 14 |
| Built-up areas | 8 |
| Croplands | 8 |
| Water | 3 |
| Grassland | 6 |
| Total | 39 |

### Data analysis

Forest cover data of the site through 2005, 2010, 2015, and 2020 were analyzed through change detection analysis. This analysis of the forest cover extent through time was used in correlation to the road network development within the watershed from 2005 to 2020. The graphical analysis helped assess the impacts of road network development on the extent of forest cover in the UMW over time.

### Change detection analysis

The classified satellite images were used under the Minimum Distance algorithm. The change detection analysis SCP tool provided a simple approach to measuring changes between two classes representing an initial and final state. In this study, 2010 and 2015 were considered initial and final states, whereas 2015 and 2020 were considered the initial and final states, respectively. Three table outputs for change detection resulted from three pairings: 2005 (initial) and 2010 (final), 2010 (initial) and 2015 (final), and 2015 (initial) and 2020. (final). A detailed analysis of the changes in the classified image was performed. The areas were calculated using the land cover classes in different years that were generalized and unified into five main land cover classes identified: forests, built areas, croplands, water, and grasslands.

## RESULTS AND DISCUSSION

Road networks in Upper Marikina Watershed

One of the specific objectives of this study is to determine the extent of the road network within the UMW and establish its relationship to the forest cover condition within the watershed through time. **Figure 2** shows a noticeable increase in the road network in the UMW, particularly in Tanay and Antipolo City, from 2005 to 2020. It was calculated that these road networks increased from 163.41 km to 914 km.

