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Aspects of the Landuse and Landcover Change Dynamics of the Riparian Corridor of the New Calabar River, Nigeria

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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ABSTRACT

Landsat 7 ETM Satellite imagery for 1987 and 2013 were used in a geographic information system to map and model changes in the Landuse and Landcover along the freshwater Riparian corridor of the New Calabar River. Percentage change in six Landuse-Landcover (LULC) features, namely Freshwater forest, Grassland, Barren-Sparse Vegetation, Scrub-Shrub, Agriculture and Urban/Builtup, were calculated from the differences between the pixels of the LULC in the imagery for 1987 and 2013. The pattern of changes along the buffer zones between 50 m and 500 m was a mixture of gains and losses in the LULC types. The freshwater forest declined between 0.6%-22%. In the Barren/Sparse vegetation category, there was a decline of between 9-16% but an increase of 323% was experienced at the 50 m buffer. The gains and losses were observed for the Grass category with 2-30% losses and 233% gain at the 50 meter buffer. Similar observations in the Scrub-Shrub category showed that losses were between 1.3-1.6% while a gain of 11% was observed at the 50 meter buffer. The Agriculture and Urban-Builtup maintained a significant increase across the buffer zones with values of 24-160% and 24-358% respectively. A grid based Riparian reach alteration zone modeling showed that high and extreme changes in LULC occurred mostly at the middle and lower reaches for Urban/Builtup (45%); Scrub-Shrub (34%); Barren/Sparse (40%). High and Extreme values in LULC extending to the Upper reaches were

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observed in Grass category (51%); Freshwater forest (40%) and Agriculture (55%). The cumulative composite model identified 33% of the grids with high and extreme value change coefficients in the middle and lower reaches. Grids of Moderate hotspots of change comprising 33% occurred at upper and lower reach zones of the Riparian study area. In all the chi-square statistics provide strong evidence of the differences ($p = 0.0382$) that accounted for the composite variation within the Riparian reaches. It also provided evidence for the differences ($p<0.0001$) in the proportion of pixels that accounted for Gain and Loss of the different LULC types within riparian buffer zone in this study. The study provides information for targeting management objectives towards Riparian ecosystem resiliency for this section of the New Calabar River.

Keywords: Riparian; reaches; grid; percentage change; landuse; landcover.

1. INTRODUCTION

Riparian corridors of the freshwater portions of rivers are known to be areas that are important habitats for aquatic invertebrates, fish, amphibians, birds and mammals. A healthy riparian habitat is necessary to protect water quality, provide food and cover and migration for a number of amphibians, birds, reptiles and fish, including sensitive and protected species. There is significant evidence in literature of the ecological and ecosystem services performed by the freshwater sections of riparian corridors [1,2,3] especially in their maintenance of biodiversity and landscape values [4,5,6]. The sustainability of these ecosystem services is dependent on continuously changing Landuse and Landcover arising from flood protection needs, residential, commercial, agricultural and recreational lands which alter the amount and condition of riparian resources [7,8,9,10]. Understanding changes in Landuse and Landcover, over space and time, is therefore essential in evaluating the interactions between anthropogenic activities and riparian resources and in providing valuable information to design management strategies for mitigation and conservation.

In order to quantify the variability of forested riparian buffers with variation in adjacent landuse, this paper utilizes satellite imagery and grid based methods in GIS to examine vegetation change between 1987-2013 at spatial scales from the watershed to riparian buffers of 100 m and 1000 m. By evaluating the gradient of change from natural to predominantly anthropogenic, the paper intends to consider how satellite imagery showing the change history can provide insights into the resilience of freshwater forested riparian corridors to edge effects.

2. MATERIALS AND METHODS

2.1 Study Area

The study area (Fig. 1.0) is the freshwater section of the New Calabar watershed (4.8188 N, 7.8418 W). The area of interest (AOI) is located between Elele-Alimini and the southern portion of the estuarine part of the Bonny River at Iwofe. The watershed covers 45,300 ha (175 sq. mi.) and contains 6.4 km of first to second order streams. Riparian vegetation is diverse and includes many tree species. Abundant species include *Annona senegalensis*, *Anthocliesta vogelii, Elias guineansis; Harungana madagascariensis* and *Musanga cecropioides.* Elevation in the watershed ranges from 7.3 m to 19.5 m. The climate is tropical and characterized by average monthly temperatures ranging from 25℃ to 28℃ and an average annual precipitation of 3000 mm.

2.2 Methods

Two dates of Landsat 7 ETM satellite imagery for 1987 and 2013 were used to assess the percentage of change from landuse activities. The imagery was processed and post processed after groundtruth with ERDAS Imagine into Landuse and Landcover classes as shown in Fig. 1. Changes along the Riparian corridor between the two dates were analyzed by extracting the corridors from the larger imagery datasets as shown in Figs. 2 and 2.1 A buffer processing routine in ArcGIS 10.2 was used to develop a corridor that traverses each of the imagery corridors to create buffer offsets. Output buffer features are created from those offsets using numeric fields to develop quotients of change at fixed distances from the existing corridor classified into 50 meters, 100 meters, 200 meters, 300 meters, 400 meters and 500 meters. The percentage change along the corridors was

