Spatial Modeling of Fire-Induced Carbon Emission in Tropical Forests: A Case Study of Afram Head Waters Forest Reserve, Ghana

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INTRODUCTION

- Tropical forests are a major reservoir of global terrestrial carbon, and thus play an essential role in the carbon cycle. However, the alarming rate of deforestation and degradation in recent times is changing the status of tropical forests in the global carbon-climate regime.

- These cover changes ultimately result in carbon emission into the atmosphere, thereby distorting the balance and stability of the climate system.

- It is estimated that tropical forest cover changes currently account for 20 - 25% of all anthropogenic global carbon emissions. Various factors are responsible for forest cover changes in the tropics; key among them is natural or human-caused forest fire.

INTRODUCTION

- However, fire does not only reduce the forest, but also implies that more carbon remain in the atmosphere because they are not sequestered. More importantly, large amounts of carbon held in the forest biomass are released into the atmosphere when the trees are burned.

- Fire is an important regulatory factor in many ecosystems. Therefore, controlling or even preventing tropical forest fires will significantly reduce global carbon emissions.

- Unfortunately, Ghana's tropical forest is not spared from this phenomenon. The high forest zone of Ghana experienced no fire until the early 1980s when wildfire swept through most of the nation's forest.

INTRODUCTION

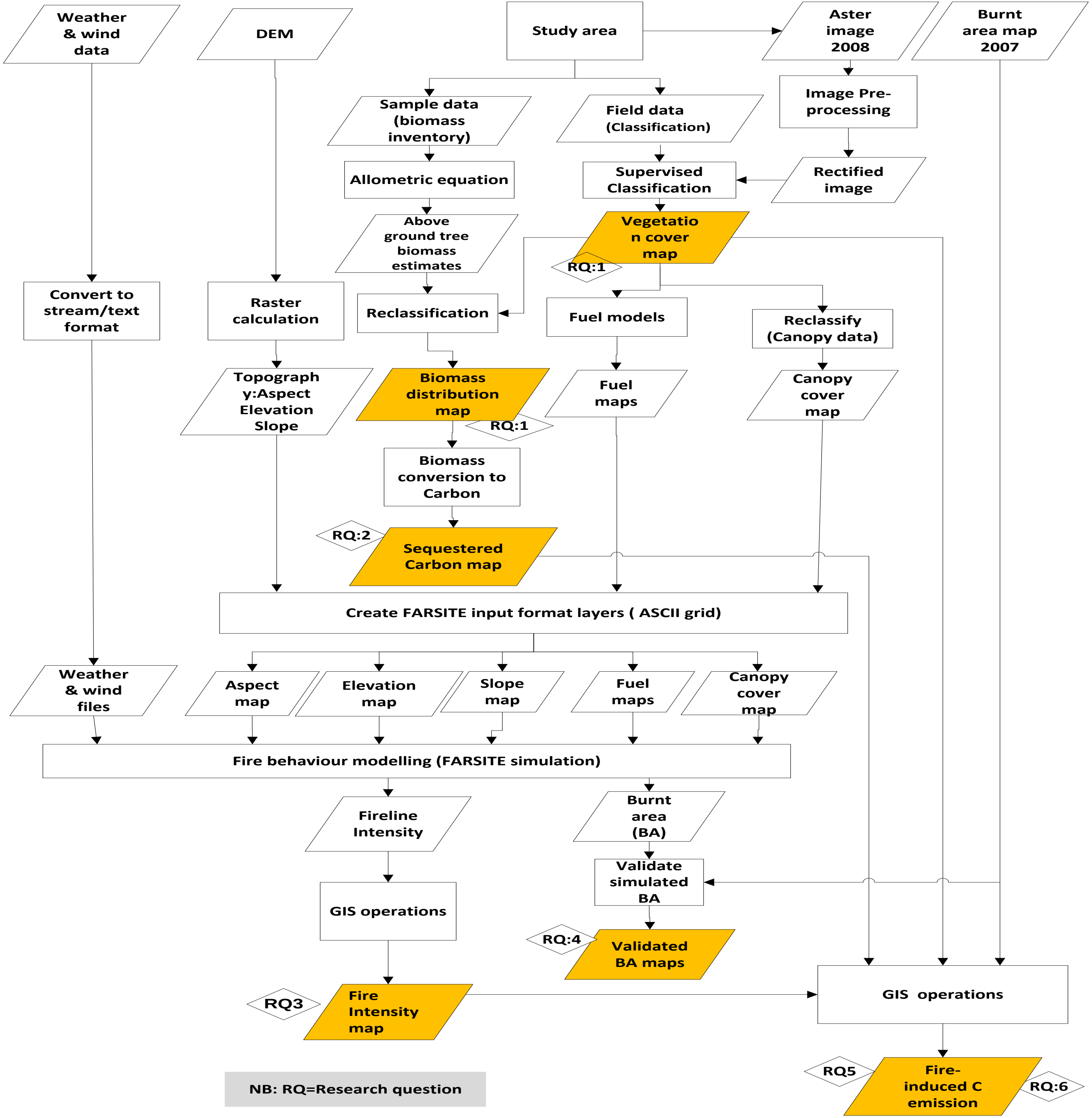
- **Since then wildfire has become an annual phenomenon and continue to plague large areas of the countries dwindling forests.**
- **Quantifying gaseous emissions from fires constitute a significant concern, both environmentally and politically, within the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol.**
- **Estimation of fire-induced carbon emission from Ghana’s tropical forest will make an essential contribution in addressing Ghana’s commitment to the UNFCCC.**

INTRODUCTION

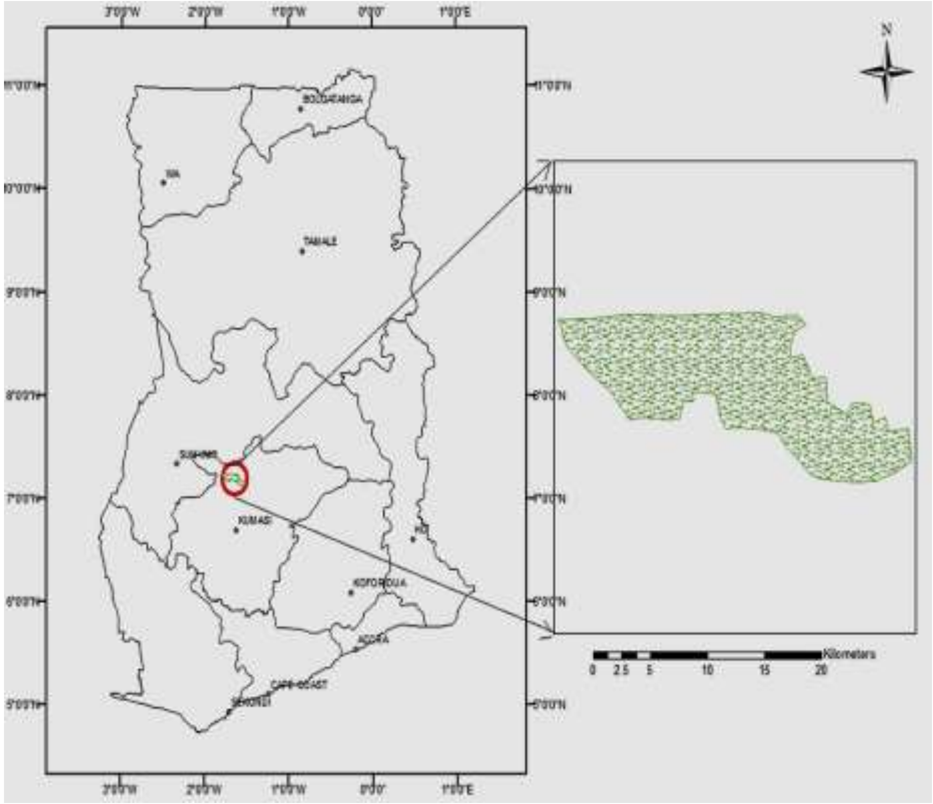
- Estimation of carbon emission from wildfires is crucial for improving our understanding of the climate - carbon cycle dynamics.
- Forest fires burn a variety of fuel depending weather conditions and topography of the burnt area.
- This results in enormous spatial and temporal variations in burnt fuel, which are directly related to carbon emissions.
- Therefore, modeling fire behavior accurately can give a good estimation of fire-induced carbon emission.