### Upper Marikina Watershed in 2005

The land cover map of the UMW for 2005 is

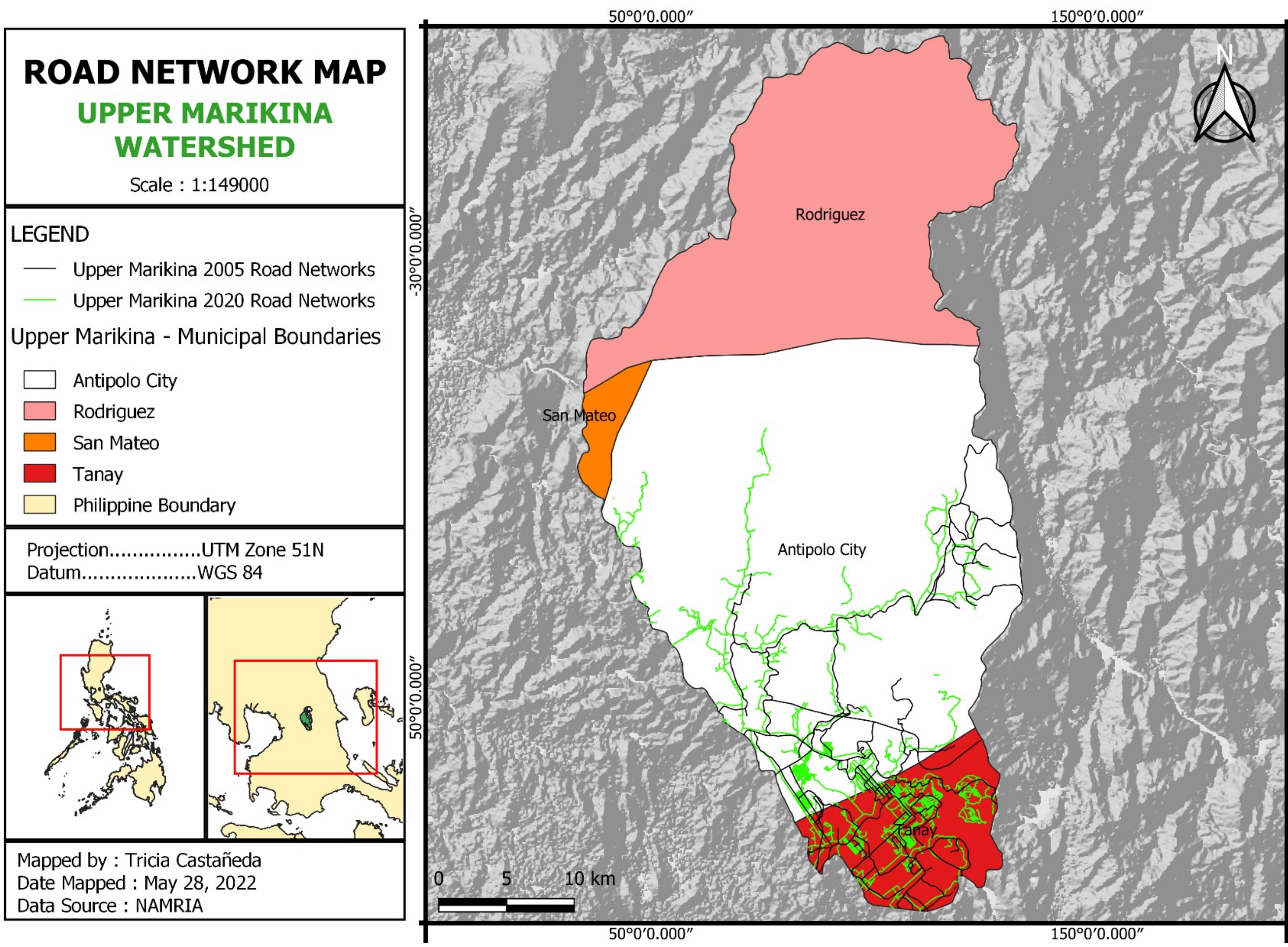


**Figure 2.** Road network map of Upper Marikina Watershed in 2005 and 2020.

shown in **Figure 3**. This study considered a closed broadleaved forest, open broadleaved forest, and shrubland as part of forested land. About 23,460 ha (about 84%) of land in the watershed was forested in 2005. Other land covers, including built-up areas and grasslands, were considered non-forested, covering about 4,491 ha (16% of the entire UMW). Figure 3 shows a large percentage of forested land in the UMW for 2005. The 0.06% or about 18 ha of built-up areas covering the site is a small number. This greatly contributes to the area's high percentage of forest cover, showing that the site is not yet exploited and degraded.

### Upper Marikina Watershed in 2010

The land cover map of the UMW for 2010 is shown in **Figure 4**. This shows that about 55% of the UMW was covered by forested land in 2010. A sum of 15,428 ha of land (45% of the entire UMW) was covered by open and closed broadleaved forest and shrub lands (*i.e.*, built-up areas, annual and perennial croplands, open barren, inland water, and wooded grasslands) that significantly contribute to the low percentage of forest cover in the area.

### Upper Marikina Watershed in 2015

The land cover map for 2015 is shown in **Figure 5**. A total of 20,791 ha of land in the watershed remain to be covered by open and closed broadleaved forest and shrublands. This shows that about 74% of the UMW was covered by forested land in 2015. About 26% (7,161 ha) of built-up areas, annual and perennial croplands, open barren, inland water, and grasslands covering the site is a large number that significantly contributes to the low percentage of forest cover in the area.

### Upper Marikina Watershed in 2020

The land cover map of the UMW for 2020 is shown in **Figure 6**. About only 18,861 ha of land in the watershed remains to be covered by forested lands. This shows that about 67% of the UMW was covered by forested land in 2020. Figure 6 shows a low percentage of forested land in the UMW for 2015. The 33% (9,090 ha) of built-up areas, croplands, inland water, and grasslands covering the site is a large number that greatly contributes to the decrease in the area's forest cover percentage.

