Mapping the Effects of Anthropogenic Activities in the Catchment of Weija Reservoir using Remote Sensing Techniques*

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Abstract

Man has contributed to land cover alteration since time-immemorial through clearing of land for residential, agriculture, recreational and industrial purposes. The emergence of adapting wild plants and animals for human use as well as industrialisation have also contributed to the alteration of land cover. Over the years, anthropogenic activities have had great impact on the Weija catchment. This study seeks to map the catchment and determine the impact of anthropogenic activities using Remote Sensing techniques. Observations and measurements were made on the field as well as classification of land cover using Landsat images of years 1991, 2003 and 2017. Results showed an increase in built-up areas by 18% from 1991 to 2017. Other classes such as shrubs increased due to decrease in dense vegetation. This study confirms the use of Remote Sensing as a valuable tool for detecting change in land cover and determining the impact of anthropogenic activities in the Weija Catchment.

Keywords: Land Cover, GIS, Remote Sensing, Weija Catchment, Anthropogenic Activities

1 Introduction

Water bodies around the world are known to be the key source of sustainable life and good ecosystems. Ghana has many water bodies that serve as a source of water supply. The Weija reservoir is a major source of water supply for millions of residents in Accra East and West (Anon., 2015).

This water body has been affected by human activities along the banks and within the reservoir itself over the years. In recent years activities such as irrigation, pollution, sand winning and encroachment on the reservoir and along its boundary have caused serious effects on the water causing harm to the surrounding ecosystem and shortage in water supply. This has raised a series of environmental concerns.

Remote sensing techniques have been used over the years and it has proven to be of great value for monitoring changes at regular intervals (Ramachandra and Kumar, 2004; Zubair, 2006). Many studies address the relationships between land use and water pollution (Yong and Chen, 2002; Bai et al., 2010; Tim and Jolly, 1994; Ahearn, et al., 2005). Generally, built-up and agricultural areas have significant positive correlations with water pollution (Huang et al., 2015; Tafangenyasha and Dube, 2008). Land use Land cover (LULC) is necessary in identifying and mapping natural resources and human activities which have a great effect on water quality deterioration. Areas that are dominated by industrial and agricultural activities are more vulnerable to water pollution (Roberts and Prince, 2010; Tafangenyasha and Dube, 2008).

This study seeks to determine the extent of human activities and its impact in the catchment of the Weija reservoir.

The Weija reservoir is located in the Ga south municipality which is part of the communities that receive water from the Weija treatment plant. The Weija reservoir, lies between geographical coordinates 5° 33′ 0″N and 5° 40′ 0″ N and 0° 20′ 0″W and 0° 24′ 0″ W (Anon., 2016). The Weija Catchment was selected because of the increase in human activities and also the importance of the Weija reservoir. The catchment lies in the coastal savannah agro-ecological zone with a bi-modal rainfall pattern and has an area of about 256 sq.km (Anon., 2017).

The Weija reservoir is 14 km long, 2.2 km wide and with a surface area of about 38 sq.km (Vanden Bossche and Bernacsek, 1990). The reservoir has been in existence for a period of 39 years after it was reconstructed by the Ghana Water Company in 1978. The reconstruction was initiated because the existing dam got breached by flood in 1968 (Asante et al., 2008). The effective storage capacity is approximately 133 million m³, calculated as reservoir volume at maximum design level of 143 million m³ (Anon., 2007). The Weija reservoir has its source from the Densu river. The Weija Catchment lies on the Western Lowlands of the Densu reservoir and characterised by a low and rolling topography with a base of about 67 metres above

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mean sea level. It is broken by steep low ridges in several places ranging from 300 to 567 metres above mean sea level. The catchment comprises of mainly gneiss and granite to the west and sandstone, siltstone and shale in the east (Kuma and Ashley, 2008). There are two rivers that drain the catchment, they are the Densu and Ponpon river. The Densu river is the larger of the two drains from the eastern region through the western portions of the area where it enters the sea (Anon., 2017). Studies have shown that due to anthropogenic activities, the earth's surface is being significantly altered and the presence of man on earth and his use of land has had a great effect on the natural environment (Opeyemi, 2008).

Over the past years, data from Earth sensing satellites have become vital in mapping the earth’s features and infrastructures, managing natural resources and studying environmental change (Longley, 2005; Mayomi, 2009).

