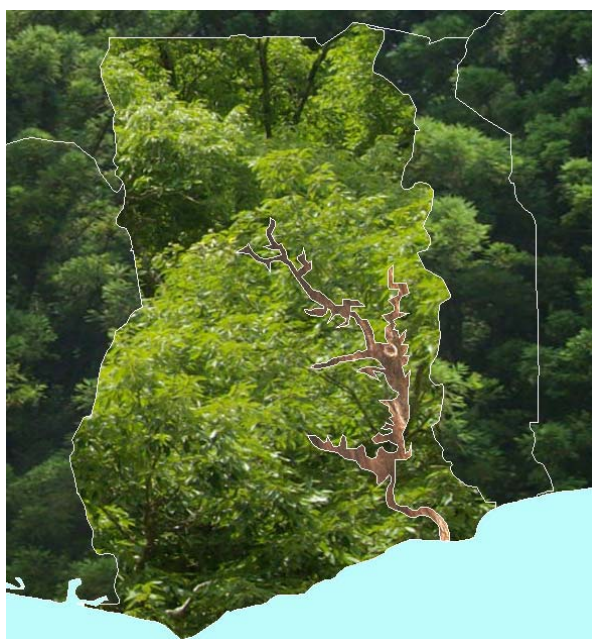# Report on

Mapping of Forest Cover and Carbon Stock in

Ghana

(Mapping Consultant's Services, the Forest Preservation Programme,
Under a Japanese Grant Aid to the Republic of Ghana)

Crown Agents' Reference No.: GHF09/11498/01

Executed by
PASCO CORPORATION, Japan
in Collaboration with FC-RMSC, CSIR-FORIG and CSIR-SRI, Ghana

PASCO
World's Leading Geospatial Group

April, 2013

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Acronyms and Abbreviations

AFOLU	Agriculture, Forestry, and Other Land Use
ALOS	Advanced Land Observing Satellite
AGC	Above Ground Carbon
AOI	Area of Interest
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVNIR-2	Advanced Visible and Near Infrared Radiometer type 2
BCG	Below Ground Carbon
CA	Crown Agents
CANR	College of Agriculture and Renewable Natural Resources
CC	Canopy Cover
CCU	Climate Change Unit
CDM	Clean Development Mechanism
CERGIS	Center for Remote Sensing and Geographic Information Services
CO$_2$	Carbon Dioxide
COP	Conference of the Parties
CSIR	Council for Scientific and Industrial Research
CHM	Canopy Height Model
CPME	Corporate Planning, Monitoring and Evaluation
CSIR	Council for Scientific and Industrial Research
DDE	Deforestation, Degradation, and Enhancement
DEM	Digital Elevation Model
DGPS	Differential Global Positioning System
DMC	Disaster Monitoring Constellation
DMCii	DMC International Imaging Ltd
DSM	Digital Surface Model
DN	Digital Number
DTM	Digital Terrain Model
EAs	Enumeration Areas
EMT	Expanded Executive Management Team Meeting
EPA	Environmental Protection Agency
ESRI	Environmental Systems Research Institute
ETM+	Enhanced Thematic Mapper plus
FAO	Food and Agriculture Organization
FBD	Fine Beam Dual
FCG (FC)	Forestry Commission of Ghana
FCPF	Forest Carbon Partnership Facility
FOGIS	Field Operations and Geographic Information System
FORIG	Forestry Research Institute of Ghana

FI	Field Inventory
FIS	Forest Inventory System
FPP	Forest Preservation Program
FRA	Forest Resources Assessment
FSD	Forest Service Division
GAEA	Ghana Automated Enumeration Area
GCP	Ground Control Point
GDB	Geo Database
GIS	Geographic Information System
GL-AFOLU	Guidelines for Agriculture, Land Use and Forestry
GNSS	Global Navigation Satellite System
GPG	Good Practice Guidelines
GPS	Global Positioning System
GoG	Government of Ghana
GoJ	Government of Japan
GRN	Geodetic Reference Network
GSD	Geological Survey Department
GT	Ground Truthing
GV	Ground Verification
HW/SW	Hardware and Software
GMet	Ghana Meteorology Agency
HH / HV	Horizontal transmit and Horizontal receive / Horizontal transmit and Vertical receive
HTTP	Hyper Text Transfer Protocol
ICT	Information and Communication Technology
ICRAF	International Center for Research in Agroforestry
IP	Internet Protocol
IPCC	Intergovernmental Panel on Climate Change
IT	Internet Protocol
ITTO	The International Tropical Timber Organization
IUCN	International Union for Conservation of Nature
JAXA	Japan Aerospace Exploration Agency
JICA	Japan International Cooperation Agency
KNUST	Kwame Nkrumah University of Science and Technology
LAN	Local Area Network
LAP	Land Administration Project
LAMP	LiDAR-Assisted Multi-source Programmes
LiDAR	Light Detection and Ranging
LMS	Legal Management Scheme
LPS	Leica Photogrammetry Suite
LULUCF	Land Use, Land Use Change and Forestry
MARV	Measuring, Assessment, Reporting and Verification
MCS	Mapping Consultant's Services
MESTI	Ministry of Environment, Science and Technology and Innovations

MLNR	Ministry of Land and Natural Resources
MM&FI	Mapping, Monitoring and Forest Inventory
MMU	Minimum Mapping Unit
MRV	Measuring, Reporting and Verification
MSS	Multi Spectral Scanner
NASA	National Aeronautics and Space Administration
NCRC	Nature Conservation Research Centre
NDVI	Normalized Difference Vegetation Index
NGO	Non- Governmental Organization
OJT	On-the-Job Training
PALSAR	Phased Array type L-band Synthetic Aperture Radar
PASCO	PASCO CORPORATION
PDA	Personal Digital Assistant
PDU	Primary Designated Use
PHP	Hyper Text Processor
PRISM	Panchromatic Remote-sensing Instrument for Stereo Mapping
PSP	Permanent Sample Plot
QC	Quality Control
RADAR	Radio Detection and Ranging
RFP	Request for Proposals
REZ	Regional Ecological Zone
RPC	Rapid positioning Capability
R-PP	Readiness Preparation Proposal
RS	Remote Sensing
REDD	Reducing Emissions from Deforestation and Forest Degradation
REDD+	REDD and forest conservation, sustainable forest management and forest enhancement
RMSC	Resource Management Support Centre
RMSE	Root Mean Square Error
SAs	Sampling Areas
SAR	Synthetic Aperture Radar
SDE	Spatial Database Engine
SOG	Survey of Ghana
SQL	Structured Query Language
SMD	Survey and Mapping Division
SRI	Soil Research Institute
SRS	Simple Random Sampling
SRTM	Shuttle Radar Topography Mission
SWIR	Short Wave Infra Red
TIDD	Timber Industry Development Division
TIR	Thermal Infra Red
TM	Thematic Mapper
TOA	Top-of-atmosphere

TOR	Terms of Reference
TVD	Timber Validation Department
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UTM	Universal Transverse Mercator
VCS	Voluntary Carbon Scheme
VPN	Virtual Private Network
VNIR	Visible and Near Infra red
VV/ VH	Vertical transmit and Vertical receive / Vertical transmit and Horizontal receive
WAFPO	West Africa Forest Programme Office
WD	Wildlife Division
WITC	Wood Industries Training Centre, Kumasi, Ghana
WWF	World Wildlife Fund

1.   Introduction

1.1.   Background

In light of the recent global climate changes, issues relating to reducing emissions from deforestation and forest degradation (REDD) in developing countries have become critical. And to the emissions, there is an urgent need to establish forest monitoring systems, which are critical for understanding the spatial and temporal changes of the remaining forest resources as well as assessing the dynamics of land use change. Furthermore, such monitoring systems are required for both quantity (i.e. area) and quality of forest to establish the prevailing health of a forest ecosystem and its potential to sequester CO_2 (one of the main constituent of greenhouse gas emission) and other services, generally termed as REDD+. The significant role of forest conservation, sustainable forest management and the enhancement of forest carbon stocks in developing countries including Ghana have been increasingly realized as a critical measure to mitigate global climate change.

Forestry in Ghana is playing an important environmental role including biodiversity; ecosystem services at regional level, maintaining river flow and natural water bodies, and others related issues. Ghanaian forests are part of global tropical forest ecosystem and have tremendous value for global environmental protection. Thus removal/degradation of forests in Ghana will contribute to greenhouse gas significantly and will have a detrimental impact on global warming, whereas conserving them will contribute both to reducing emission as well as through the CO2 sequestering mechanism.

The main government agencies responsible for the forest land management in Ghana are the Ministry of Lands and Natural Resources (MLNR) and the Forestry Commission of Ghana (FCG). In line with the above framework, the FCG is mandated to manage, develop and regulate the utilization of the nation's forest and wildlife resources, and to co-ordinate related policies. To achieve this mandate, the FCG together with its stakeholders; such as Environmental Protection Agency (EPA) and Ministry of Environment, Science, Technology and Innovations (MESTI); have developed Forest and Wildlife Management Plans, procedures and systems that give the overall direction on how to manage the nation's forest and wildlife resources.

However, there is still wider gap, specifically for forest monitoring systems and handling REDD+ mechanism, in terms of institutional technical capability and setup.

In order to reduce deforestation and forest degradation, as well as to improve sustainable forest management, donor countries and international organizations are strengthening and accelerating practical approaches for technology transfer and capacity building as well as promoting community forest conservation measures in developing countries. In response to the global movement, the Government of Japan (GoJ) proposed an integrated approach known as the "Cool Earth Partnership" initiative in order to contribute to the international efforts to combat global climate change through sustainable forest management. In this regard, the Ministry of Foreign Affairs of Japan decided to implement a project called the "Forest Preservation Programme (FPP)" in many countries including Ghana. With this background, the Government of Ghana (GoJ) and the Ministry of Foreign Affairs of Japan exchanged notes on the FPP in May, 2010.

The main purpose of FPP is to achieve sustainable forest resource conservation in Ghana. One of the components under FPP is the Mapping Consultant's Services (MCS) project which has been undertaken by FCG with the grant assistance from the GoJ along with financial contribution from the GoG. This was implemented to build the capacity of FCG for forest monitoring systems so that REDD+ benefits could be harnessed.

Main activity of the MCS is Monitoring and Forest Inventory (MM&FI) work and this has following background issues:

- ■ Whilst policy and compensation mechanisms for REDD and REDD+ are still under discussion within the United Nations Framework Convention on Climate Change (UNFCCC), there is acceptance that there are opportunities to use a variety of methods for measuring and monitoring to quantify the carbon stocks in forested lands. As a minimum, any baseline survey required to be in line with the reporting requirements for REDD+ mechanisms in addition to being good practice for protecting this national asset. This requires effective systems to be in place to aid the day to day operations of the FCG to mange the forest land.

- ■ There is also a requirement at the national level to understand the drivers of forest change. In order to inform policy makers it is a further requirement to include other land uses that may impact forest resource use in any baseline assessment and monitoring, so that informed policy about land use can be

drawn up. There is therefore an inherent requirement to produce a Land Use, Land Use Change and Forestry (LULUCF) assessment at the national level, which will form part of the baseline that will be used to monitor changes to the forest resources and carbon emissions at the national level.

■ In support of the UNFCCC REDD effort, the Intergovernmental Panel on Climate Change (IPCC) provided Good Practice Guidelines to support countries in developing carbon assessment systems, which is divided into three "tiers" according to level of accuracy.

● Tier-I, the most general approach, is based on non-spatial, or non-mapping, estimates of national forest cover and on generic estimates of forest carbon density values (e.g. tons of carbon per hectare).

● Tier-II is more detailed, and uses forest maps and forest carbon inventories that are more accurate than Tier-1 "default" values.

● Tier-III, the most rigorous approach, is based on very detailed landscape-specific or even species-specific carbon stock estimates with regular, ongoing reassessments.

Tier-I methods are already in use through organisations such as United Nations Food and Agriculture Organisation (FAO). The MCS is concerned with producing the data, developing the tools and capacity of the GoG to address Tier-II and Tier-III carbon inventory approaches based upon increasing levels of spatial detail.

In order to devise environment conservation and management plans for the forest lands and other natural resources and biodiversity along with balanced and sustainable development and REDD-Plus applications, the updated map information is urgently needed. Furthermore, the GCG currently has very basic capacity to handle geospatial data and maps, and needs to be strengthened further; both in terms of HW/SW (Hardware and Software) and human resources.

1.2. Goals

The overall goals of the MCS are:

(i)   building capacity and knowhow for forest mapping and monitoring at national level for sustainable forest management

(ii)   capturing the benefits of emerging financing for the services from the forest through REDD+ and other mechanisms.

(iii)   creation of a complete and seamless land use and forest inventory at the national level

(iv)   implementing a comprehensive forest resource change assessment for historical period 1990- 2010

(v)   developing MRV protocols for a set of sub-national REDD demonstration activities that meet the accepted principles and procedures for the estimation and reporting of carbon emissions and removals for Tier-II and Tier-III levels through detailed mapping and 3D forest structural analysis

(vi)   formulation of a comprehensive Geographic Information System (GIS) based forest management system so that it can be used for various purposes such as environmental management and planning, REDD+ application, sustainable development and conservation of biodiversity, community and agro-forestry systems.

(vii)   engaging with the international community on international standards and methods for monitoring;

1.3. Objectives of the MM&FI

In order to achieve broader goals, following specific objectives were defined for the MCS.

(i)   Gap analysis for data/information for forest and carbon stock assessment and provide specifications for procurement actions;

(ii)   Gap analysis for technical capacity within the FCG to undertaken resource assessment and monitoring and provide specifications for procurement actions;

(iii)   Creation of national LULUCF maps for the period 1990-2011 (at least three time series data);

(iv)   Creation of a detailed national forest resource baseline map;

(v) Modelling and forecasting of land use change with respect to forest resources;

(vi) Preparation of topographic/resource maps for selected forest areas (Pilot Area);

(vii) Estimation of carbon stocks in the forest lands from field sampling and LiDAR (Study Area);

(viii) Capacity building within the FCG to measure and monitor forest resources and carbon stocks;

(ix) Creation of a GIS-based forest inventory system;

(x) Capacity building with the FCG to update and maintain the forest inventory system;

(xi) Preparation of the FCG for REDD+ readiness and MRV requirements;

(xii) Reporting of achievements and outputs to key stakeholders.

In order to fulfil these objectives, the satellite data (optical) from Landsat, ALOS and DMC have been used to create an historical analysis of Land Use Change (LUC) between 1990 and 2010. One key area that has been addressed in the MCS is the consistency and robustness of Land Use (LU) classification. Many of the historical sensors are no longer operational, new ones are emerging and in particular SAR sensors are providing wall-to-wall data coverage reliably in areas that are prone to cloud cover which limits the usefulness of optical sensors. With this essence the MCS has also used the SAR data from PALSAR sensor of Japanese ALOS satellite to demonstrate the land use interpretation for its possible use for monitoring purpose.

In order to map the quality of the forest, MCS also undertakes both field plot measurements and LiDAR surveys in sub-national demonstration areas for biomass and carbon estimation. As defined in the objectives, one of the key purposes is to establish good correlation between field sample measurements and LiDAR measurements and satellite to improve the extrapolation of carbon estimates using these sampling strategies.

To carryout above activities, the MCS has also included capacity building such as On-the-Job Training (OJT), Hands-out training to the staff of FCG.

1.4. Project Area Extent

The project involved three levels of analysis and, accordingly, three kinds of project area extent were defined as illustrated in Figure 1-1and described below.

(i) National Level: Area covering whole Ghana of approximately 239,000sq.km for "Mapping and Historical Forest Resource Change Assessment".

(ii) Pilot Area: Area covering 17,186sq.km for detailed "Forest Resource Mapping" composed of four blocks, two main; in the south-west; and two smaller; in south-east; of the country.

(iii) Study Area: Area covering 864sq.km with LiDAR blocs over whole Pilot Area plus Atiwa forest reserve for "Forest Biomass Inventory".
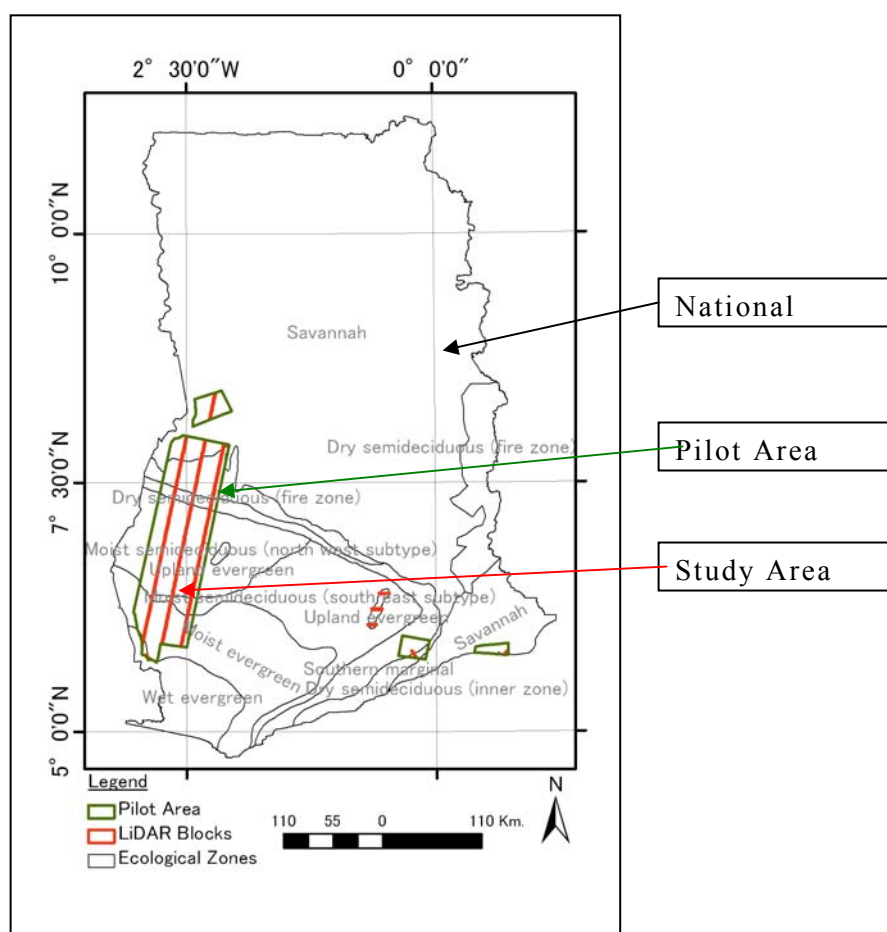
Figure 1-1: Project Areas and Their Extent

1.5. Project Phase and Schedule

Although there were not distinct phases in the project, however design of the Mapping Consultant's Services clearly indicated two phases namely, (a) Preparation, where group of tasks from 1 to 6 were defined under "Mobilisation" and (b) Implementation, where major consultancy services conducted under tasks 7 to 26 grouped into 5 major headings. The summarised group of tasks under major headings is illustrated in Figure 1-2. The first two objectives, listed above were achieved during mobilisation while others were under taken during the implementation phase.

The project was spread over about two years time starting from May 20, 2011 to April 20, 2013. The work schedule is illustrated in Figure 1-3.
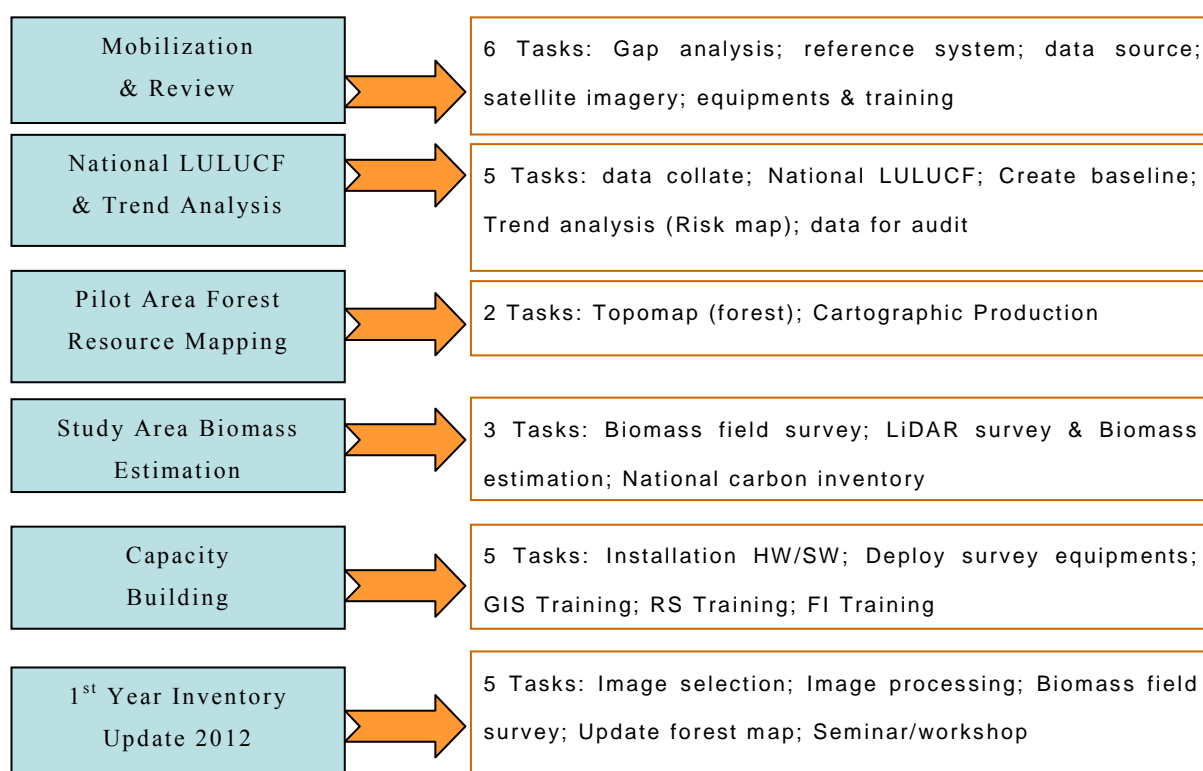
Figure 1-2: Summary of Tasks under Major Work Group Headings

Activity	Year 2011								Year 2012												Year 2013				Remarks
	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
Phase I: Inception																									Completed on time
Mobilisation and Review (Task 1 to Task 6)		▭																							
Phase II: Implementation																									
Mapping Historical Land Use and Forest Resource Change Assessment (Task 7 to 11)							Planned										Extension								Extension mainly due to delay in HW/SW, Equipments & Vehicles
Pilot Area Forest Resource Mapping (Task 12 and 13)							Planned										Extension								
Pilot Area Biomass Inventory (Task 14 to 16)							Planned								Extension										
Capacity Building (Task 17 to 21)									Planned				Extension												
Forest Resource Inventory 1st Year Update 2012 (Task 21 to 25)																		Planned	Extension						
Task 26 – Seminar/workshop																		Planned	Changed						
Draft Final Report																						▭			Completed within project time
Final Report																								▭	

Legend
Initial Plan ▭   Extension/Revision ▨

Figure 1-3: Project Schedule

As it can be seen in the Figure 1-3, there were extension of the all work activities during the implementation phase, but all tasks were completed and final report was delivered within the project time frame.

Although this report was prepared for mainly "implementation"; however a recap of "mobilisation" is given hereafter for reference. For further detail, the "Report on Mobilisation and Review" should be referred.

1.6. Phase I: Preparation

There were six tasks (listed below) under the preparation phase, which were materialised during 35 days long field mission (May 28 to July 3, 2011) and report was delivered during July 2011 for necessary procurements and preparations. A summary of the task wise outcome is given here followed by main features of the report.

(i)   Task 1: Gap analysis - review current resources and capability within the institutions responsible for land use and forestry of the Government of Ghana

FCG has identified and listed the partner organisations and categorised as main and other stakeholders. The gap, in terms of HW/SW and knowhow, was reviewed, mainly by visiting and consulting the staff and referring to the available document and necessary recommendations were made.

(ii)   Task 2: Establish reference systems and standards for mapping and resource classification

Through the consultation with relevant main stakeholders, map projection system, definition of the Land Use (LU) classification, forest inventory and field sampling survey methodology and others were defined and used during the implementation of Phase II.

(iii)   Task 3: Identify sources and initiate requests for all existing forest inventory, land use and map data from the relevant Departments of the Government of Ghana, academic institutions and International agencies

The availability of existing geospatial and other data, inside FCG and with stakeholders, were listed and filtered for the final list of data, which was deemed necessary and useful for subsequent work.

(iv)   Task 4: Identify all required archive satellite imagery, and submit satellite task requests for any new acquisitions

The availability of archive medium to high resolution satellite imagery, covering the whole Ghana from 1990 to 2010 with 5 year interval, was searched. The search results showed that (i) data form Landsat satellite series program of NASA can only be used for 1990 and 2000 with 10 year interval and (ii) data from AVNIR-2 sensor of ALOS satellite program of JAXA and DMC in year 2010 were used .The DMC data was only used in areas where could free ALOS data was not available. Thus three epochs, with 10 year interval 1990, 2000 and 2010, data were selected for national level land use mapping. In the pilot area, 2.5m resolution data from PRISM sensor of ALOS satellite were selected for detailed forest resource mapping and inventory survey for biomass/c-stock estimation.

(v)   Task 5: Identify all equipment necessary to undertake satellite image-based creation and update of the forest resource map data including GIS, image processing and other software, and field biomass estimation

After analysing the available HW/SW and forestry inventory equipments at FCG, the gaps were identified and listed for necessary procurement.

(vi)   Task 6: Identify staff to be trained in the resource mapping activities and prepare a schedule of inputs for each individual.

After interaction with potential staff who were identified by FCG to form a team comprising Remote Sensing, GIS and Survey specialists, System Administrator and Inventory Foresters, necessary training materials and on the job training programmes were identified and prepared to support the management and maintenance of the Forest Inventory System (FIS)

The main features of the mobilisation report:

- General review of FCG departments and partner organisations in support of forest mapping and REDD+
- Review of existing mapping reference system for established reference systems and standards for mapping and resource classification to be used.
- Prepared list for collection of all exiting relevant Remote Sensing and GIS data.
- Prepared list of all required archive satellite imagery and acquisition of LiDAR data for necessary procurement based on the mapping and biomass/c-stock estimation requirement analysis.
- Prepared list of identified equipments, HW and SW required to undertake satellite image-based mapping and update of the forest resource and inventory survey and biomass/c-stock estimation, followed by creation of web based forest information system.
- List of staff to be trained based on the need assessment to carry out mapping, inventory survey, handling and maintenance of Remote Sensing and GIS data and forest information system.

1.7. Phase II: Implementation

After necessary procurements of identified HW/SW, Data and Forestry Equipments by FCG, which were identified and listed during Phase I, the main work objectives were implemented during Phase II. As summarised in Figure 1-2 and listed hereafter, there were 20 tasks under 5 major headings. During execution of these tasks utmost care had been taken to fulfil all the requirements described in "Terms of Reference", "Report on Mobilisation and Review" and "Technical Proposal".

(1) Mapping Historical Land Use and Forest Resource Change Assessment

    (i)   Task 7: Collate Digital Data for Digitisation of Any Existing Data Acquired in Task 3

    (ii)   Task 8: Map the forest resource at a national level at 10 yearly intervals using historical and other data for the period 1990-2010

    (iii)   Task 9 Create a baseline forest resource map for 2010 at the national level using the agreed classification/stratification for forest inventory

    (iv)   Task 10: Undertake a land use change trend analysis and simulate future changes to forest resource taking into account identified risk factors

    (v)   Task 11: Prepare the forest resource and change assessment results for external scrutiny and verification

(2) Pilot Area Forest Resource Mapping

    (vi)   Task 12: Undertake Forest Resource Mapping and Topographic Feature Digitisation Using ALOS PRISM High Resolution Satellite Imagery for the Selected Forest Pilot Area

    (vii)   Task 13: Produce Cartographic Hardcopy Maps at the Scale of 1:50,000 Covering the Pilot Forest Areas

(3) Study Area Biomass Inventory

    (viii) Task 14: Undertake Representative Field Sampling of Biomass in all Identified Forest Classes and Strata That Will Allow Extrapolation to the National Forest Resource

    (ix)   Task 15: LiDAR Survey and 3D Structural Analysis

    (x)   Task 16: Undertake Carbon Inventory for the Total National Forest Resource Area

(4) Capacity Building

    (xi)   Task 17: Installation of GIS Software for Forest Resource Management, Image Processing Software for Remotely Sensed Data Together With Hardware and Peripherals

    (xii)   Task 18: Deployment of All Equipment for Carbon Stock Assessment for Field Survey

(xiii) Task 19: Training in GIS Forest Resource Management Software

(xiv) Task 20: Training in Image Processing Software for ALOS and Other Satellite Image1y for Forest Resource Mapping and Change Detection- Including Both Optical and SAR Image1y and LiDAR

(xv) Task 21: Training on Forest Inventory Survey and Biomass Estimation

(5) Forest Resource Inventory 1st Year Update (2012)

(xvi) Task 22: Oversee the Selection of Satellite Image1y to Allow Updating of Forest Resource Maps for the Forest Reserves and Extrapolate to the National Scale

(xvii) Task 23: Oversee the Image Processing and Forest Resource Mapping Update With Respect to the 2010 Baseline

(xviii) Task 24: Oversee Forest Inventory and Biomass Field Survey

(xix) Task 25: Oversee the Process to Update Forest Resources and Change Datasets, and the Simulation of Future Forest Using Updated Input Data

(xx) Task 26: Conduct a Seminar and Workshop to Inform Al the Relevant Stakeholders and Organisations of the Aims and Outcome of the Project

1.8. Project Execution

After the completion of Phase I in July 2011, Phase II was started in November 2012 and completed with the delivery of this Final Report in April 2013 to the FCG, Accra and Crown Agents, Tokyo. The Bar Chart of the work schedule of phase II is given in Figure 1-3.

The project was executed by three of institutions, namely (i) Client: the Forestry Commission of Ghana, (ii) Stakeholders: Various National and International Institutions located in Ghana and (iii) Consultant: PASCO Corporation, Tokyo, Japan. The list of stakeholders is given in Table 1-1. The client has assigned a group of core team (Table 1-2) who coordinated and assisted team of international and

national consultants (Table 1-3) in the execution of various activities for successful completion of the project work.