OBJECTIVE

The main focus of this research was to model tropical forest fire behavior and study the influence of forest condition, topography and weather on the severity of fire and consequently on carbon emission.


Weather & wind data
DEM
Study area
Aster image 2008
Burnt area map 2007
Sample data (biomass inventory)
Field data (Classification)
Image Pre-processing
Allometric equation
Supervised Classification
Rectified image
Above ground tree biomass estimates
Vegetatio n cover map
RQ:1
Convert to stream/text format
Raster calculation
Reclassification
Fuel models
Reclassify (Canopy data)
Topograph y:Aspect Elevation Slope
Biomass distribution map
RQ:1
Fuel maps
Canopy cover map
Biomass conversion to Carbon
RQ:2
Sequestered Carbon map
Create FARSITE input format layers (ASCII grid)
Weather & wind files
Aspect map
Elevation map
Slope map
Fuel maps
Canopy cover map
Fire behaviour modelling (FARSITE simulation)
Fireline Intensity
Burnt area (BA)
Validate simulated BA
GIS operations
RQ:4
Validated BA maps
RQ3
Fire Intensity map
GIS operations
RQ5
Fire-induced C emission
RQ:6
NB: RQ=Research question

Afram Headwaters Forest Reserve
Offinso Forest District in the Ashanti region of Ghana



Forest Reserve covers an area of 20,100 hectares. The area is categorized under the Dry Semi-deciduous forest Fire Zone subtype (DSFZ).

Study Area

Nature Forest





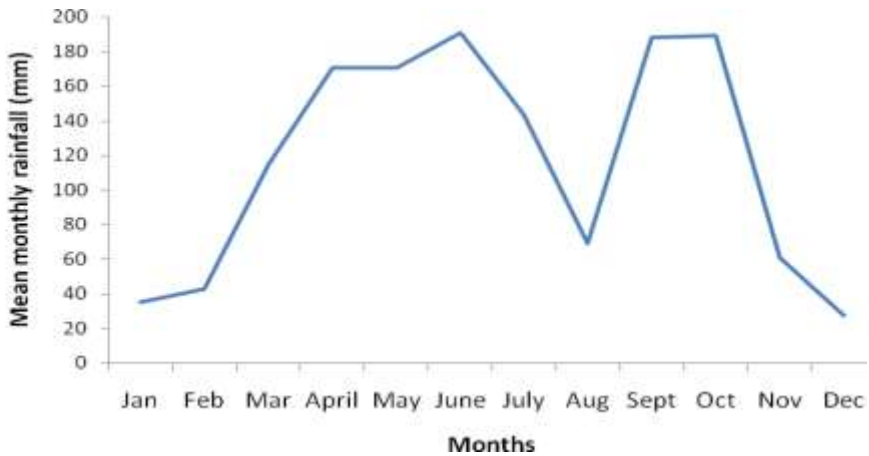
Plantation

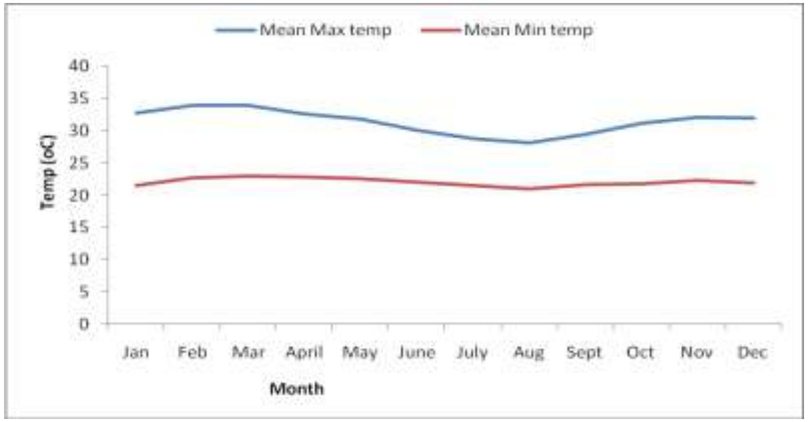
- monoculture of exotic tree species such as cedrela (Cedrela odorata) and teak (Tectona grandis)
- mixed stands of local tree species khaya grandifoliola (mahogany), Ceiba pentandra (ceiba), Terminalia ivorensis (emire), Terminalia superb (ofram)

Agro- forestry

- taungya system with teak, crops and scatter trees
- main crops: yam, cocoyam, maize, cassava, plantain, okro, palm trees

CLIMATE


Mean monthly rainfall (mm)
200
180
160
140
120
100
80
60
40
20
0
Jan Feb Mar April May June July Aug Sept Oct Nov Dec
Months


Mean Max temp
Mean Min temp
Temp (oC)
40
35
30
25
20
15
10
5
0
Jan Feb Mar April May June July Aug Sept Oct Nov Dec
Month

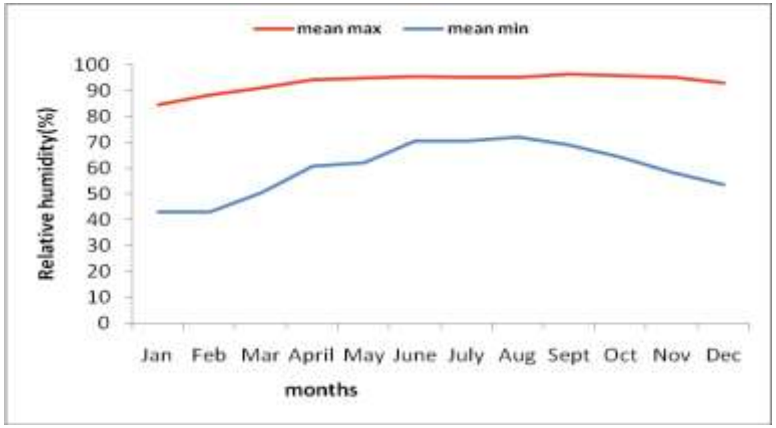

mean max
mean min
Relative humidity(%)
100
90
80
70
60
50
40
30
20
10
0
Jan Feb Mar April May June July Aug Sept Oct Nov Dec
months