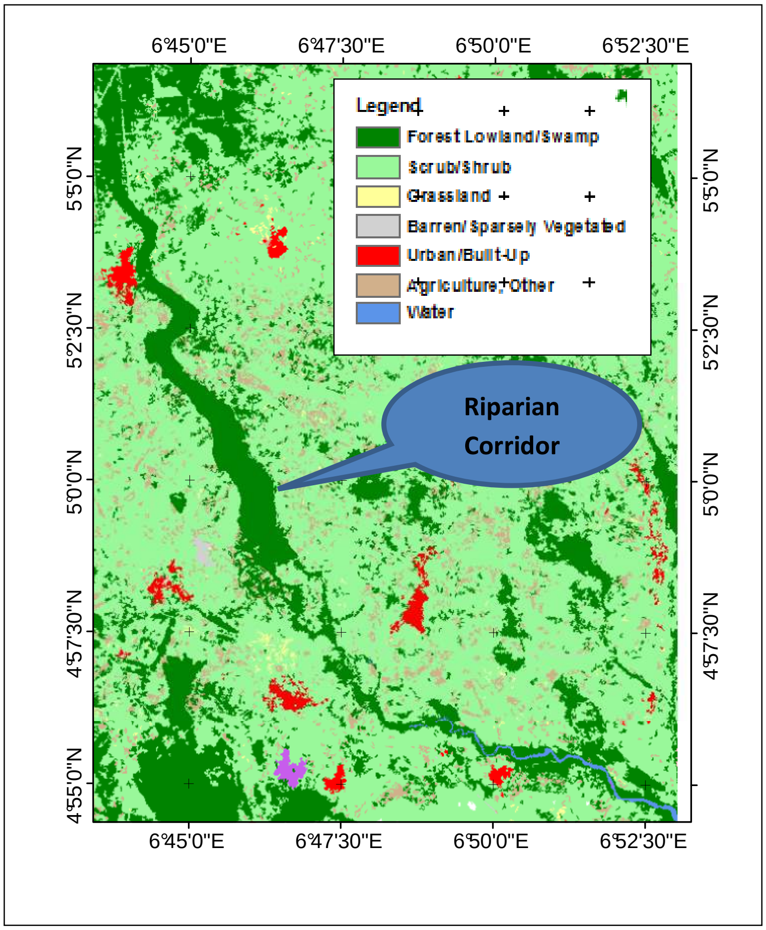


Fig. 1.0 Study area showing the riparian corridor of new Calabar River

calculated using change detection statistics to compile a tabulation of changes between two dates of imagery. The statistics measure a class-for-class image difference, for the 1987 image and 2013 image classification changes. The analysis identifies the classes where pixels changed in the final state image calculated as pixel counts, and percentages within each buffer.

The formula is given by the algebraic expression

$$\%change = \left[\frac{\text{new value - old value}}{\text{old value}} \right] \times 100 \quad (1)$$

The area of greatest change was calculated by converting the raster images to vector data. The riparian corridor which is 39 kilometers long was divided into 18 grids of 3 km^2 and used to evaluate change along the longitudinal gradient from the upper to lower reaches of the riparian corridor. The grids were used to perform a spatial join of target features providing a count of the number of polygons of each year class (1987; 2013) of Landuse-Landcover type within each 3 km^2 grid. The grids were converted to raster. A reclass process was performed with input cell values of the change percentages within each grid for each landuse category projected onto the same scale of 1-5. The value of the scale was 1 = negligible change; 2 = low change; 3 = moderate change; 4 = high change; and 5 = extreme change. A composite mapping overlay technique was used to combine the raster data layers based on the spatial concurrence of the projected raster data on a scale of 1-5. The following datasets Figs. 2.0-2.4 served as input for the study.

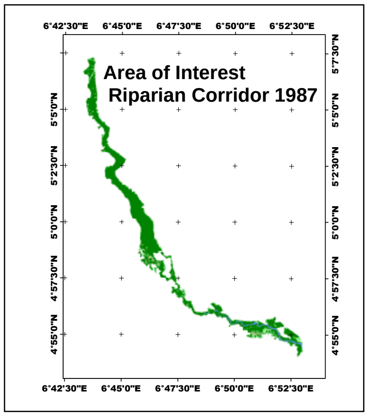


Fig. 2.0 Riparian corridor 1987

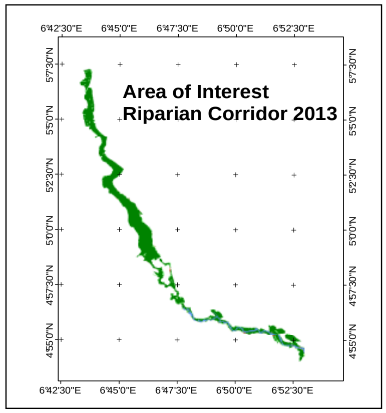


Fig. 2.1. Riparian corridor 2013

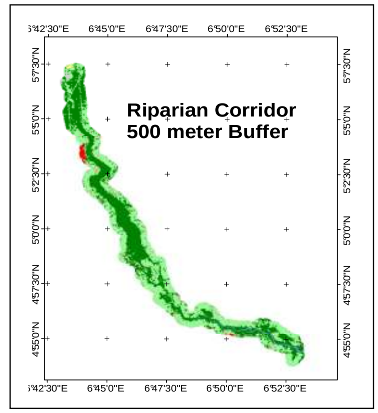


Fig. 2.2. Riparian 500 m buffer corridor

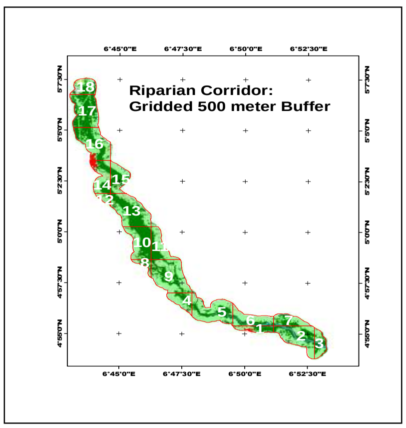


Fig. 2.3. Grid profile Riparian corridor

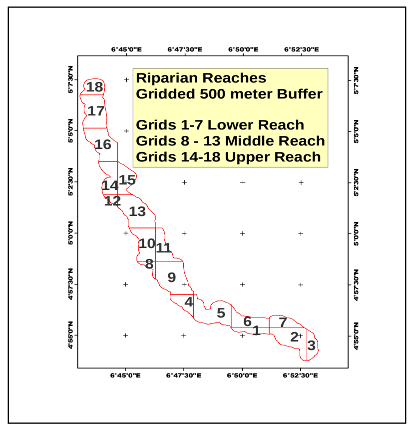


Fig. 2.4. Grid description of Riparian reaches

3. RESULTS

3.1 Buffer Zone Change Analysis

Figs. 3.0 to 3.1 show the changes within the buffer zones of 50, 100, 200, 300, 400 and 500 meters. Fig. 3 shows the changes within the 50 meter corridor between 1987 and 2013. Pixel counts of the imagery show a percentage increase in the Agriculture category by 160% (76 hectares) at 50 meters, 59% (42 hectares); at 100 meters; 45% (42 hectares) at 200 m; 51% (70 hectares) at 300 m; 37.2% (67.2 hectares) at 400 m and 24% (55 hectares) at 500 m. In the Barren/ Sparsely vegetated category, an increase of 323% (7.6 hectares) at 50 meters was observed followed by a decline of 9% (0.4 hectares) at 100 m; 21% (1.3 hectare) at 200 m; 36% (4.4 hectares) at 300 meters; 21% (4 hectares) at 400 meters and 18% (5 hectares) at 500 m.