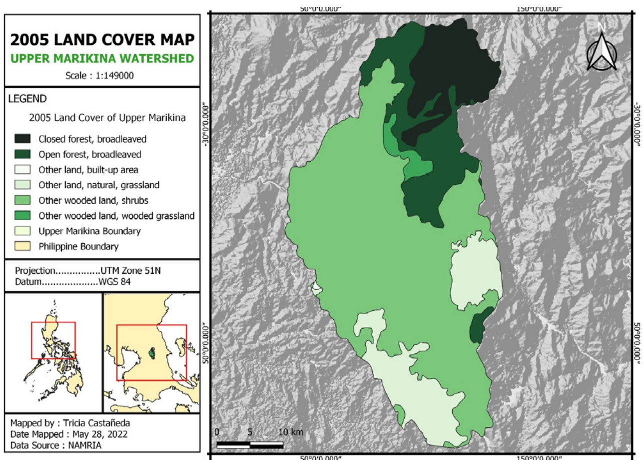


**Figure 3.** Land cover map of the Upper Marikina Watershed in 2005.

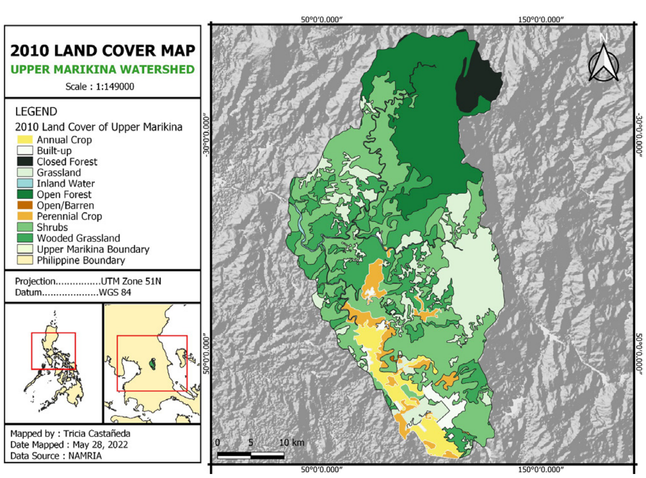


**Figure 4.** Land cover map of the Upper Marikina Watershed in 2010.

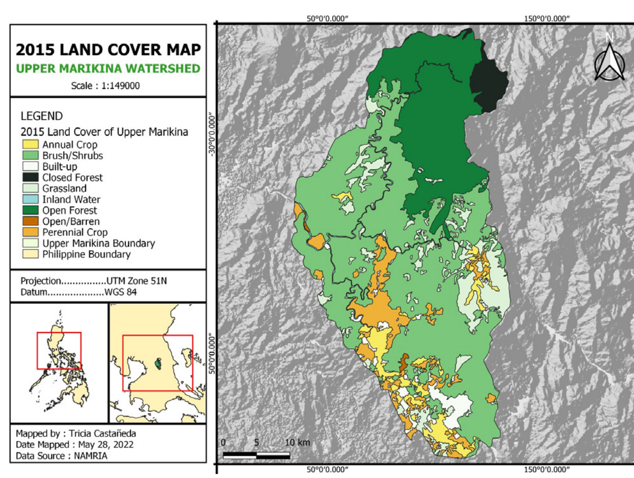


**Figure 5.** Land cover map of the Upper Marikina Watershed in 2015.

### Image processing

Image preprocessing began with atmospheric correction. This allowed the surface reflectance of satellite data to be recovered, significantly improving the image for classification. This step eliminated atmospheric absorption and scattering effects on the scene. The existence of clouds in the satellite image scene was removed through cloud masking, and the same pre-processed satellite image was used to stitch all the clouded areas in the original pre-processed satellite image. **Figure 7** shows the satellite image before and after generating the natural color band combination by matching the corresponding wavelength of the bands to the colors of band rendering – red, green, and blue to bands 4, bands 3, and bands 2, respectively.

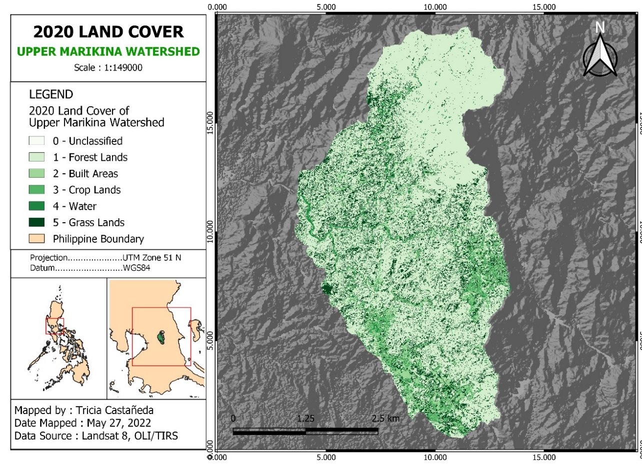


**Figure 6.** Land cover map of the Upper Marikina Watershed in 2020.

### Image classificatio

This study used supervised classification to classify the 2020 Landsat 8 image, specifying land cover classes as training data. The satellite data were classified using an algorithm that assigned classes per pixel signatures and divided the land area into five classes. There are at least 20 training sites generated for each land cover class. **Figure 7** depicts land cover thematic maps for the UMW in 2020. Forests, built-up areas, croplands, inland water, and grassland are delineated. The area covered by cloud data that cannot be further classified into a specific land cover is known as the unclassified area. Each class has a distinct identity using different colors to distinguish them. A visual interpretation was used to solve the problem of mixed pixels during classification and made a significant difference in the supervised classification results. This process resulted in thematic maps of the 2020 UMW's land cover.