Table 1: Inputs used in FARSITE simulation

Input type	Input	Usage
Landscape (GIS layers)	Latitude	Along with slope and aspect for determining angle of incident solar radiation
	Canopy cover map	Used to determine shading of surface fuels which influence fuel moisture computations and wind reduction
	Fuel map	Describes the surface fuel complex
	Vegetation map	Describes the vegetation cover
	Elevation map	For adiabatic adjustment of temperature and humidity
	Slope map	For computation of direct effect of fire spread
	Aspect map	Together with slope and latitute to determine angle of incident solar radiation
Climate	Temperature	Influences fuel moisture
	Wind speed and direction	Influence fire spread
	Relative humidity	Affects moisture conditions and rate of spread
	Precipitation	

Adopted and modified from Carmel et al. (2009) and Finney (2004)

Fire-induced carbon emission modelling

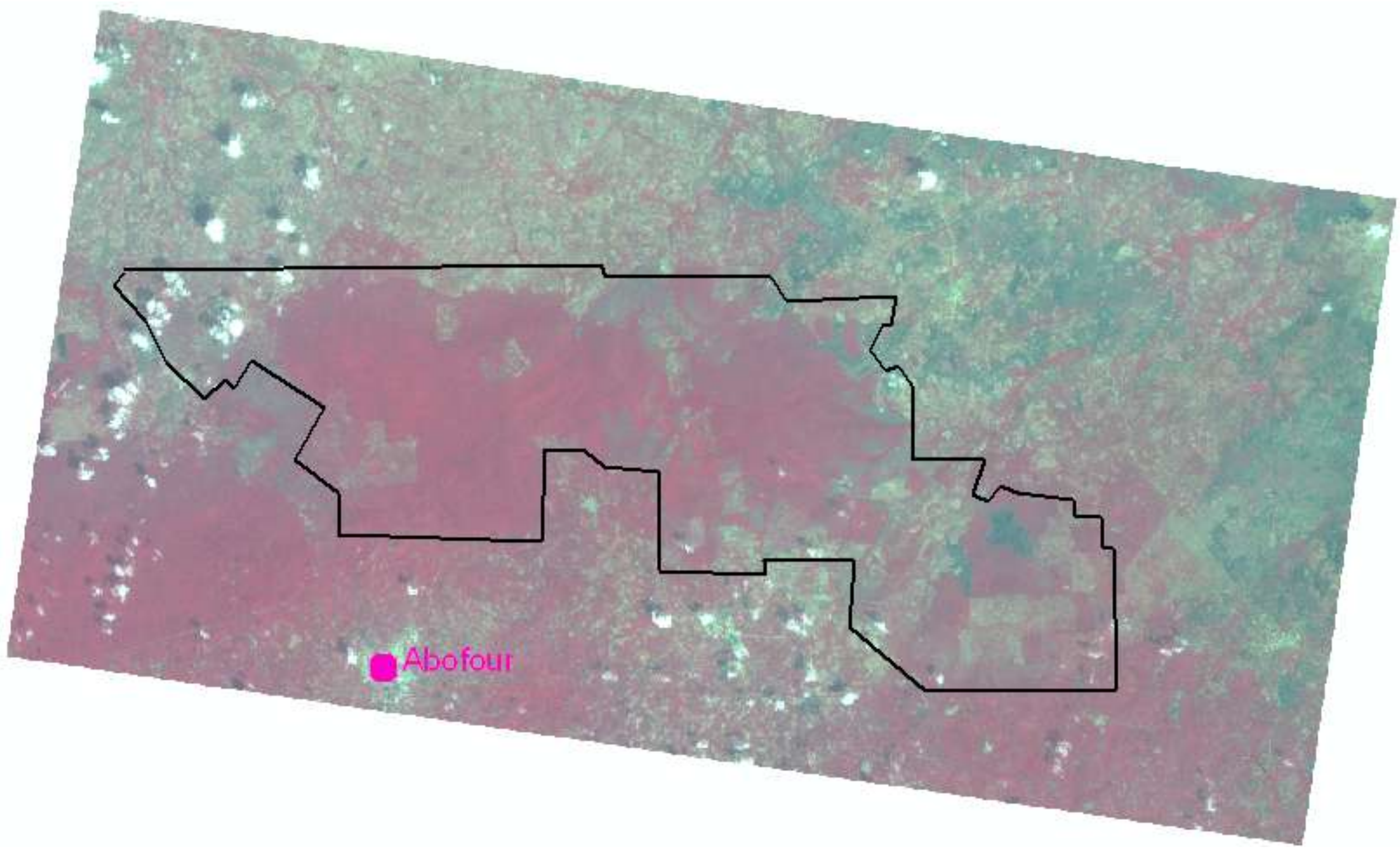
The total carbon released (C_t) from burning of biomass was estimated using the equation by Seiler & Crutzen (1980).

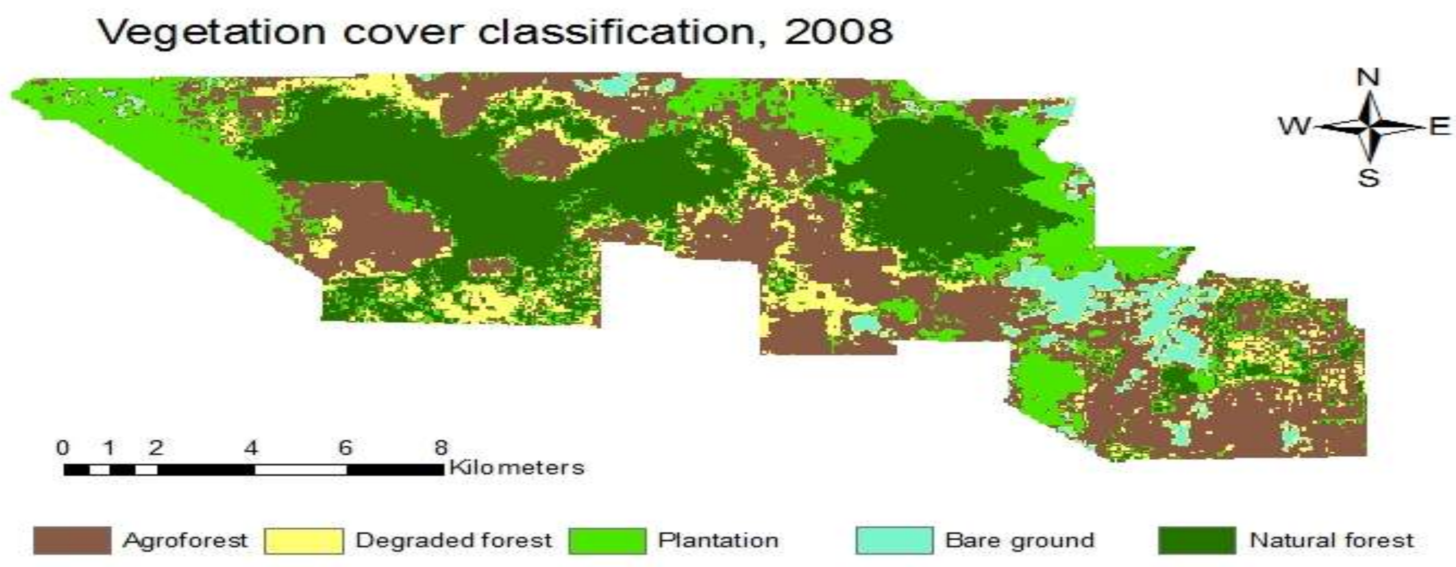
Equation for estimation of C emission from fire:

$$C_t = AB\mathit{fc}\beta$$

Where A is the area burnt (ha, from burnt area map),
B is the biomass density ($Mg.ha^{-1}$ from field biomass data),
fc is the carbon fraction of the biomass (0.5), and
β is the fraction of biomass consumed or combustion efficiency during biomass burning.