Table 1-1 List of Stakeholders

Name of Institution	Key Activities Related to the Project	Address
Main Stakeholders/Collaborators		
Forest Research Institute of Ghana (FORIG)	Forest inventory methodology, supervision of inventory survey, tree destructive sampling, physical analysis of samples and allometric modeling	P.O Box UP 63 Kumasi, Ghana
Soil Research Institute (SRI)	Soil Sampling Methodology, Supervision of soil, litter, non-tree and deadwood sampling and chemical analysis of all samples including physical analysis of soil.	Academy Post Office, Private Mail Bag, Kwadaso - Kumasi, Ghana
Survey and Mapping Department (SMD)	Providing topographic base maps and digital data and National GCPs data	P. O. BOX GP 191, Cantonment, Near EL-Wak Sports Stadium, Accra
Center for Remote Sensing & Geographic Information Services (CERSGIS)	Assisted in image interpretation and mapping, specifically for SAR imagery; provided secondary data	University of Ghana, Legon, Accra
Department of Geomatic Engineering, KNUST	Supporting with equipment and technical knowhow of GNSS survey	Kumasi, Accra
Cartographic Division, Ghana Statistical Service	Provision of statistics data	P.O. Box GP 1098, Ministry of Finance and Economic Planning, Head Office Bldg., Accra, Ghana
Other Stakeholders		
Environmental Protection Agency (EPA), Accra; International Union for Conservation of Nature (IUCN) Ghana; Nature Conservation Research Centre (NCRC); WWF West Africa Forest Programme Office (WAFPO), University of Ghana, Legon; Ghana Meteorology Agency (GMet), Accra; College of Agriculture and Renewable Natural Resources (CANR), KNUST, Kumasi; Dept of Geography & Resource Development, Uni. of Ghana, Legon; Geological Survey Department, Accra; Food and Agriculture Organization (FAO) of the United Nations, Ghana Office		

Table 1-2 List of Core Team Members

Name of Staff	Area of Expertise	Position Assigned
Core Team Members		
Mr. Edward Obiaw	Forest Inventory and Management	Advisor
Mr. Cudjoe Awudi	Planning, Project Coordination and Management	National Project Coordinator
Mr. kofi Affum Baffoe	Forest Inventory and Planning	Inventory Coordinator
Mr.Yakubu Mohamed	GIS, Geo-spatial and Remote Sensing Analysis	GIS/Remote Sensing Expert
Mr. George Rockson Odame	ICT, System Administrator	System Administrator
Mr. Emmanuel Opoku	ICT, System Administrator	Data Input Coordinator
Mr. Emmanuel Donkor	Surveying	GPS/GNSS Survey Coordinator

Table 1-3 List of Consultant's Team Member

Name of Staff	Area of Expertise	Position Assigned
International Consultant (Main Team)		
Dr. Bhuwneshwar Prasad Sah	Geostatistics, Remote Sensing, GIS, Natural Resource Management, Project Management	Project Manager
Mr. Jarno Hämäläinen	Sustainable Forest Management	Forest Inventory Expert
Mr. Awadh Kishor Sah	GIS and Remote Sensing, Satellite Image Interpretation and Analysis	Image Processing Expert
Mr. Yuzuru Kikuchi	Forestry Inventory and GIS Database	GIS/Database Expert
Mr. Selvaraj Senthil	Geo-informatics, Information Technology, Programming	IT/Web/ GIS Database Programmer
Mr. Masakuni Nakayama	Surveying, Topographic Mapping	Field Survey (Topographic) Specialist
Dr. Mitsunori Yoshimura	Application of Remote Sensing, SAR data processing	Image Processing specialist
Mr. Juha Hartikainen	Forest Vegetation Surveying and Mapping and Inventory Filed work	3D Forest Structure Processing Specialist
Mr. Olli Isotupa	Mobile Data Collection and Forest Inventory	Biomass/ C-Stock Specialist
Ms. Seimiya Nami	GIS, Project Management and Coordination	Coordinator
Addination International Consultant as a Support to the Main Team		
Mr. Ronaldo G. Buenviaje	Remote Sensing and GIS Analysis	Image Processing Expert
Mr. Anthony I. Revil	ICT, System Design and Development, Programming	IT/Web/GIS Database Programmer
Dr. Raghunath Jha	Civil Engineering and Surveying, Mapping	Field Survey (Topo) /GIS & RS Specialist
Ms. Katri Tegel	Physical Goegraphy, Remote Sensing and GIS	Biomass/C-Stock Specialist
Mr. Koichi Honji	Photogrammetry, Mapping and Project Management	Coordinator
Mr. Sato Kei	Remote Sensing and Project Coordination	Coordinator
Mr. Hitoshi Matsumoto	Marketing and Project Coordination	Coordinator
Local Consultant		
Dr. Ernest Gordon Foli	Forestry, Silviculture, Forest Inventory and Biomass Modeling	Forest Inventory & Silviculture Specialist
Ms. Tina Dzigbordi Wemegah	Surveying, Topographic Mapping	Field Survey Specialist
Mr. Francis Balfour Agurgo	Remote Sensing, GIS, General IT	IT & HW/SW (RS & GIS) Specialist

1.9. Summary of Outcomes and Results

The main output and results of the project are listed in Table 1-4.

Table 1-4: Main Output/Results and Resources

NO.	Items
National Level Data	
1	Processed Satellite image data for 1990, 2000 & 2010
2	GIS data of LU for 1990, 2000 & 2010
3	GIS data of LUC for three intervals (1990-2000, 2000-2010 and 1990-2010)
4	Baseline Forest Resource Map for Year 2010
Pilot Area Data of 17000sq.km. covering all Ecological Zones of Ghana	
5	Detailed forest resource map and inventory data
6	3-D forest structure data derived from LiDAR (864 sq. km.)
7	Allometric Biomass/C-stock models based on ecological zones
8	Lookup table for Biomass/C-stock estimation for all 6 terrestrial pools
9	Estimated Biomass/C-stock for pilot area and extrapolated to national level
Inventory Survey Capacity & Geodatabase for online information/Data Sharing	
10	All required HW/SW and Inventory Equipments and Trained Staff
11	Geo database running on the server containing both primary & secondary data
12	Data processing, operation procedure and user manuals

These resources can be summarised into four groups of main outcomes of the project, which are listed below.

1. Land Use (6 classes) maps for 3 epochs (1990, 2000 and 2010) produced using IPCC guidelines and trends of changes analysed for the periods 1990 to 2010.
2. A detailed forest resource map of the Pilot Area, which was used for LiDAR blocks sampling followed by Filed Plot Sampling design for inventory survey. These resources were used to produce Biomass/C-Stock Lookup Table to give an indication of the estimated C-stocks for different forest types.
3. Forest Information System; comprising (i) centralised Geo-Database and (ii) WebGIS Portal for stakeholder data sharing was developed.
4. The HW/SW, human resource and skill of FCG and its stakeholders had reasonably been upgraded for forest resources assessment, planning and management.

Analysis of above outcomes resulted into following important findings.

1. Forest cover change shows a continuous grain in total forest cover (open and closed forest land combined) first (1990-2000) and second (2000-2010) decades, which was about 1.19% the total area of Ghana. However, closed forest land was decreasing while open forest land showed increasing trend, meaning Ghana is having net aforestation, but with forest degradation.
2. Forest degradation (conversion from closed to open forest) and deforestation (conversion from close forest to cropland) showed reduction of Above Ground C-Stock form one-fifth to one-third of initial level.
3. With the enhanced capacity (HW/SW, Equipments and Trained human resource) and establishment of Forest Information System found to be handy for engaging stakeholders and data sharing.

1.10. Report Outline

The achievements and results from the tasks 7 to 26 accomplishment, mentioned above, have been presented in main chapters and sub-chapters. The report starts with the introduction in chapter one where, overview, goal and objective, summary of results and outcomes have been described. This chapter also describes the outcomes for each main group of task in subsequent sub-chapters. Chapter two deals with the forest resource mapping that include Land Use, Land Use Change and Forestry (LULUCF), forest land stratification and trend analysis. Chapter three describes about detailed forest resource mapping. Chapter four presents the Remote Sensing and LiDAR assisted forest inventory survey and biomass/C-stock estimation for all six terrestrial pools. Installation of HW/SW, Forestry Equipments and Training on Remote Sensing, GIS and Forest Inventory are the part of chapter five. Furthermore, chapter five also includes compilation of GIS database for FCG and online WebGIS portal for stakeholder and wider public use. Chapter six presents activities and results of 1st year updates where FCG staff performed most of the activities presented in previous chapters under the supervision of consultants. The report is concluded by concluding remarks presented in chapter seven.

2. Mapping Historical Land Use and Forest Resource Change Assessment

2.1. Task 7: Collate Digital Data for Digitisation of Any Existing Data Acquired in Task 3

2.1.1. Introduction

This task was to check, cleanse and collate the existing data identified in Task 3 of Phase I and put it into GIS together with their metadata. Collection of identified datasets and their collation were done with the consent of FCG considering the purposes of use of those GIS data i.e. assessing forest resource and its change, and for use in modelling and forecasting future changes.

2.1.2. Data Collection

The dataset listed in Table 2-1 was planned to be collected in Task 3. However, some of the datasets were not collected and/or rejected based on further considerations and data investigation. On the other hand, some other datasets, which were identified useful, were also collected. The list of finally collected datasets is presented in Table 2-2.

Note: Description of Data Administrators

Data Administrator		
Forest Commission Head Quarters	Corporate ICT Departement	1
	Timber Validation Department	2
Resource Management Support Centre(RMSC)	GIS and Mapping Unit	3
	Wildlife Departement	4
Survey Mappiong Departement(SMD)	Photogrammetry and Remote Sensing Section	5
	Cartographic and GIS Section	6
	Examination Section	7
	Geodetic Reference Network	8
Forestry Research Institute of Ghana (FORIG)	Ecosystem Services & Climate Change Division	9
Department of Geography and Resource Development		10
Ghana Statistical Service	Catography Group	11
Center for Remote Sensing and Geographic Information Services (CERSGIS)		12
Nature Conservation Research Center (NCRC)		13

Table 2-1: List of Planned Datasets for Collection

SN	Data admini strator	Type of data		Format
1	1	Other	Forest Concessions	.xls; xlsx (Microsoft Excel)
2	1	Agricurutual land use	Plantation Database	.xls; xlsx (Microsoft Excel)
3	1	Forest reserves	Concessions and Forest Reserves Maps	.shp (ArcView Shape files)
4	2	Timber Stock	TUC details & Tree enumeration/ Inventory including maps	.shp (ArcView Shape files)
5	3	Topographic maps	Topographic maps	Digital and hard copy
6	3	PSPs	Permanent Sampling Plots	Paper Document
7	4	Wildlife parks	Spatial data on Community Resource Management Areas	ESRI Shapefile
8	6	Topographic maps	Medium Scale Topographic data	E00 / DXF
9	6	Topographic maps	Small Scale Topographic Data	E00 / DXF
10	7	Topographic maps	Survey Coordinates	Ghana National Grid
11	9	Forest inventry	Forest Inventory and Growth data	Spreadsheet
12	10	Soil Map	Ghana soil data	ESRI (Raster and vector)
13	10	Soil Map	FAO Soil Classification	ESRI (Raster and vector)
14	10	Digital elevation data	Ghana slope (DEM)	ESRI (Raster and vector)
15	11	Settlement	GPS point data (locality)	Digital
16	12	Transportation	GPS line data (road network)	Digital
17	12	Forest inventry, Agricultural land use	Landcover/Land use	ESRI Shapefile
18	12	Ecological zones	Desertification Hazard	ESRI GRID
19	12	Socioeconomic	Settlement Locations	ESRI Shapefile
20	12	Topographic maps	District Boundaries	ESRI Shapefile
21	12	Transportation	Feeder Road Network	ESRI Shapefile
22	12	Forest reserves, Protected area	Reserves and Protected Area Boundary	ESRI Shapefile
23	12	Socioeconomic	Social Infrastructure (Education, Health, Water and Sanitation)	ESRI Shapefile
24	13	Forest Inventory	Carbon stock of different landuse types in Northern, Upper east and West, Western, Brong-Ahafo and Volta Regions	xls; xlsx (Microsoft Excel), .dbf
25	13	Forest Inventory	Carbon map of Ghana and satellite imagery	.tiff, .img

Table 2-2: List of Collected Datasets

SN	Data Administrator	Type of data		Format	Data Location (in Folder)
1	1	Other	Forest Concessions	.xls; xlsx (Microsoft Excel)	Others
2	1	Agricurutual land use	Plantation Database	.xls; xlsx (Microsoft Excel)	Others
3	1	Forest reserves	Concessions and Forest Reserves Maps	.shp (ArcView Shape files)	Others
4	3	Timber Stock	TUC details & Tree enumeration /Inventory including maps	Excel format	Others
5	3	PSPs	Permanent Sampling Plots	Paper Document	Others
6	4	Wildlife parks	Spatial data on Community Resource Management Areas	ESRI Shapefile	GIS
7	6	Topographic maps	Medium Scale Topo.data	E00 /DXF	GIS
8	9	Forest inventry	Forest Inventory and Growth data	PDF	Others
9	10	Soil Map	Ghana soil data	ESRI (Raster and vector)	GIS
10	10	Soil Map	FAO Soil Classification	ESRI (Raster and vector)	GIS
11	12	Forest inventry, Agricultural land use	Landcover/Land use	ESRI Shapefile	GIS
12	12	Ecological zones	Desertification Hazard	ESRI GRID	GIS
13	12	Socioeconomic	Settlement Locations, Health, Sanitation, Education and Water	ESRI Shapefile	GIS
14	12	Topographic maps	District Boundaries	ESRI Shapefile	GIS
15	12	Transportation	Feeder Road Network	ESRI Shapefile	GIS
16	12	Forest reserves, Protected area	Reserves and Protected Area Boundary	ESRI Shapefile	GIS
17	13	Forest Inventory	Carbon map of Ghana and satellite imagery	.tiff , .img	GIS
18	3	Regional Ecological Zones (REZ)	Regional Ecological Zones (REZ)	ESRI Shapefile	GIS
19	3	Primary Designated Use (PDU)	Primary Designated Use (PDU)	ESRI Shapefile	GIS
20	3	Legal Management Scheme (LMS)	Legal Management Scheme (LMS)	ESRI Shapefile	GIS

In addition to above, in coordination with SMD, index map for 1:100,000 scale covering whole Ghana was also created.

2.1.3. Data Check and Cleansing

2.1.3.1.   Methodology

All collected datasets were checked and cleansed based on the following methods:

a) If a dataset was not defined with projection system, it was defined with the same projection system in which data had been created and then re-projected to the projection system that has been agreed for this FPP Mapping project. If projection system of the collected dataset was different from the one that was used for this project, it was converted to this projection system.

b) Wherever possible, the existing GIS data was checked by comparing with the GIS data of collected topographic maps or other such datasets.

The GIS data of 1: 50,000 Topographic maps obtained from Survey and Mapping Division (SMD) was used in possible checking and comparing the other GIS data. And, for this, all GIS data were made having same projection system; that is, as decided for this project, which is as follows:

Vertical Datum:

Mean Sea Level of Tema, Ghana.

Horizontal Datum:

Map Projection: Universal Transverse Mercator (UTM)

Zone: 30N

Spheroid: WGS 84

Datum: WGS 84

Central Meridian: 3° West

Origin of Latitude: 0° (Equator)

Scale Factor at Central Meridian: 0.9996

Linear Unit: Meter

False easting: 500000 meter

False northing: 0 meter

2.1.3.2.   Work Conducted

(1) Projection Transfer

The GIS dataset such as 1:50,000 topographic maps covering whole Ghana (as 102 tiles of 1:100,000 index) that obtained from the Survey & Mapping Division (SMD) of Ghana was in Transverse Mercator (TM) with Spheroid British War office map Projection system. Thus, the original tiles in interchanged (.EOO) format extracted and imported into ArcMap. First the original coordinate system was assigned to all these datasets, which was then converted to the UTM Zone 30N as decided for this Project and then the tiles were merged to one yielding single shape file covering whole Ghana. The step by step procedure of extracting the 1:50,000 topographic SMD data covering whole Ghana is presented in Manual 1. Followings layers were created, (Table 2-3):

Table 2-3: List of Layers Created from Topographic GIS Data from SMD

SN	GIS Data Description	Feature Type	Shape file Name
1	Polygon Cultural Features	Polygon	cultural_poly.shp
2	Line Cultural Features	Line	cultural_l.shp
3	Point Cultural Features	Point	cultural_p.shp
4	Forest Features	polygon	forest.shp
5	Hydrographical Features	Line	hydrographic.shp
6	Hypsographical Features (Contours)	Line	hypsographic.shp
7	Landforms	Line	landform.shp
8	Transportation Features	Line	tranport.shp
9	Utility Features	Line	utility.shp
10	1:50,000 index	polygon	sd50.shp

(2) Checking the Existing Datasets

i)   Protected Areas against composite forest topographic map of Ghana

Comparing the forest GIS data generated from the tiles topographic map sheets from SMD with that from CERSGIS, it was noticed that most of the forest reserved polygons in the CERSGIS dataset were within the boundaries of forest GIS from topographic map (shown in red outlines in map below). Although a few others extend outside some of the boundaries, refer to Figure 2-1. Moreover, it shall be noted that Forest reserve data included in Legal Management Scheme (LMS) was used in producing Baseline Forest Resource Map.
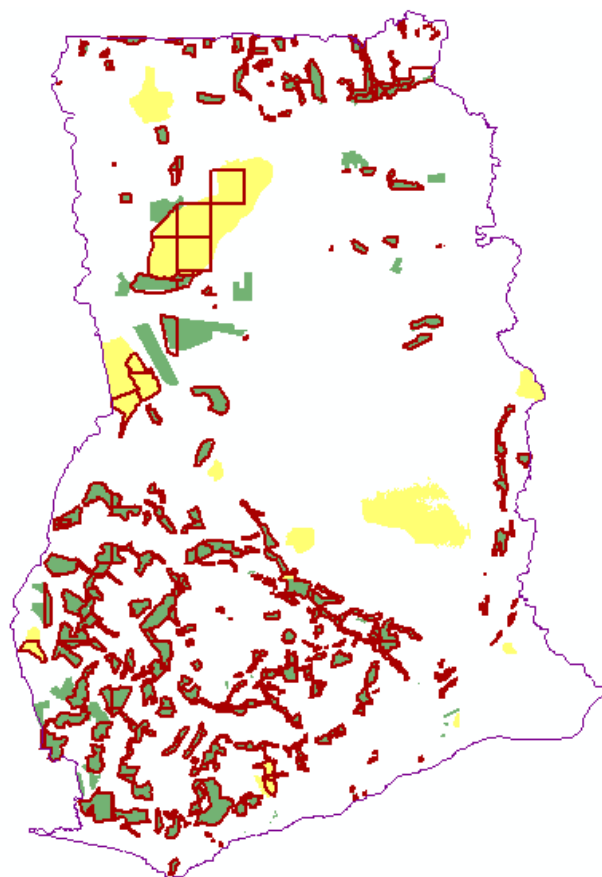
Figure 2-1: Comparison of Forest Data from CERSGIS with that from Topographic Map

ii) District Map of Ghana

The district map of Ghana obtained from CERSGIS revealed 173 districts in the datasets. However, in Ghana there are 170 districts as of 2010 comprising of 6 metropolitan, 40 municipals and 124 districts (*www.ghanadistricts.com/pdfs/all_mmdas_in_ghana.pdf*). Upon careful examination, there were 3 sliver polygons in the dataset as shown in Figure 2-2.
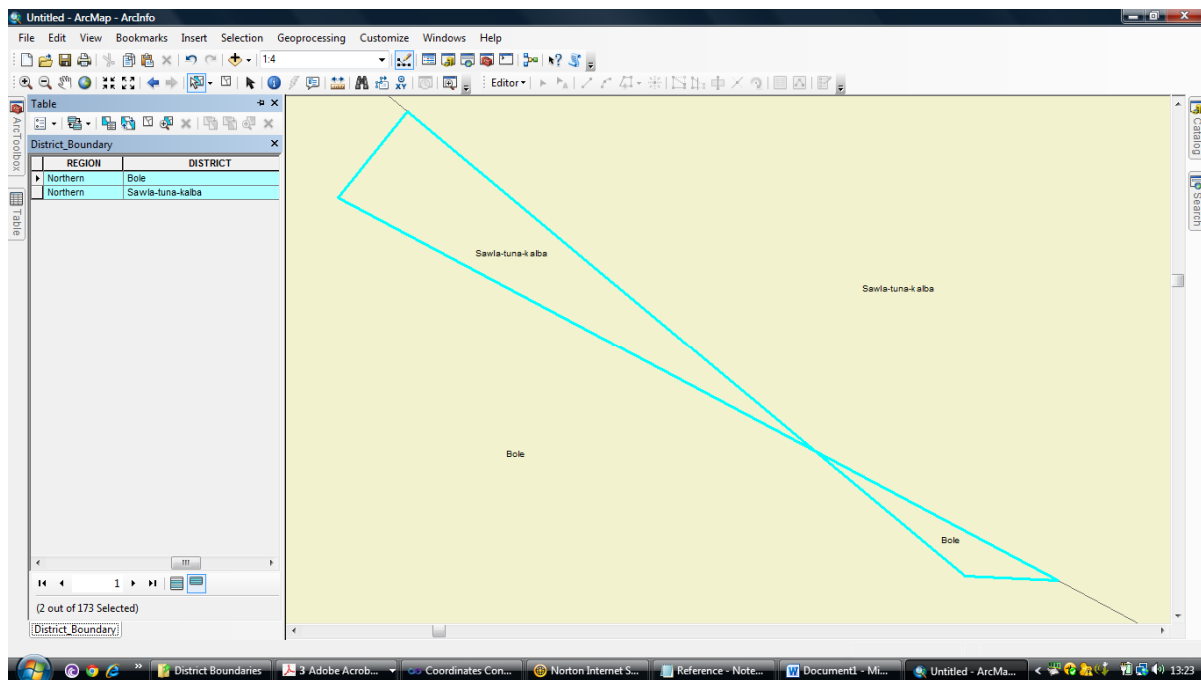
Figure 2-2: An Example of Error as Sliver Polygon

The revelation of these errors was noticed by comparing the 170 district names in the downloaded 'pdf' and the districts names in the attribute table of the district map obtained from CERSGIS. It was found that three districts names (Bole, Tuna and Nzema East) have appeared twice and each district had silver polygon. Necessary editing was carried out. Additionally, it was found that one district which was supposed to be in the Eastern region (Kwahu North), was mistakenly appended to Ashanti region. This error was corrected for by appending it to the Eastern region.

iii) Creation of 1:100,000 Scale Index Map

An index map of 1:100,000 scale was created from the 1:50,000 scaled index map, which has 351 map sheets each covering a ground area of 15' x 15' longitude / latitude. This was done by merging the digital data for four adjacent map sheets of

1:50,000. The index map of 1:100,000 scale, refer to Figure 2-3, was used in the creation of LU and LULUCF maps.
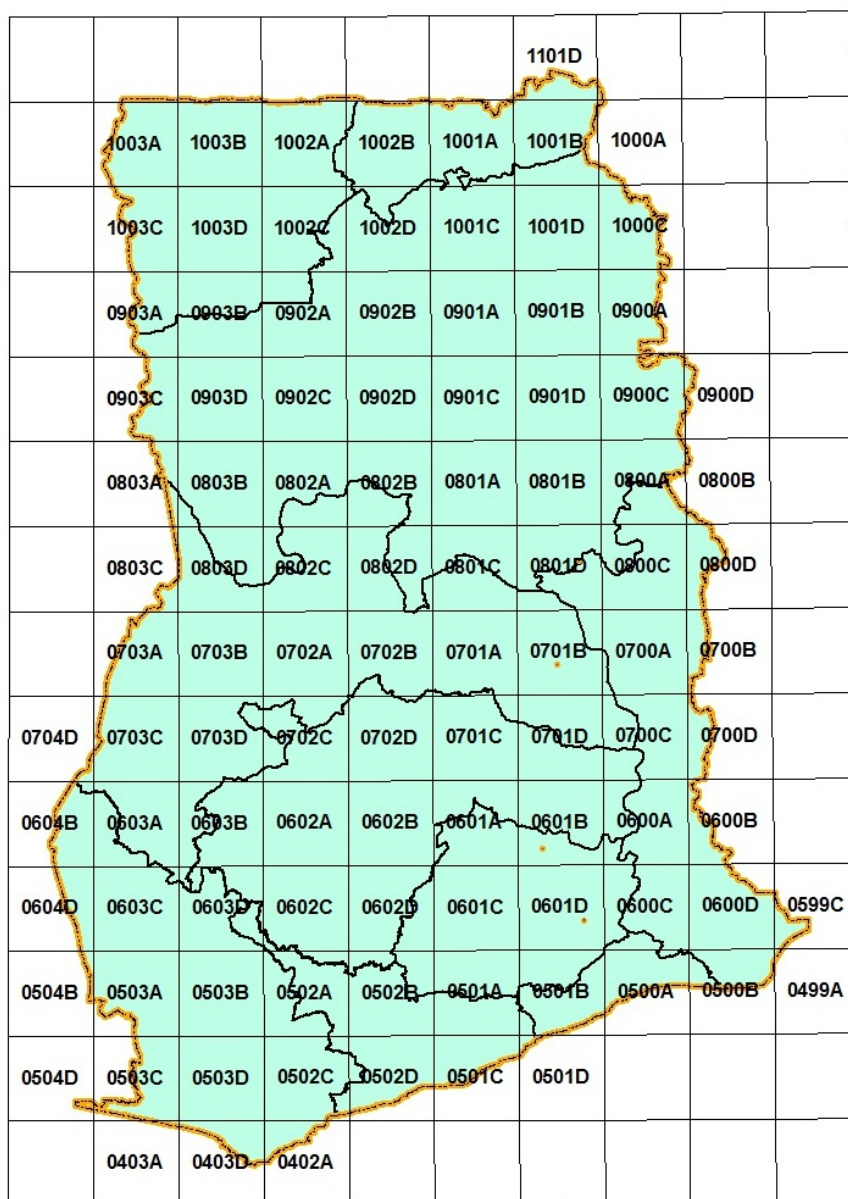
Figure 2-3: Index Map of 1: 100,000 scale

2.1.3.3.   Metadata Creation for GIS Datasets

The 'ArcMap Options' under 'Customize' menu was used for creation of meta data for GIS Datasets. The desired meta data format for this project was chosen as "North American Profile of ISO 19115 2003". A sample metadata created is shown in Figure 2-4.
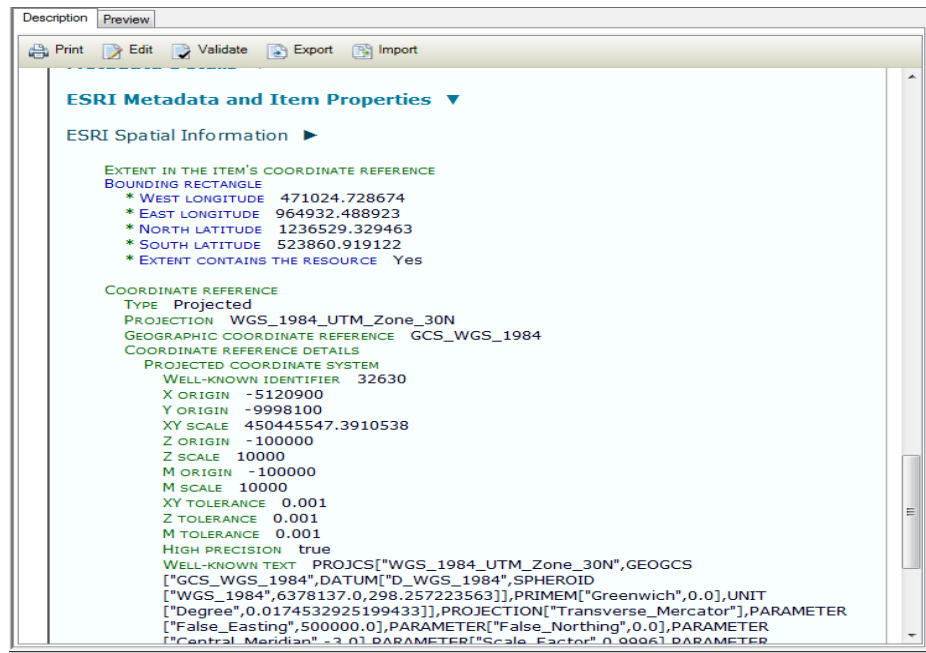
Figure 2-4: A Sample of Metadata

The Metadata has been created by including the possible available information and these are related to following items. The steps of creating are presented in Manual 1.

- ✓ Citation & responsible party information
- ✓ Spatial representation information (Vector)
- ✓ Reference System information
- ✓ Area Extent information
- ✓ Unit of measurements
- ✓ Identification information
- ✓ Distribution information
- ✓ Metadata extension (.shp)
- ✓ Maintenance information

2.1.3.4.   Outputs

Table 2-4 shows the outputs of Task 7.

Table 2-4: Outputs of Task 7

NO.	Item	Type	Where to Find
1	Collated Existing Digital GIS Data and database files together with associated metadata	GIS Data	GIS Server @ RMSC /Task7_Data

2.1.3.5.   Conclusion

All the useful existing GIS datasets have been collated along with metadata in the same projection system that has been decided for this Project.

2.2.   Task 8: Map the forest resource at a national level at 10 yearly intervals using historical and other data for the period 1990-2010

2.2.1. Introduction

For the assessment of Wall-to-Wall Land Use Change using LULUCF Classes, satellite imageries of medium (1990, 2000) and high (2010) resolution were procured. The Land Use (LU) classes were defined as per IPCC guidelines, which have six classes including Forest Land. In addition, to facilitate stratification (as part of dataset preparation for Task 9), the Forest Land was divided into two classes, employing Crown Cover (CC) threshold; Dense forest (> 60%) and Open forest (<60%). For analysis, Erdas Imagine Software was used. All datasets were

maintained with the same projection system, UTM Zone 30, as decided for this Project.

As presented in Figure 2-5, the satellite data was pre-processed for Geometric correction and then converted to Exoatmospheric (or top-of-atmosphere, TOA) Reflectance Then, after estimating Normalized Difference Vegetation Index (NDVI), LU classification was carried out.
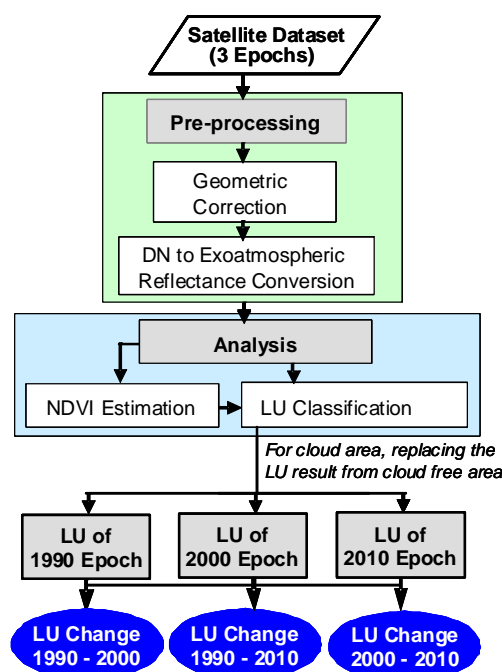
Figure 2-5: Work-flow of LULUCF Analysis

2.2.2. Geometric Correction

2.2.2.1.   Preparation of Satellite Data

For 1990 and 2000 epochs Land Use (LU) analysis, Landsat (TM/ETM+) with spatial resolution 30m was used. Similarly, for 2010 epoch LU, ALOS AVNIR-2 with spatial resolution 10m was used, which was supplemented by DMC satellite data (spatial resolution 22m) for the area where ALOS AVNIR-2 was lacking. Details of data to be included in these epochs are presented below:

i) **Epoch 1990:** Landsat Thematic Mapper (TM) images (spatial resolution 30m) of 1988-1991 covering the whole Ghana (*http://edcsns17.cr.usgs.gov/NewEarthExplorer/*) were used for classification

of Land Use (LU) for 1990 epoch. Altogether 16 Landsat scenes were analyzed, refer to Table 2-5 with location of corresponding Path/Row in Figure 2-6.