The Freshwater forest had a loss of 22% (408 hectares) at 50 meters and subsequently showed losses of 1.4% (27 hectares) at 100 m; 1.3% (26 hectares) at 200 meters; 2% (43 hectares) at 300 meters; 1.3% (30.4 hectares) at 400 m and 0.6% (15 hectares) at 500 meters. There was an increase of 233% (7%) in the Grass category at 50 meters; and 3% (0.2 hectares) at 100 meters; losses of 2% (0.2 hectares) at 200 m; 24% (3 hectares) at 300 meters; 30% (5.1hectares) at 400 meters and 21% (5.2 hectares) at 500 meters. At 50 meters, there was an increase in the Scrub category by 11% (81 hectares); a decline of 1.6% (16 hectares) at 100 meters; 1.3% (16 hectares) at 200 meters; 1.3% (24 hectares) at 300 meters; 1.5% (33 hectares) at 400 meters and 1.3% (35.4 hectares) at 500 meters. A 358% (9 hectares was observed for the Urban category at 50 meters; 24% (1.4 hectares) at 100 meters; 17% (20 hectares) at 200 meters; 11% (3 hectares) at 300 meters; 11% (4 hectares) at 400 meters and 6% (3.3 hectares) at 500 meters.

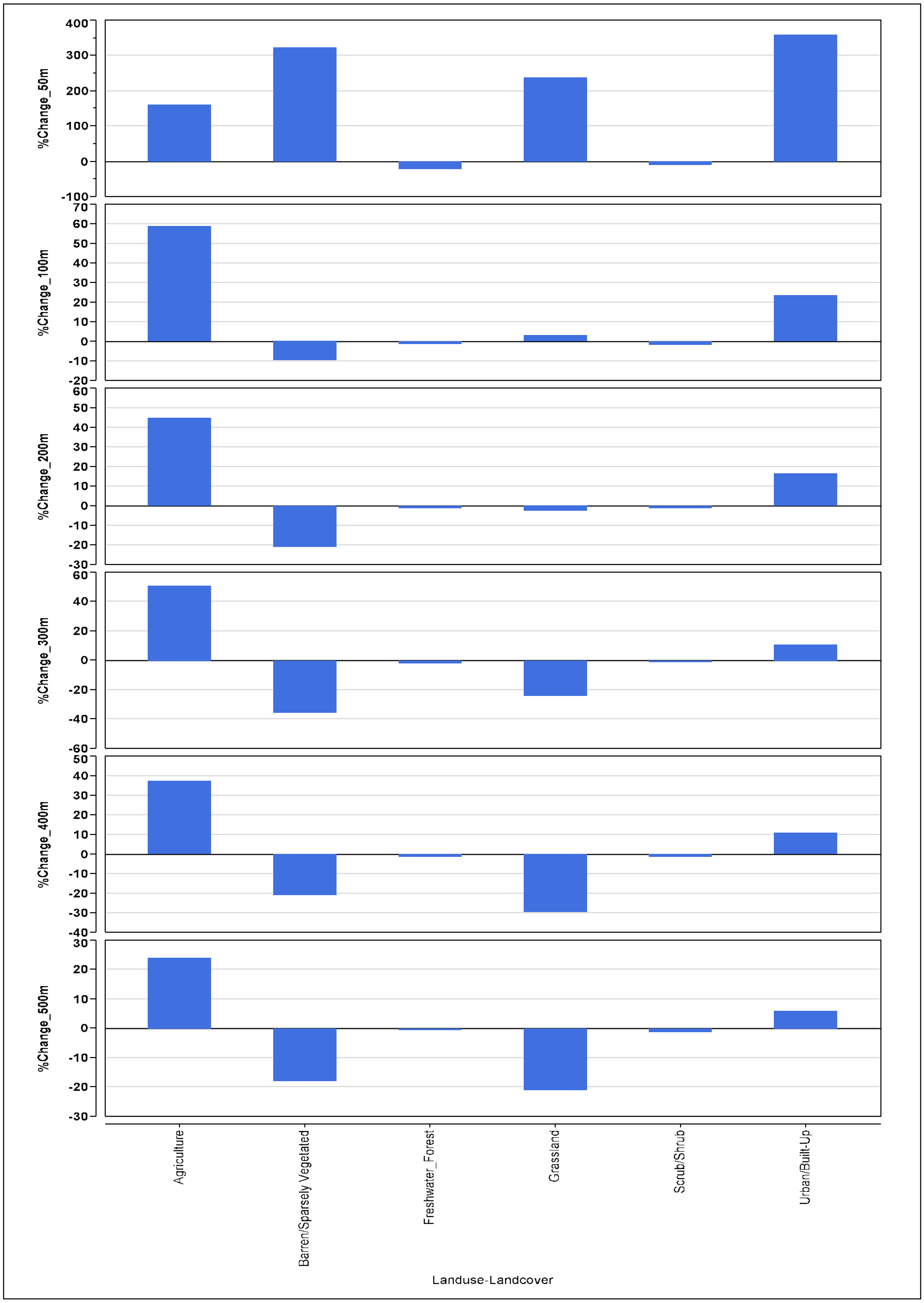


Fig. 3.0. Pixel based calculations of percentage change of LULC features between 1987 and 2013