Aster Image of 24 February 2008





Cover type	Description
Natural Forest	Forested areas showing characteristics of the original natural vegetation cover of mixed tree species
Plantation	Forest plantations of made up of Teak monoculture
Agroforest/Farm	Young forest plantations of 1-4 years, interplanted with food crops through the *Taungya* system. Large areas are occupied with grasses.
Degraded forest	Degraded forest portions with isolated trees and low canopy cover. Most areas are occupied by the invasive tree species *Broussonetia papyrifera*. The shrub layer is dominated by the highly combustible invasive shrub *Chromolaena odorata*. Grass such as *Pennisetum spp*, *Panicum maximum* are present.
Bare ground	Includes areas of exposed soil surface, settlements and rocky areas

Classification Accuracy

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy	Kappa
Forest	41	35	32	78.05%	91.43%	0.87
Plantation	27	31	23	85.19%	74.19%	0.67
Agro-forest/Farm	20	28	16	80.00%	57.14%	0.49
Degraded forest	24	20	16	66.67%	80.00%	0.75
Bare	11	9	9	81.82%	100.00%	1.00
Totals	123	123	96			
Overall Classification Accuracy				78.1%		
Overall Kappa Statistics				0.72		

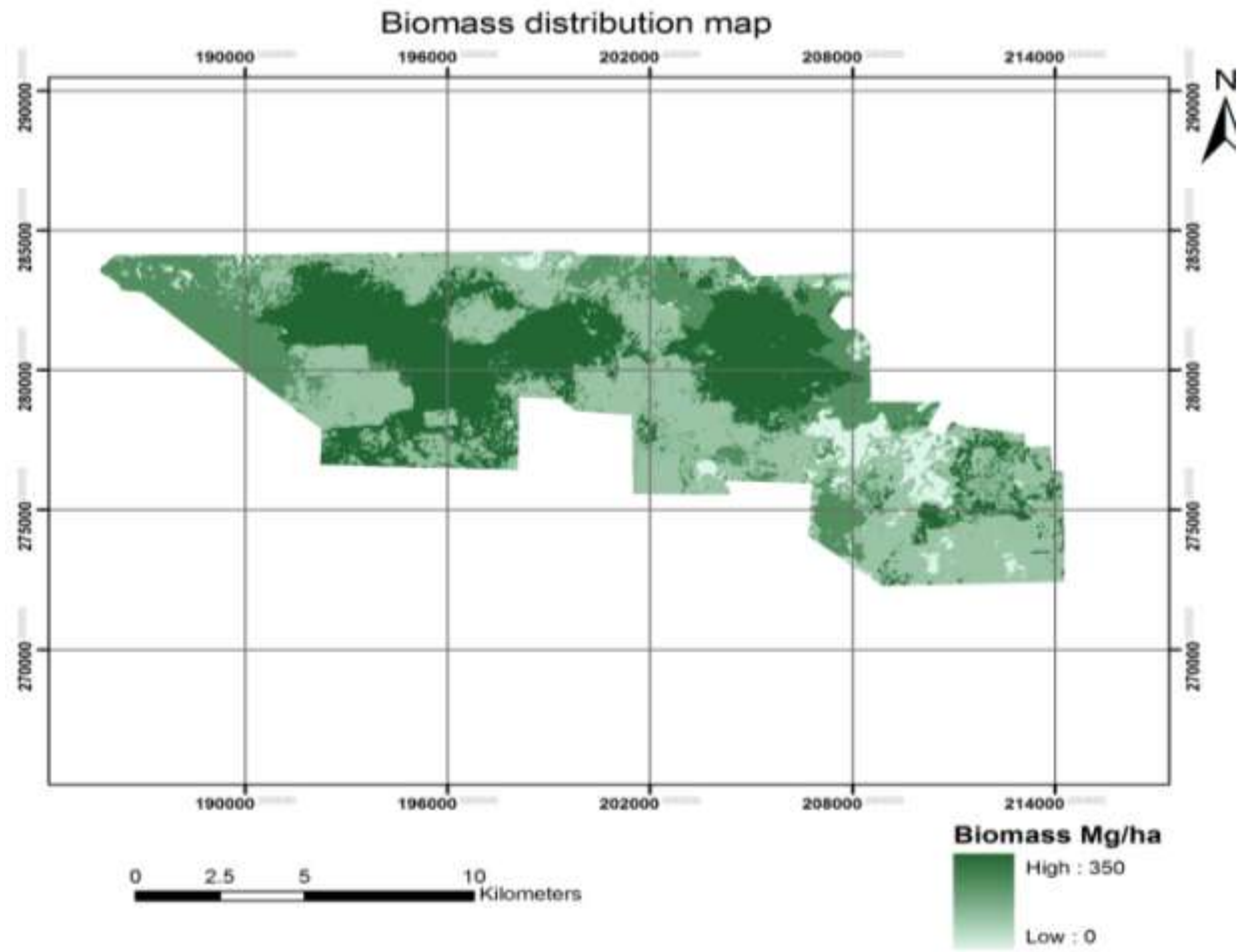


Table 8: Forest cover types and aboveground live tree biomass stocks

Cover type	Area (ha)	Percent area (%)	Mean AGB* (Mg.ha^{-1})	Total AGB* (G g)	Percentage of total biomass (%)
Natural forest	5,724	32.5	349.6	2,001.2	54.3
Plantation	3,446	19.5	240.8	829.6	22.5
Agro-forest	5,794	32.9	107.8	624.4	16.9
Degraded forest	1,808	10.3	127.8	231.1	6.3
Bare ground	854	4.8	-	-	-
Total area	17,626	100		3,686	100