Table 2-5 List of Landsat TM used for Land Use Classification for 1990 Epoch

SN	Landsat Scene Identifier	Path/Row	Date Acquired	Cloud Cover (in %
1	LT41920561991003XXX03	P192/R056	03-01-1991	0.0
2	LT41930531988034XXX03	P193/R053	03-02-1988	0.0
3	LT41930541991010XXX03	P193/R054	10-01-1991	0.0
4	LT41930551991010XXX04	P193/R055	10-01-1991	10.0
5	LT41930561991010XXX03	P193/R056	10-01-1991	10.0
6	LT41940521990334AAA04	P194/R052	30-11-1990	0.0
7	LT41940531990334AAA03	P194/R053	30-11-1990	0.0
8	LT41940541990334AAA03	P194/R054	30-11-1990	10.0
9	LT41940551990350XXX03	P194/R055	16-12-1990	0.0
10	LT41940561991001XXX04	P194/R056	01-01-1991	0.0
11	LT41940571991001XXX03	P194/R057	01-01-1991	1.0
12	LT41950521991008XXX03	P195/R052	08-01-1991	0.0
13	LT51950531990253MPS00	P195/R053	10-09-1990	0.0
14	LT41950541991008XXX03	P195/R054	08-01-1991	0.0
15	LT41950551989002XXX02	P195/R055	02-01-1989	0.0
16	LT41950561989002XXX06	P195/R056	02-01-1989	0.0

With the first launch in 1972, Landsat has the latest Landsat7 of its series in the orbit. Up to Landsat 5 both sensors MSS (Multi Spectral Scanner) and TM (Thematic Mapper) were included while Landsat7 has only ETM+ (Enhanced Thematic Mapper plus) sensor. MSS has 4 bands data in VNIR (resolution of 80m), and TM has 7 bands; 4 in VNIR, 2 in SWIR, 1 in TIR (resolution of 30m for VNIR & SWIR and 120m for TIR), and ETM+ has all bands of TM plus a Panchromatic band (resolution 15m).
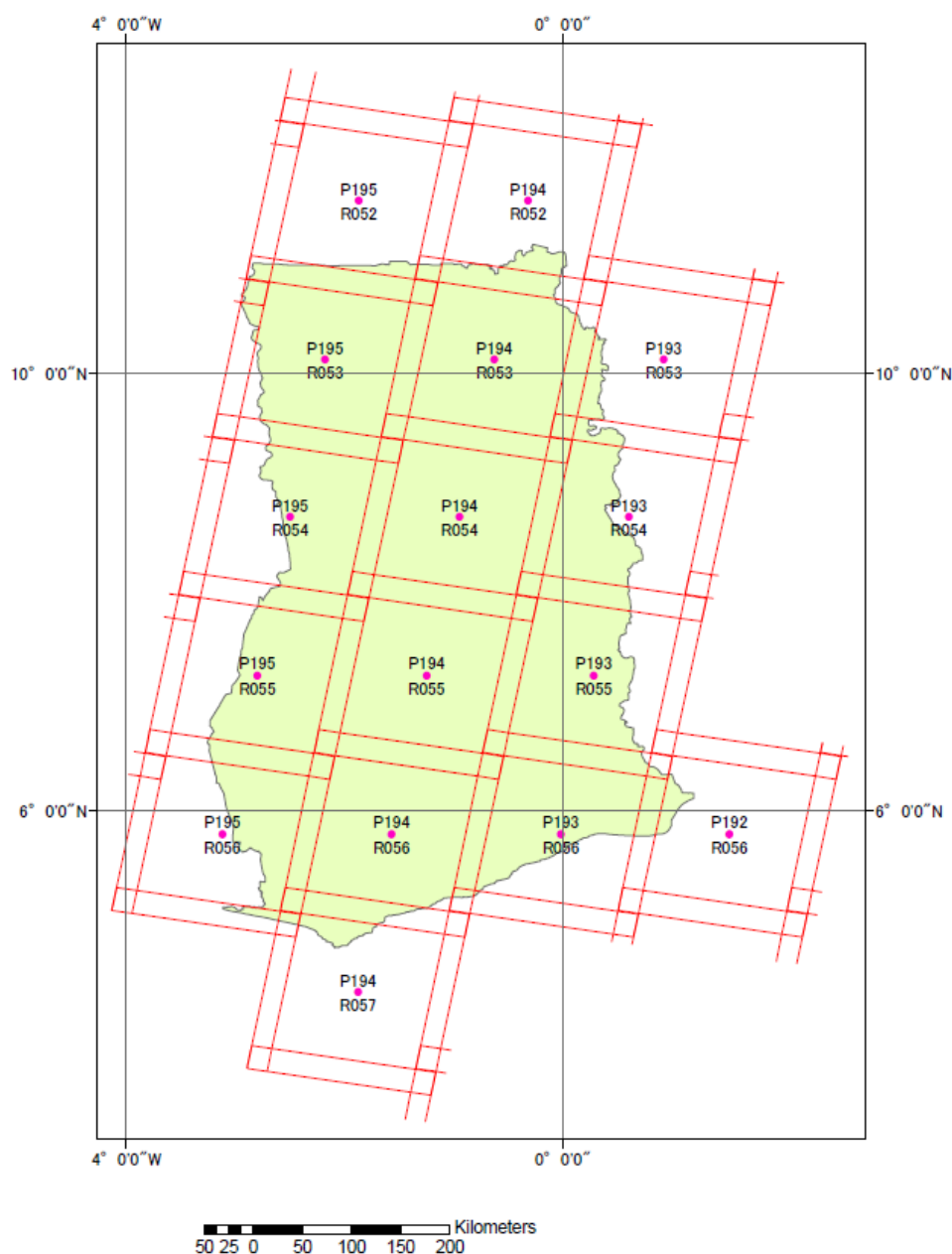
Figure 2-6: Coverage of Landsat TM/ETM+ Path/Row

ii) **2000 Epoch:** Landsat Enhanced Thematic Mapper plus (ETM+) images (spatial resolution 30m) of 2000-2001 were used for LU classification for 2000 Epoch. List of all 16 scenes is presented in Table 2-6 and their location of corresponding scene in Figure 2-6.

Table 2-6: List of Landsat ETM+ used for Land Use Classification for 2000 Epoch

SN	Landsat Scene Identifier	Path/Row	Date Acquired	Cloud Cover (in %
1	LE71920562001094EDC00	P192/R056	2001/4/4	0.4
2	LE71930532000339EDC00	P193/R053	2000/12/4	0.0
3	LE71930542000339EDC00	P193/R054	2000/12/4	0.0
4	LE71930552000339EDC00	P193/R055	2000/12/4	3.4
5	LE71930562000035EDC00	P193/R056	2000/2/4	0.0
6	LE71940522000314EDC00	P194/R052	2000/11/9	0.2
7	LE71940532000314EDC00	P194/R053	2000/11/9	0.0
8	LE71940542001012EDC00	P194/R054	2001/1/12	0.0
9	LE71940552000074EDC00	P194/R055	2000/3/14	6.8
10	LE71940562001092EDC00	P194/R056	2001/4/2	5.1
11	LE71940572000138EDC00	P194/R057	2000/5/17	10.0
12	LE71950522000305EDC00	P195/R052	2000/10/31	0.1
13	LE71950532000353EDC00	P195/R053	2000/12/18	0.0
14	LE71950542001051EDC00	P195/R054	2001/2/20	0.0
15	LE71950552000033EDC00	P195/R055	2000/2/2	0.0
16	LE71950562000033EDC00	P195/R056	2000/2/2	0.0

iii) **2010 Epoch:** For the LU classification of 2010 epoch**,** the archived ALOS AVNIR-2 (Advanced Visible and Near Infrared Radiometer type 2) images with spatial resolution 10m *(https://auig.eoc.jaxa.jp/auigs/top/TOP1000Logout.do)* of 2009–2011 were used. 79 AVNIR-2 scenes were analyzed, refer to Figure 2-7 for their location (refer to Annex 2-2A for detail list).
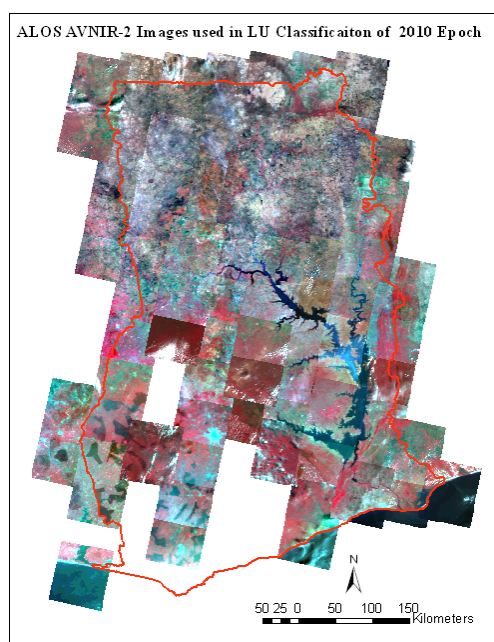
Figure 2-7: Archived ALOS AVNIR-2 Images

ALOS was the Japanese satellite useful mainly for the purpose of land observation such as for cartography, regional observation, disaster monitoring, and resource surveying. The AVNIR-2 is one of three sensors of ALOS which with a visible and near infrared radiometer provides land cover and land-use information with higher spatial resolution to perform the monitoring of regional environments. The other two sensors of ALOS are PRISM (Panchromatic Remote-sensing Instrument for Stereo Mapping) for digital elevation mapping, and PALSAR (Phased Array type L-band Synthetic Aperture Radar) which can acquire data regardless of cloud.

As it is clear from Figure 2-7, some of areas were not covered by the available archived ALOS AVNIR-2 images. For such area, Disaster Monitoring Constellation (DMC) images (http://www.dmcii.com/products.htm) were included in the analysis, which also helped in discarding the cloud area in ALOS AVNIR-2. 3 DMC scenes were used, refer to Table 2-7 for their list and Figure 2-8 for their coverage location.

The Disaster Monitoring Constellation (DMC) consists of a number of remote sensing satellites and is capable of multispectral imaging of any part of the world every day. The DMC Consortium members work together through DMCii (DMC International Imaging Ltd) for commercial sales and for collaborative Earth observation campaigns.

Table 2-7: List of Used DMC Scenes

SN	Image Name	Acquisition Date
1	U2000982_000000_015499_p	19/01/2011
2	U20009a0_000000_015499_p	22/01/2011
3	U20009a0_015000_030499_p	22/01/2011
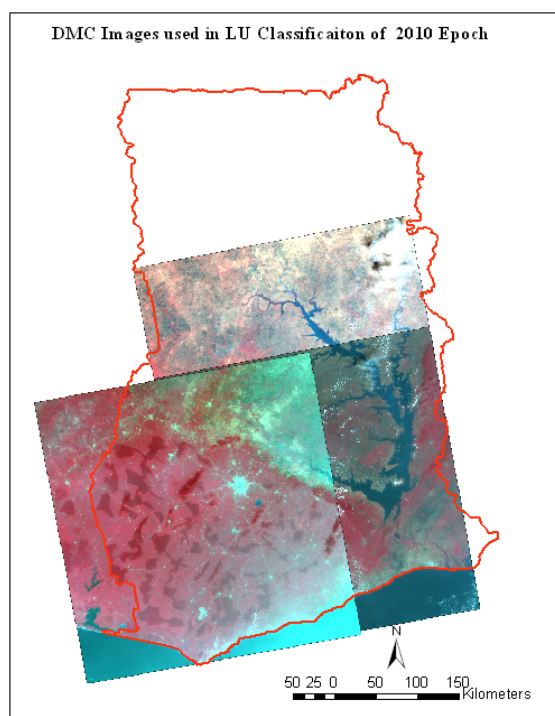
Figure 2-8: Analyzed 3 DMC Scenes

The processing level of procured satellite data of 3 epochs was as listed below in Table 2-8.

Table 2-8: Processing Level, and Product Format of Procured Satellite Data

SN	For Epoch	Satellite Data	Product Information	Quantity (scenes)
1	1990	LANDSAT (TM)	**Multispectral**: Bands 1 to 5 and 7 with 30m pixel **Processing Level**: L1T; **Product Format**: GeoTIFF.	16
2	2000	LANDSAT (ETM+)	**Multispectral**: Bands 1 to 5 and 7 with 30m pixel **Processing Level**: L1T; **Product Format**: GeoTIFF.	16
3	2010	ALOS AVNIR2	**Multispectral:** (4 bands) with 10m pixel; **Processing Level:** 1B1; **Product Format:** CEOS (with	79
4		DMC	**Multispectral:** 3bands with 22m pixel; **Processing Level:** L1T; **Product Format:** GeoTIFF.	3

To get better geo-metric corrected images including the removal of inter-scene locational discrepancy, all the images were ortho-rectified employing Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM). For Ground Control Points (GCPs), the features such as road crossing and road river crossing were used from the existing Topographic maps so acquired from Survey of Ghana (SOG). Moreover, considering that such GCPs are less in numbers and not uniformly

distributed throughout the country as well as the maps are relatively of older than the images, the existing ortho-rectified Landsat images.

2.2.2.2. Preparation of DEM and Reference Dataset

i) Downloading and compiling SRTM DEM

SRTM DEM (spatial resolution 90m) was downloaded from Web site (*http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp*). It was re-projected to the projection adopted for this Project, that is, UTM, Zone 30 with spheroid and Datum WGS84. The SRTM DEM covering whole Ghana is presented in Figure 2-9.
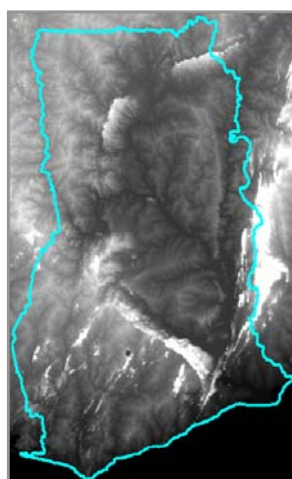
Figure 2-9: SRTM DEM Covering Whole Ghana

ii) Preparing the Reference Data for GCPs

As mentioned above, for ortho-rectification the reference datasets were required to collect GCPs. For this, the existing road and river GIS data were used. However, with limited number of such GCPs from exiting GIS data, wherever necessary additional GCPs were collected from the existing ortho-rectified Landsat images available at Webpage; *http://glcf.umiacs.umd.edu/*. To avoid discrepancy between existing GIS data and existing ortho-rectified Landsat images, multi-dated Landsat images were downloaded and compared with GIS data especially for road crossing which were found relatively stable. And, the Landsat image which was found having less discrepancy was selected as reference image. The list of those reference images are presented below in Table 2-9.

Table 2-9: List of used Reference Landsat Image for GCPs

SN	Landsat scene (Path/Row)	Acquisition Date
1	P192R056	2001/4/4
2	P193R053	2000/12/4
3	P193R054	2000/12/4
4	P193R055	2001/12/7
5	P193R056	2000/2/4
6	P194R052	1999/11/7
7	P194R053	1999/11/7
8	P194R054	2000/5/17
9	P194R055	2002/3/20
10	P194R056	2002/1/15
11	P194R057	2002/1/15
12	P195R052	2001/7/14
13	P195R053	2000/6/9
14	P195R054	2000/2/2
15	P195R055	2000/2/2
16	P195R056	2000/2/2

2.2.3. Ortho-rectification of Satellite Data

The procured ALOS AVNIR-2 satellite images were not rectified. On the other hand, most of Landsat images were rectified; however some scenes had greater level of discrepancy. Similarly, all 3 scenes of DMC were found to be re-rectified in order to locationally match with ALOS AVNIR-2 scenes. Thus, to achieve images with better locational accuracy, ortho-rectification was carried out employing the above compiled SRTM DEM for height source and GCPs from reference datasets.

   i)   **Ortho-rectification of AVNIR-2**: In Erdas Imagine Software, 'ALOS RPC model' was used. In , a) is an ALOS AVNIR-2 scene before ortho-rectification and b) is after ortho-rectification. For detail, refer to Manual 1.
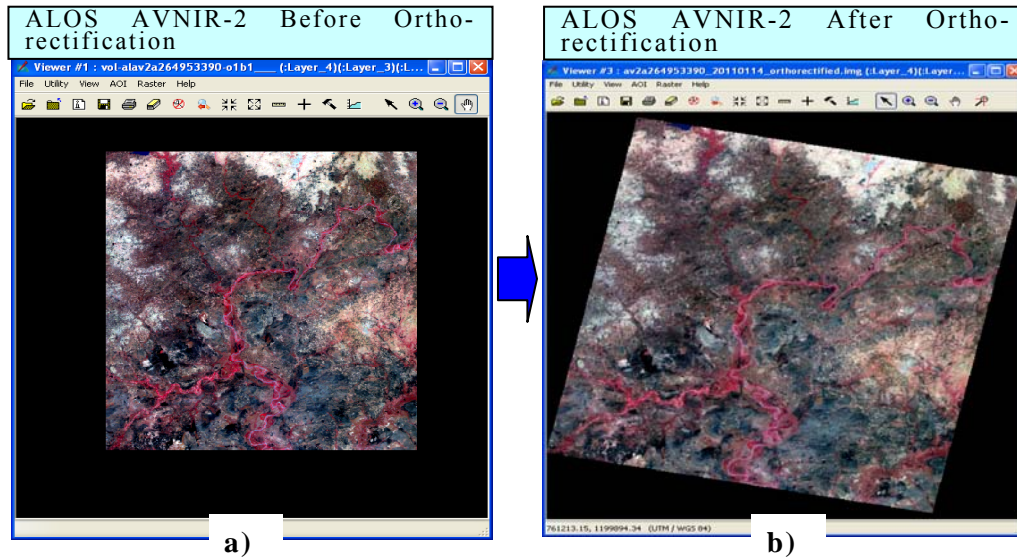
Figure 2-10: ALOS AVNIR-2 Scene; a) Before b) After Ortho-rectification

ii) **Ortho-rectification of Landsat**: This was carried out using 'Landsat Model' of Erdas Imagine Software. Step by step detail of procedure is included in Manual 1.

iii) **Ortho-rectification of DMC**: This was carried out with 'Projective Transformation Model' of Erdas Imagine Software. For detail, refer to Manual 1.

2.2.4. Cloud and Shadow Removal

After extracting the cloud and shadow area in the ortho-rectified images, such area in the classified images was replaced with the classified result of other dated image. In the ortho-rectified image, cloud and shadow was replaced while creating mosaicked image for whole Ghana.

2.2.5. Converting DN to Radiance and then to TOA Reflectance

The reflectance value of an object is considered as relatively more consistence compared to Digital Number (DN). With this essence, DN value of pixels was converted to Radiance and then to Exoatmospheric (or top-of-atmosphere, TOA)

Reflectance prior to start analysis for LU classification. The conversion of DN to radiance and then to TOA Reflectance was carried out using the equation mentioned in "Landsat 7 Science Data Users Handbook-Data Products".

i) **Conversion of DN to Radiance:** The general equation for DN to Radiance is as follows:

$$L\lambda = Grescale * QCAL + Brescale$$

Where,

$L\lambda$ = Spectral Radiance at the sensor's aperture (W/m2/sr/μm)

Grescale = Rescaled gain

QCAL = Digital Number (DN)

Brescale = Rescaled bias

ii) **Conversion of Radiance to TOA Reflectance:** Following equation was used to convert radiance to TOA reflectance:

$$\rho_p = \frac{\pi.L_\lambda.d^2}{ESUN_\lambda.\cos\theta_s}$$

Where,

ρ_p = Unitless planetary reflectance

L_λ = Spectral radiance at the sensor's aperture

d = Earth-Sun distance in astronomical units from nautical handbook

$ESUN_\lambda$ = Mean solar Exoatmospheric irradiances

θ_s = Solar zenith angle in degrees

The detail of DN to Radiance and then to Reflectance conversion is included in Manual 1.

2.2.6. Analysis

2.2.6.1.   Estimation of NDVI

Normalized Difference Vegetation Index (NDVI) was estimated using the following equation, refer to Manual 1 for detail procedure.

$$NDVI = \frac{(NIR - \mathrm{Re}d)}{(NIR + \mathrm{Re}d)}$$

Where,

    NIR: Near Infra-Red band

    Red: Red band

2.2.6.2.   Included Land Use (LU) Classes for 3 Epochs

With respect to Land Use (LU) classes, following six (6) broad classes were included based on the UNFCCC Good Practice Guide (GPG 2003) and the Guidelines for Agriculture, Land Use and Forestry (GL-AFOLU 2006):

1. Forest Land
2. Cropland
3. Grassland
4. Wetlands
5. Settlements
6. Other Land

These six classes were used as they are:

- Reasonably consistent with the IPCC Guidelines
- Robust as a basis for carbon estimation
- Reasonably mappable by remote sensing methods
- Complete in that all land areas should be represented in one

The definition of these classes is as follows:

1) **Forest Land (2000):** This includes all land with woody vegetation consistent with thresholds used to define Forest Land in the national greenhouse gas inventory. It also includes systems with a vegetation structure that currently fall below, but in situ could potentially reach the proposed national values used by to define the Forest Land category in Ghana as follows:

- Minimum Mapping Unit (MMU) is 1.0ha
- Minimum crown cover is 15%
- Potential to reach minimum height at maturity (in situ) as 5m

2) **Cropland (1000):** This includes crop land (currently cropped or in fallow), including rice fields, and agro-forestry systems where the vegetation structure falls below the thresholds used for the Forest Land category. This includes land where over 50% of any defined area is used for agriculture.

3) **Grassland (3000, 4000):** This includes rangelands and pasture lands that are not considered Cropland. It also includes herbs and brushes that fall below the threshold values used in the Forest Land category such as the other wooded land following the FAO definition in Ghana:

- CC < 15% and > 10%, height > 5m, MMU > 0.5ha
- CC 5% - 10%, height > 5m, MMU > 0.5ha
- Shrubs, bushes and trees CC > 10%, Height < 5m, MMU > 0.5ha

4) **Wetlands (7000, 8000):** These include areas of peat extraction and land that is covered or saturated by water for all or part of the year (e.g., peat lands) and that does not fall into the forest land, cropland, grassland or settlements categories. It also includes reservoirs as a managed sub-division and natural rivers and lakes as unmanaged sub-divisions.

5) **Settlements (5000):** These include all developed land, including transportation infrastructure and human settlements of any size, unless they are already included under other categories.

6) **Other Land (6000):** This category includes bare soil, rock, ice, and all land areas that do not fall into any of the other five categories.

Moreover, as part of Task 9, that is, dataset preparation for creation of baseline forest resource map, Forest land was divided into two classes based on Crown Cover (CC) threshold; Closed (Dense) forest (> 60%) and Open forest (<60%). Also water body such as river and reservoir was initially separated from other wetlands. Thus, altogether 8 LU classes were considered during classification, which was finally compiled to above 6 LU classes.

2.2.6.3.   Collection of Interpretation Keys

The interpretation keys for some of model locations with respect to all included LU classes were collected by conducting the Ground Truthing (GT) survey using the satellite image of 2010 epoch. In all, 5 teams were formed to conduct GT survey covering the entire country, each one comprised of 4 members; a team leader, a data recorder, a labour, and a driver. As part of planning, the possible candidate sites and plan route were selected by displaying the images into computer and overlaying the road network and settlement datasets. During the GT survey, along with collecting the coordinates, existing Land Use (LU) class, and others, photo was taken to all 4 directions in order to have better understanding of the LU of surroundings, refer to Figure 2-11.

| North | East | South | West |
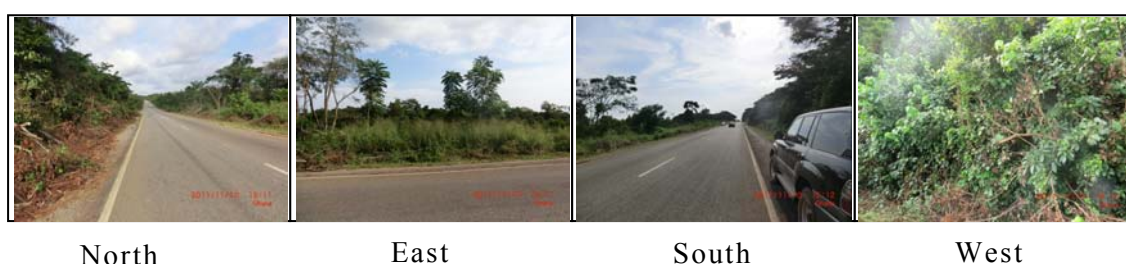
Figure 2-11: 4-Directional Photos Taken during Ground Truthing (GT)

Altogether, interpretation keys were conducted for about 1,057 sites spreading across the whole country. The distribution of these sites is presented in Figure 2-12:
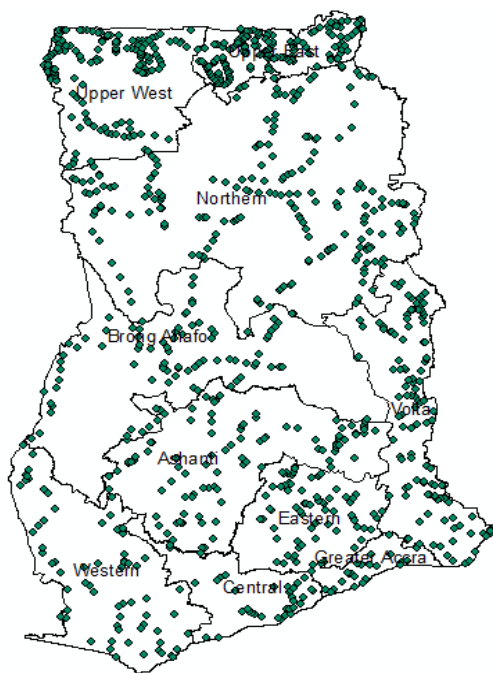
Figure 2-12: Distribution of points for Interpretation Keys

2.2.6.4.   Image Classification

Employing the threshold to NDVI, each image of 2010 epoch was first classified grossly into three groups:

- Vegetation A (with higher NDVI values),
- Vegetation B (with middle range of NDVI), and
- Non-vegetation (with lower NDVI values).

Comparison of NDVI values with the displayed ortho-rectified image helped in deciding about the NDVI threshold for each image scene. After dividing the whole scene into above three gross groups, the ortho image was masked and separately run for unsupervised classification (ISODATA Clustering) for 20 classes, which were recoded to the classes so mentioned in section 2.2.7.2 in order to get the draft LU result of 2010. During both steps; deciding for NDVI threshold, and recoding for classes, the information of collected interpretation keys was used. Dividing the image into above three groups, helped in getting higher degree of accuracy for Forest land as most of dense forest was generally found included in 'Vegetation A' group. And, conversely 'Non-vegetation' area rarely included Forest land. The detail of LU classification is presented in Manual 1. Majority of Settlements areas were created

by manual digitization. The cloud and shadow area was replaced by getting the classified LU result of the alternate dated image

The draft LU classification result of 2000 and 1990 epoch images were carried out adopting the same procedure.

2.2.6.5.   Ground Verification

Considering time and resource constraint, Ground Verification (GV) was carried out on sampled locations. This was further modified by accessibility was impossible. Taking the draft LU classification result of 2010 epoch, GV was carried out for 2,213 locations. The distribution of those locations is presented as blue dots in Figure 2-13.
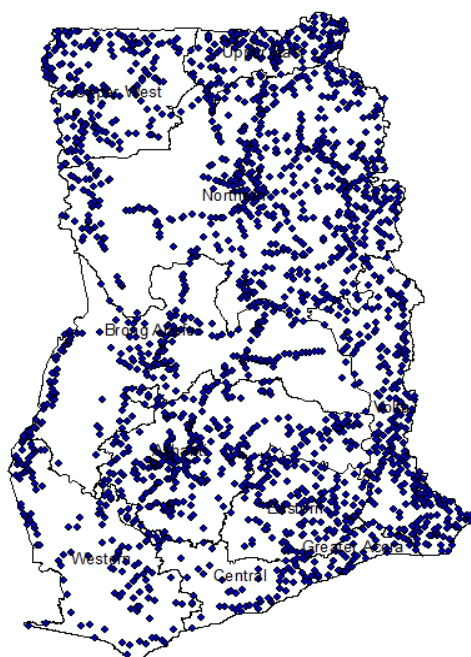
Figure 2-13: Locations of Conducted Ground Verification (GV) Survey

During the GV survey, along with verifying the resulted LU class with the existing one, photo was taken to all 4 directions, similar to as taken during GT survey.

2.2.6.6.   Editing and Finalising the LU Classification

i)   Editing Draft LU Classification

For this task, mis-classification errors in the draft LU classified images were grouped into two classes: ***localized*** and ***generalized,*** depending on their magnitude or level of spread. Isolated errors within a scene were described as local errors while similar error that cut across the repeated locations in the scene were classified under general errors. In order to edit a draft classified LU scene, its corresponding otho-rectified image and GV point shapefiles, and Google Earth image and field pictures were employed. All these editing were done using Erdas Imagine 2011 Software.

For localized mis-classification errors editing, the Area of Interest (AOI) was delineated covering the area and then it was replaced with the appropriate class. For generalized editing, the preliminary classified result of the scene; that is, the unsupervised classification with 20 classes, was checked and then appropriate class was assigned by recoding for the class representing the mis-classification. This corrected class area was then overlaid on to the previous image result to achieve updated one. Editing was carried out first to 2010 epoch LU result followed that by 2000 and 1990.

ii)   Finalizing the LU Classification

This involved mainly the edge matching among the neighbouring scenes and then mosaicking them to create single dataset. Edgematching was carried out by editing mis-matches at the edges with the neighbourhood scenes by creating AOI and then assigning the matching LU class. During this, the ortho-rectified image was always displayed side by side to assign appropriate LU class. After edge matching the individual edited scenes were mosaicked using the Mosiac Pro tool in Erdas and subsequently subsetted using the boundary of Ghana.Lastly, the resultant LU imagery were recoded to six (6) LU classes.

All three epochs (2010, 2000, and 1990) final LU classification map was achieved adopting this procedure. Figure 2-14 shows the distribution of six LU classes. The

main challenge was to ensure high quality of the classification result for the base year, 2010. Thus, more time and effort was dedicated in producing the 2010 LU map which was then used as base for producing the 1990 and 2000 LU maps.

a) LU Map (1990)   **b) LU Map (2000)**   **c) LU Map (2010)**

Legend: IPCC Class

🟩	Forest land	🟪	Grassland	🟦	Wetlands
🟨	Cropland	🟥	Settlements	⬜	Other land
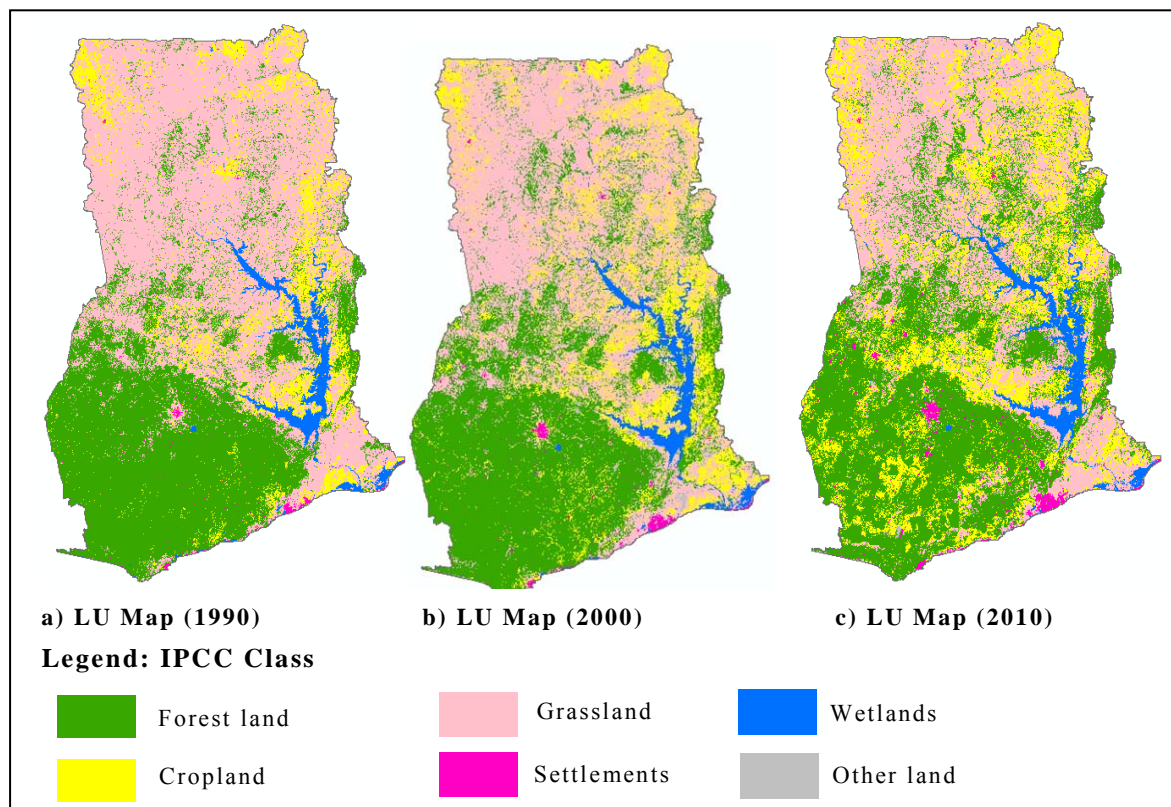
Figure 2-14: LU Maps of a) 1990 Epoch, b) 2000 Epoch, c) 2010 Epoch

From the figure above, it can be realised that the Forest land in Ghana is mostly found in the South-western part of the country. Moreover, in the northern part of Ghana is mostly grasslands and cropland. Similary, majority of the wetlands are located in the South-eastern (Volta region) part of country.