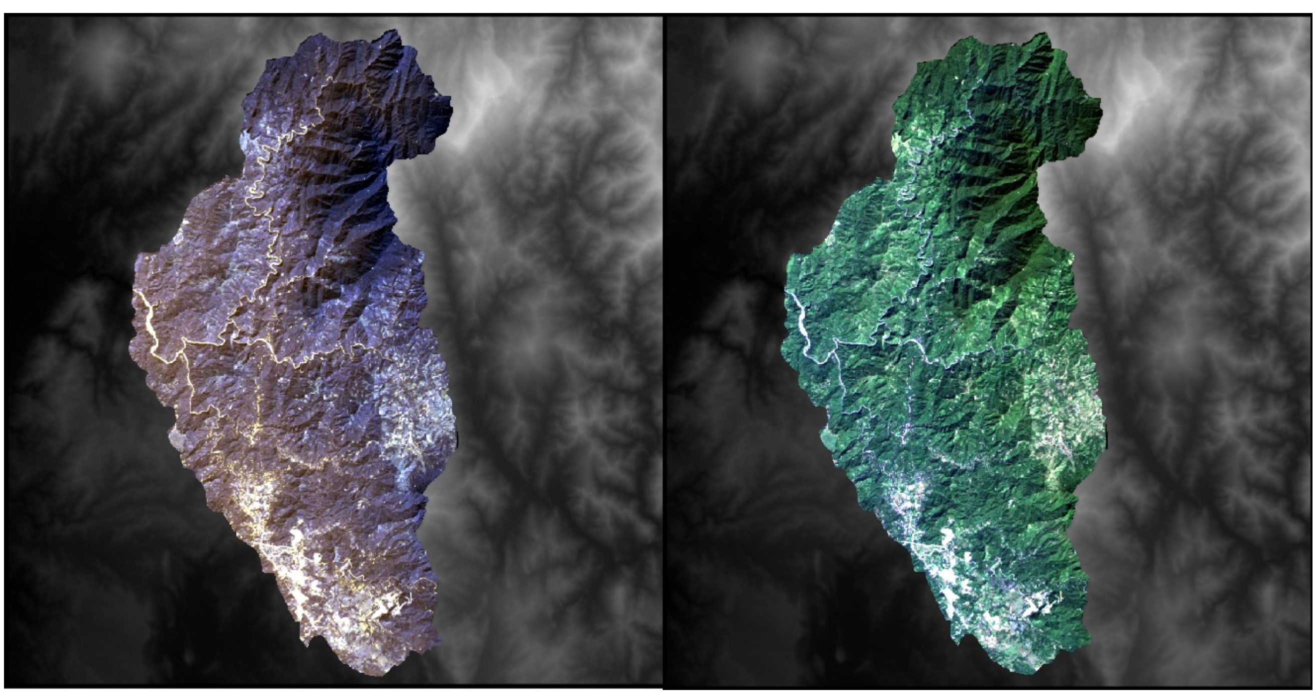

**Figure 7.** Unprocessed satellite image (left) vs. pre-processed satellite image (right).

The classified image through the minimum distance supervised classification algorithm and the generated NDVI of the pre-processed satellite is shown in **Figure 8**. It also shows the closeness and appropriateness of the computed NDVI and the generated classified satellite image. The NDVI represents the greenness of the study site.

### Accuracy assessment

Thirty-nine random training samples (**Figure 9**) were selected for each predetermined land cover type using ESRI's QGIS polygon designation around representative sites. The spectral signatures for the various land cover types were recorded in the pixels enclosed in these polygons. These training samples were used as ground truth data, requiring visual interpretation, and compared to the reference data to determine classification accuracy. The confusion matrix was generated using the 39 ground truth samples, and it calculated the overall accuracy of each classification in 2020. The overall classification accuracy for the minimum distance algorithm in 2020 is shown in **Table 4**. The confusion matrix in the SCP plugin in QGIS was used to assess this.

The assessment of the classified Landsat 8 satellite image yielded an overall accuracy of 54.89% and a kappa hat classification of 0.37 using the minimum distance algorithm of the supervised classification. Specifically, forests or the MC ID 1 yielded 83.82% producer’s accuracy, while MC ID 2, 3, and 4 or the built-up area, croplands, and water classes have yielded a 100% producer’s accuracy, respectively. MC ID 5, or the grasslands land cover, has yielded a 23.78% producer’s accuracy percentage.

Although four out of five classes showed high to perfect accuracy, one class had a very low producer's accuracy, leading to an overall relatively low accuracy in the study due to the small number of classes. The reason for having only five classes was that only forest cover and its changes through time were assessed and not the other land cover classes. Despite a low accuracy assessment percentage of the classified satellite Landsat 8 image, it was still used for the change detection analysis as a forest. The MC ID 1 yielded a reasonably good producer’s and user’s accuracy percentage.