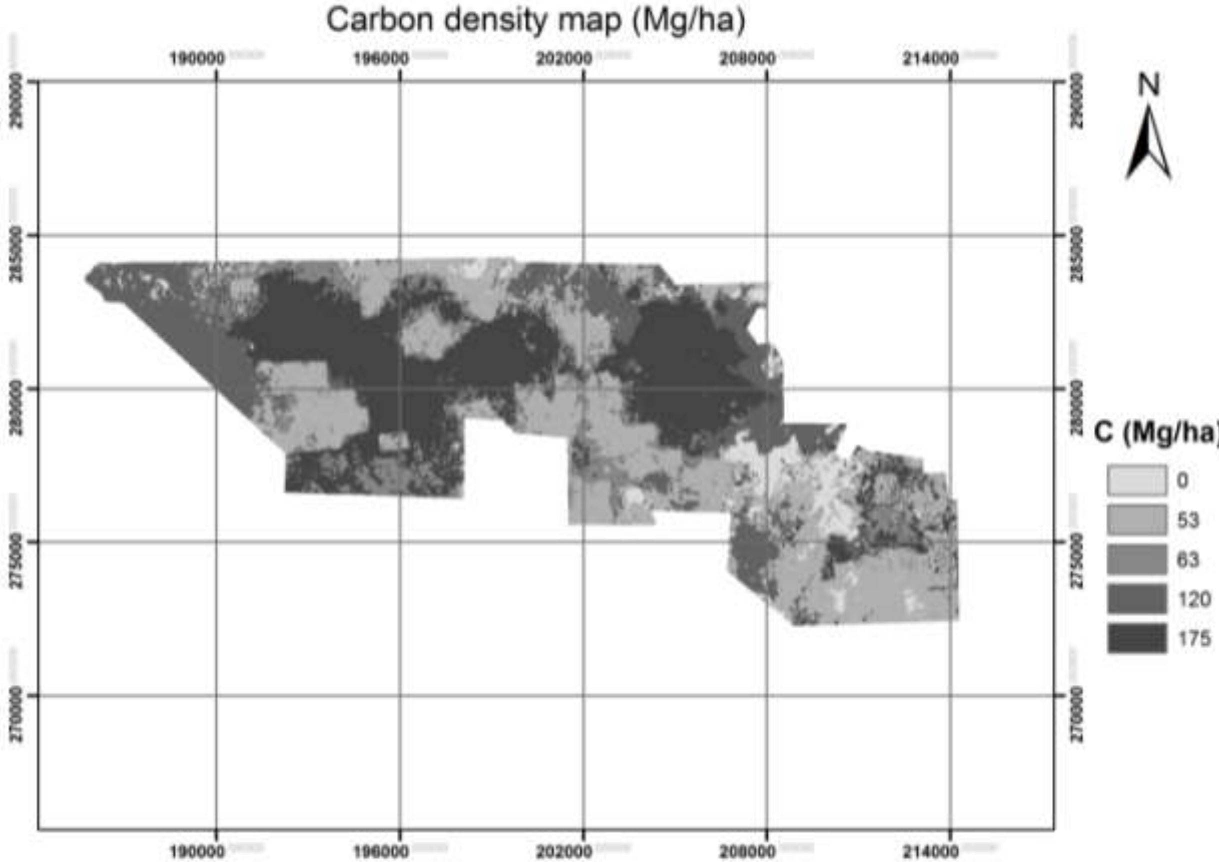


Table 10: Mean Carbon densities and total sequestered carbon in the cover types

Cover type	Area (ha)	Average aboveground Carbon stock (Mg.ha-1)			Total sequestered C (G g)	Percentage of sequestered C (%)
		Live trees	Herbaceous plants & litter	Total AGB Carbon		
Natural forest	5,724	171.2	3.6	174.8 ± 36	1,000.6	54.3
Plantation	3,446	117.9	2.5	120.4 ± 42	414.8	22.5
Agro-forest/Farm	5,794	52.4	1.5	53.9 ± 14	312.	16.9
Degraded forest	1,808	59.7	4.2	63.9 ± 13	115.5	6.3
Bare ground	854	-	-	-	-	-
Total area	17,626				1,843.1	100