2.2.6.7.   Accuracy Assessment of Classification Result

Quality checking of the result was carried out for each step of processing before moving to next one and this helped in achieving accuracy in LU classification. As mentioned in Section 2.2.7.5., the Ground Verification (GV) of the draft classified LU of 2010 was conducted for 2,213 sample locations.

Accuracy Assessment was performed employing the result of above 2,213 GV points distributed throughout Ghana and thus it was carried out only for 2010 LU epoch LU classification result (that is, at spatial resolution 10m). This was performed using the Classifier tool of Erdas Imagine. The procedures involved following steps:

- Clicking the 'Erdas' - 'Supervised' – '*Accuracy Assessment*' to display dialog box.
- From the dialog box, the final 2010 classified image was browsed and the viewer with the displayed classified image linked.
- Then, using the "*User-defined points*" under **Edit menu** the field verification points was imported displaying its X – Y coordinates in the table.
- For the corresponding point, the classified reference code associated with the Land Use (LU) classes (during image classification) was entered in the "*Reference*" column.
- The accuracy report was created by clicking 'Report' – 'Accuracy Report'. The generated report was generated as an Error Matrix in form of text file and it had the overall accuracy, user's and producer's accuracy, refer to Table 2-10.

Table 2-10: Accuracy Assessment Result of LU Map of 2010

Classified data / Reference data	Forest land	Cropland	Grassland	Settlements	Wetlands	Other land	Classified Total	Users Accuracy (%)
Forestland	520	48	39	0	0	0	**607**	85.67
Cropland	57	493	48	1	0	2	**601**	82.03
Grassland	55	44	384	0	0	9	**492**	78.05
Settlements	17	13	12	283	1	5	**331**	85.50
Wetlends	0	0	1	0	152	0	**153**	99.35
Otherland	2	0	3	0	0	24	**29**	82.76
Reference Total	**651**	**598**	**487**	**284**	**153**	**40**	**2213**	-
Producer Accuracy (%)	79.88	82.44	78.85	99.65	99.35	60.00	-	**83.87**

Moreover, the accuracy was also assessed employing the same above procedure by dividing the whole Ghana into blocks to know its variation in different areas. For this, the finalised mosaicked 2010 LU image was divided into 13 blocks, refer to Figure 2-15 below.
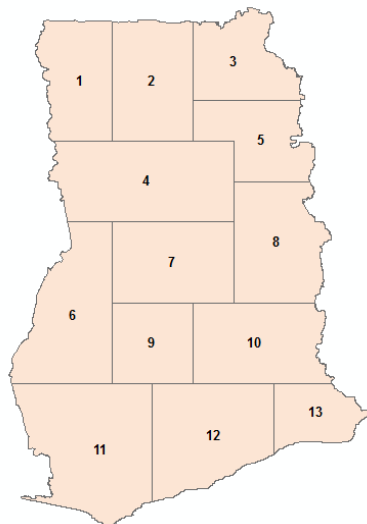
Figure 2-15: Blocks Created for Assessing Accuracy of 2010 LU Map

In assessing the accuracy of each block, a total of up to 200 GV locations were used. The accuracy assessment result of each block is presented in Annex 2-2B.

The 2010 LU map was used to editing and achieving final LU map of 2000 and 1990 and with this essence, these are also believed to be with similar accuracy as of 2010 LU map.

2.2.6.8. Land Use Change Detection Analysis

From the LU Map of 3 epochs, Land Use Change (LUC) was carried out to quantify the land cover changes that have taken place, providing information (in the form of change map) on what class changes to what (the from – to conversions information). For this, the LU thematic image of two epochs was pre‑requisite in assessing the changes that has taken place within that interval. The *Matrix Union* tool under Thematic toolbar (of Erdas Imagine 2011) was employed in assessing the changes that have taken place within the epochs 1990 – 2000, 2000 – 2010 and 1990 – 2010. The resulted LUC maps are presented in Figure 2-16.

a) LUC Map (1990-2000) **b) LUC Map (1990 -2010)** **c) LUC Map (2000 -2010)**

Legend:

Forest land to Forest land   Non-Forest to Forest land

Forest land to Non-Forest   Non-Forest to Non-Forest
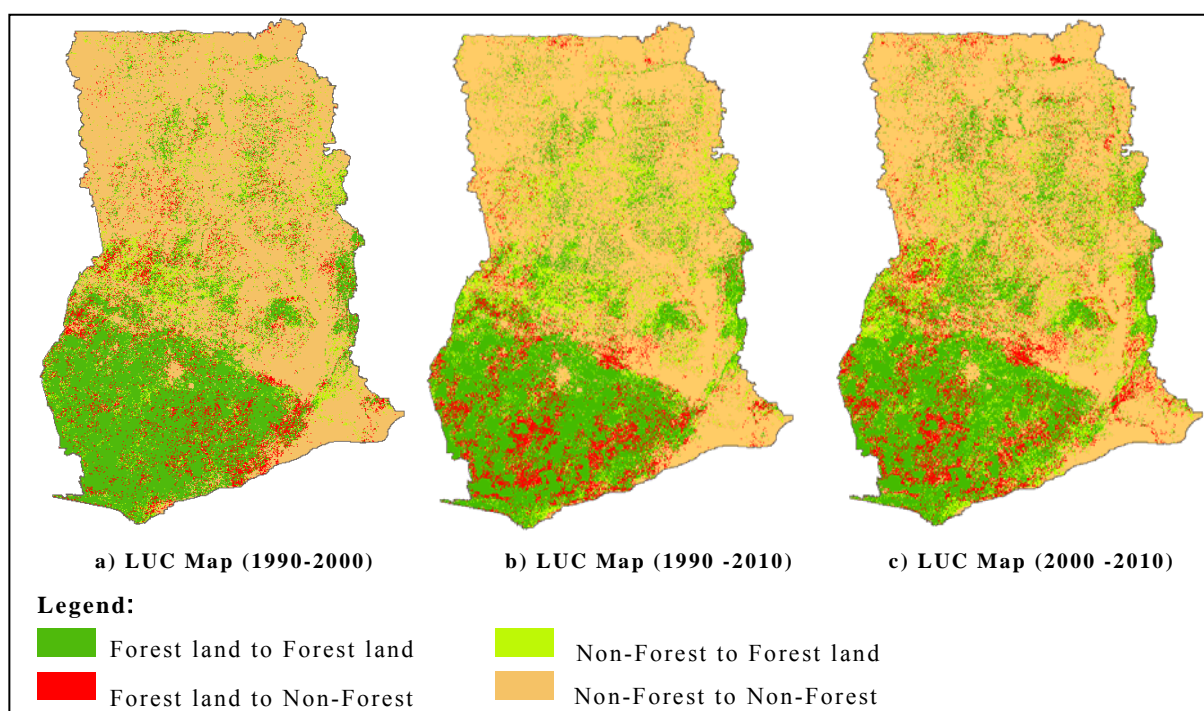
Figure 2-16: LUC Maps of 3 Intervals; 1990-2000, 2000-2010, 1990-2010

The LUC maps of 3 intervals indicate that the overall conversion activities 'to and from' Forest land was relatively more during 2000 – 2010 period compared to 1990 – 2000. This is further supported by LU conversion Matrix Tables of 3 intervals presented in Table 2-11, Table 2-12, and Table 2-13. These matrix tables contain 'to and from' areal conversion of all 6 LU classes during the specified interval. For instance, in the Table 2-11 (LU Conversion matrix 1990-2000), regarding Forest land:

i) Area equal to 6,993,246.4Ha was found Forest land in both LU results; 1990 and 2000, that is, no change.

ii) Areas equal to 283,868.4Ha, 1,629,578.3Ha, 0.1Ha, 3,159.2Ha, and 1,573.3Ha were as Cropland, Grassland, Settlements, Wetlands, and Other Land, respectively in 1990, but in 2000 it was Forest land. That is, during 1990 – 2000, these lands were converted '**to Forest land**'.

iii) Areas equal to 590,605.4Ha, 994.922.9Ha, 13,457.3Ha, 9,330.2Ha, and 25,839.7Ha were Forest land in 1990 but these were Cropland, Grassland, Settlements, Wetlands, and Other Land, respectively, in 2000. That is, during 1990 – 2000, these lands were converted '**from Forest land**'.

iv) The total Forest land area in 1990 and 2000 was 8,627,401.9Ha and 8,911,425.6Ha, respectively.

v) The net change in Forest land area (between 1990 and 2000), was increased by 284,023.7Ha.

Table 2-11: Land Use Conversion Matrix 1990-2000

2000 / 1990	Forest land	Cropland	Grassland	Settlements	Wetlands	Other land	Total LU Area in 1990 (Ha)
Forest land	6,993,246.4	590,605.4	994,922.9	13,457.3	9,330.2	25,839.7	**8,627,401.9**
Cropland	283,868.4	1,672,234.6	846,942.6	22,414.1	3,920.7	7,643.5	**2,837,023.8**
Grassland	1,629,578.3	1,632,816.8	8,092,349.3	62,789.5	26,375.4	120,832.3	**11,564,741.5**
Settlements	0.1	0.0	0.3	102,586.2	0.0	0.0	**102,586.6**
Wetlands	3,159.2	4,616.6	12,231.1	287.2	752,365.8	1,081.9	**773,741.8**
Other land	1,573.3	4,298.2	7,894.5	2,309.9	686.7	1,285.6	**18,048.2**
Total LU Area in 2000 (Ha)	**8,911,425.6**	**3,904,571.6**	**9,954,340.7**	**203,844.2**	**792,678.8**	**156,683.0**	**23,905,495.6**
Net LU Change Area (Ha)	*284,023.7*	*1,067,547.8*	*-1,610,400.9*	*101,257.7*	*18,937.0*	*138,634.7*	

Table 2-12: Land Use Conversion Matrix 1990-2010

2010 / 1990	Forest land	Cropland	Grassland	Settlements	Wetlands	Other land	Total LU Area in 1990 (Ha)
Forest land	6,718,627.1	1,218,912.3	615,327.7	45,828.3	11,302.5	17,404.1	**8,627,401.9**
Cropland	520,482.3	1,253,507.9	965,965.8	53,953.9	27,624.2	15,489.7	**2,837,023.8**
Grassland	1,950,799.5	2,741,931.7	6,566,839.7	136,399.9	92,576.6	76,194.1	**11,564,741.5**
Settlements	0.0	0.0	0.0	102,586.6	0.0	0.0	**102,586.6**
Wetlands	1,955.9	5,046.6	17,686.5	2,699.0	745,940.3	413.5	**773,741.8**
Other land	3,271.8	2,050.0	7,582.9	3,580.7	1,340.2	222.8	**18,048.2**
Total LU Area in 2010 (Ha)	**9,195,136.6**	**5,221,448.5**	**8,173,402.6**	**345,048.3**	**878,783.9**	**109,724.1**	**23,923,543.9**
Net LU Change Area (Ha)	*567,734.7*	*2,384,424.6*	*-3,391,339.0*	*242,461.7*	*105,042.1*	*91,675.9*	

Table 2-13: Land Use Conversion Matrix 2000 -2010

2010 / 2000	Forest land	Cropland	Grassland	Settlements	Wetlands	Other land	Total LU Area in 2000 (Ha)
Forest land	6,700,952.2	1,233,155.0	927,424.7	20,711.7	12,022.8	17,159.2	**8,911,425.6**
Cropland	812,670.3	1,791,822.5	1,209,277.7	44,173.2	27,978.2	18,649.7	**3,904,571.6**
Grassland	1,655,716.6	2,174,157.3	5,908,042.4	72,840.4	74,491.7	69,092.3	**9,954,340.7**
Settlements	3.6	0.5	1.4	203,838.8	0.0	0.0	**203,844.2**
Otherlands	4,803.8	3,786.8	22,997.3	2,168.6	758,167.7	754.7	**792,678.8**
Wetlands	20,990.2	18,526.5	105,659.0	1,315.6	6,123.5	4,068.2	**156,683.0**
Total LU Area in 2010 (Ha)	**9,195,136.6**	**5,221,448.5**	**8,173,402.6**	**345,048.3**	**878,783.9**	**109,724.1**	**23,923,543.9**
Net LU Change Area (Ha)	*283,711.0*	*1,316,876.9*	*-1,780,938.1*	*141,204.1*	*86,105.1*	*-46,958.9*	

2.2.6.9.   Tiling of LU and LUC Datasets

Tiling of the LU and LUC Datasets were carried out in accordance with 1:100,000 index map using the Subset tool in Erdas Imagine. First, all the individual sheets of the adopted map sheets of Ghana were extracted and converted to AOIs. Using the *copy and paste* tool, the individual shape files of the map sheets were saved as AOIs. Subsequently, the individual map sheets AOIs were used in tiling the LU and LUC datasets, employing the Subset tool. A tiled image of LU and LUC is presented in Figure 2-17.

The map layout for each 102 tiled LU image of all 3 epochs (1990, 2000, and 2010) along with background data was compiled in ArcGIS at 1:100,000 scale. The compiled map was saved as MXD and exported as PDF format. Similarly, the layout for each 102 tiled LUC image of 3 intervals (1990-2000, 1990-2010, and 2000-2010) along with background data was prepared at same scale, which was saved as MXD and exported as PDF format. Figure 2-18 presents the sample map of LU of 2010 for Tile 0500A. In this sample, the detail LUC classes have been simplified to depict 4 considering conversion.

Legend: LU IPCC

🟩	Forest land	🟪	Settlements
🟨	Cropland	🟦	Wetlands
🟪	Grassland	⬜	Other land

Legend: LUC

🟩 Forest land to Forest land
🟥 Forest land to Non-Forest
🟩 Non-Forest to Forest land
🟧 Non-Forest to Non-Forest

a) Tile 0500A of LU Map 2010   **b) Tile 0500A of LUC Map 1990 - 2010**
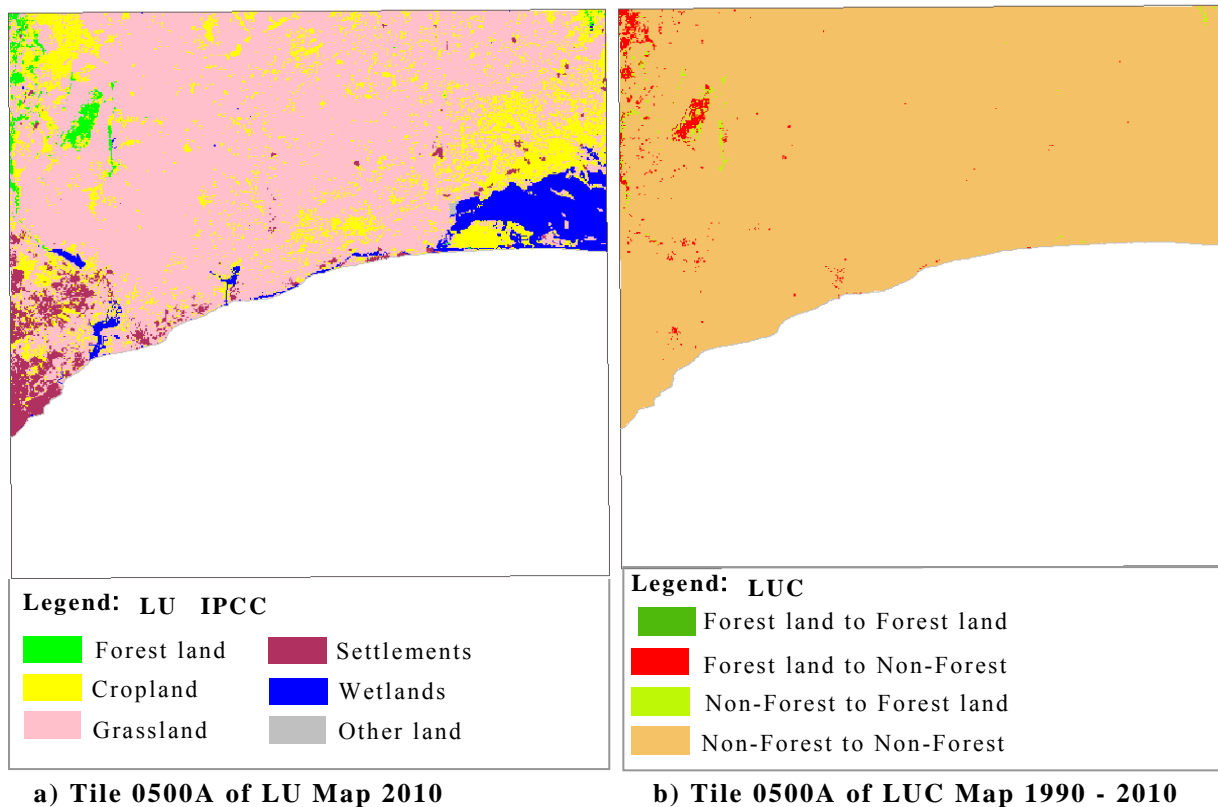
Figure 2-17: Tile 0500A of a) LU Map 2010, b) LUC Map 1990 – 2000
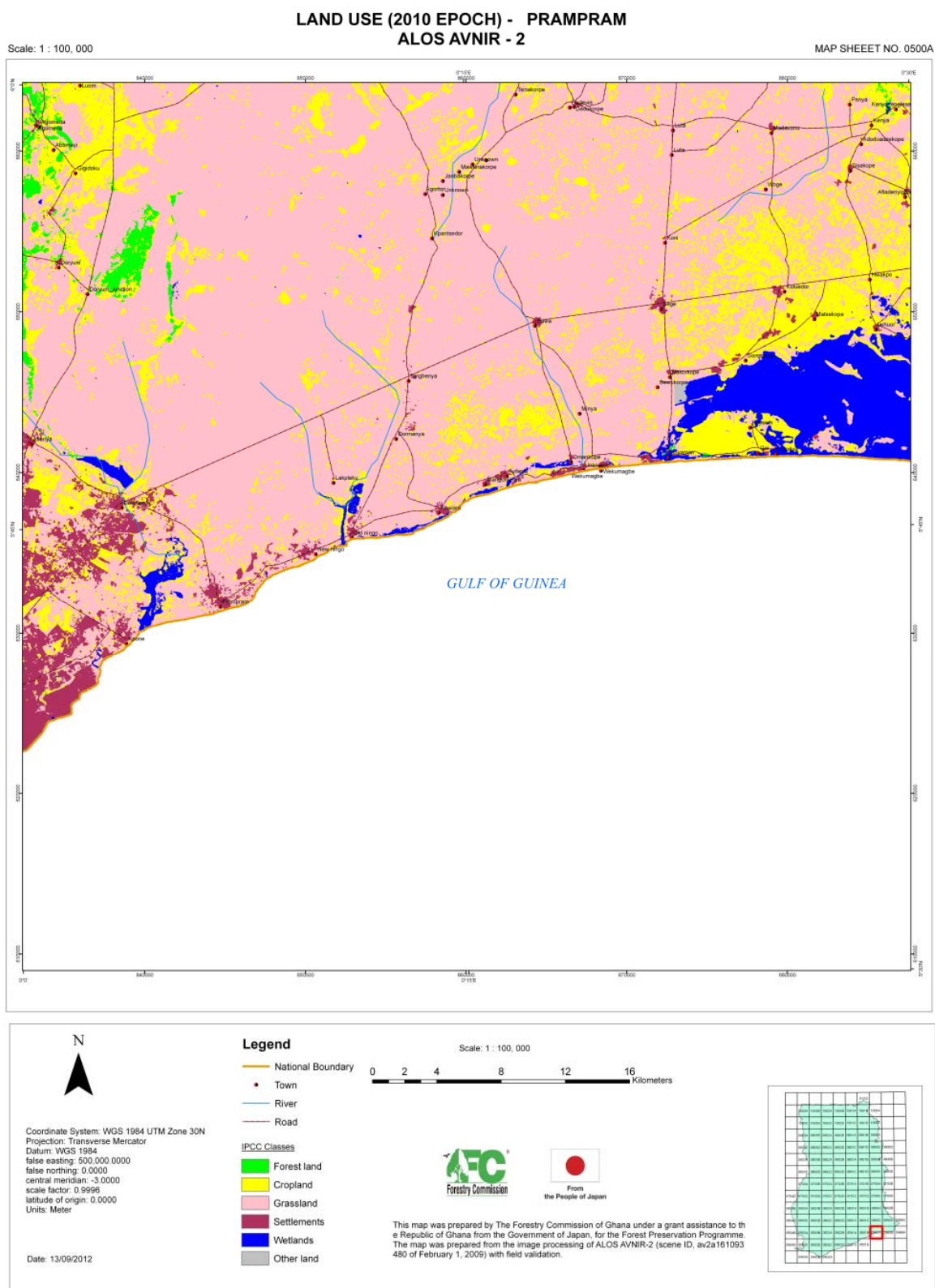
Figure 2-18: Layout file of Tile 0500A of LU Map 2010

2.2.6.10.   Mosaicking, Color Balancing and Preparation of Tiles

Mosaicking of the ortho-rectified images was carried out using the Mosaic Pro function of Erdas Imagine Software. Mosaicking was done for the images of all 3 epoch images, ALOS AVNIR-2 and DMC for 2010, and Landsat (TM/ETM+) for 2000, and 1990. Since the DMC images were having three (3) bands (Green, Red, and Infra-red), in order to make it compatible with 4 bands (Blue, Green, Red, and Infra-red) images of ALOS AVNIR-2, a dummy Blue band was added as band 1 in DMC using the Layer Stack tool in Erdas. Moreover, due consideration was given to the color balancing across the scenes. The mosaicked images of 3 epochs are presented in Figure 2-19.

a) Mosaicked 1990 Landsat   b) Mosaicked 2000 Landsat   c) Mosaicked 2010 AVNIR-2,
    TM Images   ETM+ Images   DMC Landsat
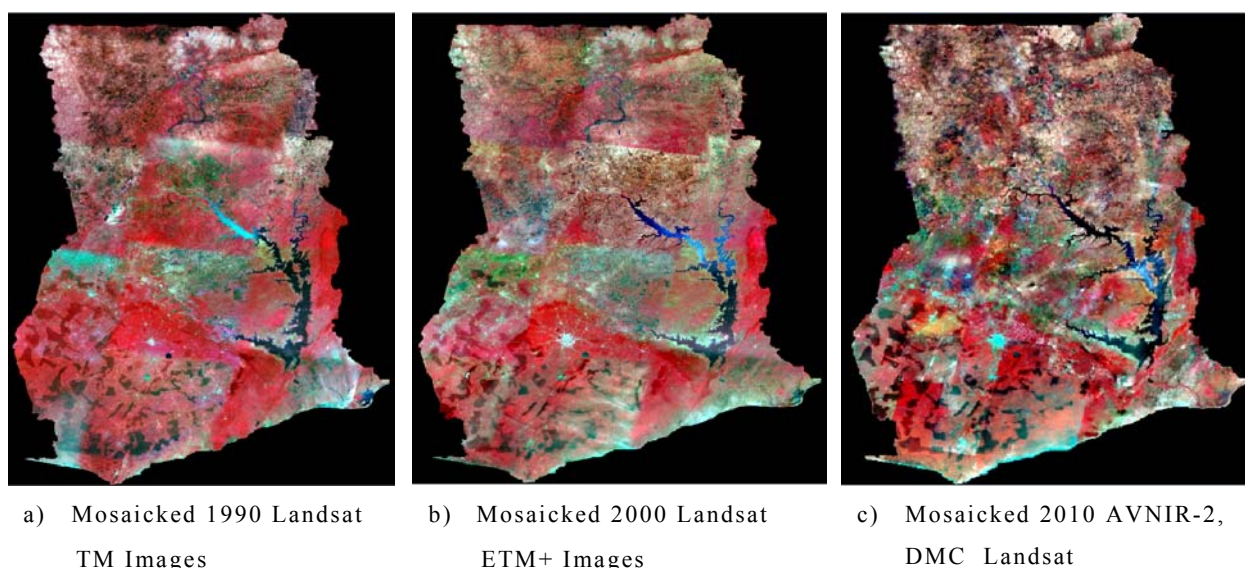
Figure 2-19: Mosaicked Images of 3 Epochs; a) 1990 Landsat TM, b) 2000 Landsat ETM+, c) 2010 AVNIR-2, DMC

The same tiling approach adopted for LU and LUC images so mentioned in section 2.2.6.9 was employed in tiling each of the three (3) ortho-rectified epochs (1990, 2000 and 2010). Layout of these individual subset images of 3 epochs was generated in ArcGIS at the scale of 1:100,000 by incorporating background data such as town location in MXD and PDF format. Figure 2-20 presents the layout file of Tile 0500A of 2010. The displayed image combination is Near-Infrared, Red, and Green bands as R, G, B, which has been mentioned as Layer_4, Layer_3, and Layer_2, respectively in the layout.

ORTHORECTIFIED (2010 EPOCH) - PRAMPRAM
ALOS AVNIR-2

Scale: 1 : 100, 000

MAP SHEEET NO. 0500A
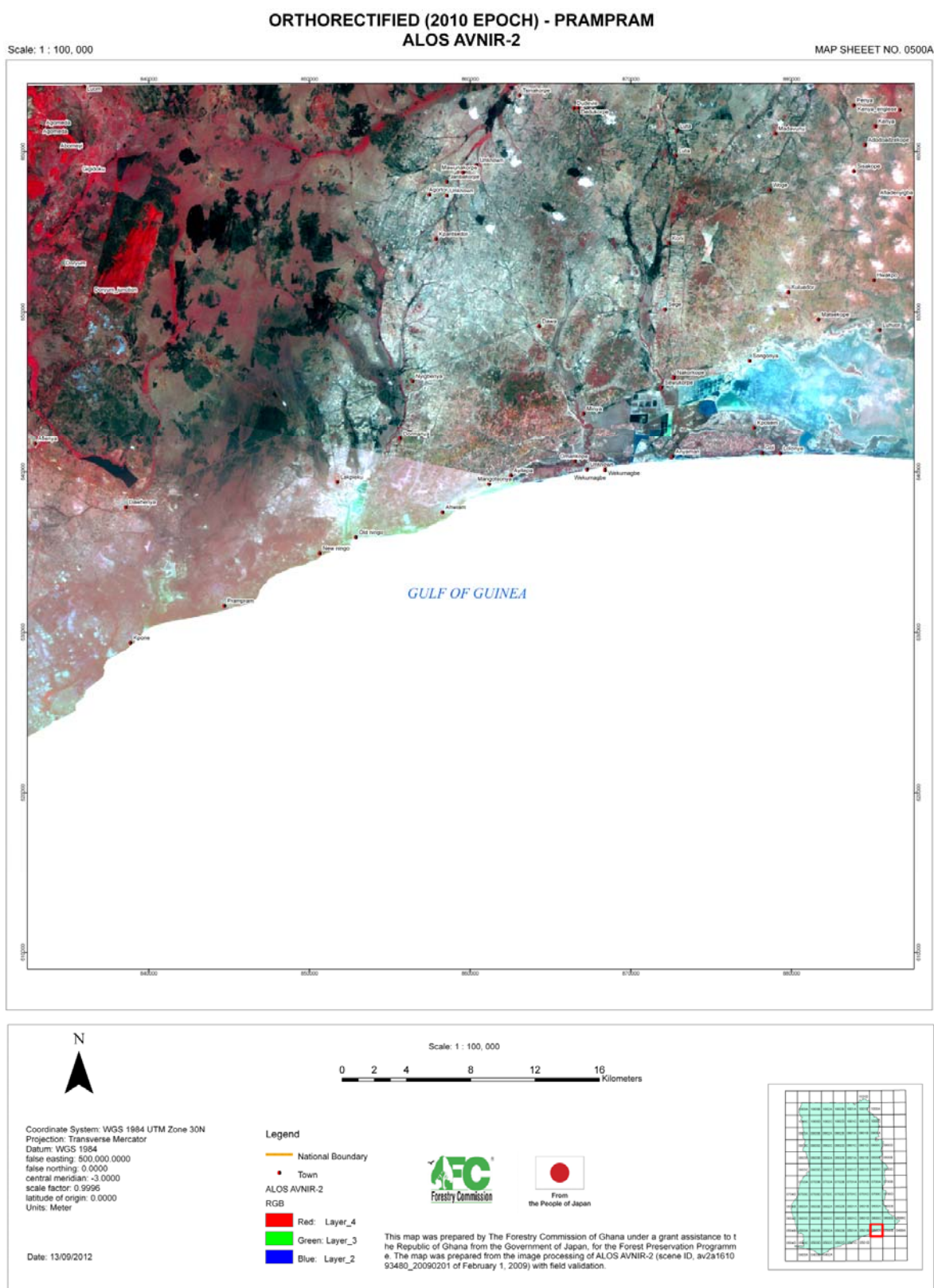
Figure 2-20: Layout file of Tile 0500A of Ortho-image of 2010 Epoch

2.2.7. Outputs

Table 2-14 shows the outputs of Task 8.

Table 2-14: Outputs of Task 8

NO.	Item	Type	Where to Find
1	Satellite image data for each epoch processed, tiled into sizes and format as defined	Data	GIS Server @ RMSC /External HDD
2	GIS files of LU cover for each epoch	Data	GIS Server @ RMSC /External HDD
3	GIS files of LUC for each interval	Data	GIS Server @ RMSC /External HDD
4	Statistics files showing a conversion matrix between the land classes for each time interval	Document	This Report (Table 2-11, table 2-12, Table 2-13)
5	Ground verification data records	Document	This Report, Annex 2-2B
6	Procedure manual	Manual	Manual 1

2.2.8. Conclusion

The Wall-to-Wall Land Use Change using LULUCF classes has been accomplished for 3 epochs; 2010, 2000, and 1990 covering whole Ghana. Medium (for 1990 and 2000) and high (for 2010) resolution satellite data have been used as source data for this forest resource mapping. The latest epoch, 2010 mapping has been accomplished mainly from ALOS AVNIR-2 images, which has a spatial resolution of 10m. The draft LU result of 2010 epoch was verified at 2,213 locations and the accuracy assessment carried out using these verified points has revealed overall accuracy of 2010 LU map as 83.87%, which is quite satisfactory.

2.3. Task 9 Create a baseline forest resource map for 2010 at the national level using the agreed classification/stratification for forest inventory

2.3.1. Introduction

This task involved preparation of required datasets including further classification of Forest Land from the LULUCF map under Task 8 into sub-classes (as defined in inception report of Phase I) and creating baseline forest resource map for 2010.

2.3.2. Creation of Baseline Forest Resource Map of 2010

Following GIS datasets were used in the analysis to create the baseline forest map for 2010:

- Classified data of Forest land based on based on Canopy Cover (CC)
- Regional Ecological Zones (REZ)
- Primary Designated Use (PDU)
- Legal Management Scheme (LMS)

The classification of Forest Land with respect to Crown Cover (CC) was accomplished using the same images mentioned in Task 8.

2.3.2.1.   Preparation of Required Datasets

(1) Classification of Forest Land based on Canopy Cover (CC)

Based on Canopy Cover (CC), the forest land was divided into two categories, as follows:

  i)   Closed (Dense) forest – CC > 60%
  ii)   Open forest – 15% < CC < 60%
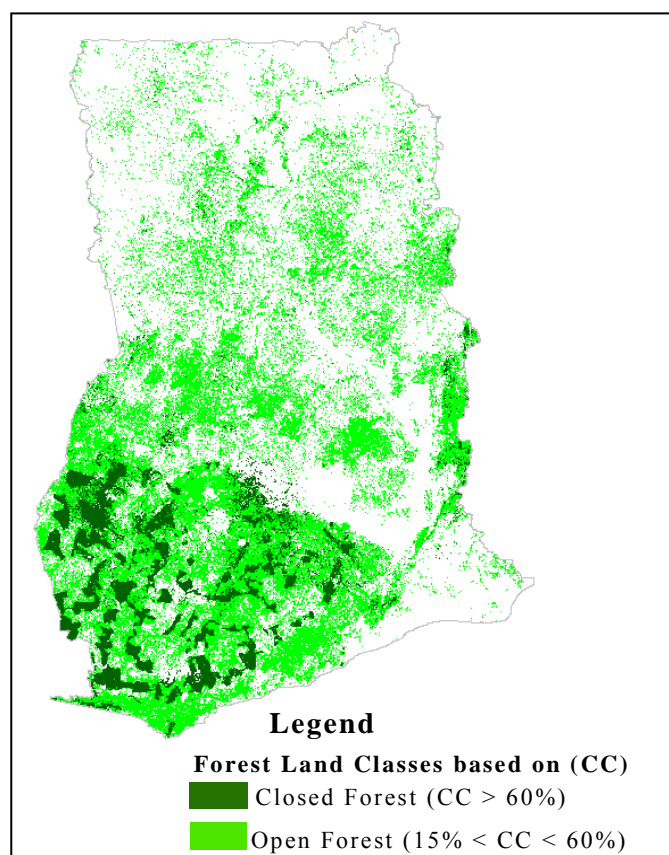
Figure 2-21: Classified Forest Land Based on Canopy Cover (CC)

These two forest classes were achieved while classifying the satellite images for other LU classes and thus the same satellite images, ALOS AVNIR-2 and DMC were used for this task. The DMC images were used as alternative source for the areas where ALOS AVNIR-2 was lacking or had cloud. Also, the classification methodology for these classes was similar to that adopted for other LU classes of Task 8. Information collected during ground truthing (GT) and other supporting

materials remained vital in achieving this dataset with quality. The distribution of these two forest land classes is presented in Figure 2-21.