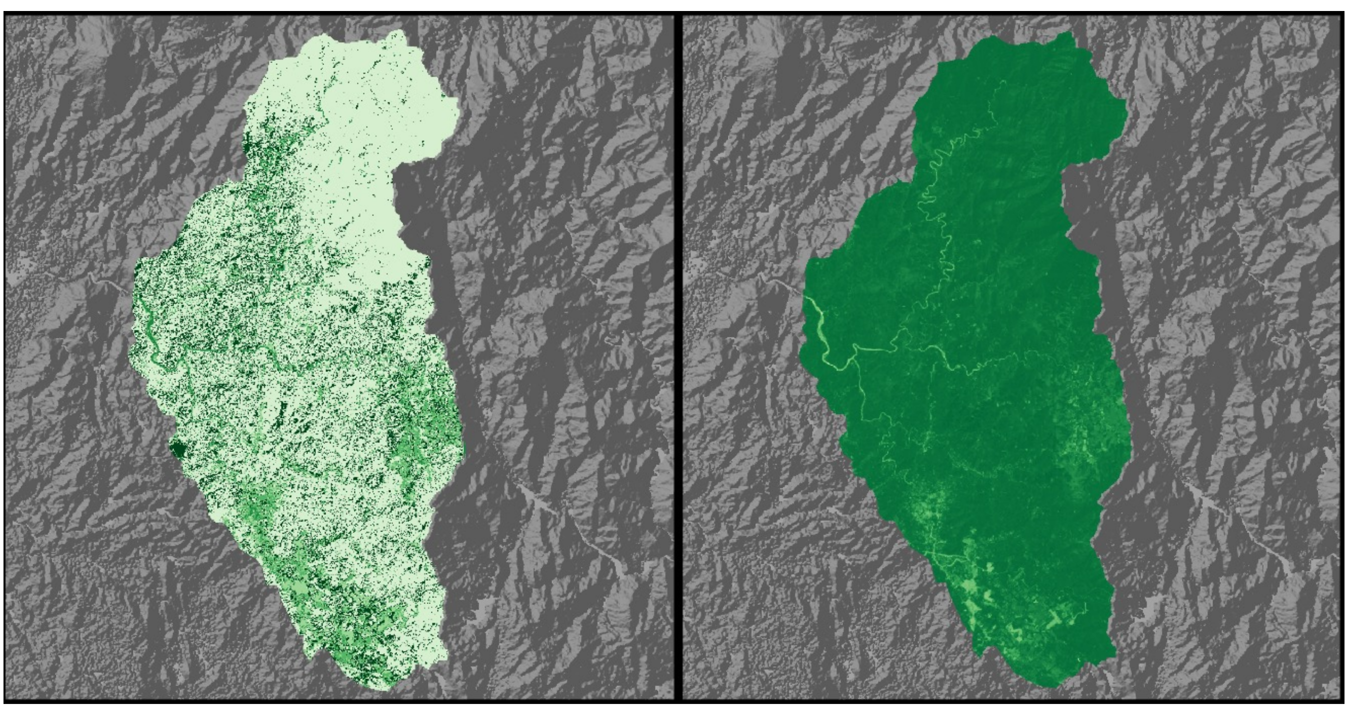

**Figure 8.** Minimum distance classification of the Landsat 8 satellite image (left) and the calculated NDVI of the satellite image of the site (right).

**Table 4.** Summary of the accuracy report.

| | Reference | MC ID 1 | MC ID 2 | MC ID 3 | MC ID 4 | MC ID 5 |
|---|---|---|---|---|---|---|
| S.E. area | 0 | 13558 | 1834 | 13433 | 113 | 0 |
| 95% CI area | 0 | 26574 | 3594 | 26329 | 222 | 0 |
| P.A. [%] | nan | 83.82 | 100 | 100 | 100 | 23.7772 |
| UA [%] | 0 | 100 | 0.0377 | 0.1992 | 0.0054 | 100 |
| Kappa hat | 0 | 1 | 0.0004 | 0.0019 | 0.0001 | 1 |
| S.E. area | 0 | 13558 | 1834 | 13433 | 113 | 0 |
| 95% CI area | 0 | 26574 | 3594 | 26329 | 222 | 0 |
| Overall accuracy [%] = 54.8912 | | | | | | |
| Kappa hat classification = 0.373 | | | | | | |

### Change detection analysis

The land cover classes for 2005, 2010, and 2015 from the NAMRIA were harmonized for the change detection analysis (**Table 5**). These harmonized shapefiles from NAMRIA were rasterized and used to detect the forest cover changes through time. Land cover for 2005 was compared to 2010, 2010 to 2015, and 2015 to the classified satellite image of 2020. The change detection analysis report highlighted pixel values that changed from forests to other classes and *vice versa*. **Tables 6** to **8** show the summary of the change detection analysis report.