AGB = aboveground biomass

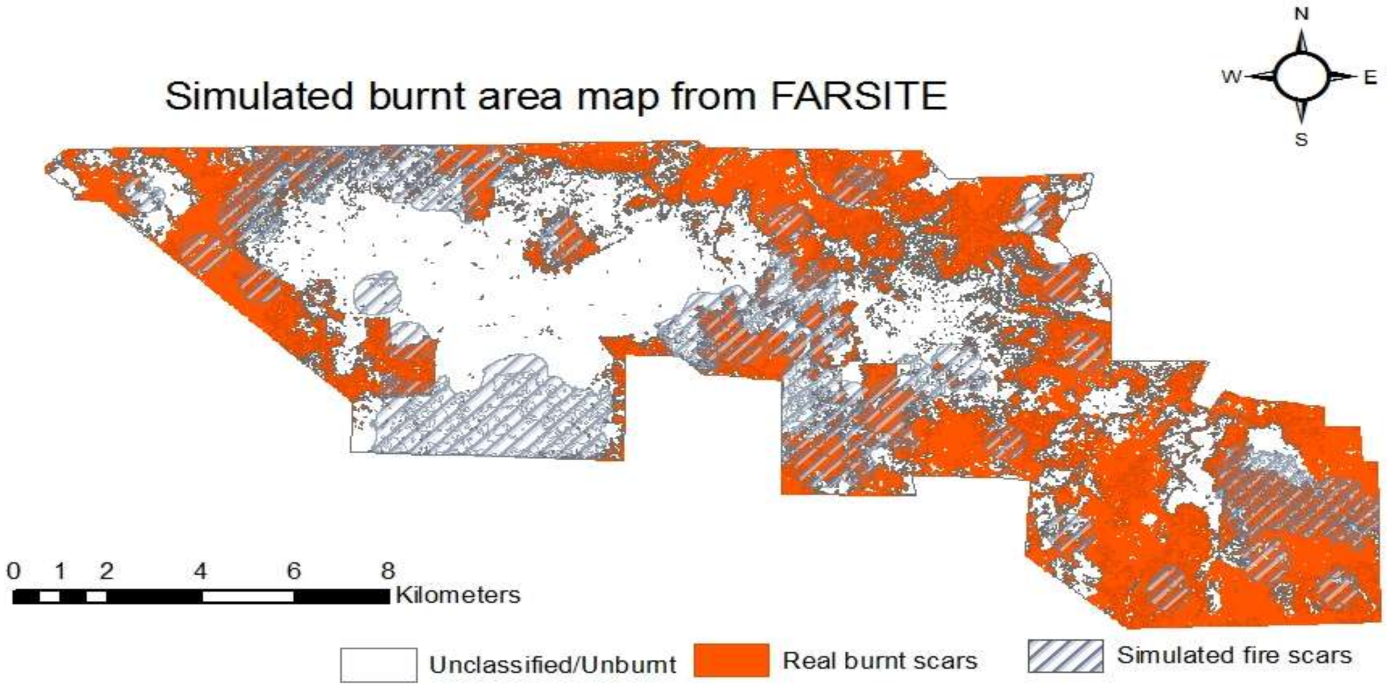
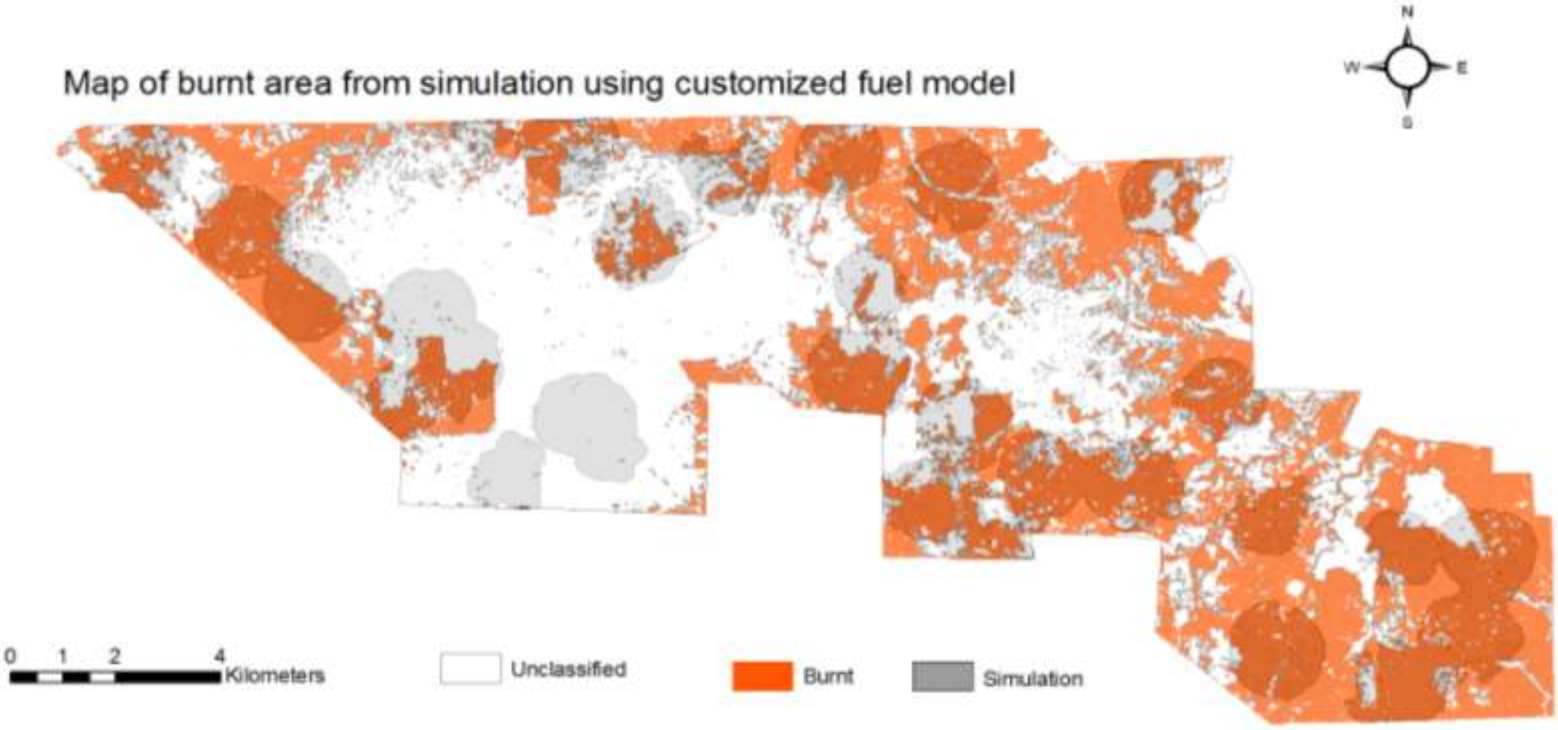
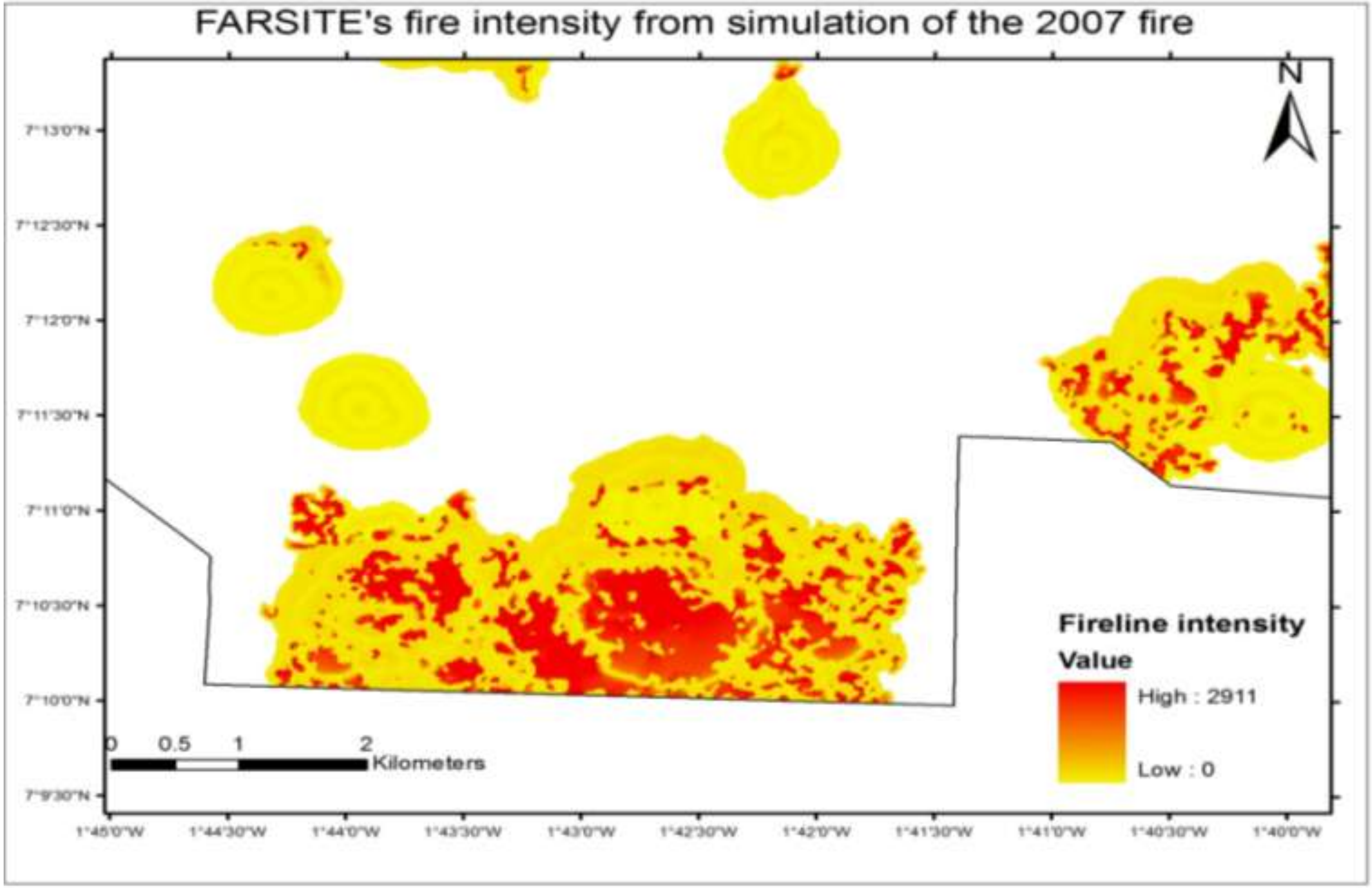


Table 12: Results of burnt area by real fires and FARSITE simulation using standard fuel models