Land cover is composed of arrays due to a variety of natural and human-derived processes which includes vegetation, non-vegetation and man-made features such as roads, rivers, quarries, buildings, etc. (Rozenstein and Anon., 2011).

For land use, various approaches are proposed in literature (Mücher et al., 2001). Two main “schools” may be distinguished. In terms of functional dimension, Land use agrees with the description of areas in terms of their socio-economic purpose in terms of functional dimension: areas used for residential, industrial or commercial purposes, for farming or forestry, for recreational or conservation purposes, etc. Links with land cover are possible; it may be possible to infer land use from land cover and conversely. But situations are often complicated and the link is not so evident. Another approach, termed sequential, has been particularly developed for agricultural purposes. The definition is a series of operations on land, carried out by humans, with the intention to obtain products and/or benefits through using land resources. For example, a sequence of operations such as ploughing, seeding, weeding, fertilizing and harvesting (Mücher et al., 2001).

2 Materials and Methods Used

2.1 Materials Used

The materials used for this study include; Landsat 4 Thematic Mapper, Landsat 7 Enhanced Thematic Mapper and Landsat 8 Operational Land Imager (OLI) images obtained from the United States Geological Survey (USGS); Environmental System and Research Institute (ESRI) shapefiles of Weija catchment obtained from the Geomatic Engineering Department of the University of Mines and Technology (UMaT) were used for this study. Trimble Juno SB handheld GPS receiver was also used to collect data for ground truthing.

2.2 Methods Used

The methods used for this study have been grouped in stages as shown in Fig. 1.

![Fig. 1 Flowchart of Summary of the Methods Used](image)

2.2.1 Image Acquisition and Pre-Processing

The initial stage of this work considered the collection of data. Data sets in the form of Landsat Imagery for the years 1991, 2003 and 2017 were collected from the U.S. Geological Survey. Geometric and radiometric corrections were performed on the imageries in order to correct for altitude and attitude, scanner distortions, earth motion, variable detector response, etc. using tools in ArcGIS software. The pre-processing involved conversion of digital numbers to Radiance then from Radiance to reflectance. The corrected images were then combined or stacked.

2.2.2 Unsupervised classification of images

An unsupervised (Iterative Self-Organising cluster) classification was then performed on the layers which were stacked together. The stacked layer was divided into five classes. The number of classes were determined after field reconnaissance. The output image was then analysed to obtained more information about the various land cover classes present.

2.2.3 Supervised Classification

Supervised classification was performed to classify the image into different LULC classes as supervised classification has higher accuracy compared to unsupervised classification since the classes were trained. Hence, selected control points that included the LULC classes were sampled to create a signature file to help train the algorithm to classify the entire study areas. Care was taken to
minimise error by avoiding mixed pixels. Maximum likelihood classifier was used for the supervised classification and five land cover classes were generated as described in Table 1.

Table 1 Land Cover Classes and Composition

| Land Cover Classes | Detailed Composition                 |
|--------------------|--------------------------------------|
| Water Body         | Lakes and rivers                      |
| Dense vegetation   | A canopy of trees coverage            |
| Shrubs             | Areas were vegetation is dominated by shrubs |
| Built-up area      | This include Residential and Commercial facilities |
| Barelands          | Lands with exposed surfaces due to human activities |

2.2.4 Accuracy Assessment

Accuracy assessment was performed on the classification results. The accuracy was assessed using the results of error matrix which provides a clear foundation for accuracy assessment (Congalton, and Green, 1993; Canters, 1997) was generated from this study on satellite imagery for 2017. Reference data for the various land classes was obtained from the study area by ground truthing. The overall accuracy of 85.00% was obtained for this study. This accuracy is acceptable from literature (Anderson et al., 2001; Congalton, and Green, 1993; Canters, 1997).

3. Results and Discussion

3.1 Results

Five land cover classes as shown in Figs. 6, 7 and 8 were obtained from each of the three satellite images acquired. The images were from the years 1991, 2003 and 2017. The results on the extent of change was found and the area of each land cover for the three years determined in sq. km of which percentages were also calculated as represented in Table 2, Table 3 and Table 4 for 1991, 2003 and 2017 respectively. Graphical representations of the areas were also shown in Fig. 2 for 1991, Fig. 3 for 2003 and Fig. 4 for 2017. Fig. 5 shows the proportions of landcover from 1991 to 2017.