### Forest cover in Upper Marikina Watershed from 2005 to 2020

After the forest cover extent in UMW in different years was defined, its changes every five years were analyzed. **Table 9** shows that UMW's forest cover changed from 2005 to 2020. A 2.35% or about 658 ha out of 27,952 ha of UMW forest increase was recorded from 2005 to 2010, along with a massive decrease of 31.08% or 8,686 ha. From 2010 through 2015, it was found that a 6,477 ha or 23.17% forest increase happened, with a 4% forest decrease or only 1,117.44 ha of forest cover loss. Moreover, a 10.28% forest cover increase happened from 2015 to 2020, or about 2,873 ha, along with a 17.23% or 4,816 ha forest cover decrease in the UMW site.

### Assessment of the impact of road network developments on the forest cover in the Upper Marikina Watershed

The data gathered and presented above shows that the forest cover in the UMW has changed over time. These changes were either increased or decreased forest cover (**Figure 10**). From 2005 to 2010, a noticeable change in forest cover was recorded. The massive land conversion in the area contributes to decreased forest cover in the UMW. Along with these land conversions, road networks are developed to open the area for more access to these converted lands. There will always be environmental and social consequences when a road is built. However, Southeast Asia will likely have the least research on these effects among tropical regions. The study by Clements (2013)

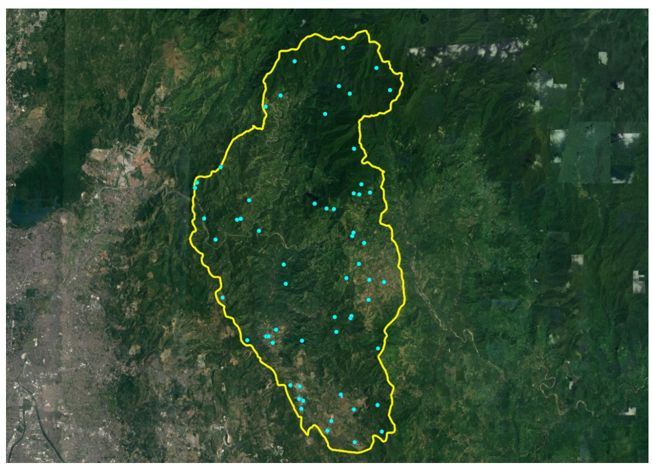

**Figure 9.** Ground truth points to the accuracy assessment of the classified satellite image

**Table 9.** Summary of the road network and forest cover change through time.

| | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|
| Amount of forest cover | 83.93% | 55.20% | 74.38% | 67.48% |
| Road network increase | 0% | 25% | 50% | 100.00% |

**Table 5.** Land cover classes to be used for change detection analysis.

| MC ID | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|
| 1 | Open forest | Open forest | Open forest | Forests |
| | Closed forest | Closed forest | Closed forest | |
| | Shrub | Shrub | Brush/Shrub | |
| 2 | Built-up areas | Built-up areas | Built-up areas | Built-up areas |
| 3 | Croplands | Annual crop | Annual crop | Croplands |
| | | Perennial crop | Perennial crop | |
| | | Open/Barren | Open/Barren | |
| 4 | - | Inland water | Inland water | Water |
| 5 | Grassland | Grassland | Grassland | Grassland |
| | Wooded grassland | Wooded grassland | | |

**Table 6.** Summary of the change detection analysis for 2005 to 2010.

| Pixel value | New class | Reference class | No. of pixels | Area (ha) |
|---|---|---|---|---|
| 2 | 1 | 2 | 8 | 0.72 |
| 8 | 1 | 5 | 7308 | 657.72 |
| 3 | 2 | 1 | 1679 | 151.11 |
| 5 | 3 | 1 | 10844 | 975.96 |
| 7 | 4 | 1 | 3176 | 285.84 |
| 10 | 5 | 1 | 80815 | 7273.35 |

**Table 7.** Summary of the change detection analysis for 2010 to 2015.

| Pixel value | New class | Reference class | No. of pixels | Area (ha) |
|---|---|---|---|---|
| 2 | 1 | 2 | 324 | 29.16 |
| 4 | 1 | 3 | 3621 | 325.89 |
| 7 | 1 | 4 | 1200 | 108 |
| 11 | 1 | 5 | 66821 | 6013.89 |
| 3 | 2 | 1 | 700 | 63 |
| 6 | 3 | 1 | 6590 | 593.1 |
| 10 | 4 | 1 | 926 | 83.34 |
| 15 | 5 | 1 | 4200 | 378 |