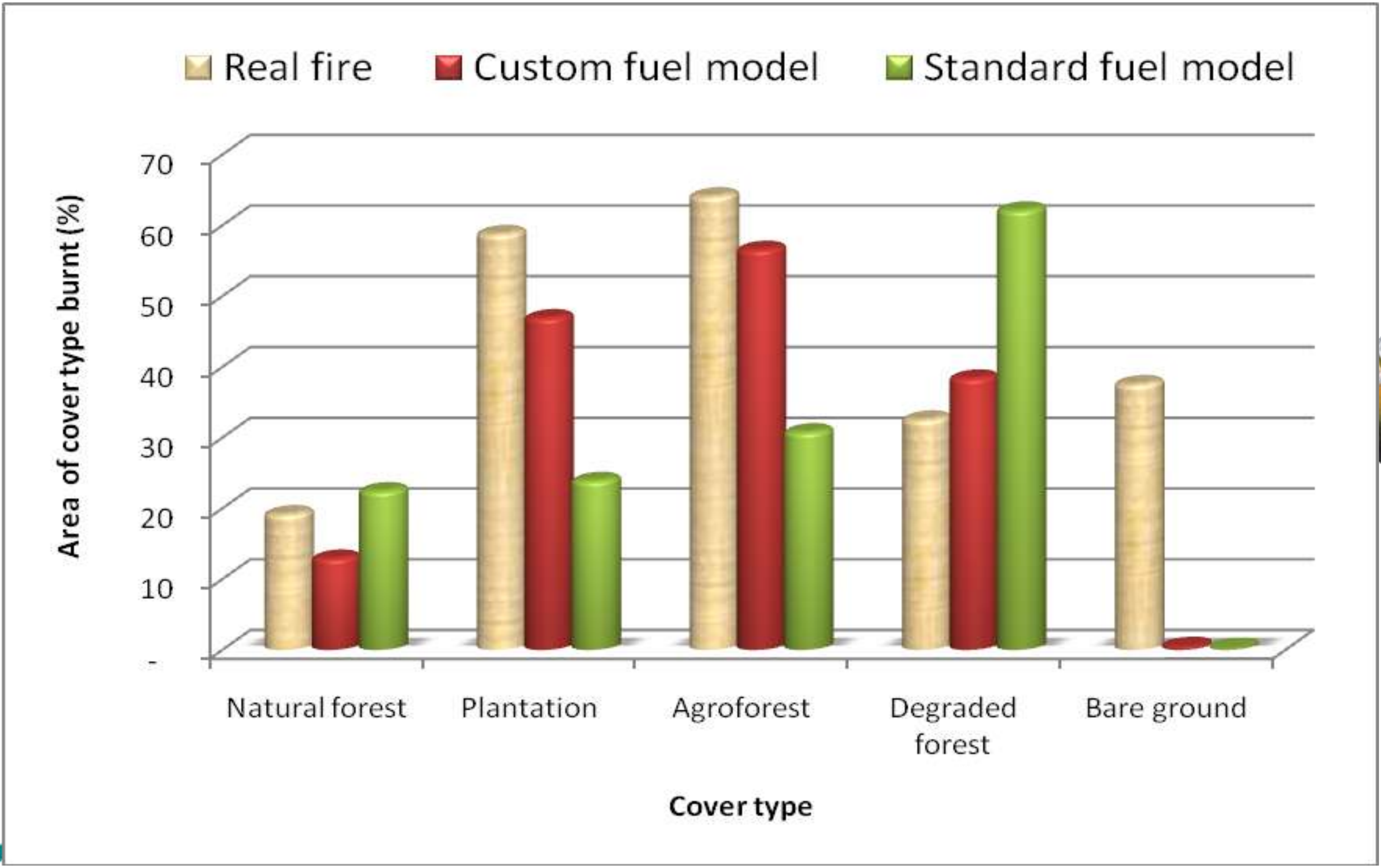
Fuel model	Cover type	Total area (ha)	Area burnt (ha)		Percentage cover burnt (%)	
			Real scar	Simulation	Real	Simulation
10	Natural forest	5,724	1,099	1,285	19	22
9	Plantation	3,446	2,027	824	59	24
5	Agro-forest	5,794	3,717	1,784	64	31
4	Degraded forest	1,808	589	1,124	33	62
99	Bare ground	854	321	2	38	0
	Total area	17,626	7,754	5,018	44	28

Map of burnt area from simulation using customized fuel model




FARSITE's fire intensity from simulation of the 2007 fire
N
Fireline intensity
Value
High : 2911
Low : 0
0 0.5 1 2
Kilometers
7°13'0"N
7°12'30"N
7°12'0"N
7°11'30"N
7°11'0"N
7°10'30"N
7°10'0"N
7°9'30"N
1°45'0"W
1°44'30"W
1°44'0"W
1°43'30"W
1°43'0"W
1°42'30"W
1°42'0"W
1°41'30"W
1°41'0"W
1°40'30"W
1°40'0"W