Table 2 Land Use Area for 1991

| Class            | Sq. km | %  |
|------------------|--------|----|
| Water Body       | 26.437 | 10.327 |
| Dense vegetation | 89.140 | 34.820 |
| Shrubs           | 41.007 | 16.018 |
| Built-up area    | 19.967 | 7.799  |
| Bareland         | 79.447 | 31.034 |
| Total            | 255.998 | 100.000 |

Table 3 Land Use Area for 2003

| Class            | Sq. km | %  |
|------------------|--------|----|
| Water Body       | 25.966 | 10.143 |
| Riverine vegetation | 75.910 | 29.653 |
| Shrubs           | 71.798 | 28.046 |
| Built-up area    | 67.664 | 26.431 |
| Bareland         | 14.660 | 05.727 |
| Total            | 255.998 | 100.000 |

Table 4 Land Use Area for 2017

| Class            | Sq. km | %  |
|------------------|--------|----|
| Water Body       | 25.966 | 10.143 |
| Riverine vegetation | 75.910 | 29.653 |
| Shrubs           | 71.798 | 28.046 |
| Built-up area    | 67.664 | 26.431 |
| Bareland         | 14.660 | 05.727 |
| Total            | 255.998 | 100.000 |

Fig. 2 Chart of Land Cover for 1991

Fig. 3 Chart of Land Cover for 2003

Fig. 4 Chart of Land Cover for 2017
Table 5 Land Cover Change from 1991 to 2017

| Class          | Change Sq. km | %    |
|----------------|---------------|------|
| Water Body     | -0.471        | -0.184|
| Riverine vegetation | -13.229       | -5.167|
| Shrubs         | 30.791        | 12.027|
| Built-up area  | 47.697        | 18.631|
| Bareland       | -64.787       | -25.307|

Note: Negative sign indicates a decrease

Fig. 5 Proportions of Land Cover: 1991 to 2017

Fig. 6 A Land Cover Map of 1991

Fig. 7 A Land Cover Map of 2003

Fig. 8 A Land Cover Map of 2017

3.2 Discussion

The results obtained from the Landsat images show changes in the various land use over the period of 26 years. Between the years of 1991 and 2003 there was an increase in area of water body which decreased in the year 2017.

In 1991, Dense vegetation was at its peak but subsequently decreased in 2003 and increased again in 2017 as shown in Fig. 5. Dense vegetation decreased overall by 5.167% bringing about an increase in shrubs by 12.027% (Table 5). Built-up areas which have a positive correlation with water pollution increased by 18% in total from 1991 to 2017 in the catchment. Built-up areas was at a low of 7.8% in 1991 and increased massively to 25.892% in 2003 and also by 26.431% of total land cover in 2017.

Increase in urbanisation and industrialisation is seen to have been the cause of increased in the rate of settlement in the catchment due to the inflow of people looking for barelands to put up structures.

4. Conclusions and Recommendations

4.1 Conclusions

In this study, five land cover classes were distinguished from the satellite images of 1991, 2003 and 2017 for the Weija catchment to monitor anthropogenic activities over a twenty-six-year period.

The catchment area has witnessed increase in built-up areas due to rapid urbanisation and industrialisation. The nearness of the catchment area to Accra and high demand for lands for residential purposes and other activities have resulted in population increase in the area.

Built-up area which have a positive correlation with water pollution (Pijanowski and Kanownik,
1997), increased by 18% in the catchment. Dense vegetation decreased by 5.167% bringing about an increase in shrubs by 12.027%. Bare lands were as a result of clearing of the lands for agricultural purposes and stone winning and this has decreased as a result of monitoring of the area by army personnel an initiative of the government of Ghana. The northern part of the area seemed to have a good amount of vegetation cover and this can be protected.

4.2 Recommendations

This study recommends that environmental by-laws and other laws regulating the acquisition of land, waste disposal, farming and fishing practices should be enforced by the GWCL and EPA to ensure proper management of the land in the areas. Also, a buffer should be created along the reservoir to protect it from further encroachment.

Tree planting or afforestation program should be implemented to increase the number of dense vegetation. Continuous monitoring of the perimeter of the reservoir should be continued.

Public awareness and Further studies such as regular water quality checks should be conducted in the area.

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