(2) Regional Ecological Zone (REZ)

This dataset was obtained from Resource Management Support Center (RMSC) of the FCG Ghana. This data provide information on the regional characteristics of the environment in terms of the distribution of the vegetation zones and climatic condition. In Ghana, the vegetation zone has been divided into nine (9) namely:

    i)   Savanna,
    ii)   Dry semi-deciduous (fire zone),
    iii) Moist semi-deciduous (North-west subtype),
    iv)   Moist semi-deciduous (South-east subtype),
    v)   Upland evergreen,
    vi)   Moist evergreen,
    vii) Southern marginal,
    viii) Dry semi-deciduous (inner zone), and
    ix)   Wet evergreen.
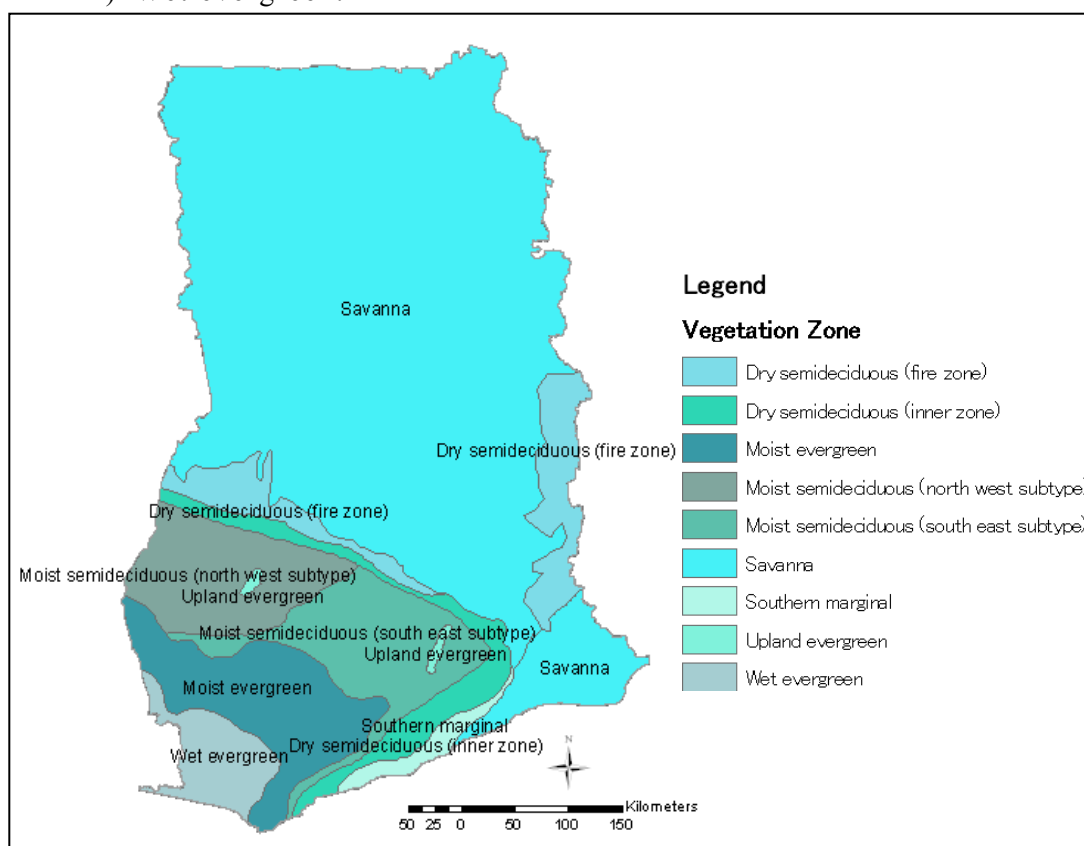
Figure 2-22: Vegetation Zones in Ghana

The data obtained was in Arc Coverage file format, so using ArcGIS, the file was converted to the Shape file and also its attribute table was structured for the overlay with other datasets. As indicated from Figure 2-22, majority of area in Ghana is Savanna and Evergreen zone is located in South-west part.

(3) Primary Designated Use (PDU)

This dataset was obtained from Resource Management Support Center (RMSC) of the FC Ghana. This data contains the information regarding the areas which have been designated as Timber production and Non-Timber production in Ghana. The data obtained was in Arc Coverage file format. Using ArcGIS, the file was converted to the Shape file and also its attribute table was structured for the overlay with other datasets.
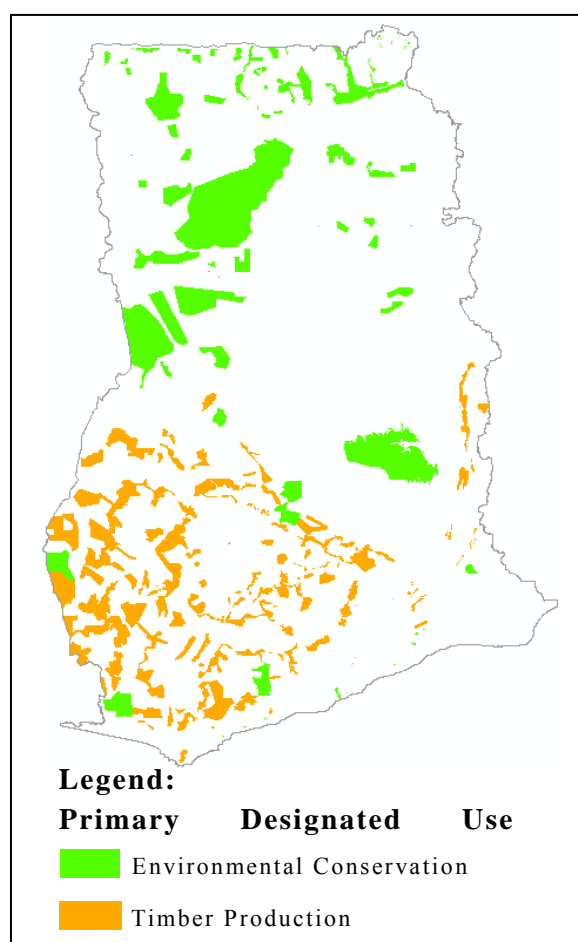
Figure 2-23: Area Designated for Primary Use

From the Figure 2-23, it is clear that timber production areas are located mainly in South while areas for environmental conservation are spread in other part of Ghana.

(4) Legal Management Scheme (LMS)

This dataset was obtained from Resource Management Support Center (RMSC) of the FC Ghana. The data refers to the reserves in Ghana including the Forest reserves, Wildlife, and the National Parks. The data obtained was in Arc Coverage file format, so using ArcGIS, the file was converted to the Shape file and also its attribute table was structured for the overlay with other datasets.
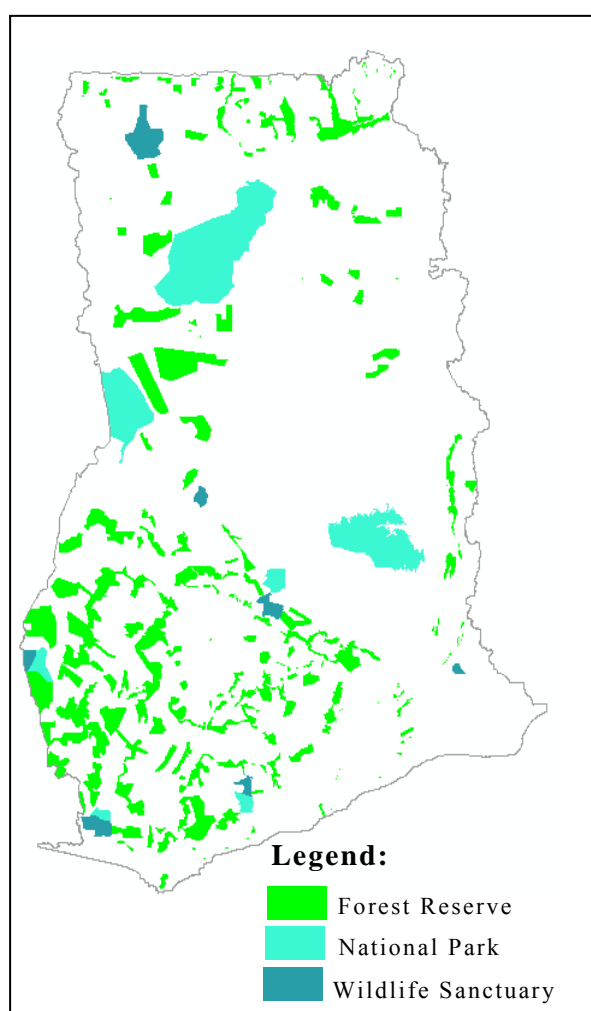
Figure 2-24: Reserve Areas in Ghana

2.3.2.2.   Creation of Baseline Forest Resource Map of 2010

The stratification of Forest Land for 2010 epoch derived in Task 8 was carried out by overlaying the above mentioned four thematic maps data to create Baseline forest Resource map of 2010. This work was done using the Union overlay tool in ArcGIS Software, two at a time, refer to Manual 2 for detail steps. Thus, first the LMS and the PDU were overlaid, and the resultant data was later overlaid with the REZ dataset. Subsequently, it was further overlaid with the extracted Forest land CC classes. The Figure 2-25 shows a created 2010 baseline forest map of Ghana.

With 2 Forest land CC classes, 9 vegetation zones, 2 PDU classes, and 3 reserve classes, the Baseline Forest Resource Map has about 108 combinations or strata. For instance, one stratum is Closed forest (CC> 60%) – Wet Evergreen – Timber Production – Forest Reserve.
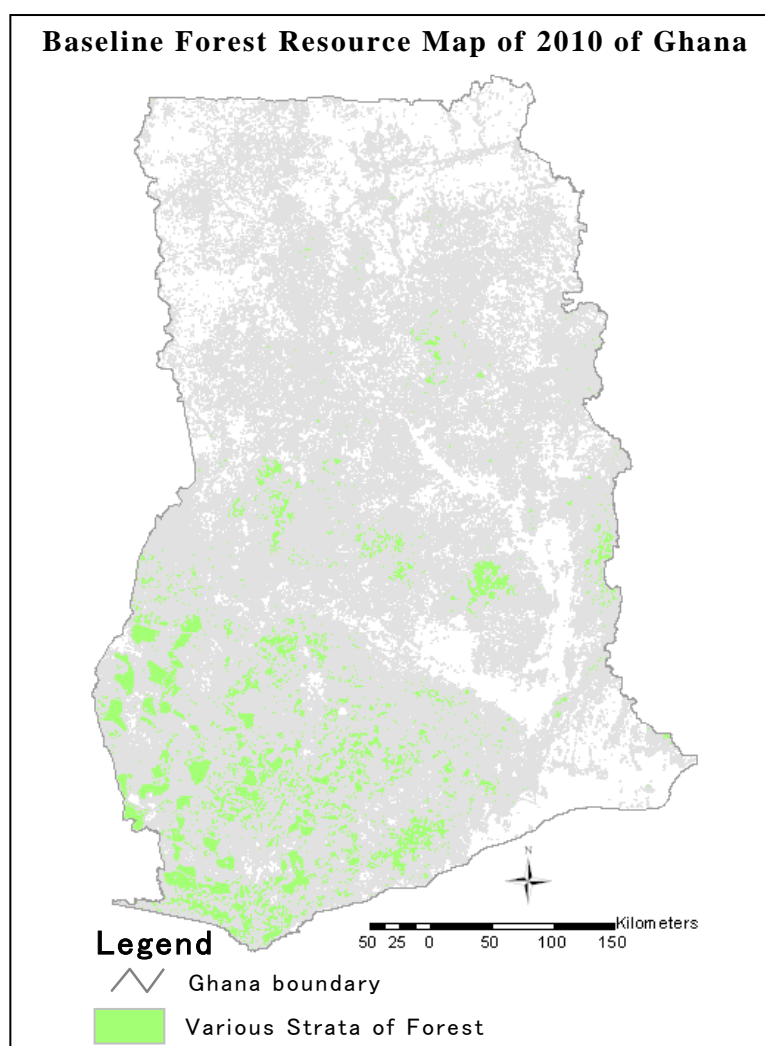
Figure 2-25 Baseline Forest Resource Map of 2010 of Ghana

2.3.2.3. Ground Verification and Accuracy Assessment

In the creation of Forest Resource Map of 2010, the dataset 'Classification of Forest land Based on Canopy Cover (CC)' was extracted from satellite image and other 3 datasets were acquired as existing ones. Thus, due consideration was given to accurate extraction of the CC based Forest land classes. And, this resulted dataset was verified using the information collected during the ground verification survey. With the overall accuracy of LULUCF classification as around 83% (refer to section 2.2.6.7.), the CC based forest land classification result is supposed to have similar level of accuracy.

2.3.3. Processing of PALSAR Satellite Image

ALOS PALSAR imagery was used to establish a correlation with the optical image classification allowing the extraction forest classes and strata directly from the PALSAR imagery (with some verification using optical imagery) in future for forest monitoring. For this the list of procured 95 ALOS PALSAR FBD scenes and 26 ALOS PALSAR Polarimetric scenes are listed in Annex 2-3A and Annex 2-3B, respectively.

These images were processed for mainly following steps:

1. Radiometric Terrain Correction

2. Radar Speckle Suppression (Image Filtering)

3. Texture Analysis

4. Creating Indices Image

5. Layer Stack

6. Interpretation of PALSAR

7. Land Use Classification of PALSAR

8. Tiling of PALSAR Image

The detail of all above processing is included in Manual 2.

2.3.4. Outputs

Table 2-15 shows the outputs of Task 9.

Table 2-15: Outputs of Task 9

NO.	Item	Type	Where to Find
1	A baseline forest resource dataset for 2010 in GIS format with associated metadata	Data	GIS Server @ RMSC , External HDD
2	Ground verification data and protocol for collection	Document	GIS Server @ RMSC , External HDD This report,
3	PALSAR Satellite image data, tiled into sizes and format agreed	Data	GIS Server @ RMSC , External HDD
4	A comprehensive accuracy assessment of the methodology and results	Document	This Report, Annex 2-2B
5	Procedure manual	Manual	Manual 1 and 2

2.3.5. Conclusion

For the creation of baseline forest resource map of 2010, three GIS datasets; Regional Ecological Zones (REZ), Primary Designated Use (PDU), and Legal Management Scheme (LMS) were received from Resource Management Support Center (RMSC) of the FC Ghana which is believed to have optimum accuracy. The 4th GIS dataset; Forest Land Crown Cover (CC) classification has been extracted from the satellite images of 2010 epoch. As mentioned earlier, the draft classification result was verified in the ground and its accuracy is quite satisfactory. Moreover, while combining these 4 GIS datasets, overlaying was carried out with tolerance less than 1m and thus their detailness was kept intact.

The created Baseline Forest Resource map has detail information regarding forest status. It is expected that such information will play a vital role in monitoring of Forest Land use in future.

2.4. Task 10: Undertake a land use change trend analysis and simulate future changes to forest resource taking into account identified risk factors.

2.4.1. Introduction

Forest management has become very important in the era of climate change. In order to achieve this, forest land need to be monitored considering the risk that the forest land stands for destruction. This brought about the creation of the Forest Conversion Risk Map. Thus, in this Task, attempt has been made to present the trend of forest land between 1990 and 2010 and creation of forest conversion risk map incorporating the risk factors. This work was carried out using ArcGIS Software.

2.4.2. Land Use Change Trend Analysis

The forest Resource maps (LU) at 3 epochs; 1990, 2000, and 2010 were analyzed to estimate change between the intervals. Thus, three land use change results were achieved; 1990-2000, 1990-2010, and 2000-2010. Overlay functions of ArcGIS Software was used for this work. The matrix of LUC is presented in sub-section 2.2.7.8, which contains detail record of change in area of each LU class at all these three intervals. The general trend of each LU from 1990 to 2010 is presented in Table 2 16 below as percentage of total country area and as graph in Figure 2-26.

Table 2-16: Trend Analysis of Land Use Change

LU/LU Change	Area in % (Ha)					
	Forest land	**Cropland**	**Grassland**	**Settlements**	**Wetlands**	**Other land**
LU in 1990	36.06 (8,627,401.9)	11.86 (2,837,023.8)	48.34 (11,564,741.5)	0.43 (102,586.6)	3.23 (773,741.8)	0.08 (18,048.2)
LU in 2000	37.25 (8,911,425.6)	16.32 (3,904,571.6)	41.61 (9,954,340.7)	0.85 (203,844.2)	3.31 (792,678.8)	0.65 (156,683.0)
Net LU Change 1990 -2000	*1.19 (284,023.7)*	*4.46 (1,067,547.8)*	*-6.73 (-1,610,400.9)*	*0.42 (101,257.7)*	*0.08 (18,937.0)*	*0.58 (138,634.7)*
Average LU Change/Year (1990-2000)	*0.12 (28,402.4)*	*0.45 (106,754.8)*	*-0.67 (-161,040.1)*	*0.04 (10,125.8)*	*0.01 (1,893.7)*	*0.06 (13,863.5)*
LU in 2010	38.44 (9,195,136.6)	21.83 (5,221,448.5)	34.16 (8,173,402.6)	1.44 (345,048.3)	3.67 (878,783.9)	0.46 (109,724.1)
Net LU Change 1990 -2010	*2.37 (567,734.7)*	*9.97 (2,384,424.6)*	*-14.18 (-3,391,339.0)*	*1.01 (242,461.7)*	*0.44 (105,042.1)*	*0.38 (91,675.9)*
Average LU Change/Year (1990-2010)	*0.12 (28,386.7)*	*0.50 (119,221.2)*	*-0.71 (-169,566.9)*	*0.05 (12.123.1)*	*0.02 (5,252.1)*	*0.02 (4,583.8)*
Net LU Change 2000-2010	*1.19 (283,711.0)*	*5.50 (1,316,876.9)*	*-7.44 (-1,780,938.1)*	*0.59 (141,204.1)*	*0.36 (86,105.1)*	*-0.20 (-46,958.9)*
Average LU Change/Year (2000-2010)	*0.12 (28,371.1)*	*0.55 (131,687.7)*	*-0.74 (-178,093.8)*	*0.06 (14,120.4)*	*0.04 (8,610.6)*	*-0.02 (-4,695.9)*
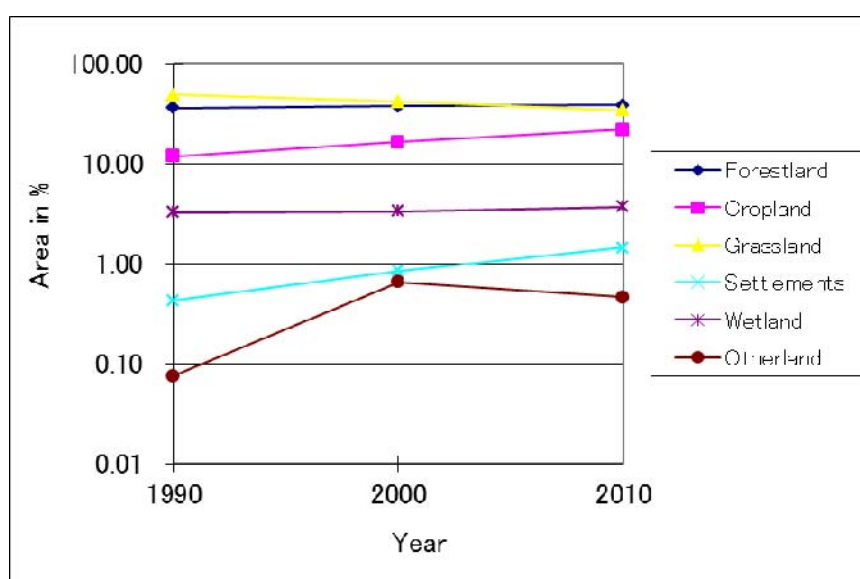
Figure 2-26: Trend Analysis of Land Use Change

As clear from Figure 2-26, the total area of Forest land has increased during the analyzed period, which on average basis, remained 0.12%/yr for both 1990-2000 and 2000-2010 intervals, resulting same increment rate over the 20 years (1990-2010).

2.4.3. Creation of Forest Conversion Risk Map

Considering the possible factors that might cause conversion of forest land to other LU under Ghana condition, three (3) factors; Settlements, Road, and Slope were included in the GIS analysis for the creation of forest conversion risk map, as per decision made in the meeting among the involved parties (FCG, FORIG, RUDAN Engineering, and FPP) on 19th July, 2012. Moreover, with the consideration that settlements pose more risk than slope, it was decided that following weight be applied for each of these factors in the analysis, refer to Annex 2-4A.

Risk Factor	Weight
1. Settlement	0.5
2. Road Network	0.3
3. Slope	0.2

2.4.3.1.　　　Preparation of GIS Data of Risk Factors

(1) Settlements

Settlements play a great role in the degradation of forest land as the residing people exert pressure for its conversion to cropland. For this exercise, two different types of settlements data were used;

- **As Polygon**: which were relatively larger in size and thus was extracted from the 2010 classified satellite imagery produced in task 8.
- **As Point**: which were relatively smaller in size and thus was not extracted from 2010 satellite imagery. The existing point settlement GIS data was collected from CERSGIS.

The entire polygon settlements data resulted from Task 8 of the Forest Preservation Programme (FPP) project was used in the analysis and this was complemented by the existing point settlement GIS data. For these both settlement layers (polygon and point), buffer of 5km and 10km were created. Then the resulted buffered dataset of up to 5km was overlaid on to buffered result up to 10km. While combining, the buffers resulted from polygon and point settlements, for the overlap area, higher

weight was considered. Lastly the resulted shape file with these two buffers was overlaid on to Shapefile covering whole Ghana to assign the rest of area under category area more than 10km. The final result depicting the distribution of three categories of buffer areas is presented in Figure 2-27. These three (3) buffer zones were named and also considering the risk level, weight was weighted, as in Table 2-17.
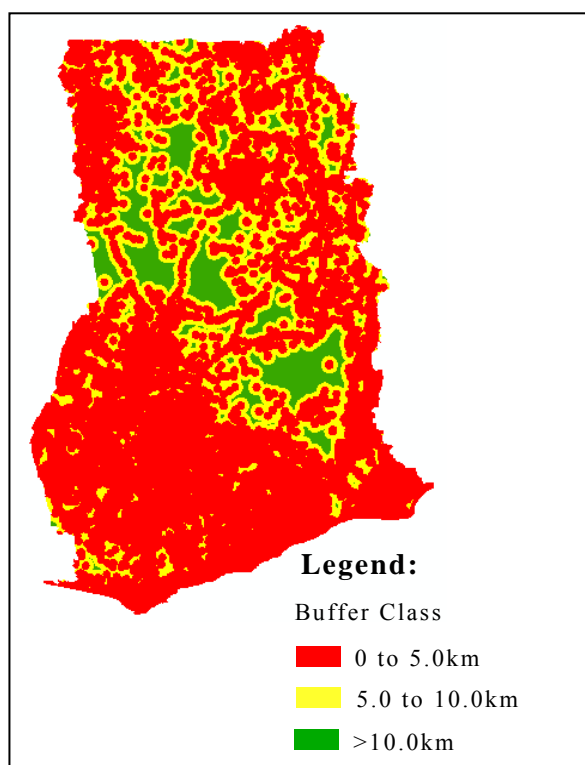
Figure 2-27: Merged or Combined buffers (5km, 10km, and >10km)

Table 2-17: Weight Assigned to Buffered Classes of Settlements

Class	Class Name	Weight to Class	Final Weight with Risk Factor (0.5)
0 to 5.0km	High Vulnerable Zone	3	1.5
5.0 to 10.0km	Medium Vulnerable Zone	2	1
> 10.0km	Low Vulnerable Zone	1	0.5

The weight assigned to each class was modified by the Risk factor weight which was 0.5 for Settlements. For instance, for buffer class, 0 to 5.0km the final weight was 1.5 (that is, 3*0.5).

(2) Road

Road is considered as a risk factor because the availability of road provides accessibility which makes easier for people to reach the forest resources to cause destruction. Thus, the more good roads are provided in the forest areas, the more accessible and vulnerable the forest resources become.
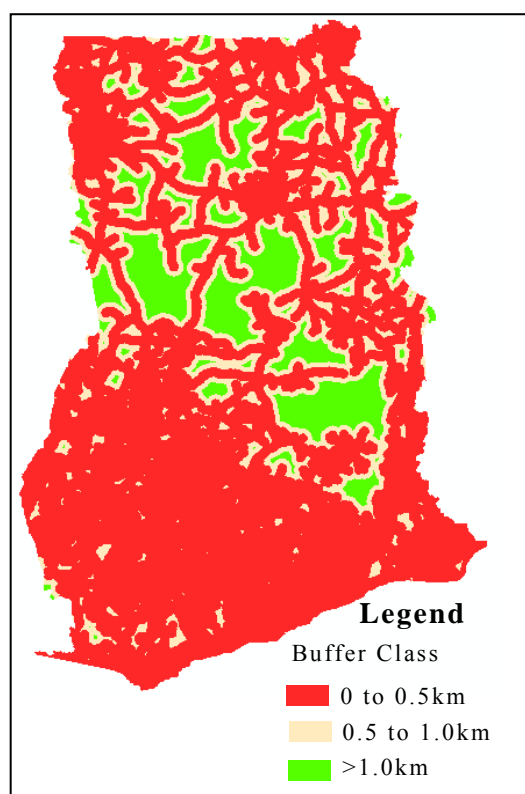
Figure 2-28: Final classification of the road buffers

The existing GIS road data collected from CERSGIS / Ghana Statistical Service was used in this analysis. Considering the distance from the road, buffers were created for three (3) sets of distances: 0 – 0.5km, 0.5 – 1.0km, and > 1.0km. Figure 2-28 presents the classified areas based on road buffers.

As the forest land closer to road has more risk of affected by human activity than farther from it, weight was assigned to each buffer class as listed in Table 2-18.

Table 2-18: Weight Assigned to Buffered Classes of Road

Class	Class Name	Weight to Class	Final Weight with Risk Factor (0.3)
0 to 0.5km	High Vulnerable Zone	3	0.9
5.0 to 1.0km	Medium Vulnerable Zone	2	0.6
> 1.0km	Low Vulnerable Zone	1	0.3

The weight assigned to each class was modified by the Risk factor weight which was 0.3 for Settlements. For instance, for buffer class, 0 to 0.5km the final weight was 0.9 (that is, 3*0.3).

(3) Slope

Slope represents the steepness or inclination and thus a higher slope value indicates steeper inclination. Thus, there will be more human activity in forest resource causing destruction when the slope is relatively flat as compared to when it is steeper.

The slope (in %) was created with the 3D analyst tool in the ArcGIS software by using the Digital Elevation Model (DEM) of 90 meter cell size from SRTM dataset, which was used in the FPP project to ortho-rectify the satellite images. The resulted slope was then vectorized (to Shape file format) and re-classified into three classes 0 – 20%, 20 – 40%, and > 40% along with assigning weight ranging from 1 - 3 to each class, refer to Table 2-19:

Table 2-19: Weight Assigned to Slope Classes

Class	Class Name	Weight to Class	Final Weight with Risk Factor (0.2)
0 to 20.0%	Gentle Slope	3	0.6
20.0 to 40.0%	Medium Slope	2	0.4
> 40.0%	Steep Slope	1	0.2

The weight of 1 refers to low risk factor while 3 refer to the highest risk factor. The Figure 2-29 below presents the generated slope classes. It can be deduced that most of area in Ghana has slope within 20%.
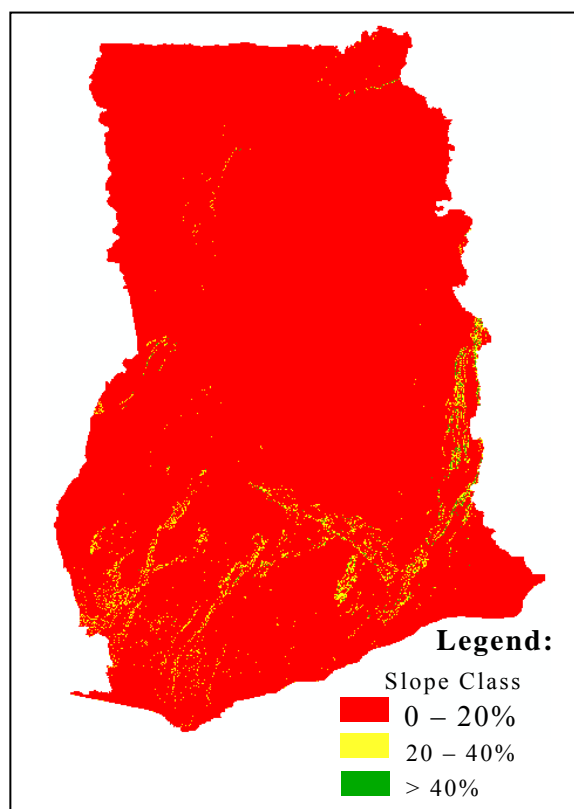
Figure 2-29: Classified slope Map

The weight assigned to each class was modified by the Risk factor weight which was 0.2 for Settlements. For instance, for slope class, 0 to 20%, the final weight was 0.6 (that is, 3*0.2).

2.4.3.2.   Overlaying and Result Interpretation of Deforestation Risk Map on to Forestland

The final deforestation risk map was produced by overlaying the risk map resulted by buffering Settlements and Road, and classifying the Slope map (That is, the maps presented in Figures 2-27, 2-28, and 2-29). The overlaying was done using the Analysis Tool of ArcGIS.

For the final classification of overlaid result of all the above factors with their (maximum of 3.0) total score, it was categorized into 5 classes considering the equal

interval and named as below in Table 2-20, as decided in meeting held on 19th July 2012, refer to Annex 2-4A.