**Table 8.** Summary of the change detection analysis for 2015 to 2020.

| Pixel value | New class | Reference class | No. of pixels | Area (ha) |
|---|---|---|---|---|
| 1 | -999 | 1 | 4311 | 387.99 |
| 7 | 1 | 2 | 1808 | 162.72 |
| 9 | 1 | 3 | 16993 | 1529.37 |
| 12 | 1 | 4 | 503 | 45.27 |
| 16 | 1 | 5 | 12615 | 1135.35 |
| 8 | 2 | 1 | 3561 | 320.49 |
| 11 | 3 | 1 | 7707 | 693.63 |
| 15 | 4 | 1 | 1609 | 144.81 |
| 20 | 5 | 1 | 36319 | 3268.71 |

found that existing roads contribute to forest conversion. Moreover, the findings of the study have resulted in the same analysis as the study of Milien *et al.* (2021) about roads, deforestation, and the mitigating effect of the Chico Mendes Extractive Reserve in the southwestern Amazon, where it was found that deforestation is also known to be caused by roads. Nepstad *et al.* (2001), Southworth *et al.* (2011), and Barber *et al.* (2014) have all found that deforestation is concentrated in road corridors in the Amazon.

Furthermore, the UMW Coalition has reported that the UMW was being exploited by extractive activities such as quarrying and mining in the area. According to the coalition, at least six Mineral Production Sharing Agreements (MPSAs) exist or overlap with the UMRBPL, covering approximately 1,500 ha of protected forestland. Another 658 ha appear to be covered by MPSAs in nearby protected and conserved areas. The existence of mining and quarrying sites calls for the existence of road networks for transportation. These MPAs greatly contribute to the increasing presence of road network developments and the decrease of forest cover over time.

The UMW was put into the UMRBPL status in November 2011. The initial efforts of this mandate have contributed to strengthening the protection of the watershed resulting in fewer extractive activities in the area that have caused a forest cover increase in this period. From 2010 to 2015, an increase in forest cover was recorded on the site (**Figure 11**).

Even though the UMW was put into a protected landscape status, the data above for 2015 to 2020 shows that a decrease in forest cover is still happening in the area. Many small but numerous