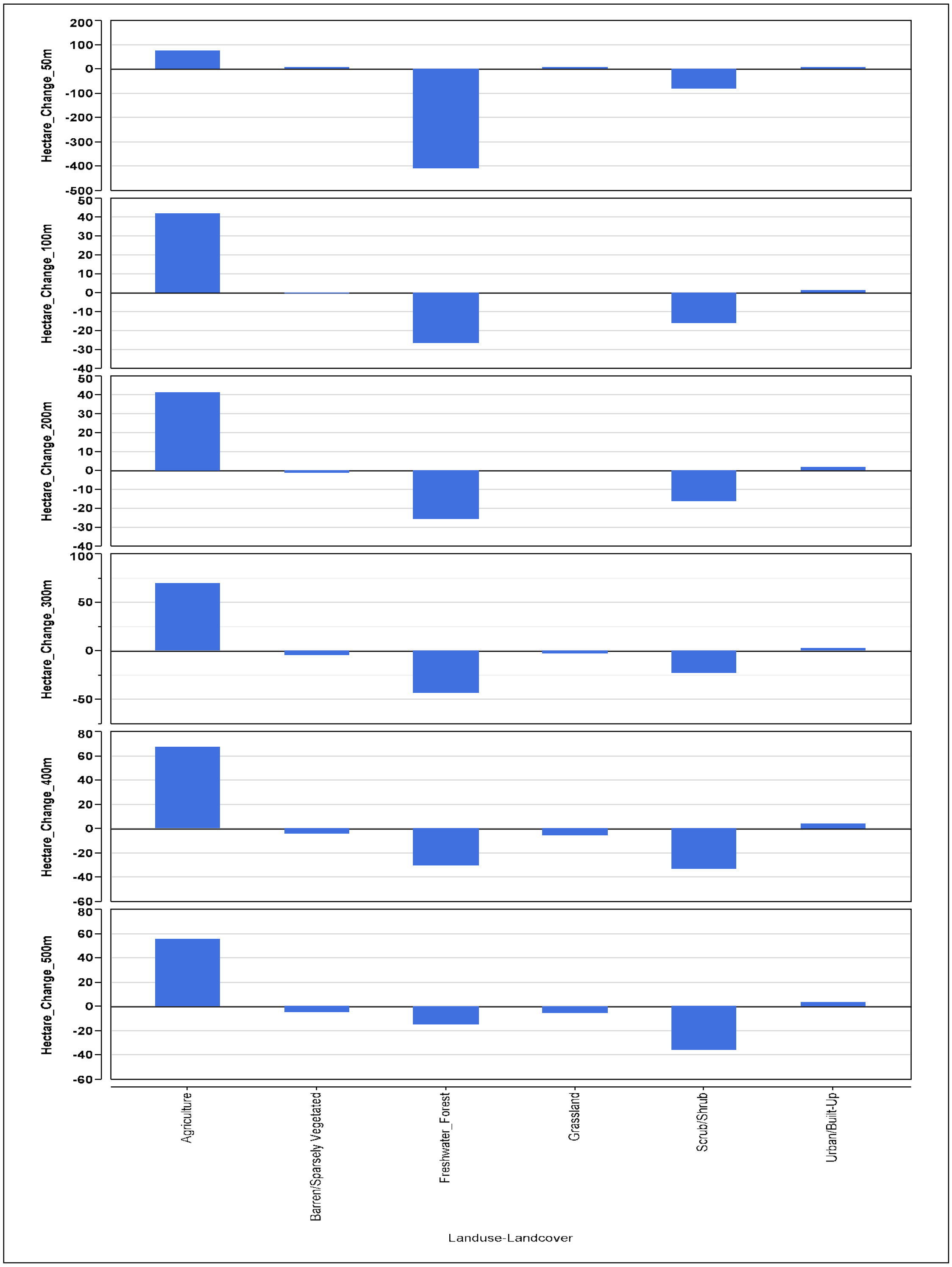


Fig. 3.1. Pixel based calculations of hectares of change in LULC features between 1987 and 2013

Fig. 3.2 is the mosaic plot which shows the relative proportions of the percentage changes between 1987 and 2013 for each Landuse-landcover (LULC) feature within the riparian buffer. The increase in the LULC is represented by the red portion of the mosaic plot while the loss of LULC feature is represented by the blue portion of the mosaic plot. The width of each column also represents the relative pixel numbers of each feature.

The details of the mosaic plot are explained in the Contingency Table (CT) 1.0 showing a total of 10548 pixels of change. The table shows the column and row percentages of the Gain and Loss in pixels for each LULC. In the CT Col% 91.7% of the total pixels accounting for Gain for 1987 and 2013 were in the Agriculture category with the least of 1.48% in the Barren/Sparse category. The CT Row% also shows a Gain of 100% for a total of 4590 pixels that represents changes for 1987 and 2013 in the Agriculture LULC category. Other CT ROW% Gains were 28.35% for the Barren-Sparse vegetation for a total of 261 pixels; 34.75% for Grass for a total of 259 pixels; and 5.03% for Urban-Built-up for a total of 252 pixels. The CT Row% Loss shows 71.65% for the Barren-Sparse LULC for a total of 261 pixels; 100% for the Freshwater forest LULC for a total of 3511 pixels; 65.25% for the Grass LULC category for a total of 259 pixels and 100% for the Scrub-Shrub LULC category for a total of 1675 pixels. There is a strong evidence of the difference in the proportion of pixels that accounted for Gain and Loss of the different LULC types ($p < 0.001$).

Table 1.0 Contingency analysis for proportion of pixels changed in LULC

Count Col % Row %	Gain	Loss	Pixels
Agriculture	4590 91.69 100.00	0 0.00 0.00	4590
Barren-Sparse vegetation	74 1.48 28.35	187 3.37 71.65	261
Freshwater forest	0 0.00 0.00	3511 63.35 100.00	3511
Grass	90 1.80 34.75	169 3.05 65.25	259
Scrub-Shrub	0 0.00 0.00	1675 30.22 100.00	1675
Urban builtup	252 5.03 100.00	0 0.00 0.00	252
Total	5006	5542	10548

Tests

N	DF	-LogLike	RSquare (U)
10548	5	6974.7877	0.9558

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	13949.58	<.0001*
Pearson	10099.86	<.0001*