Table 2-20: Classification of Resulted Score after Overlaying

S.N.	Score Class	Forest Risk Class Name
1	2-61 -3.00	Very High Risk Zone
2	2.26 - 2.60	High Risk Zone
3	1.91 - 2.25	Medium Risk Zone
4	1.56 - 1.90	Low Risk Zone
5	1.20 - 1.55	Very Low Risk Zone

These classes were visualized by considering equal interval within the range of total accumulated points, refer to Figure 2-30 below:
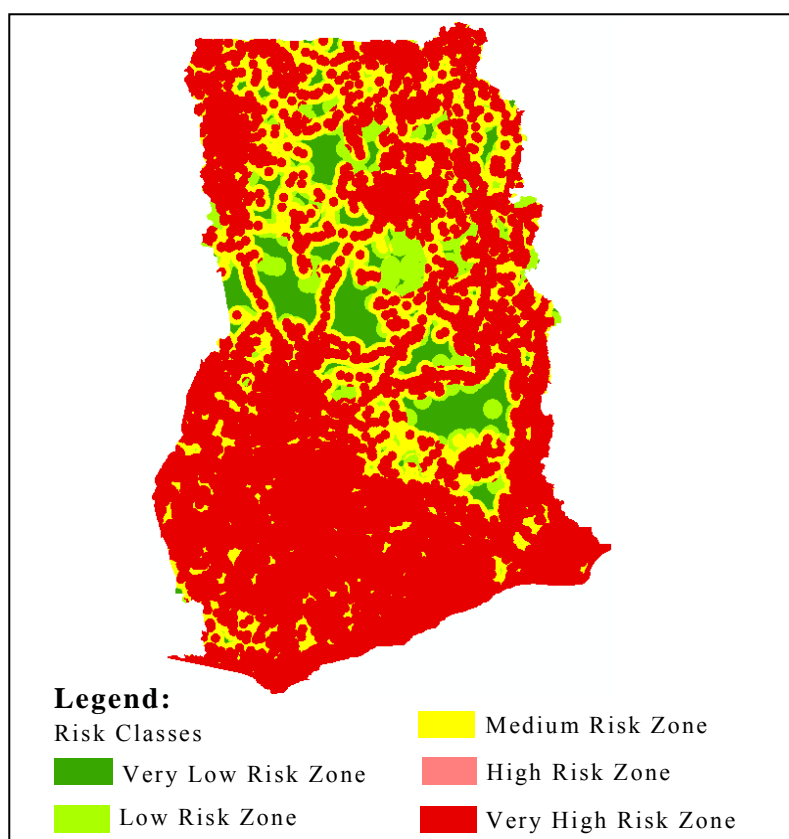
Figure 2-30: Resulted Conversion Risk Map Covering whole Ghana
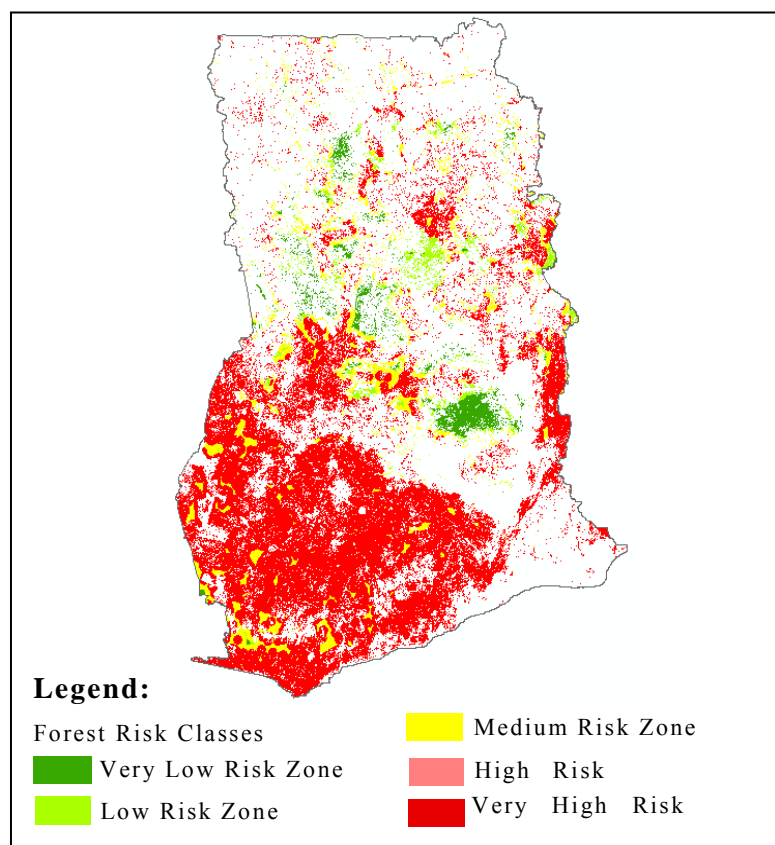
Figure 2-31: Resulted Conversion Risk Map within the Forest Land of 2010

The above risk map was clipped with the forest land of 2010 to know the extent of risk within this area. And, the result is presented in Figure 2-31, which reveals that majority of forest land in Ghana, is under 'Very High Risk Zone'.

2.4.4. Outputs

Table 2-21 shows the outputs of Task10.

Table 2-21: Outputs of Taks10

NO.	Item	Type	Where to Find
1	Forest conversion risk map	Data	GIS Server @ RMSC / External HDD
2	Manual of procedures to update the risk data, create the conversion risk maps and forecast conversion	Document	Manual 2 and Manual 3
3	Recommendations as to how to focus resources and inform policy makers on how to reduce the risks.	Document	This Report, Annex 2-4A

2.4.5. Conclusion

The forest risk map has been created considering the main factors such as Settlements, Road, and Slope, which are main driving factors for human activities within the forest land. And, the result indicates that majority of forest land is under very high risk zone meaning these are closer to settlement and road, and have gentle slope. In such forest land, human activity is possible with the greatest degree.

2.5. Task 11: Prepare the forest resource and change assessment results for external scrutiny and verification

2.5.1. Task Overview

In this Task, the result of Forest Resource mapping of 3 epoch and change assessment results have been prepared for external verification.

2.5.2. Forest Resource and Change Assessment Results

2.5.2.1.   Preparation of Forest Resource Maps of 3 Epochs

The Forest resource maps of 3 epochs; 1990, 2000, and 2010 have been created by including 6 LU classes based on UNFCCC Good Practice Guide (GPG 2003) and the Guidelines for Agriculture, Land Use and Forestry (GL-AFOLU 2006). For this, archived satellite imageries of medium resolution such as ALOS AVNIR-2, DMC (for 2010), and Landsat TM/ETM+ (for 2000, and 1990) have been employed. Based on the information collected during ground truthing and other ancillary materials, image classification carried out for all three epochs using the ortho-rectified Reflectance (the Exoatmospheric or top-of-atmosphere, TOA) image. Draft LU result of 2010 epoch was verified in the field verification at 2,213 locations. The accuracy assessment carried out using these verified points has revealed overall accuracy of 2010 LU map as 83.87% (refer to section 2.2.6.7.). Image processing was carried out using ERDAS Imagine Software. For detail procedure, refer to chapter 2 of this report and manuals, which can be found as mentioned in Table 2-22:

Table 2-22: List of Manuals and Their Location

SN	Manual	where to find
1	Ortho-rectification of ALOS AVNIR-2	Manual 1
2	Ortho-rectification of Landsat image	Manual 1
3	Ortho-rectification of DMC image	Manual 1
4	Converting DN to Radiance and Reflectance	Manual 1
5	NDVI Estimation and LU Classification	Manual 1
6	Accuracy Assessment of 2010 Epoch LU	This Report

2.5.2.2. Forest Resource Change Result

The forest Resource maps (LU) at 3 epochs; 1990, 2000, and 2010 were analyzed to estimate change between the intervals. Thus, three land use change results were achieved; 1990-2000, 1990-2010, and 2000-2010. Overlay functions of ArcGIS Software was used for this work. The matrix of LUC is presented in sub-section 2.2.6.8. of this report, which contains detail record of change in area of each LU class at all these three intervals.

2.5.2.3. Creation of Baseline Forest Resource Map

The Forest Land, resulted from LULUCF classification from Task 8, was further classified into forest sub-classes. This along with other datasets were analysed to create baseline forest resource map for 2010. Following GIS datasets were used for this analysis:

- Classified data of Forest land based on based on Canopy Cover (CC)
- Regional Ecological Zones (REZ)
- Primary Designated Use (PDU)
- Legal Management Scheme (LMS)

The classification of Forest Land with respect to Crown Cover (CC) was accomplished using the same images those have been mentioned in Task 8, ALOS AVNIR-2 and DMC. And, the information collected during ground truthing (GT) and other supporting materials remained vital in achieving this. The overlaying of all 4 kinds of GIS datasets was done in ArcGIS Software. With 2 Forest CC classes, 9 vegetation zones, 2 PDU classes, and 3 reserve classes, the Baseline Forest Resource

Map has wide range of combinations or strata. For instance, one stratum is Closed forest (CC> 60%) – Wet Evergreen – Timber Production – Forest Reserve. Detail procedure of this is included in sub-section 2.3.2 of this report.

2.5.2.4.   LUC Trend Analysis and Creation of Forest Risk Map

The LUC analysis between the intervals has shown slight increasing trend of the overall area of forest land between 1990 and 2010, which is by 2.38% of total country area. However, with the easy accessible topography in almost throughout the country, future monitoring becomes important to maintain the forest land. With this essence, Forest Risk Map has been created using the prioritized Risk factors; Settlements, Road, and Slope. Considering the level of risk of human interference, the resultant map has presented the categorization of forest land of 2010 epoch into five (5); Very High Risk Zone, High Risk Zone, Medium Risk Zone, Low Risk Zone, and Very Low Risk Zone. Detail regarding analysis procedure is included in sub-section of this report.

2.5.3. LiDAR-assisted Carbon Stock Inventory

Plot measurement data has been collected from the pilot areas for developing a carbon look-up table including 6 forest carbon pools and defined strata. The forest carbon pools are namely aboveground, belowground, deadwood, soil, litter and non-tree carbon pools. The pilot areas have been selected to cover 9 regional ecological forest types defined by Hall and Swaine (1981) and two mangrove forests areas. The regional ecological zones (REZ) and 6 principal IPCC classes from 2010 have been used as the only stratification criteria, because there is the limited representation for the various Primary Designated Use (PDU) and Legal Management Scheme (LMS) categories within the pilot areas.

The plot sample plan relies on a weighted cluster sample and 85 percentile heights have been applied as weights for the population units (Manual 5-1). The field sample measurement and quality assurance procedures for carbon stock assessment have been developed to measure 120 clusters (Manual 5-2). Each cluster has three nested square sub-plots within 500 meter intervals (Figure 4-2). Field data has been

collected on the paper sheets, cleansed in Open Foris Collect and exported as xml files from the database application for the tree- and plot-level carbon-stock computation with the ArboWebForest-SIMO tool (Manual 6-1) or on an Excel spreadsheet. The applied computation formulas are described for all the pools in Manual 5-4.

A large set of allometric regression equations have been derived and their quality properties assessed to model tree-level aboveground and belowground carbon stock (Manual 5-4). For that purpose a destructive sample dataset consisted of 116 trees with a dbh range of 2.3-159.3 centimeters has been collected and 58 of them have been uprooted from wet, moist, dry climatic zones and mangroves inside the pilot area boundaries.

The plot-level results have been exported from the ArboWebForest tool as a csv-file for strata-level aggregation in MS Excel and conversion into a shape format for LiDAR-based aboveground biomass modeling in ArboLiDAR. The LiDAR data has been received from the acquisition company as pre-processed and classified point cloud data in las-format (Manual 5-3). The ground pulses are classified separately from the vegetation (default) and error pulses. The elevation variation effects on the analysis are eliminated through normalization (Manual 6-2). The selected LiDAR height and density features for the regression modelling and the outlier exclusion criteria are explained in Tables 4-11 and 4-12 (Manual 6-3). The satellite imagery (ALOS AVNIR-2) based spectral and textural features may become selected as explanatory variables for the lidar-based models or producing a wall-to-wall aboveground carbon stock map (Manual 6-4).

The computed mean values for each carbon pool are applied to develop a national carbon map (Manual 6-5).

As summarized, the main steps for developing a look-up table are as following:

1) Computing plot-level carbon density (tonC/ha) for 6 pools

Input:

- digitized field sheets (xml) containing bio-physical field plot measurements for 6 carbon pools
- allometric aboveground and belowground biomass models
- average carbon fraction (0.48) for aboveground and belowground biomass
- model for decomposition coefficient for standing deadwood
- from lab-analysis: wood densities (g/cm^3) for downed deadwood samples for 3 different decomposition classes
- from lab-analysis: dry weights (g) of collected litter and non-tree sub-samples
- from lab-analysis: carbon contents (%) for deadwood, litter and non-tree sub-samples
- from lab-analysis: bulk density (g/cm^3) and organic carbon contents (%) for soil sub-samples from three depths (10 cm, 20cm and 30 cm)

Output:

- plot-level carbon density (tonC/ha) for 6 pools

2) Developing regression models using plot-level above-ground carbon density (tonC/ha)

Input:

- above-ground carbon density plot data (tonC/ha) as dependent variables
- LiDAR metrics as independent variables
- Regional ecological zone and land use class based stratification (vector file)
- Broad stratification for modelling:
  i) Closed forests
  ii) Wet zone open forests and croplands
  iii) Moist zone open forests and croplands
  iv) Dry zone open forests and croplands

Output:

- Specific LiDAR based regression models for forestland and cropland

3) Computing aboveground carbon density (tonC/ha) for a result grid by applying the LiDAR based regression models for forestland and cropland over all the ecological zones

Input:

- Specific LiDAR based regression models for forestland and cropland
- Regional ecological zone and land use class based stratification (vector file)
- Wall-to-wall grid with 20 meter x 20 meter cells for the study area (vector file)

Output:

- Result grid with aboveground carbon density values over all the strata within the study area

4) Computing mean and confidence interval estimates for aboveground carbon density values (tonC/ha) for forestland and croplands within the study area

Input:

- Regional ecological zone and land use class based stratification (vector file)
- Result grid with aboveground carbon density values over all the strata within the study area
- Conversion factor from C to CO_2 (44/12)

Output:

- Look-up table including mean aboveground carbon density values ($MgCO_2$-e/ha) and estimated confidence intervals (± % of mean) for forestland and cropland.

5) Computing mean carbon density values (MgCO$_2$-e/ha), estimating variances (MgCO$_2$-e/ha) and confidence intervals (± % of mean) for all the strata including 5 carbon pools

Input:

- Inverse cluster sampling weights
- Plot-level carbon density (tonC/ha) output for 5 remaining pools
- Regional ecological zone and land use class based stratification (vector file)
- Conversion factor from C to CO$_2$ (44/12)

Output:

- Look-up table including mean carbon density values (MgCO$_2$-e/ha) and confidence intervals (± % of mean) for all the pools and strata

2.5.4. Outputs

The outputs of Task 11 are mentioned in Table 2-23.

Table 2-23: Outputs of Task 11

NO.	Item	Type	Where to Find
1	GIS and satellite image data bundle for "Forest Resource and Change Assessment Results"	Data	GIS Server @ RMSC, External HDD
2	Procedures manual for all biomass calculations	Manual	Manual 5 (5-1, 5-2, 5-3, 5-4) Manual 6 (6-1, 6-2, 6-3, 6-4, 6-5)
3	Inventory, satellite image and LiDAR data bundle for "LiDAR-assisted Carbon Stock Inventory"	Data	GIS Server @ RMSC, External HDD

2.5.5. Conclusion

The trend of forest coverage over the entire Ghana was successfully revealed through this challenge of change detection. The outputs of Task 8, Task 9, and Task 10 can be a base for "forest resource change accounts" that will be offered for external

verification by independent auditors in the future. It is recommended to extend the data to firm a clue for building the base line of biomass estimates with more sound analysis of socioeconomic consideration.

3.   Pilot Area Forest Resource Mapping

3.1. Task 12: Undertake Forest Resource Mapping and Topographic Feature Digitisation Using ALOS PRISM High Resolution Satellite Imagery for the Selected Forest Pilot Area

The forest resource mapping was conducted as part of forest inventory and as a input for forest inventory survey planning and for biomass/C-stock estimation. With the delay in delivery of software and hardware from supplier, consultant used different Photogrammetric software than LPS (that is, the software procured to FCG) for some of the works in this Task in order to meet the deadline of forest resource mapping. Moreover, the procedure manual for all works in this Task (refer to Manual 4 and Manual 10) has been prepared for LPS and also the training for LPS including Hardware was conducted in the month of November, 2012.

3.1.1. Ground Control Points (GCP) Collection

3.1.1.1.   Introduction

As part of the FPP a Forest Resource Map has to be produced for the pilot area, which covers approximately 19,000sqkm of the total area of Ghana. 59 ground control points were established to be used in aerial triangulation from ALOS satellite imagery for the forest resource map. Out of 59 GCPs, 31 GCPs were established in west Pilot area and 28 were established in east pilot area.

3.1.1.2.   Scope of the Work

It is required that survey beacons should be established in the pilot area to serve as control points in the aerial triangulation in the map production process.

The followings are the scope of the work:

- ❖ Establishment of survey beacons as GCPs within the pilot area.
- ❖ Description and measuring of all GCPs with DGPS to obtain its x, y, z coordinates.

The pilot area is shown in Figure 3-1, including positions of ground controls established.
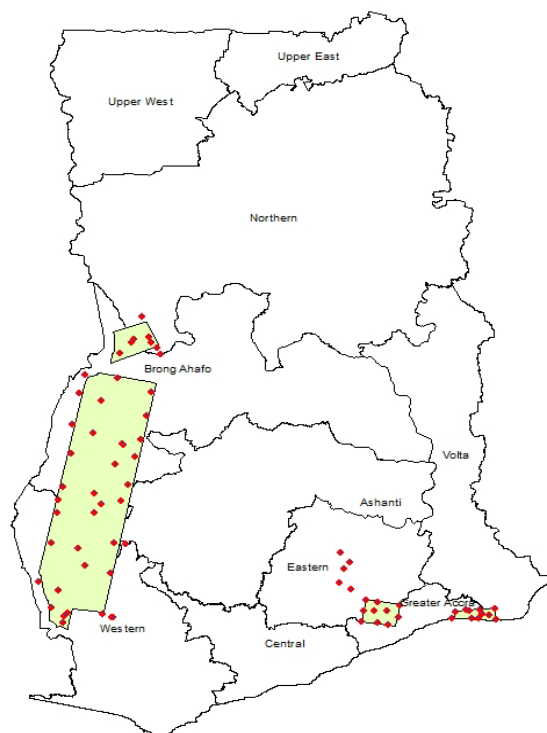
Figure 3-1: Location of GCP used in Mapping

3.1.1.3.   Methodology

An appropriate methodology was adopted in order to achieve accurate data for the pilot area. The GCPs (survey beacons) covering the entire pilot project area were established. The GPS measurement was done in a triangular network form such that the integrity of the established points was preserved.

(1) Establishment of Ground Control Points

The positions of the 59 ground control points were carefully planned and marked on existing topographic map sheets of scale 1: 50,000 covering the project area. These topographic map sheets were obtained from the Survey and Mapping division of the Lands Commission of Ghana.

To locate the position of the ground control points on the ground, all the coordinates of the chosen points were determined from the topographic map in Ghana's local system i.e. "War Office". The War Office coordinate system was then transformed to World Geodetic System (WGS84) UTM zone 30N using Spectrum Survey and Global Mapper software. The coordinates of these GCPs were then obtained in both UTM and Geographical Latitude and Longitude format. These coordinates were uploaded in handheld GPS receivers. These handheld navigational GPS receivers were used as a pathfinder to locate the approximate positions of the points on the ground. Beside the navigational GPS, features such as streams, hills, valleys, tracks and footpaths from digital topographic maps, were other landmarks used to facilitate the identification of the control points.

Most of the ground control points were casted in-situ with Concrete monuments of dimension (24cmx24cmx54cm). Out of 54cm height, 24cm were kept above the ground surface and rest 30cm below the ground surface. However some of these monuments were made to be almost level to the ground surface at places where it was likely to be destroyed due to heavy human activities. These points were numbered using the Regional Numbering System specified and provided by the Survey and Mapping division of the Lands Commission of Ghana. Refer Annex 3-1B for control point description sheets and pictures of these control points.

(2) GPS Measurement

South S86-S dual frequency Global Positioning System was used to collect X, Y, and Z coordinates of the entire control points forming network for the points. Static GPS measuring technique has been employed to get the accurate position. Observation time at each GCP was varied between 1 hour to 1 hour 30 minutes taking into consideration the baseline length between the base station and the rover point.

(3) Observation Planning

Spectrum Survey Planning Module (software of South GPS), a pre-survey tool, was used to determine the most appropriate time to collect GPS data. Variety of satellite graphs indicating satellite visibility and geometry were generated and analyzed to determine adequacy of satellite coverage as shown in Figure 3-2.
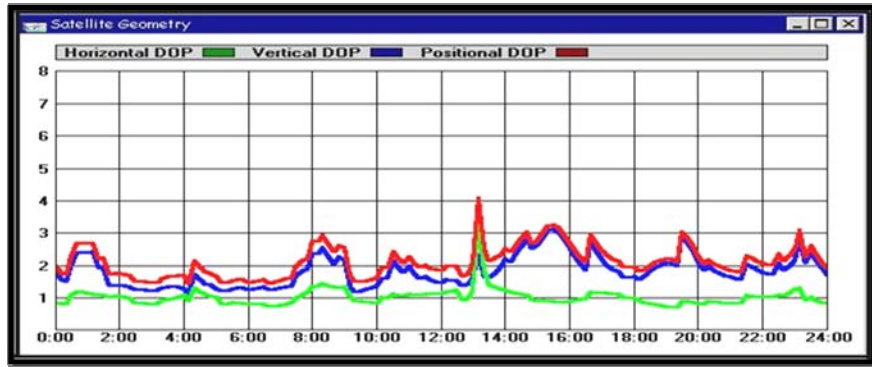
Figure 3-2: Satellite Geometry Graph 1

The Satellite Geometry graph represents the Horizontal, Vertical and Positional Dilution of Precision that can be expected at different times of the survey day. Observations were not taken at times of the day when Dilution of Precision values were expected to be higher. This was to avoid the introduction of errors and reduction of accuracy in the measurement. Dilutions of Precision values ranging from five and above are considered unacceptable.
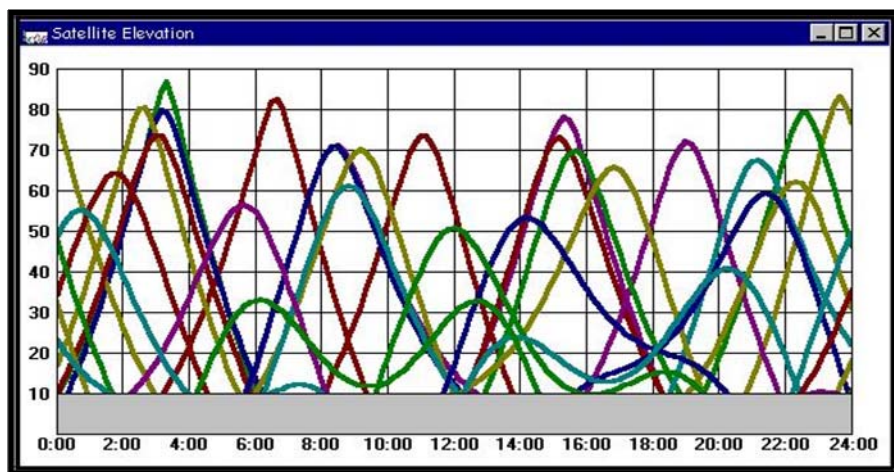
Figure 3-3: Satellite Geometry Graph

The Satellite Elevation graph plots the elevation of the satellite versus time. The elevation mask of 10^0 is represented in Figure 3-3. This helped to choice of location of points for less canopy cover.

Although weather conditions have no direct influence on data collected during observation, the planning was scheduled such that rainy and stormy conditions were avoided during the observation. Strong windy conditions could affect the stability of the GPS antenna thereby affecting readings being taken during measurement.

(4) Network Design

A well-structured network was designed comprising the existing controls in the project area, which were used as base stations for new GCPs established. Considerable lengths of baselines were chosen to achieve better accuracy. Each solution point was observed and processed from one of the known control point which is usually the nearest Geodetic Reference Network (GRN) control provided by the Survey and Mapping division of the Lands Commission of Ghana.

Solution points were carefully chosen for adequate view of satellite to avoid canopy cover. Reflective surfaces such as metal structures were avoided to prevent multipath error although the post processing software corrects it. Multipath is radio interference caused by satellite signals that have traveled different paths to reach the receiver.

Observation times were scheduled such that enough overlap of time is realized between base stations and corresponding rover stations.
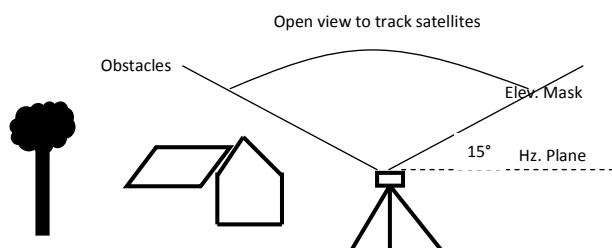
Figure 3-4: Elevation Mask

(5) Observation and Processing Parameters

The following parameters were set or ensured before and during observation to obtain a good quality:

- Geometric Dilution of Precision (GDOP): **Not greater than 4**
- Observation time at a station: **Not less than one hour**
- Elevation mask set for observation: **+15°.** (This was to model terrain obstruction since points selected were free of buildings, trees and mountains.)
- Minimum log satellites before recording of epochs: **4**

The Elevation Mask of 15^0 as shown in Figure 3-4 was set to get rid of obstacles around the antenna for optimum tracking of satellites. Only those know control points were selected, which has no obstructions from building, mountains, trees and other features. The following parameters were set during the data collected to ensure accurate results:

- Troposphere correction: **Measured**
- Ionosphere correction: **On**
- Ambiguity resolution: **Search**
- Rejection criteria: **3 x rms.**
- Epoch period: **Begin to End**

(6) GPS Data Processing

Spectrum Survey Version 4.20, a GPS post-processing software was used to find the unknown coordinates of the survey points by differentially processing data concurrently collected by GPS receivers. Carrier phase difference techniques were used for GPS observations at different positions.

The software automatically generated these baselines by comparing overlapping epochs from the receiver data collected on each point. One end of the baseline was held as fixed, and relative positioning was used to solve the coordinates for the other end. The coordinates from the point list were then exported to Excel and compiled into a table kept in Annex 3-1A.

Pictures of all control points, coordinates and their descriptions with reference to other features on the ground are illustrated in Annex 3-1B and control points with their corresponding root mean squares are in Annex 3-1C.

3.1.1.4.   Quality Assurance

Adequate planning, project control and management ensured that the survey work done achieved its goal for establishing the ground controls for the mapping.

To ensure that the survey work was accurate, several accuracy checks and precautionary measures were undertaken. Some of which are; the testing of existing ground controls, making sure the coordinates obtained were within the accuracy proposed and tracking sufficient satellites before measurements were carried out. The processed coordinates of the ground control points obtained gave an indication of the reliability of the points and subsequent accuracy achievable in the aerial triangulation and mapping.

The network of ground control points designed and established were adequate and efficient enough to be able to carry out mapping of the pilot area.

3.1.2. AT, DSM and Ortho-rectification

Using all established control points, Aerial Triangulation of ALOS satellite image were done. The ALOS/PRISM has 3 sensors viewing front, nadir and rear, the front and rear sensors observe 23 degree towards the orbit direction. Image captured in 1 band panchromatic with 2.5m spatial resolution. Images captured in 3 different directions are used to extract highly accurate digital elevation models.

ALOS/AVNIR-2 sensor is a multispectral sensor with four spectral bands, three bands in visible and one band near-infrared regions of the electromagnetic spectrum. The spatial resolution is 10m. The PIXELFACTORY4.0 imaging system software, produced by Astrium-GEO Information Company, was used for image processing, using 144 scenes (48Triplet) of PRISM image and 27 scenes of AVNIR-2 image. The detail process of AT, DSM and Ortho Creation is explained in Manual 4, Section 2.1.

3.1.2.1. Workflow

The workflow of producing DSM and orthophoto map is shown in Figure 3-5.
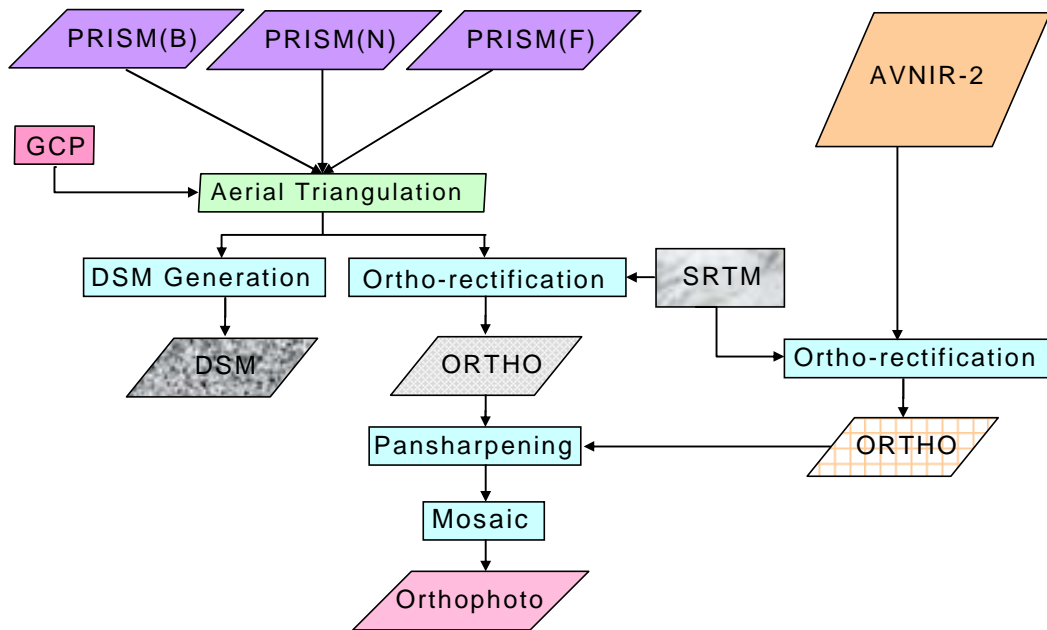
Figure 3-5: Workflow of Aerial triangulation and Ortho-rectification

Aerial Triangulation was carried out using the ALOS PRISM, 3 sensors data. Using the result, DSM extraction and ortho-rectification were performed. In addition, SRTM 3ArcSecond resolutions were used in the ortho-rectification where DSM data was not available due cloud cover and poor color harmony of the original data.

3.1.2.2. AT (Aerial Triangulation)

Since the area was divided into 2 blocks, the east block and the west block, AT work was carried out in two separate blocks. Summary of each block is listed as in Figure 3-6 and Table 3-1.
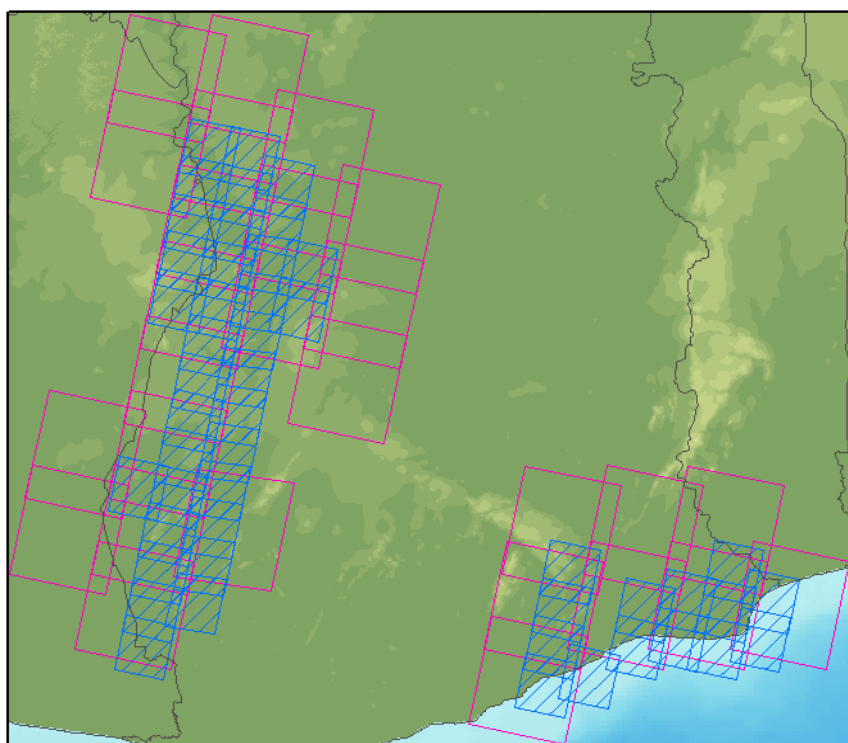
Figure 3-6: Division of pilot area for AT

Table 3-1: Summary of Blocks

	GCP	PRISM	Triplet Model
EAST	28	42	14
WEST	31	102	34

The AT work, reference point was measured in PRISM image, among the tie point acquired automatically and manually, calculated adjustment was made.