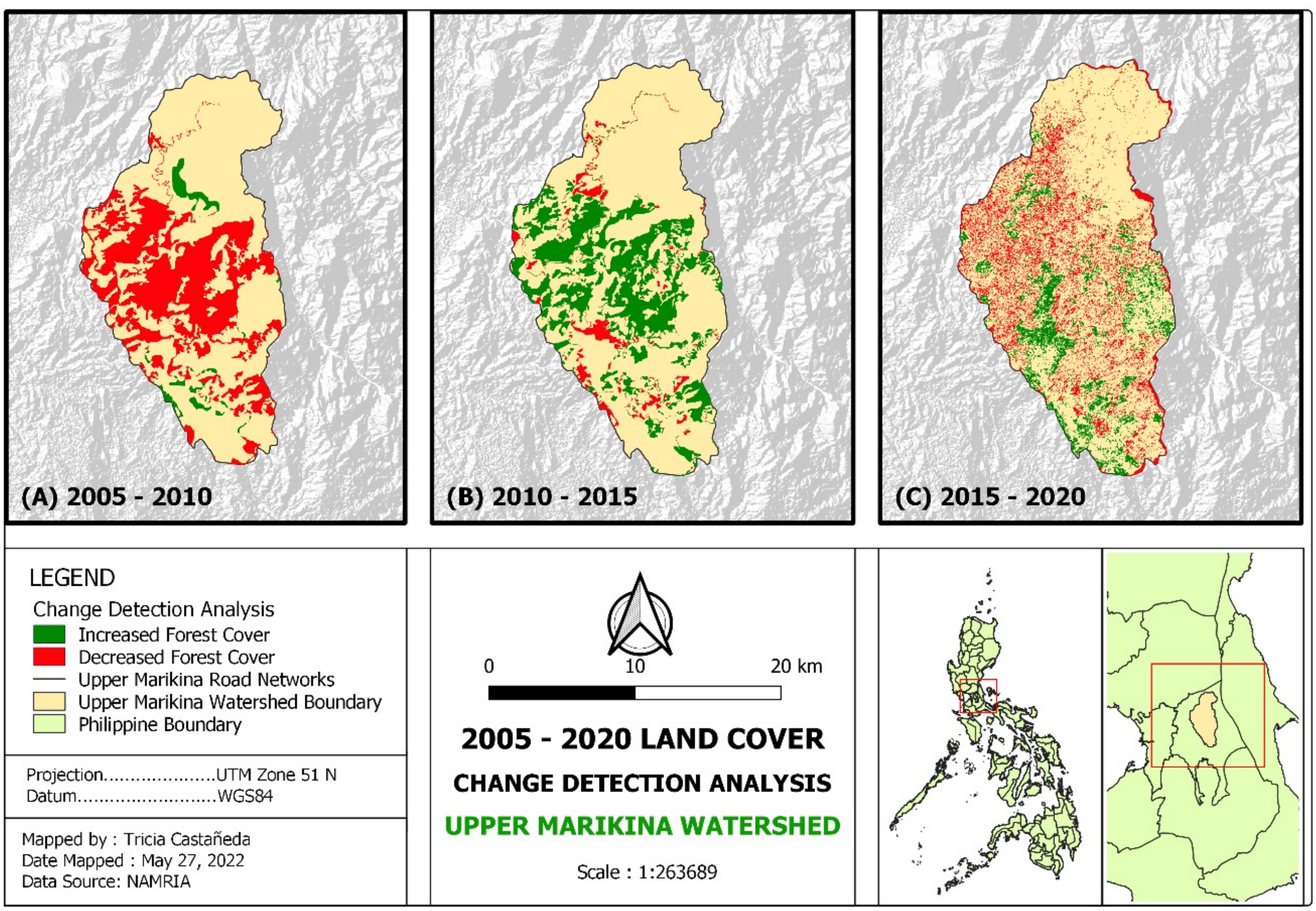


**Figure 10.** Change of forest cover in Upper Marikina Watershed from 2005 to 2020 (right).

watershed regions have shown a 17.23% forest cover decrease from 2015 to 2020, along with a 10.28% forest cover increase. The protected landscape status change from a reserve, as defined by R.A. 7586, is a lenient move involving man in nature compared to a reserve. This protected landscape status may have opened opportunities for road network establishments as transportation in this area is a need if human exists and thrives in the area. Moreover, the study by Poor *et al.* (2019) found that the improved forest access along the forest boundary is due to roads that are a major driver of deforestation and degradation. It was discussed in this study that protected areas worldwide must address roads and their consequences on ecosystem fragmentation in their conservation plans.

Overall, **Figure 11** shows that the area's road networks show an inverse relationship with the forest cover in the UMW. Data from 2005 to 2020 show that forest cover decreases as road network development increases. With the increase or massive growth of road networks in the area, the forest cover showed a noticeable change over time. As road networks develop through time, changes in forest cover in the UMW occur. The period from 2010 to 2015 shows an increase in forest cover, and it can be concluded that putting the UMW into a protected landscape status effectively contributed to this increase. Generally, the graph and the table showed an inverse relationship between the road network and forest cover in UMW. When the road network was developed increasingly in the area, the forest cover decreased.

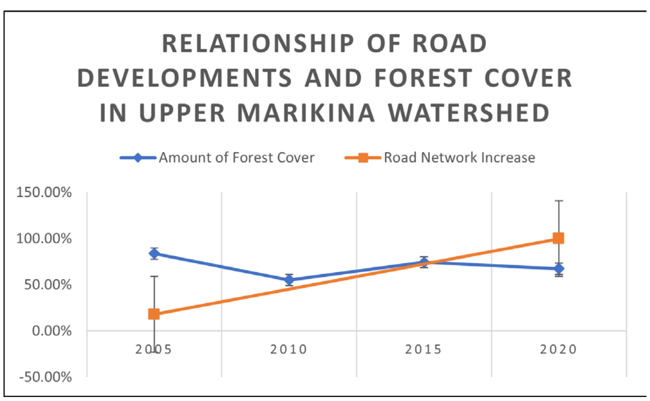


**Figure 11.** Line graph showing the relationship between road network developments and forest cover in Upper Marikina Watershed.

## CONCLUSION AND RECOMMENDATIONS

Destructive activities, unregulated exploitation, and excessive land conversion have threatened UMW. Analysis showed that the forest cover of the UMW has changed over time. From 2005 to 2010, a significant decrease in forest cover was recorded, while a noticeable increase occurred between 2010 and 2015. However, as years go by, a continuous decrease in forest cover occurred from 2015 to 2020 based on the results and analysis of this study. All these changes in forest cover due to further land conversion in the area create opportunities for road network developments. Furthermore, the lack of tenure security, coupled with the perception of open access to the forest as a shared resource, has negatively impacted forest cover due to road network development in the UMW.

The findings revealed significant changes in forest cover in the UMW between 2005 and 2020. Specifically, the expansion of the road network in the area inversely correlates with forest cover. This study can contribute to improved land use planning, strengthened policy enforcement, and policy formulation in land resource planning, monitoring, and management.

For future studies, field verification of the land cover and road network extent in the area would be useful in enhancing the accuracy of the data. Also, a study using satellite images taken in various years and more specific land cover classification could better assess land cover change in the area.

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