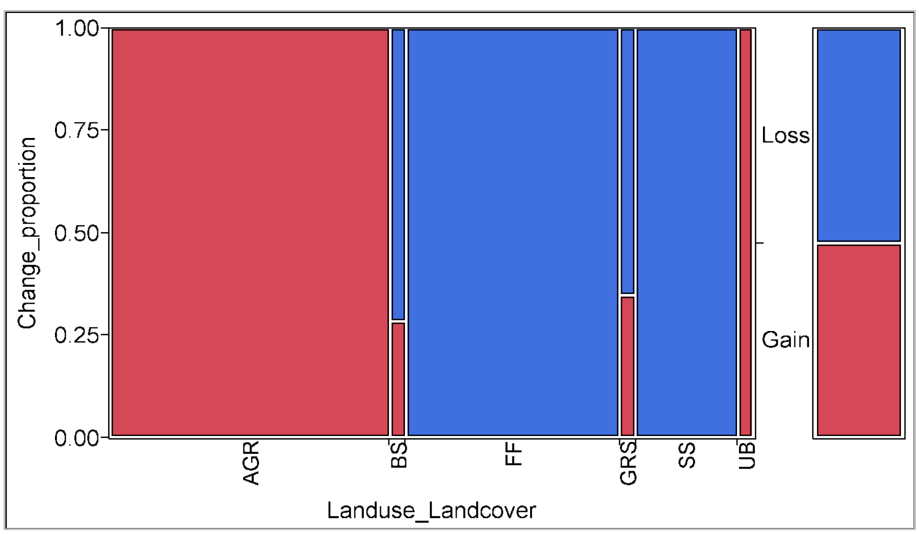
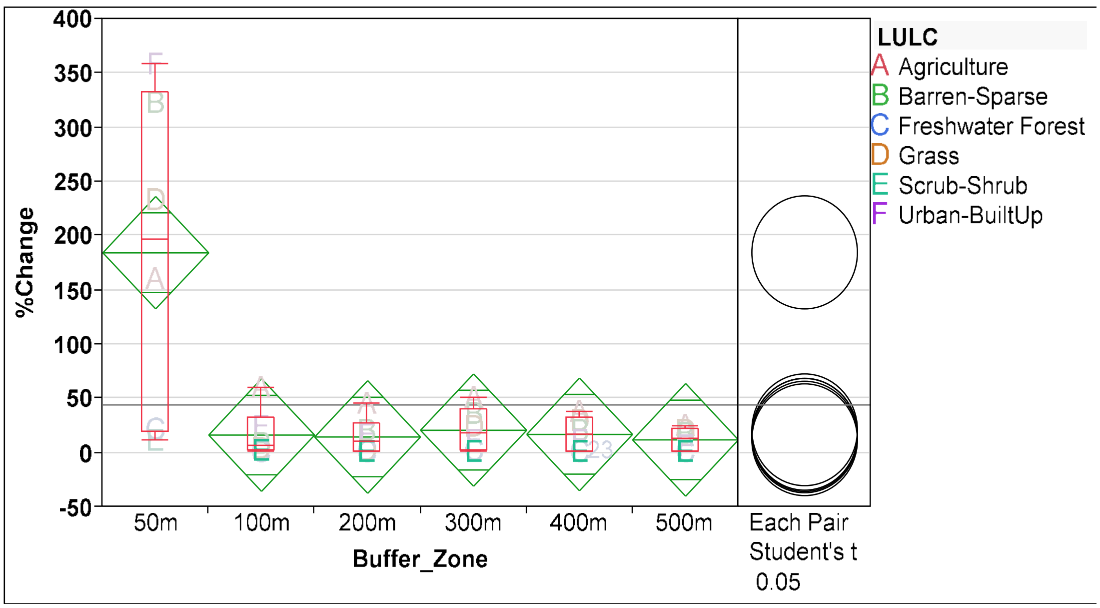


Fig. 3.2. Mosaic Plot of relative proportions of the percentage changes of the pixel count between 1987 and 2013 for each LULC (*AGR=agriculture; BS=Barren-Sparse; FF=Freshwater Forest; GRS= Grass; SS= Scrub-Shrub; UB= UrbanBuiltUp)*

Fig. 3.3 compares the percentage changes of LULC along the Riparian buffer distances of 50-500 meters. The buffer zones (100 m, 200 m, 300 m, 400 m and 500 m) have means diamonds that are close to the grand mean. Their overlapping confidence intervals show there is no significant difference ($p > 0.05$) in changes that occurred in these zones. In contrast, the differences in the mean of changes at 50 m show a significant difference ($p > 0.05$) in the zones from 100 m – 500 m. The boxplot of most of the data, except at 100 meters, is symmetrical, being split at the median in contrast to the data at 100 meters that is skewed right since most of the data is concentrated on the low end of the scale.

3.2 Riparian Reach Analysis

Figs. 3.4a and 3.4b to 3.9a and 3.9b show percentage changes, in LULC features, along a longitudinal gradient partitioned into 18 grids of 3 km^2. In Fig. 3.4, the percentage change in the agriculture category reclass on a scale of 1-5 indicates that 55% of grids in the upper, middle and lower reaches were observed with (high and extreme) changes being most significant at the middle reach.



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Level			Mean
50 m	A		184.50000
300 m		B	20.88333
400 m		B	16.96667
100 m		B	16.33333
200 m		B	14.60000
500 m		B	11.88333

Positive values show pairs of means that are significantly different.

Fig. 3.3. One way analysis of variance of percentage change of LULC between 1987 and 2013 within Riparian buffer zones (50 -500 meters)

In Figs. 3.5a and b, the percentage changes in the Barren/Sparse vegetation category reclass on a scale of 1-5 indicate that 40% of grids in the middle and lower reaches were the most with significant (high and extreme) changes.

In Figs. 3.6a and b, the percentage change between 1987 and 2013 in the freshwater forest reclass on a scale of 1-5 shows that 40% of grids in the upper and lower reaches were the most with significant (high and extreme) changes.

In Figs. 3.7a and b, the percentage changes between 1987 and 2013 in the Grass category reclass on a scale of 1-5 indicate that 51% of grids in the upper, middle and lower reaches were observed with significant (high and extreme) changes being most significant at the lower reach.

In Figs. 3.8a and b, the changes in the scrub-shrub reclass on a scale of 1-5 show that 34% of grids in the middle and lower reaches expressed the significant (high) changes.

In Figs. 3.9a and b, the percentage change in the urban category reclass on a scale of 1-5 shows that 45% of grids in the middle and lower reaches were the most with high and extreme changes.

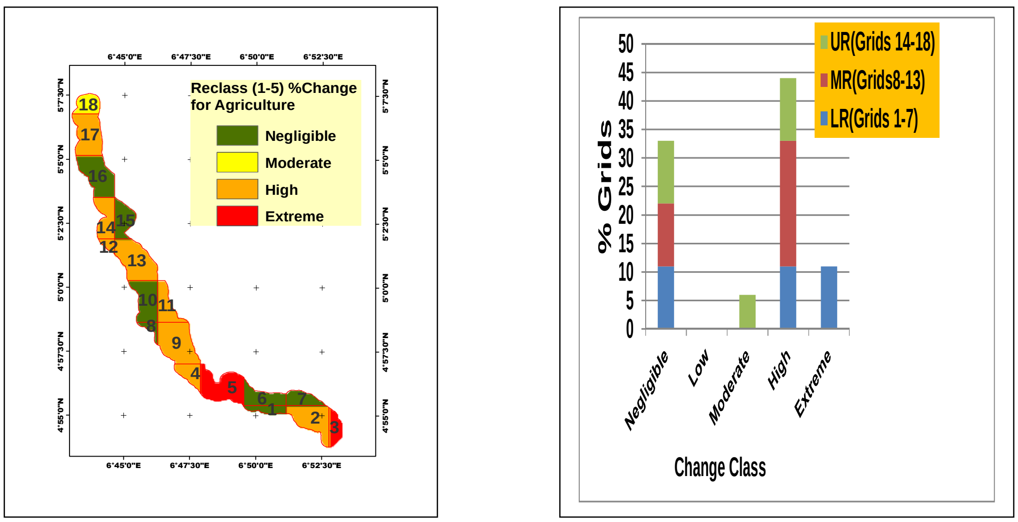


Fig. 3.4a and b. Reclass of percentage change of agriculture between the Riparian reaches (LR=Lower Reach; MR=Middle Reach; UR=Upper Reach)