（1）East Area

Figure 3-7 illustrates the ground control points as well as residual error (Table 3-2) and the tie point distribution (Table 3-3). Adjustments were made using the 1,027 points of tie point and 18 points of ground control points. The map scale level of the original block is 1:50,000 scale and 0.1mm on map is 5.0m on ground. The residual error in the ground control points was delivered within 2.5m and obtained within 0.1mm on map precision. In addition, the residual error in the tie point in the image was kept within 2 pixels, which is supposed to be a good result.
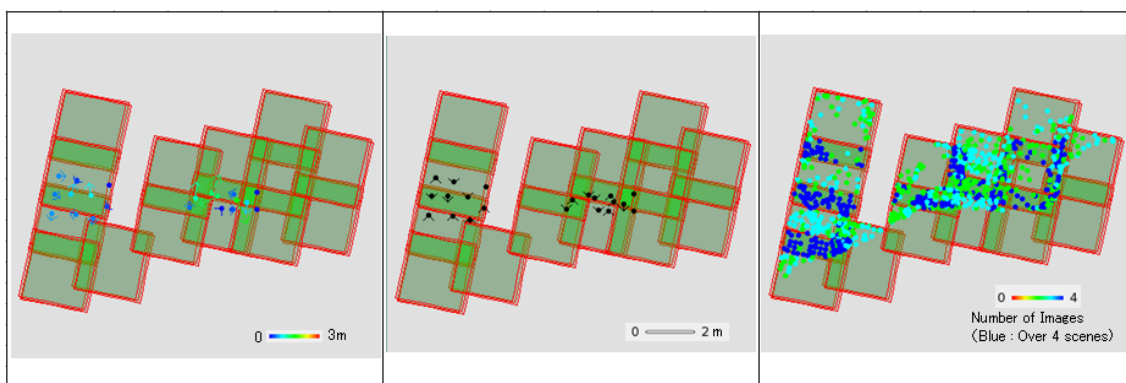
Figure 3-7: Horizontal Residual at GCP/ Altitude Residual at GCP/ Tie point Distribution

Table 3-2: Residual at GCP (meter)

	X	Y	XY	Z
Average	0.00	0.01	0.58	-0.04
Max	-1.13	-1.41	-1.55	-0.27
Std Dev	0.39	0.62	0.42	0.10
RMSE	0.38	0.60	0.71	0.11

Table 3-3: Imagery Residual at Tie Point (pixel)

	X	Y	XY
Average	0.00	0.00	0.20
Max	0.96	1.00	1.03
Std Dev	0.21	0.16	0.18
RMSE	0.21	0.16	0.27

（2）West Area

Figure 3-8 illustrates the ground control points as well as residual error and the tie point distribution. Adjustments were made using 1,679 tie points and 31 ground control points. The maximum residual error in the ground control points was 2.0m and obtained within 0.1mm on map precision. The residual error in the tie point in the image was kept within 2 pixels. All errors are within the limits.
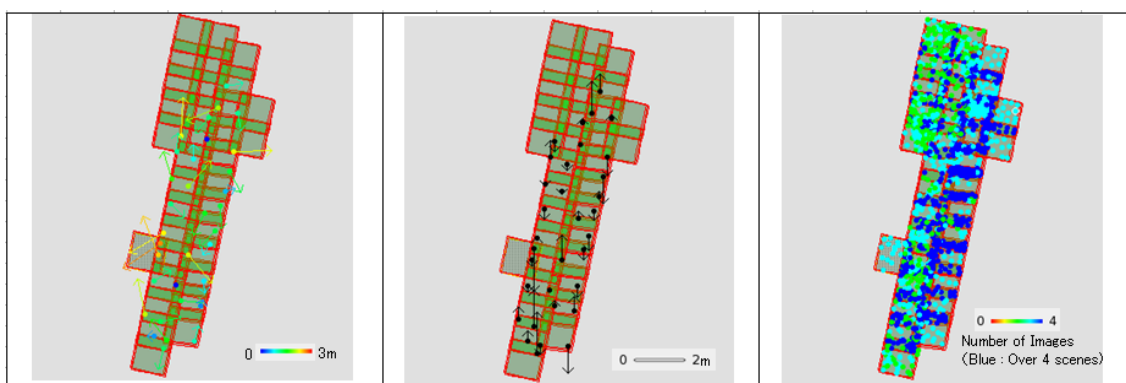
Horizontal Residual at GCP/ Altitude Residual at GCP/ Tie point Distribution

Figure 3-8: Residuals of GCPs

Table 3-4: Residual at GCP (meter)

	X	Y	XY	Z
Average	-0.01	0.01	1.45	0.02
Max	2.28	2.31	2.69	-1.63
Std Dev	1.06	1.21	0.63	0.72
RMSE	1.04	1.19	1.58	0.71

Table 3-5: Imagery Residual at Tie Point (pixel)

	X	Y	XY
Average	0.00	0.00	0.31
Max	-1.52	-1.55	1.59
Std Dev	0.27	0.29	0.25
RMSE	0.27	0.29	0.40

Using the RPC file which is the result from AT, exported in the stereo plotting system and measured the X, Y, Z coordinate values. The results for both areas are shown in Table 3-2 and Table 3-4.

In the east area, 5 points each of Songor Lagoon Area and Shai Area were measured and verified that the maximum residual error was less than 2.5m. While in the west area, 9 points were measured and verified that the maximum residual error was at 2.7m. It was also confirmed that in both areas, the map precision was within 0.1mm.

3.1.2.3.   DSM Generation

Using the result of AT, the orthometric height was extracted by the image matching with the correlative window using GEOID model EGM96. The format of the Digital Surface Model is as follows:
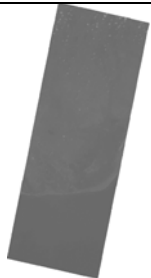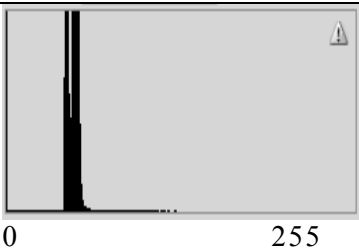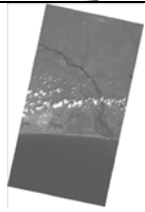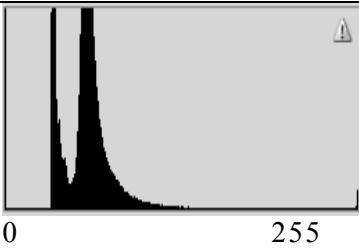
File Format   : GeoTiff format

Resolution   : 10m

Datum surface   : EGM96

Data type   : Signed 16-bit (elevation unit: meter)

General view of the extracted DSM is shown in Figure 3-9.
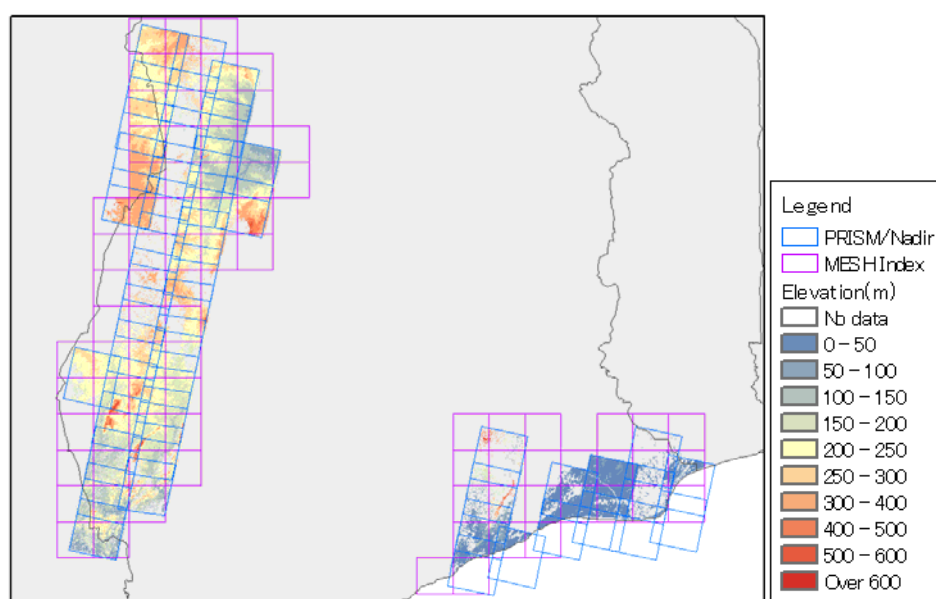
Figure 3-9: View of DTM

The portion of the pilot area, which were not extracted by the automatic matching are due to poor colour harmony, areas covered by cloud and water surface in the original image, were supplemented by SRTM datasets. Figure 3-10 shows an example of the difference result in matching base on different photography conditions. The original photography condition was contrast. If there are no clouds, matching is almost achievable.

Observation Date	Image	Histogram	DSM Data
2011/1/21		0 255	
2010/12/6		0 255	

Figure 3-10: Different result in matching base on different photography conditions

3.1.2.4. Ortho-rectification

After having orthorectified images using the result of AT as well as SRTM DTM, Pansharpened process was performed in the PRISM of spatial resolution 2.5m and AVNIR-2 images with spatial resolution 10m**.** Figure 3-13 shows that panchromatic retains high resolution of 2.5m and data keeps colour information.

PRISM image (2.5m)   AVNIR-2 image (10m)   Pansharpened image (2.5m)
Figure 3-11: PRISM, AVNIR-2 AND PANSHARPENED IMAGES

In addition portion of the area which was not covered by AVNIR-2 images of same time with PRISM images, Pansharpening was done for that area using PRISM images

captured in different time. Figure 3-12 and Figure 3-13 show the overview of the PRISM ortho image and panshapened image.
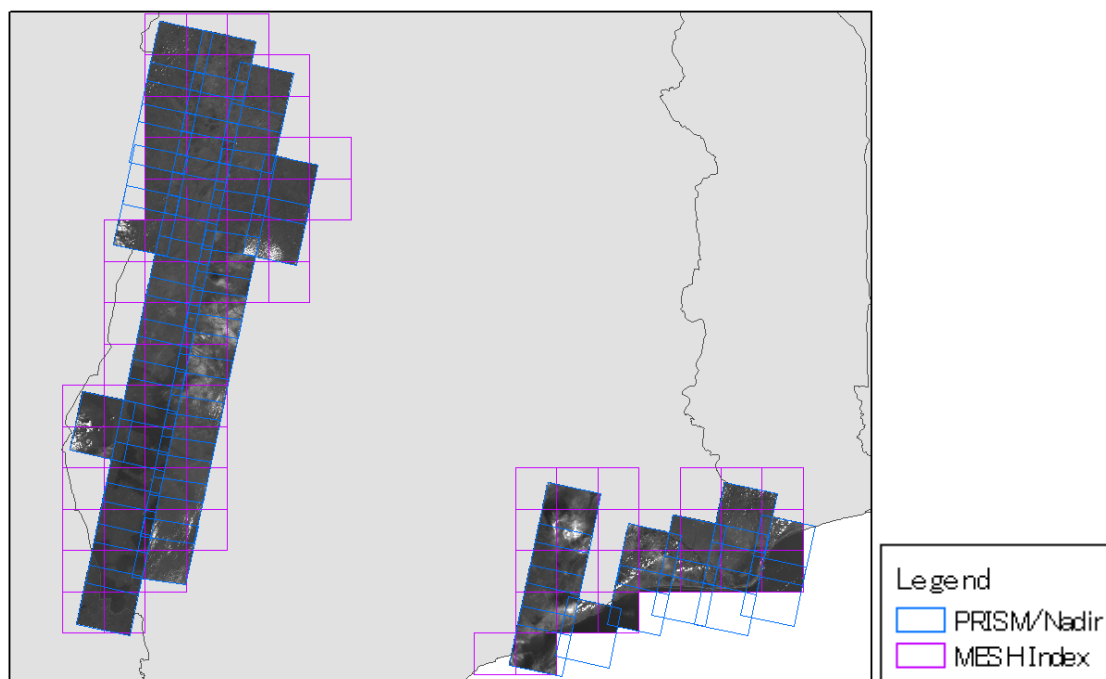
Figure 3-12: PRISM ortho image
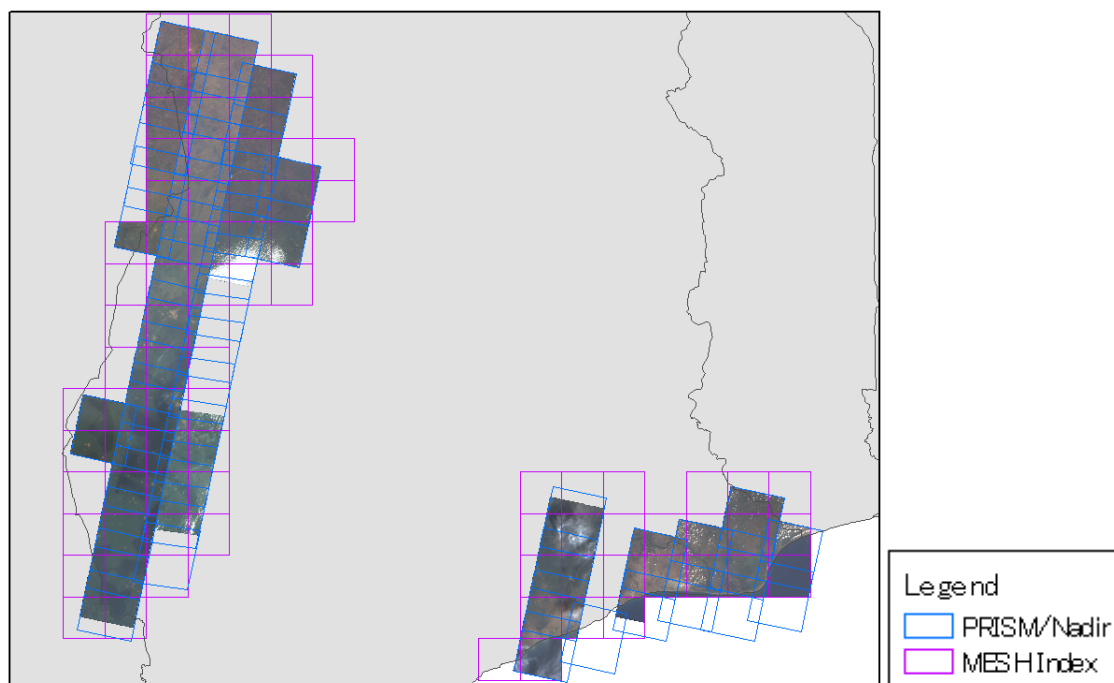
Figure 3-13 Pansharpened image

3.1.3. Feature Extraction

3.1.3.1.   Introduction

The 1:50,000 scale topographical maps are one of the largest scaled maps providing full coverage of Ghana, surveyed and mapped by the Survey and Mapping Division of the Land Commission of Ghana. The series consists of a total of 408 sheets and a standard 1:50,000 scale map sheet covers a rectangle of 15' minutes of latitude by 15' minutes of longitude. These topographic maps accurately depict the location of natural and man-made features by means of symbols and color, and elevation by means of spot-heights and contours (20m interval). Additional information added is place names, boundaries, magnetic data, etc. These maps contain essential information for planning and decision making but also have many other uses.

These forest resource maps were produced covering an approximate land area of 19, 000 sq.km (including the original area shape of 17,000 sq.km plus 2km area buffer). This forest resource map is a hybrid of digitised topographic features captured from the use of ALOS PRISM high resolution satellite imagery of a selected forest Pilot area and 2010 Land Use of Ghana. Remote sensing technology has over the years contributed significantly in the mapping of land use which is needed when it comes to developmental projects. Changes in land use are foreseen, and the quantum and magnitude of changes can be assessed with the help of remote sensing approach. In light of these developments, it is possible to carry out detailed forest inventories and monitoring of land use at various scales such as local, regional and global if satellite data is judiciously used along with sufficient ground data.

3.1.3.2.   Data Preparation

After completing Aerial Triangulation of ALOS PRISM images, it is saved in project files. The project files were imported into LPS, PRO600 software and TIFF image files copied into appropriate directories for easy identification and the extension for all RPC files were then changed to text files for the software to recognize. The Tiff files were imported into the LPS PRO600 software with their corresponding RPC files to form stereo pairs. Settings were done choosing the correct coordinate system,

datum, units and height system. The zone chosen was UTM zone 30 N and the vertical datum was based on EGM 96 since ellipsoidal heights were used in the Aerial Triangulation. The linear units were in meters.

Using LPS PRO600 software, features were viewed in 3D and Captured in Microstation mode with a second 2D screen displaying the data in Microstation for editing.

3.1.3.3. Methodology

(1) Data Capture – 3D

Almost all features were extracted in 3D except land use which was not visible in satellite imagery and therefore was done using LULUCF data.

All images with their corresponding RPC files were matched to form stereo models in the LPS PRO600, capture for Microstation software. Looking on the feature code list supplied, the Microstation layers were created to do the data captures. As per our in-house quality control by a checklist, features were captured accordingly. In all about 48-models covering the pilot areas were digitized to form the basis for the forest resource map. Data were captured in layers / thematic areas, as shown in Annex 3-1D and Annex 3-1E. Data was captured using satellite images and at places where features were obscured due to cloud cover, data capture was augmented using Google earth images, ortho-rectified ALOS images and other topographic maps. This was done mainly in 2D as described in the next subsection.

A detail step of the 3-D digitization is explained in Manual 4, Section 2.2.3.
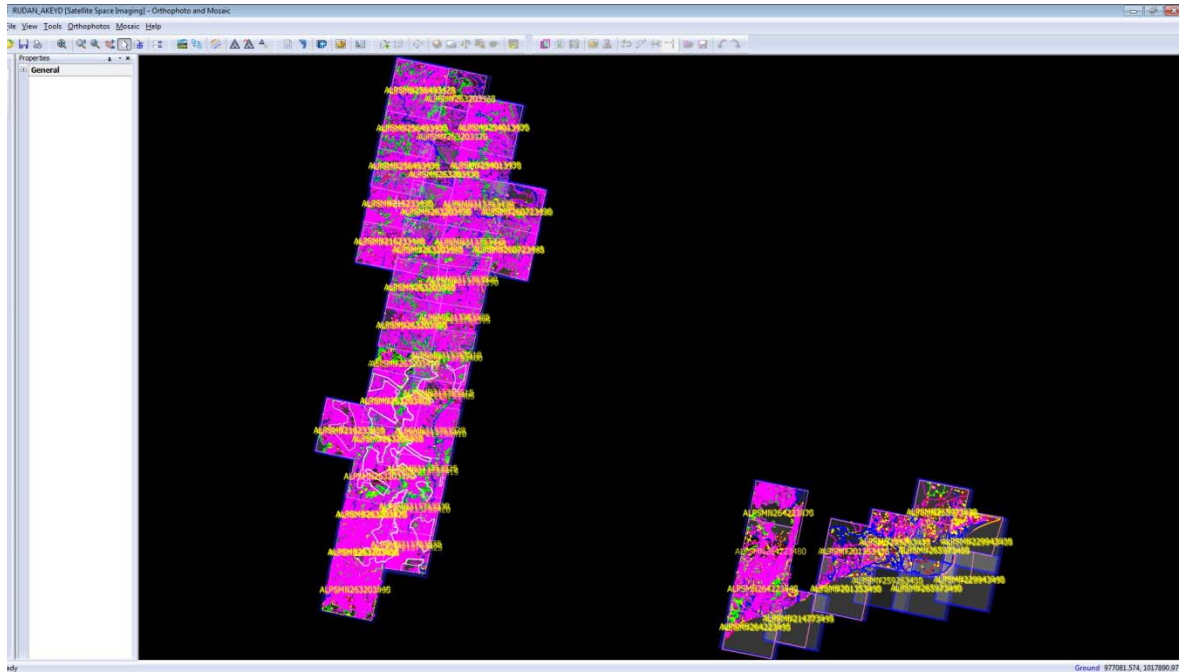
Figure 3-14: Snap shot of Digitized pilot area in AUTOCAD

Figure 3-15: Data Collection in LPS PRO600 and Microstation

(2) Data Capture – 2D

The nature of the images (black and white) prevented Land Use classes to be seen in images. Due to this, classified images from 2010 LULUCF data were digitised in 2D to differentiate different Land Use classes within the pilot area. This was done by importing the captured sheet into ARCGIS and converting to shape file. Land use classes were then superimposed on the appropriate sheet and polygons drawn around each class extent falling in the sheet. The same procedure was done for ortho-rectified ALOS images. For Google earth images, the Mircrostation captured dgn files were exported to kml files and open into Google Earth. The draw feature tool in Google earth was then used to digitise features that were unclear in the satellite imagery; mostly land use classes.

Detail steps of the 3-D digitization is explained in Manual 4, Section 2.2.2

3.1.3.4.   Quality Assurance and Checks

Stereo quality is based mainly on accuracy of aerial triangulation. If AT is done correctly, then data capture can be checked for data consistency and making sure all features are captured into their correct layers and no feature is omitted. All data captured underwent a stringent quality check procedure by the team manager or supervisor. Figure 3-16 shows an example of the tight check procedures that the managers adopted before accepting data for final compilation.

Figure 3-16: Sample of quality checklist carried out

3.1.4. GIS Data Compilation

3.1.4.1. Methodology

Data captured from 3D and 2D photogrammetric methods as described above was imported into   ARCGIS and converted to shape files for further structuring and compilation into a GIS. Detail of compilation of GIS data is presented in Manual 4, Section 2.3.

3.1.4.2. Indexing

The first step of the GIS compilation was to divide the pilot area into workable and printable map size as 15'x 15'. A topographical map sheet shape file of Ghana was used. This was generated using the Fishnet tool in ArcMap and its attributes data assigned. The sheets falling under the pilot area were extracted as final sheets to be used as extent of the map. Total 42 sheets were found to be falling under the pilot area. A final index map sheet falls under the pilot area are shown in Figure 3-17.
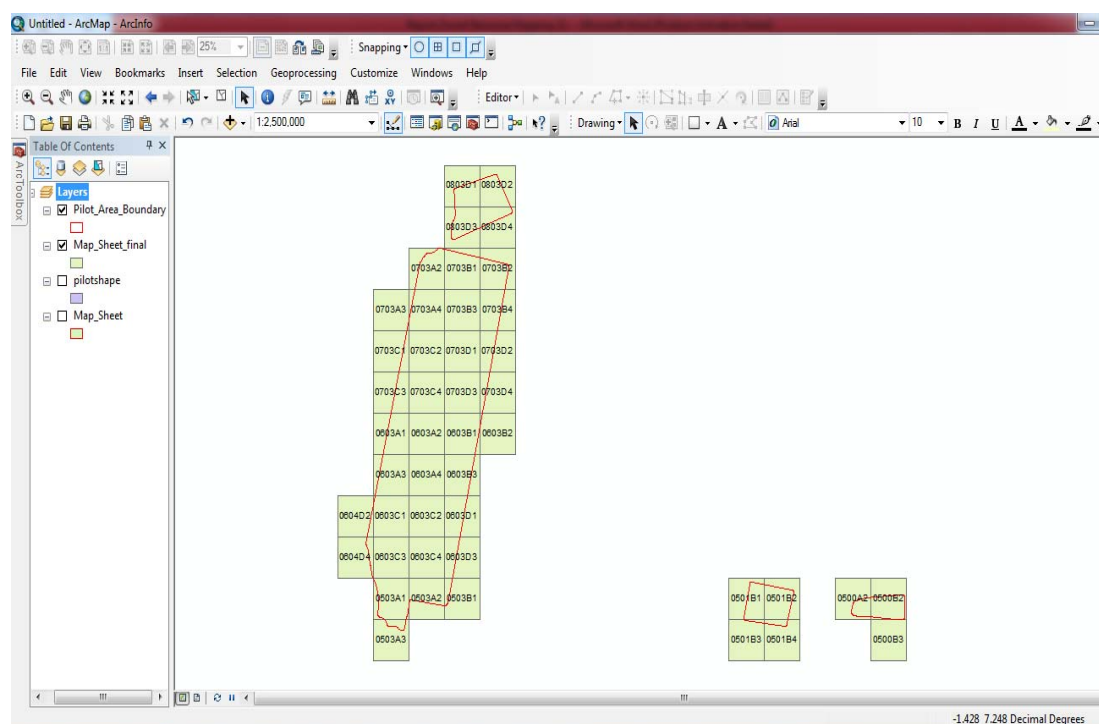
Figure 3-17: Index Map of Forest Resource Map

3.1.4.3.   Data Extracted from ALOS Satellite Imagery

Data captured from satellite imagery include contours, water bodies (streams, rivers, etc), power lines, transportation data (roads, footpath, railway lines, tracks, etc). Detail descriptions of these datasets are in Annex 3-1D and Annex 3-1E.

3.1.4.4.   Data Collected from Secondary Source

Data from secondary source i.e. GIS data assembled earlier on in another task of the project was used to augment the captured data. These include Land use, town annotation and boundaries (district, regional, pilot area, forest reserve, etc). Details descriptions of these data sets are in Annex 3-1D and Annex 3-1E.

3.1.4.5.   Quality Assurance and Checks

Topological errors of the captured datasets (Linear and Land Use) were checked. The following rules were used in checking the topological errors

- For the Linear, the following rule was applied
  - Must not have dangles - This was used to check the over shoot and the under shoot, gaps and breaks in the datasets.
  - Checking for consistency – The relationship of where river flows and contours were checked to make sure it follows the conventional agreement that exists between where river flows and contours.
  - Must be a Single line – Contour lines were checked to make sure that there were no breaks in the lines in the data.

- For the Land Use, the following rules were applied
  - Must not have Gaps – This was done in checking for Gaps in the land use layers.
  - Must not overlap - This was done in checking for overlaps in the land use layers.

3.1.5. Field Completion and Verification

Field completion was done by selecting vantage points from the digitized features to measure the ground coordinates and compare it with the coordinates of the selected points on the map to ascertain the integrity of the data captured. Names of selected features (rivers, mines, airports and towns/villages) were obtained during field verification and completion by updating names that were not in the secondary data. Data captured was sent to pilot area to check for any data which was not captured.

Field verification was also done for the Land Use classes by visiting some selected points and confirming and correcting the land use classes. Photographs were taken in this effect.

The tables and sample pictures, shown in Annexes 3-1F and 3-1G, show the sample points taken during the fieldwork to verify the land use digitised. The major data collected in the field included:

- Spot Number, showing the sequence of points taken.
- Date and Time
- Geographic and UTM coordinates.
- Type of Land Use and furthermore, if Forest Land, then whether Closed canopy or Open canopy.
- Photographs taken in all direction North, East, South, and West. In addition, its location on ortho-image is also shown.
- Description at the points taken.

Examples of Photographs taken and marked location on Ortho-Image are also shown in the Annexes 3-1F and 3-1G.

3.1.6. Outputs

The output of Task 12 is given in Table 3-6.

Table 3-6: Outputs of Taks12

NO.	Item	Type	Where to Find
1	DSM	Data	GIS Server at RMSC / External HDD
2	GIS datasets for extracted features.	Data	GIS Server at RMSC / External HDD
3	Orthorectified satellite image, tiled and formatted as per the agreed specification in Task2.	Data	GIS Server at RMSC / External HDD
4	A procedure manual describing the process of digitising the features and the automatic generation of the DSM.	Manual	Manual 4

3.1.7. Conclusion

ALOS satellite imagery data proved to be effective to derive 1:50,000 Forest Resource mapping quickly. All features were extracted using ALOS PRISM and ALOS AVNIR-2 data. However Google earth map was used to extract the features under the clouds of ALOS PRISM images. Due to lack of GEOID model of project area, orthometric height could not be derived from ellipsoidal height of the GCP. The ellipsoidal height was used for AT of ALOS PRISM images and universal GOEID (EGM96) was used to create contour and spot heights in orthometric height. For LiDAR data acquisition and GNSS survey for field plot sampling, Ellipsoidal height were used, because the absolute height is not required as tree height can be derived with relative height of DTM. It is recommended that Survey and Mapping Division of Ghana, should work in the direction to create an accurate Geoid model of the country, so that GNSS and LiDAR data can be transferred to the Orthometric height for other engineering application purposes.

3.2. Task 13: Produce Cartographic Hardcopy Maps at the Scale of 1:50,000 Covering the Pilot Forest Areas

3.2.1. Introduction

According to the Survey and Mapping Division, topographical maps 1:50,000 scale map could be best represented on an A1 portrait. In light of this, the layouts for the forest resource maps were compiled in A1 paper size. The data frame grids were displayed both in Measured and Geographic grid systems and the appropriate symbology (Font styles and sizes) for the captured layers according to the existing 1974 / 1999 topographic map were assigned. The other map elements such as title, data frame, legend, text, pictures and so on were also designed and approved by Forestry Commission.

3.2.2. Cartographic Map Composition

The detail process of composing cartographic map is shown in Manual 4, Section 3. The layout for the final map production for the individual map sheets were created and kept on server. A sample layout of one of the sheet is shown in Figure 3-18. The layouts were saved in mxd, Tiff and pdf file format and kept on server.
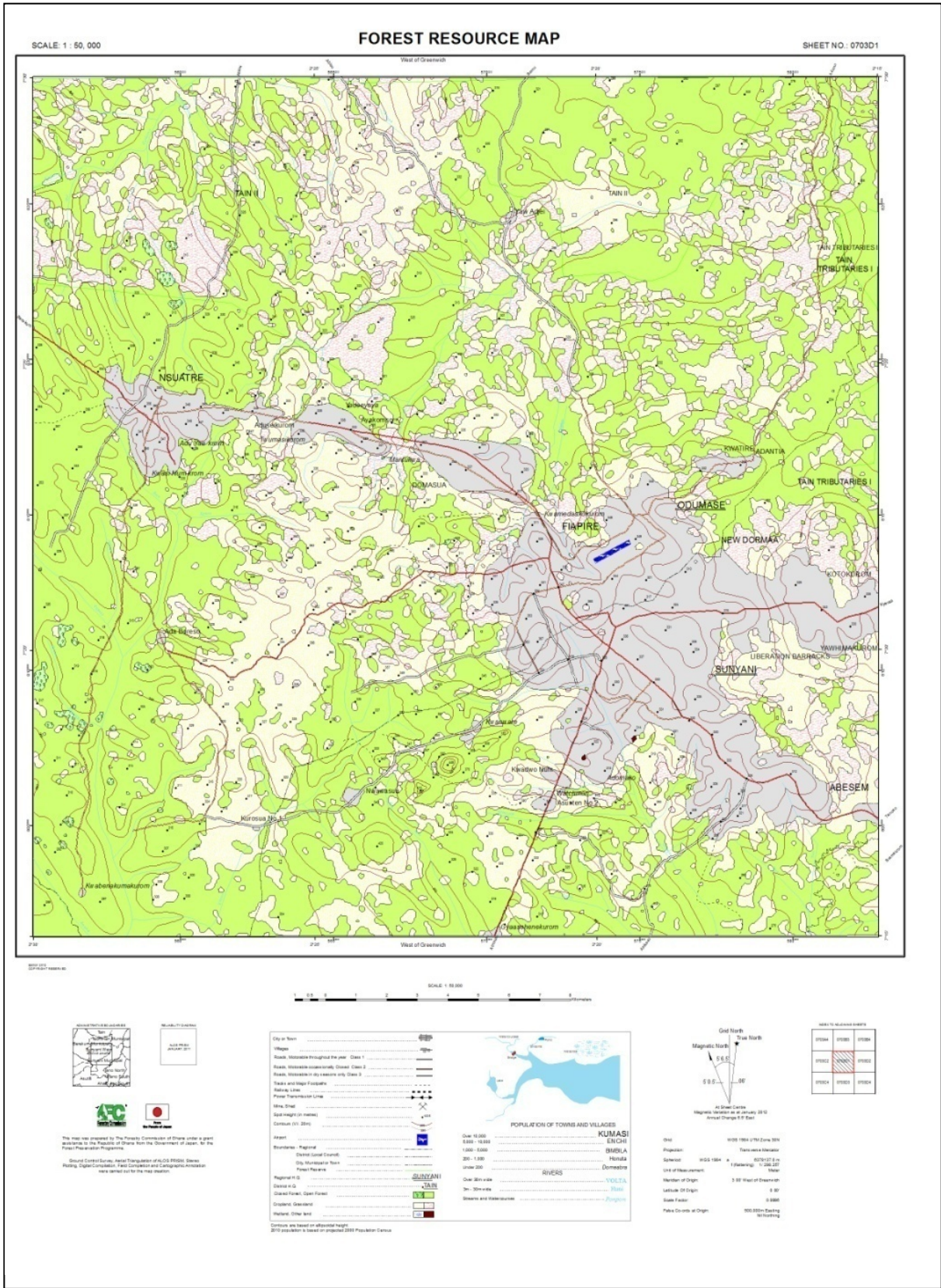
Figure 3-18: Sample Layout of Forest Resource Map

3.2.3. Outputs

The outputs of the Task 13 are shown in Table 3-7.