Comparison of cover type burnt using standard and custom fuel models



Modelling of fire-induced carbon emission

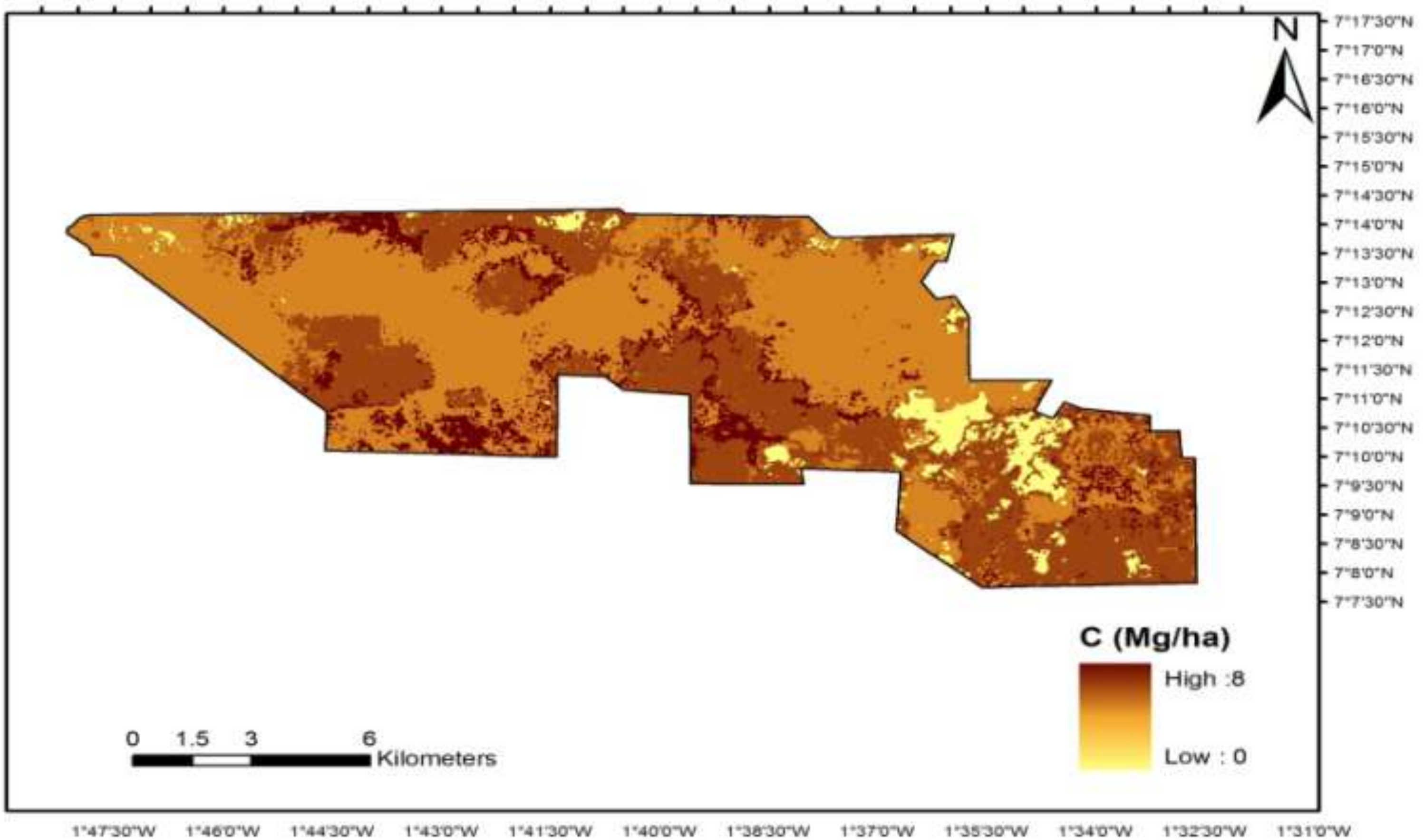
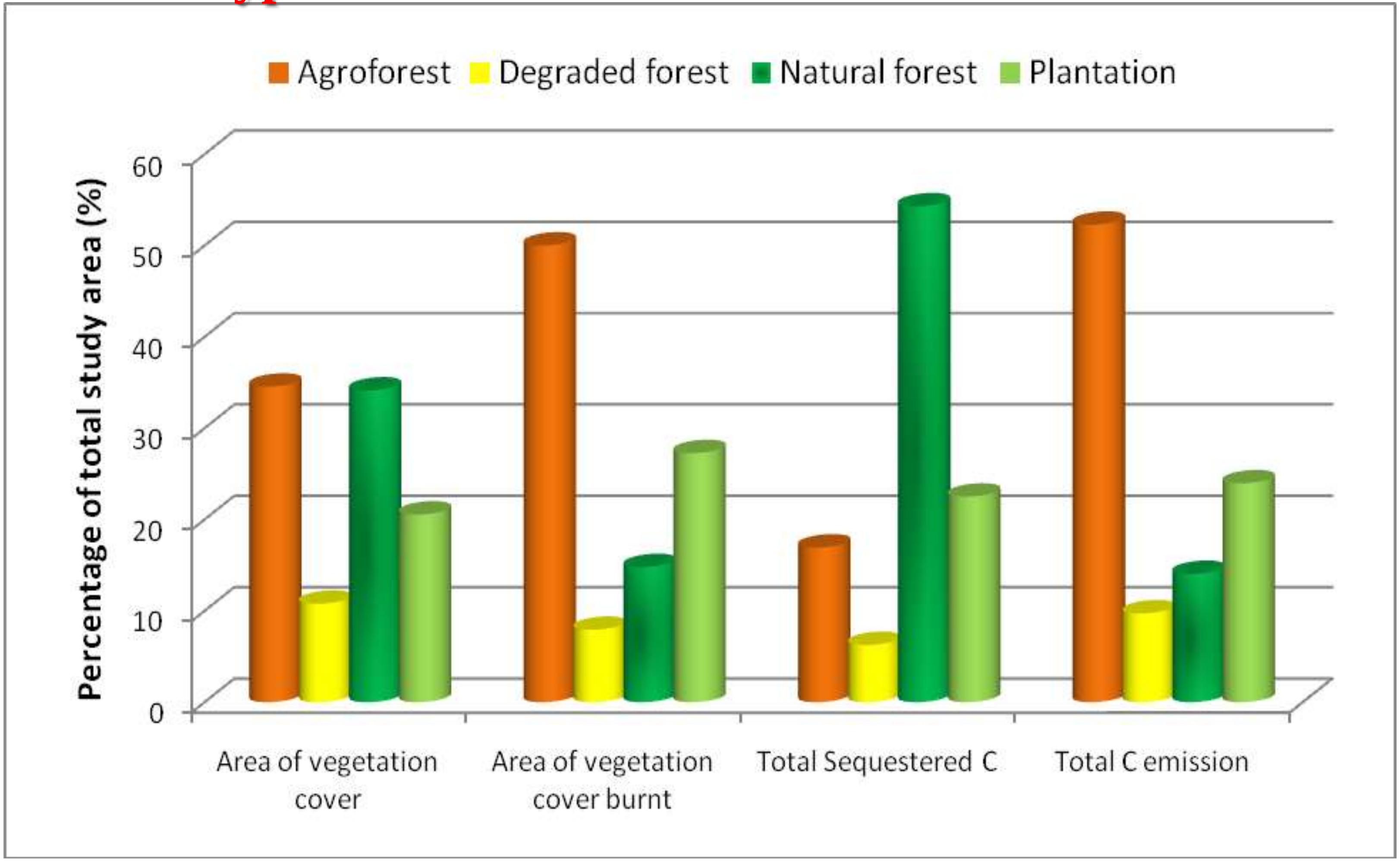


Table 14: Estimates of fire-induced carbon during the 2007 forest fire

Cover type	Mean fire-induced C emitted (Mg/ha)	Total C emission	Portion of Sequestered C emitted
	(Mg/ha)	(Gg)	(%)
Agroforest	6.5	24.2	7.7
Degraded forest	7.6	4.5	3.9
Natural forest	5.9	6.5	0.6
Plantation	5.5	11.1	2.7
Grand Total		46.2	2.5

Pattern of burnt covers and C emission in different cover types



CONCLUSIONS

What are the forest cover types in the study area and their aboveground biomass stocks?

Four forest cover types (natural forest, plantation, agro-forest and degraded forest) were identified along with bare ground.

Natural forest had 349.6 Mg.ha^{-1}; plantation 240.8 Mg.ha^{-1}; degraded forest 127.8 Mg.ha^{-1} and agro-forest 107.8 Mg.ha^{-1}

Total living aboveground biomass amounted to 3,686 Gg dry matters.

What are the aboveground carbon densities of the forest cover types; and the total sequestered carbon of the study area?

Natural forest recorded the highest C density of 174.8   36 Mg.ha^{-1}, followed by plantation with 120.4   42 Mg.ha^{-1}, degraded forest 63.9   13 Mg.ha^{-1} and agro-forest 53.9   14 Mg.ha^{-1} C.

CONCLUSIONS

Sequestered C in living aboveground biomass totaled 1,843.1 Gg C.

Which areas experience the most intense fire under known weather conditions in the study area?

Degraded forest experienced the most intensity fires. Least intensities were found in natural forest and plantation cover types.

Which fuel model gives better representation of fire spread, standard or custom?

Burnt area size was 65% of actual burnt area. Simulation generally under-estimated burnt area fire spread.

CONCLUSIONS

Custom fuel models improved burnt area from 65% to 82% of real fire scars, and gave good representation for cover types whose burnt areas had previously been over-estimated or under-estimated by standard fuel models.

What are the estimates of fire-induced carbon emitted from forest cover types and the overall emission during the March 2007 fire in the study area?

Emission densities/rates were 5.5 Mg.ha^{-1} C; 5.9 Mg.ha^{-1} C; 6.5 Mg.ha^{-1} and 7.6 Mg.ha^{-1} C for plantation, natural forest, agro-forest and degraded forest, respectively.

Overall 46.2 Gg of C was released during the 2007 fire. Agro-forest emitted the largest amount of C totaling 24.2 Gg (52.3% of total emission); followed by plantation 11.1 Gg C (24% of total emission).

CONCLUSIONS

Which forest cover types emitted the most fire-induced carbon from the 2007 fires?

Third largest emitter was Natural forest with 6.5 Gg (14% of overall emission). Degraded forest with 4.5Gg C or 9.7% of the overall total emission was the least emitting cover.

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