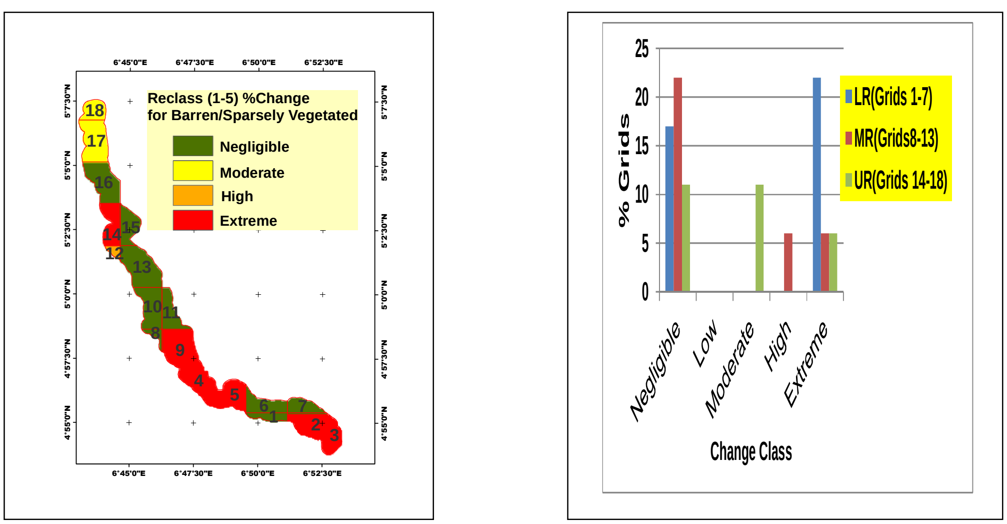
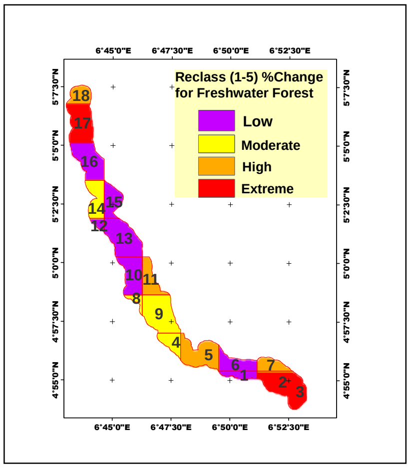


Fig. 3.5a and b. Reclass of percentage change of barren/sparse vegetation between the Riparian reaches (LR=Lower Reach; MR=Middle Reach; UR=Upper Reach)



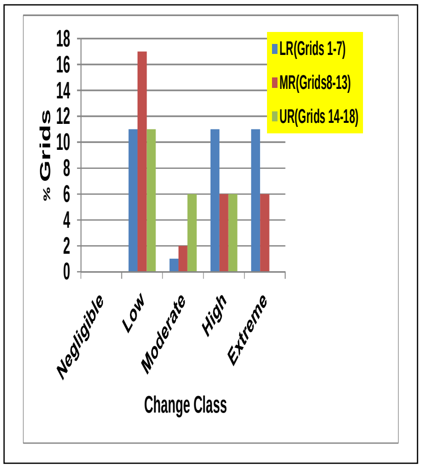
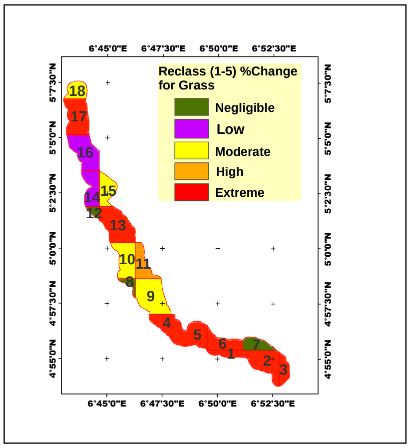


Fig. 3.6a and b. Reclass of percentage change of freshwater forest vegetation between the Riparian(LR=Lower Reach; MR=Middle Reach; UR=Upper Reach)



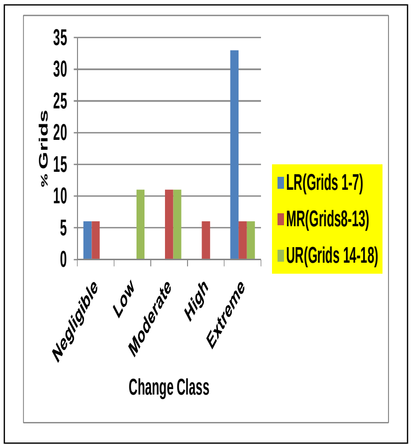
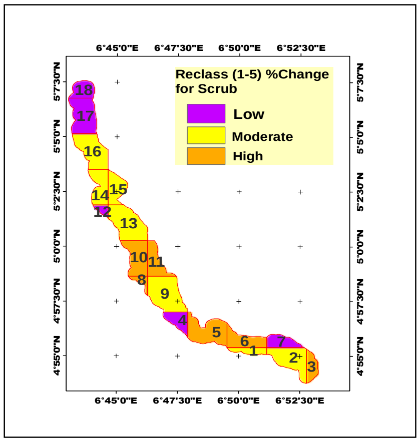


Fig. 3.7a and b. Reclass of percentage change of grass between the Riparian reaches (LR=Lower Reach; MR=Middle Reach; UR=Upper Reach)



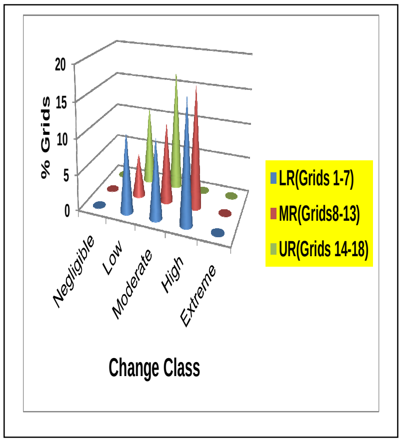


Fig. 3.8a and b. Reclass of percentage change of Scrub-Shrub vegetation between the Riparian reaches (LR=Lower Reach; MR=Middle Reach; UR=Upper Reach)

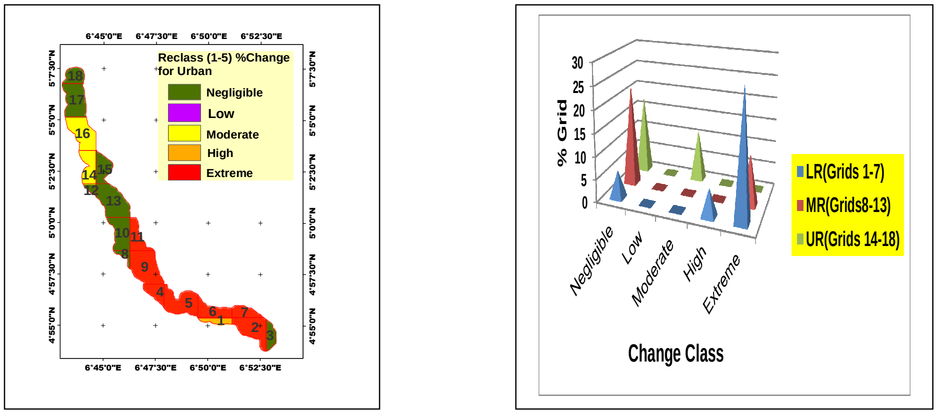


Fig. 3.9a and b. Reclass of percentage change of urban between the Riparian reaches (LR=Lower Reach; MR=Middle Reach; UR=Upper Reach)

4. COMPOSITE MODEL

Figs 4.0 and 4.1 show the results of the cumulative combination of the scaling coefficients of the LULC into a composite map. Fig. 4.0 shows the individual scaling coefficients of the individual LULC combined in an arithmetic averaging iteration to produce the composite map. Fig. 4.1a and 4.1b show that the cumulative composite model identified 33% of the grids to be of high and extreme value change coefficients. Similarly 33% of grids were of Moderate hotspots of change coefficients. The Low change category occurred in 28% of the analysis grid and 2% consisted of the Negligible change category.

Fig. 4.2 is the mosaic plot showing the categorical distribution of the percentage change of LULC features along the longitudinal gradient of the riparian reaches (lower, middle and upper). The mosaic plot which is explained by the Contingency Table 2.0 shows that 100% of the grids accounting for percentage change in Extreme values were in the lower reach of the riparian corridor. This was followed by a 66.67% High change category at the middle reach while the Moderate change category occurred equally at 50% at the Lower and Upper reaches. A significant value of 80% in the Low change category occurred in the Middle reach. The Negligible change category occurred at 100% at the Middle reach. There is strong evidence of the difference (p = 0.0382) in the proportion of percentage change that accounted for Extreme, High and Moderate change categories between the Lower Reach the Middle and Upper Reaches.

Table 2.0. Contingency analysis for proportion of change by Riparian reach zone

Count Col % Row %	Extreme	High	Moderate	Low	Negligible	Grid
Lower Reach	3	1	3	0	0	7
	100.00	33.33	50.00	0.00	0.00	
	42.86	14.29	42.86	0.00	0.00	
Middle Reach	0	2	0	4	1	7
	0.00	66.67	0.00	80.00	100.00	
	0.00	28.57	0.00	57.14	14.29	
Upper Reach	0	0	3	1	0	4
	0.00	0.00	50.00	20.00	0.00	
	0.00	0.00	75.00	25.00	0.00	
Total Grids	3	3	6	5	1	18

Tests

N	DF	-LogLike	RSquare (U)
18	8	10.668334	0.4005

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	21.337	0.0063
Pearson	16.307	0.0382

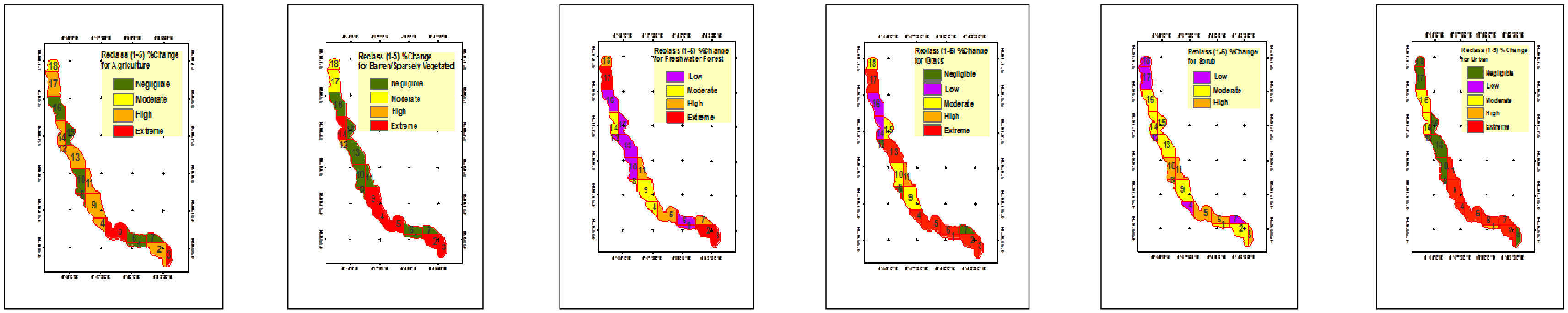


Fig. 4.0. Reclass scaling coefficients of agriculture, barren/sparsely vegetated, freshwater forest, grass, scrub-shrub and urban-built-up

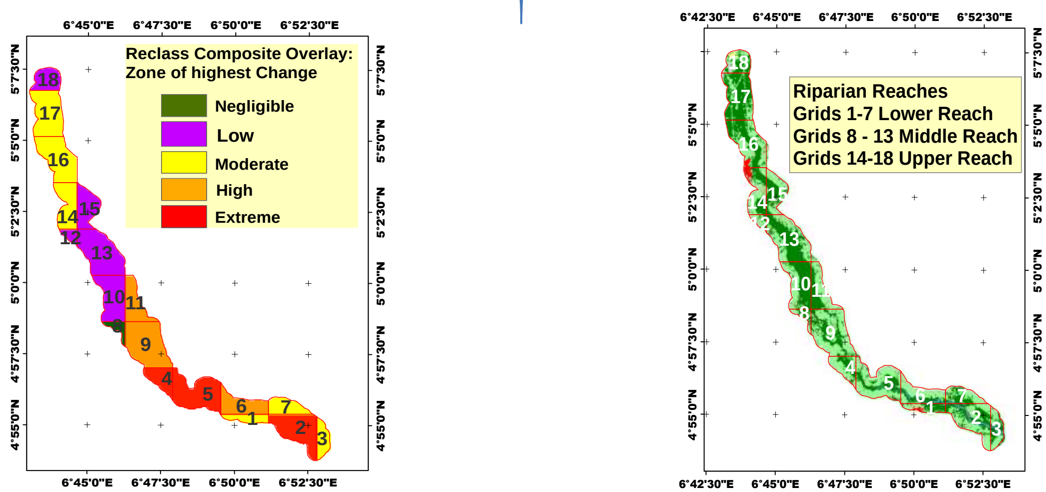


Fig. 4.1a and b. Composite surface map of percentage change containing the arithmetic average of scaling coefficients of LULC classes (Agriculture, Barren/Sparse, Freshwater forest, Grass, Scrub, and Urban)

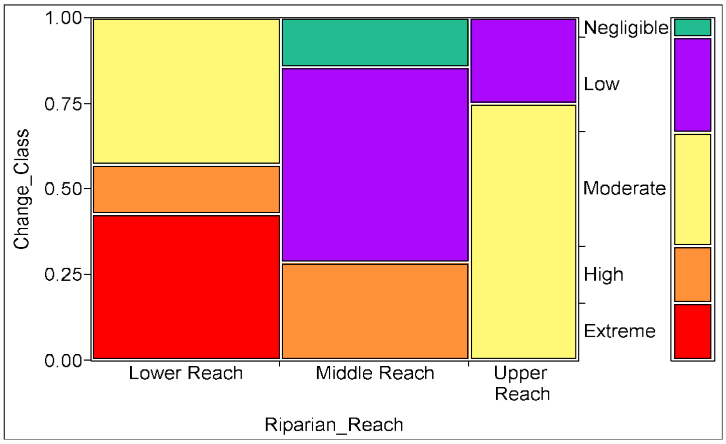


Fig. 4.2. Contingency analysis of composite change by Riparian reach zones

5. DISCUSSION

The study shows evidence of changes in LULC between 1987 and 2013 with significant differences along the lateral sections of the Riparian buffer and its longitudinal Reach sections. Along the lateral sections, the study showed that the categories of landuse and landcover such as Urban Built-up, Barren/ Sparse, Grass and Agriculture, in the following order, experienced greater conversion mostly within 50 meters buffer of the riparian forest. However, beyond 50 meters of the core riparian forest, Agriculture maintained more than any other landuse and landcover category with an increase of above 40% at 100 m, 200 meters and 300 meters. In contrast to the gain in agriculture and urban built-up, the complete loss of freshwater forest occurred throughout the lateral zones of the riparian buffer being highest at 50 meters where 22% representing 408 hectares were lost.

The loss of freshwater forest at 50 meters is significant due to the loss in function of creating complex edge habitats that are highly beneficial for many wildlife species [11,12,13,14,15,16]. Documented evidence shows that variability is greater along the riparian edge when compared to interior sites [17,18,9,19,20,21,22]. The replacement of the freshwater forest by agricultural and Grass LULC categories offers a mixture of advantages and disadvantages to riparian habitat and ecological stability. Agriculture is documented to impact the ecological value services of riparian forest in a number of ways. Research shows that changes in vegetation lead to a loss of hydrological function leading to rain splash, overland flow and stream bank erosion [23]. However, the combination of riparian agriculture-grassland edge offers the advantages of creating likely new habitats that can introduce new species of birds different from those that use riparian freshwater forest vegetation [24,25]. Documented evidence also shows that new food sources from agricultural crops and mosaic of habitat conditions provided by a combination of grass, herbs and shrubs promote a variety of wildlife [26,27,28,29,30,31].

These effects and impacts will most likely occur at the middle and lower reaches where 33% of the grid based composite model shows evidence of high and extreme value coefficients. The Moderate hotspots of change which also constitute 33% of the total analysis grid were shown to be at the upper and lower reach zones of the riparian study area.

Overall, the long term fluctuations in the landuse and landcover changes from 1987 to 2013 are indicative of patterns found elsewhere [6,32,33,34,35,36,37]. In this study, the identification of overall change along the entire riparian corridor and the locations of significant areas of change provide elements of specific information to be considered for priority setting in policy and in developing a management plan. The lack of any guidance of law or policy or lack of enforcement is demonstrated by the unregulated ways in which many stakeholders especially sand mining groups and associated infrastructure occupy the buffer areas of this riparian corridor. The current unregulated continuity has implications from threats posed by climate change to biodiversity as well as to other riparian services such as flood control and water delivery. The study provides a path to developing policy and management objectives. By quantifying the geographic variation of riparian LULC over time, the study provides an empirical change model that can be used to engage with decision makers on policy and management objectives.

6. CONCLUSION

The study analyzed changes in the freshwater section of the Riparian corridor using satellite imagery from 1987 and 2013. The study used buffer intervals of 50 meters, 100 meters, 200 meters, 300 meters, 400 meters and 500 meters to evaluate lateral changes throughout the 30 kilometer riparian corridor. Over the span of 26 years (1987 -2013), two dominant landuse types increased significantly namely, Agriculture (24%-160%) and Urban-Builtup (24%-358%) while Freshwater Forest decreased significantly (0.6-22%) within this period. A spatial analysis modeling of the scaling coefficients of the LULC provided isolation of composite locations (middle and lower reaches) where unusual changes occurred along the riparian corridor. By understanding how lateral and longitudinal changes contribute to riparian ecosystem resiliency, decision makers can develop new strategies that can effectively respond to challenges unique to this section of the New Calabar River.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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