Table 3-7: Outputs of Taks13

NO.	Item	Type	Where to Find
1	GIS templates for the cartographic compositions.	Data	GIS Server at RMSC / External HDD
2	Print ready digital copy of the topographic maps.	Data	GIS Server at RMSC / External HDD
3	Procedures manual for cartographic map production.	Manual	Manual 4

3.2.4. Conclusion

The forest resource map of 1: 50,000 scale covering whole Pilot Area were prepared in three formats (MXD, PDF and Tiff) and saved in server. An index map was also prepared showing all 42 maps. The Geodatabase of the whole Pilot Area are saved on server. If the Geodatabase is updated with new features, it will automatically reflect in the MXD file. Then print out should be taken from MXD file and a new set of PDF and TIFF file should be created for fast print out.

4. Study Area Biomass Inventory

4.1. Task 14: Undertake Representative Field Sampling of Biomass in All Identified Forest Classes and Strata That Will Allow Extrapolation to the National Forest Resource

4.1.1. Introduction (objective)

The purpose of the field measurement campaign was to enhance the capacity of RMSC and FCG staff in the use of modern technology and to develop best practices for inventory work, so that they are prepared to carry out future forest biomass and carbon stocks assessment and monitoring activities.

Accurate plot measurement data was also needed for LiDAR (Light Detection and Ranging) modelling to assist in deriving a carbon look-up tables including 6 forest carbon pools per broad forest classes (strata). These forest carbon pools are namely above-ground (trees), below-ground (root system), deadwood, soil, litter and non-tree carbon pools.

4.1.2. Stratification

Satellite imagery based land use (LU) classification was performed, which was further stratified by incorporating with the ecological zones. With respect to LU classes, all the six principal IPCC LU classes were included, namely: Forest Land, Cropland, Grassland, Settlements, Wetlands, and Other Land. In addition, two sub-categories of forest canopy cover, Forest Land - Closed canopy (Canopy cover > 60%), and Forest Land - Open canopy (Canopy cover < 60%) were considered. Thus, altogether seven (7) LU classes were included in LU classification. The LU result was validated through independent field verification data and used as a reference when planning the LiDAR sampling acquisitions.

4.1.3. Field sampling: Cluster and Plot Design

The field sample planning procedure is described in details in Manual 5-2. The sample plots have been distributed over the ecological zones according to the following scheme:

1) Savannah, Dry semideciduous (fire zone), Dry semideciduous (inner zone)
- 30 sample clusters, total 90 plots

2) Moist semideciduos North-West zone
- 40 sample clusters, total 120 plots

3) Moist semideciduous South-East zone, Moist evergreen, Wet evergreen
- 30 sample clusters, total 90 plots

4) Upland evergreen
- total 39 randomly sampled plots

5) Southern Margin
- total 12 randomly sampled plots

6) Mangroves
- total 10 randomly sampled plots

The weighted cluster sampling has been applied using LiDAR height metrics (85 percentile height) as weights. Each cluster consist of three plots, with the sample plots distributed within a distance of 500 m of each other balancing between transportation time, overall costs and to avoid spatial autocorrelation effects between plots. The primary cluster reference point is the centre point of the most southern plot within a cluster.

The pilot area extent and clusters along with 9 ecological zones division can be seen in Figure 4-1. The planned field sampling intensity over the pilot area of 9 ecological zones and mangrove forests corresponds to 0.0008%, This can be considered extremely low to produce accurate plot-based mean values but meets the minimum conditions of LiDAR-based aboveground carbon modeling over three aggregated sampling strata (1-3).
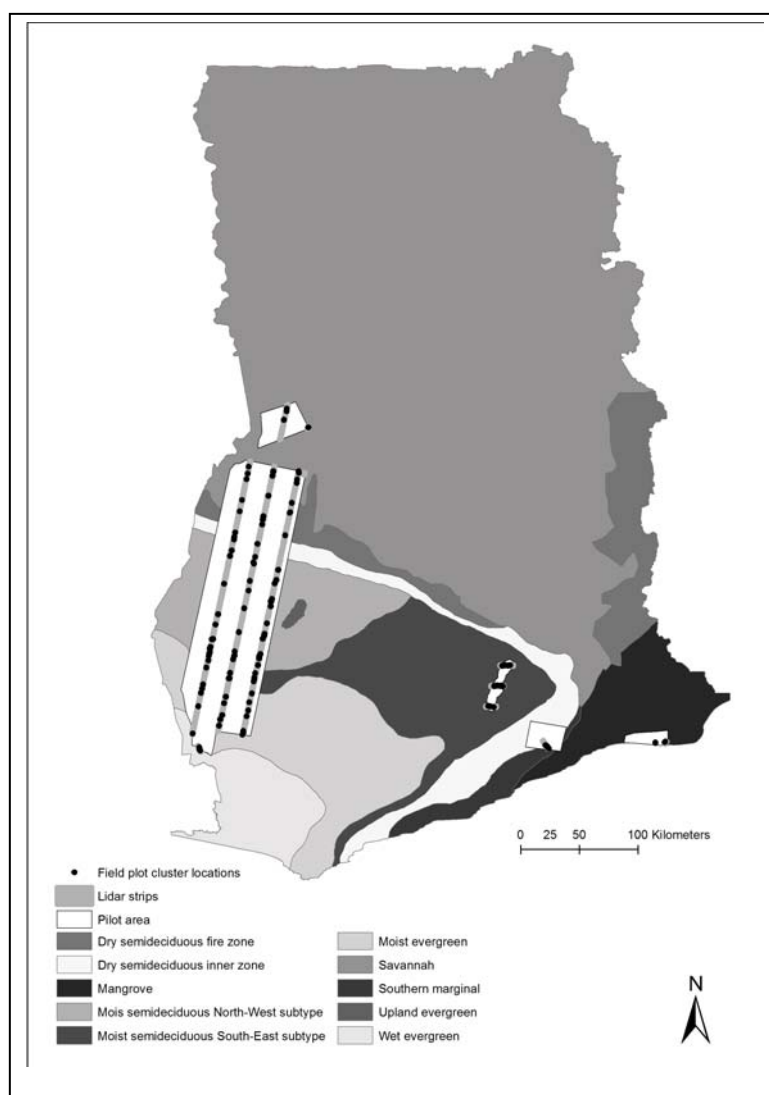
Figure 4-1: Ecological zones, pilot area, LiDAR sample strips and field plot cluster locations

Quadratic plots equivalent to an area of 400 m2 (20 x 20 meters) were used (Figure 4-2). Tally and standing dead trees were measured over the entire plot. Juvenile trees and downed deadwood were enumerated from 10 meter times 10 meter subplots. The sub-plot size for seedling measurements was 5 meter times 5 meter. Litter, non-tree and soil samples were collected from two 1-m^2 subplots located on the south-west – north-east diagonal line, 5 meters apart from the plot centre. The detailed measurement procedures and attributes are described in the Manual 5-1.

Figure 4-2: A sample cluster with sub-plots.
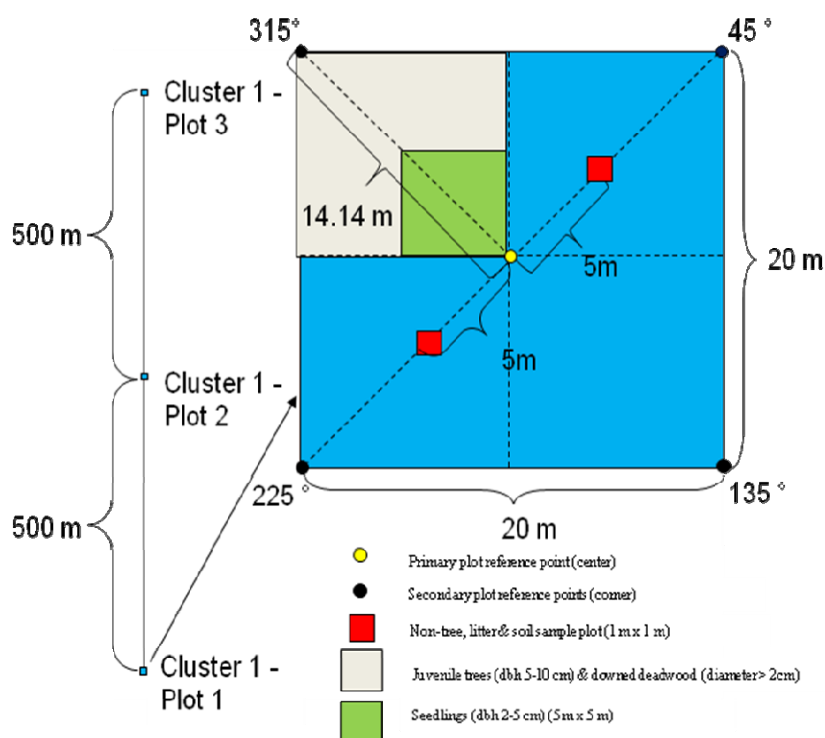
4.1.4. Field work and quality assurance

4.1.4.1.   Inventory Team

The clustered sample plots were enumerated by four field plot measurement teams and one navigation team. The field measurement team composition was consisted of 9-10 members including:

- Team Leader (Booker)

- Debuty Team Leader

- Botanical Assistant

- GNSS Operator

- Non-tree/Litter/Soil Sampler

- Driver

- Labourers

The navigation team was formed of the following members:

- Handheld GPS-navigator

- Plot measurement member to locate the plot centre and prepare layout

- Laborer to clean a path for the plot measurement team

- Driver

The role of the navigation team was to move ahead of main enumeration team; early in the morning; from the camp with an assistant to find, to mark the plot centre and corner points using a linear tape and a compass. If a plot was found to be located on a sloppy terrain, the so called step-chaining approach was followed. While enumeration team was taking measurement, the navigation team moved to next plot of the cluster to navigate and mark the plot.

The list of forest inventory team members can be found in Table 4-1.

Table 4-1: Biomass/C-stock inventory members and their designations

No	Name	Designation	Remark
1	Kwame Oteng Awuah	Team Leader	Inventory Team 1
2	Emmanuel Ampomah	Deputy Team Leader	Inventory Team 1
3	Atinga John Parker	Litter Sampler	Inventory Team 1
4	Thomas Owusu	Botanist	Inventory Team 1
5	Kwabena Oteng	Botanist	Inventory Team 1
6	Francis Addai	Botanist	Inventory Team 1
7	Raymond Votere	Team Leader	Inventory Team 2
8	Frank Ankrah	Deputy Team Leader	Inventory Team 2
9	James Osei Gyimah	Litter Sampler	Inventory Team 2
10	Yaw Nkrumah	Botanist	Inventory Team 2
11	Kwesi Pinkrah	Botanist (acts as labourer)	Inventory Team 2
12	Ernest Appiah	Botanist (acts as labourer)	Inventory Team 2
13	Anim Bafour	Soil Sampler	Soil Sampling Team
14	S. K. Yankyerah	Soil Sampler	Soil Sampling Team
15	Akwasi Appiah	Soil Sampler	Soil Sampling Team
16	Frimpong Samuel	Soil Sampler	Soil Sampling Team
17	Wiredu Stephen	Soil Sampler	Soil Sampling Team
18	Anim Boafo	Soil Sampler	Soil Sampling Team
19	Emmanuel Donkor	Team Leader	GIS/GPS Team
20	Godwin Agyeman	Deputy Team Leader	GIS/GPS Team
21	David Baidoo	Member	GIS/GPS Team
22	Theresa Adjaye	Member	GIS/GPS Team
23	Lawrence Akpalu	Data editing & transfer	GIS/GPS Team

24	Emmanuel Opoku	Data editing & transfer	GIS/GPS Team
25	Nii Ofori Tackie-Oblie	Member	GIS/GPS Team
26	Richard Aidoo (KNUST)	GPS Operator	APRIL 17th - 30th (Enchi)
27	Jeffery Ablade (KNUST)	GPS Operator	APRIL 17th - 30th (Enchi)
28	Kofi Affum-Baffour	Supervisor/RMSC	General Supervisors
29	Gabriel Quansah	SRI	General Supervisors
30	Dr. Ernest Foli	FORIG	General Supervisors
31	Dr. Stephen Bredu	FORIG	General Supervisors
32	Tina Wemegah	RUDAN	General Supervisors
33	Gideon Dada	Driver	Inventory Team 1
34	Ben Yemoh	Driver	Inventory Team 2
35	Michael Asuboah	Driver	Soil Sampling Team
36	Joseph Afrifah	Driver	Truck
37	Simon Teye	Driver	
38	Addae Samuel	Driver	Mr.Yakubu's Car
39	Tawiah	Driver	Rudan pick-up
40	Gifty Anim	Logistics	Logistics

4.1.4.2. Inventory data management workflow

The field data management from data collection to the data quality control followed the workflow illustrated in Figure 4-3 to maintain data consistency and quality throughout the entire inventory process.

As step one, the plot locations to be visited are planned and generated based on the sampling intensity determined for each stratum over the area of interest. There are various sampling design options such as simple random, weighted random and systematic sampling applying stratification and clustering plots. The ArboWebForest (AWF) plots generation tool can be used to plan the field plot sampling (Manual 6-1). The tool also allows a user to define a sampling design for any given inventory area, sample the plot centre coordinates and export the information as xml field forms with a pre-defined format and to transfer the forms to robust mobile data collection devices procured for the field campaign.

As the second step, data is recorded either using mobile handheld devices or paper field sheets. In case the data has been collected on a digital field form, the recorded plot attributes can be transferred as a xml-file directly for data cleansing on a field server database application (Open Foris Collect) installed on a laptop PC. If the plot

attribute data has been recorded on the paper field sheets, it must be entered before cleansing in Open Foris Collect.

As soon as the cleansed xml-forms have been exported from Open Foris Collect and an internet connection is available, they can be uploaded to the central database and for automatised aboveground, belowground, and deadwood computation in AWF. The computed plot-level and tree-level results were downloaded in csv-format for the further carbon stock estimation in any external application. The xml files can be also opened as individual spreadsheets in MS Excel for carbon density calculation of these same pools and besides litter, non-tree and soil C-stock. The models and the formulas configured in the AWF plot computation tool are described in Manual 5-4.

The AWF data management tools installation and operation instructions are found in Manual 5-4. The access to web-based inventory management tools can be gained with the administrative login details.
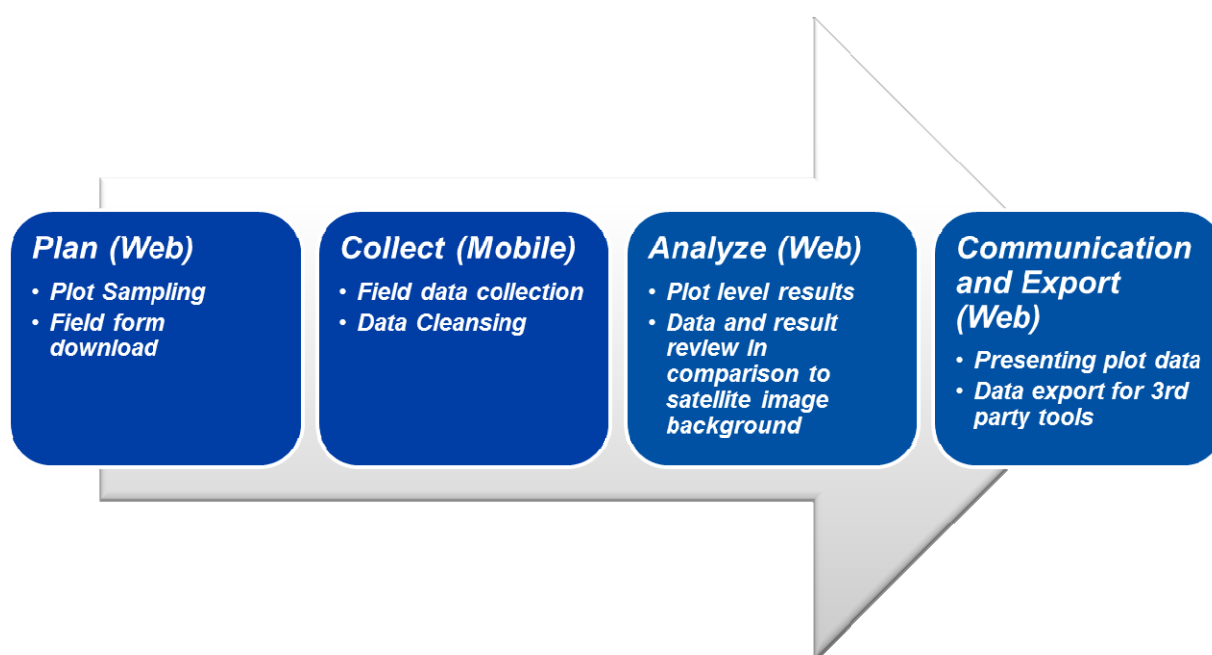
Figure 4-3: Forest Inventory Data Management Workflow

4.1.4.3. Quality control

Total randomly selected 15 plots in Moist Evergreen, Moist-Semideciduous South-Eastern and North-Western zones were revisited as quality control plots. Finally 12

out of these plots were revisited in field for quality control being 3.3 per cents out of the total 358 planned plots and 4.1 per cents of the plots with measured data.

(1) GNSS measurements

Handheld GPS were used to navigate to the plot. Only a few markers were left in their original location so the center point of the plot position had to be taken from handheld GPS. Four corners were laid out with the help of a compass and a tape. Center point along with four corners GNSS data were observed. Total 41 points were collected from 12 plots. These 41 points were post processed using corresponding base station data and Trimble software (Trimble Business Center) and the positions were calculated.

The comparison of position has been conducted using the QC GNSS data and GNSS data collected during the original field work period. It has been found that only 27 common reference points are found in GNSS data. These 27 points were compared and the results are shown in Table 4-2 and Table 4-3.

Table 4-2: GNSS observation comparison between the original sample and QC plots

SN	ID	QC Plots			Sample plots			Difference in (m)		
		East (m)	North (m)	Ele (m)	East (m)	North (m)	Ele (m)	X	Y	Z
1	PN 114_0	520380.8	715995.4	253.256	520377.9	715995.8	245.911	2.880	-0.401	7.345
2	PN 178_2	554228.9	770753.4	279.436	554223.8	770753.6	269.884	5.131	-0.155	9.552
3	PN 178_3	554208.2	770750.4	271.955	554205.3	770752.2	274.140	2.908	-1.735	-2.185
4	PN 183_0	533480.2	777458.9	274.118	533475.4	777456.1	273.761	4.800	2.801	0.357
5	PN 183_1	533489.2	777470.3	274.656	533485.1	777466.2	274.517	4.081	4.110	0.139
6	PN 183_2	533491.7	777450.8	274.526	533485.6	777446.5	273.876	6.047	4.281	0.650
7	PN 183_3	533470.5	777448.6	273.184	533466.5	777445.1	272.980	4.026	3.545	0.204
8	PN 183_4	533468.6	777467.3	274.074	533464.6	777465.5	273.771	3.955	1.858	0.303
9	PN 212_4	561735.2	811026.1	316.128	561734.9	811026.3	317.443	0.282	-0.207	-1.315
10	PN 212_1	561755.2	811027.7	318.916	561754.6	811027.4	316.949	0.574	0.311	1.967
11	PN 212_3	561736.5	811007.1	315.879	561736.5	811006.1	316.945	-0.053	0.921	-1.066
12	PN 212_2	561756.2	811009.3	317.063	561755.4	811006.3	318.531	0.817	2.953	-1.468
13	PN 213_0	561846.1	811509.3	339.048	561846.3	811505.0	339.136	-0.144	4.386	-0.088
14	PN 213_1	561855.4	811519.9	321.158	561855.5	811515.6	339.267	-0.022	4.350	-18.109
15	PN 213_2	561856.9	811500.1	339.137	561857.1	811495.9	339.158	-0.196	4.211	-0.021
16	PN 213_3	561836.4	811499.1	338.833	561837.0	811494.1	338.837	-0.593	4.959	-0.004
17	PN 213_4	561835.3	811518.3	338.737	561835.5	811514.0	338.792	-0.219	4.313	-0.055
18	PN 239_0	589481.2	837471.1	238.384	589482.3	837467.0	238.155	-1.166	4.126	0.229
19	PN 239_1	589490.4	837481.2	237.465	589489.9	837477.7	241.106	0.589	3.594	-3.641

20	PN 239_2	589491.4	837461.7	238.365	589492.2	837457.0	238.759	-0.793	4.734	-0.394
21	PN 239_3	589471.5	837460.7	238.368	589473.2	837456.4	238.904	-1.656	4.346	-0.536
22	PN 239_4	589470.7	837480.5	236.814	589471.9	837476.4	237.238	-1.244	4.098	-0.424
23	PN 240_0	589578.5	837959.7	231.963	589580.2	837956.0	232.438	-1.719	3.660	-0.475
24	PN 240_1	589586.9	837969.4	232.060	589589.2	837966.8	231.175	-2.319	2.619	0.885
25	PN 240_2	589589.5	837951.2	232.029	589591.2	837947.4	232.591	-1.686	3.826	-0.562
26	PN 240_3	589569.0	837949.1	233.258	589571.1	837945.5	234.257	-2.016	3.621	-0.999
27	PN 240_4	589568.0	837969.2	233.661	589569.1	837964.9	232.656	-1.106	4.284	1.005

Table 4-3: Difference statistics of QC and sample plot GNSS data

SN	Difference	Positional Difference,%		
		dx	dy	dz
1	< 1m	40.7	18.5	63.0
2	1-5m	51.9	81.5	25.9
3	>5m	7.4	0.0	11.1

As summarised, 40.7% of the X positions are within 1.0m positional error. Y positional accuracies are not good, it is only 18.5% are within 1.0m error, whereas Z accuracies are good, 63% points are within 1.0 of error.

The main cause of these errors in x and y positions are uncertainty in identifying the reference points of the plots. So the above presented positional accuracies in x and y are not from GNSS but from the handheld GPS. Z accuracies are better, but still only 63% less than 1.0m error.

The positional accuracies are also affected by the satellite receptions. In dense forest the receptions of satellites are not good and it gives the errors in x, y and z.

(2) Carbon pool attributes

The carbon pool attribute measurements were carried out following the same procedure as during the original field campaign (Manual 5-2). However, litter, non-tree, soil and deadwood samples were not extracted during QC measurements.

The original field campaign and QC plot mean attribute values including difference statistics are found in Table 4-4 and Table 4-5. There are two outlier plots (178 and 198) where the large deviation compared to the original measurements suggests that the plot locations are not matching precisely. Some of the differences can be attributed to harvesting activities. By analysing mean attribute differences, it can be said that height measurements of tall trees have been dominantly underestimations. The same observation can be also made when comparing original campaign measurements against LiDAR height model. Even though the average differences between the original and quality control measurements are found statistically insignificant (t-test), the maximum average diameter and height differences are found to be up to 11.5 cm and 8.5 meter based on the field measurements excluding the outlier plots. For 75 percents of the plots AGC and BGC values deviate less than 30 percents between two measurement times.

Table 4-4: The original and QC plot mean attribute values

Plot No	Original				Quality Check				Difference				
	AGC	BGC	H	D	AGC	BGC	H	D	AGC	BGC	H	D	Comment
34	163.2	22.8	27.9	39.2	120.9	14.1	19.8	27.8	42.3	8.8	8.1	11.5	
35	137.1	15.3	19.6	31.9	144.5	17.4	22.3	36.7	-7.4	-2.1	-2.7	-4.7	
87	36.7	23.3	18.0	24.8	39.4	23.7	19.8	24.1	-2.7	-0.5	-1.8	0.7	
109	162.9	31.5	22.8	38.8	135.6	34.1	31.3	48.3	27.4	-2.6	-8.5	-9.5	
114	50.4	19.8	24.6	28.6	55.9	20.1	25.8	30.8	-5.6	-0.3	-1.2	-2.2	
178	1.6	2.3	11.7	15.0	211.3	9.1	43.1	113.4	-209.7	-6.8	-31.4	-98.4	Outlier
183	11.9	7.1	10.9	40.3	20.8	8.0	15.6	43.6	-8.9	-0.9	-4.8	-3.4	
198	92.3	19.9	29.2	45.3	200.1	28.3	38.0	51.7	-107.8	-8.5	-8.8	-6.3	Outlier
212	17.4	15.6	11.5	11.9	22.0	18.1	13.1	12.2	-4.6	-2.6	-1.6	-0.3	
213	1.1	0.8	7.9	15.1	0.0	0.0	0.0	0.0	1.1	0.8	7.9	15.1	No trees on QC plot
239	2.4	0.8	8.4	25.2	1.4	0.4	8.7	26.3	1.1	0.4	-0.3	-1.1	
240	0.1	0.3	2.8	5.5	0.0	0.0	0.0	0.0	0.1	0.3	2.8	5.5	No trees on QC plot

Table 4-5: Difference statistics of the original and QC plot mean attribute values

Difference	% of plots inside error limit			
	AGC	BGC	H	D
<20%	50	75	62.5	75
20 - 30%	25	0	12.5	25
30 - 50%	12.5	25	25	0
50 - 75%	12.5	0	0	0

(3) Soil and plant analysis

A total of 253 samples, 108 soil and 145 plant samples, were delivered to the ICRAF laboratory in Nairobi for 10 % quality control (QC) of the carbon contents analysis. However, 11 soil samples were not analysed due to their inadequate quantities, once at minimum 20 grams of a soil sample is required for reliable testing and results. All the other samples were analysed using the Bruker Multi-Purpose Analyzer (MPA) which works in the Near-Infrared (NIR) region of the electromagnetic spectrum. The referred technique does not allow direct measurement of the carbon contents but it can be predicted indirectly with calibration models.

Soil and plant spectra are different due to the differences in their characteristics which require that one need to have separate calibration models for both of them. The Plant carbon estimation has not been conducted because of lack of a suitable calibration set (i.e samples with both NIR and carbon data). The plant samples have been only classified into three classes (high, low) according to their carbon contents. The ICRAF report and analysis results are found in Annex 4-1F, 4-1G and 4-1H. The difference statistic of the original (analysis at SRI) and QC soil sample analysis is found in Table 4-6.

Table 4-6: Difference statistics of the original and QC soil sample analysis

	Soil Depth				
Diffference	**0-10 cm**	**10-20 cm**	**20-30 cm**	**Total**	**%**
< 10 %	5	7	2	14	15
10-20 %	4	3	6	13	14
20-50 %	8	12	12	32	34
>50 %	14	9	12	35	37

4.1.5. Destructive sampling for allometric above- and belowground biomass models

The field campaign for destructive sampling was coordinated and executed by a research team from the Forestry Research Institute of Ghana (FORIG) with the following composition:

- 1 Scientist
- 2 Technicians
- 1 Chainsaw operator
- 1 Driver
- 4 Casual Labourers

The statistics for 116 tree individuals felled for destructive sampling is found in Table 4-7. The felled trees were be stratified into four tree components, namely stump with buttress, trunk or main stem, big branches (with basal diameter greater than 10 cm) and small branches (with basal diameter smaller than 10 cm). All the biomass particles were weighted and their volume measured in field. Sampled disks for these different compartments were extracted for assessing wood density and carbon contents analysis in the laboratory. Total 58 trees were uprooted for belowground measurements (Figure 4-4).

Table 4-7: Distribution of destructive sampled trees and their diameter class ecological Zone plus mangrove forest

Broad Ecological Zones	Diameter Class								Total
	0-20 cm	21-40 cm	41-60 cm	61-80 cm	81-100 cm	101-120 cm	121-140 cm	141-160 cm	
Dry	14	4	5	5	2				30
Mangrove	20								20
Moist	5	17	9	3	1	1	1	1	38
Wet	7	15	1	1		4			28
Total	46	36	15	9	3	5	1	1	116

Figure 4-4: Weighing tree roots for belowground biomass models

4.1.6. Allometric above- and belowground biomass models

Allometric biomass modelling to establish the relationship between the tree variables and mass of the above- and belowground tree components was conducted by Dr. Stephen Adu-Bredu at FORIG. The SAS statistical software package was applied to test the explanatory power of different combinations of the primary variables, such as of d_{bh}, tree height (H) and wood density (ρ), surrogates of tree cross sectional area (d_{bh}^2) and surrogates of tree phytomass (d_{bh}^2 x H x ρ) were used. The modelling data is found in Annex 4-1A.

There were a number of models generated for the broad climatic zones (Wet, Moist, Dry) or guilds, as well as a set of general models. The best models for each zone were selected based on a statistical review of model quality by comparing their properties as the R-squared vale, root mean squared error (RMSE) and bias. The AGB model sensitivity for height measurement errors was also tested with the destructive sample data. The species wise AGB models were developed for red and white mangrove trees. The tested and selected model types are listed and documented in Manual 5-4.

4.1.7. Laboratory analysis of litter, non-tree, soil and deadwood samples

Physical and chemical analysis of soil samples were carried out at the Soil Research Institute laboratory (Figure 4-5). Soil organic carbon and organic matter was determined by the modified Walkley-Black method as described by Nelson and Sommers (1982). Bulk density was determined by the core method described by Blake and Hartge (1986). Besides the chemical analysis to determine the organic matter was carried out with dry combustion (ignition) method for litter, non-tree and deadwood samples. The more detailed methodological references are found in Annex XIII of Training Manual 5.

Deadwood sample dry weight and volume were measured for calculating wood density in the wood laboratory of the Forestry Research Institute of Ghana (Figure 4-6). The laboratory analysis results are found as Annexes (4-1B, 4-1C, 4-1Dand 4-1E)

Figure 4-5: Soil Research Institute laboratory

Figure 4-6: Deadwood sample density analysis at FORIG

4.1.8. Carbon look-up table development

The measured attributes from total 313 plots were applied to derive the look-up table. The bio-physical measurements for tally trees, juvenile trees and seedlings were converted into tree-level above-ground and belowground biomass by applying the allometric models developed by FORIG and qualified by the FPP expert team. The model qualification approach is described in Manual 5-4. The same manual also provides calculation formulas for standing and downed deadwood, litter, non-tree, and soil carbon on the basis of the laboratory analysis results.

At the next stage the tree-level AG, BG and deadwood carbon values were summed up at the entire plot or sub-plot level. The plot totals were divided by the plot or sub-plot area in order to have carbon stock (ton) per area unit (hectare). Deadwood, Litter, non-tree and soil carbon stock densities were calculated as ton per hectare.

Each plot was attributed with a weight during the sample generation based on the LiDAR forest height at the sampling phase. In order to produce unbiased values for the look-up table, the weighted plot average values were computed for each stratum applying inverse weights. The formula for both the computation of plot based means and estimated variances are found in Manual 5-4. The LiDAR-estimated AGC values were adopted for the look-up table (Table 4-8 and 4-9).

Table 4-8: The look-up table for 6 forest carbon pools in the pilot area

Zone	Land Use	Plots	AG* x̄	AG* CI	BG x̄	BG CI	Deadwood x̄	Deadwood CI	Litter x̄	Litter CI	Non-tree x̄	Non-tree CI	Soil x̄	Soil CI
WE	Closed Forest	5	455	0.7	29	108	101	184	10	32	NA	NA	341	48
	Open Forest	0	111	2.3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Cropland	3	76	4.6	14	165	22	227	14	126	NA	NA	163	103
ME	Closed Forest	30	511	0.2	89	28	2914	69	10	33	2	40	324	14
	Open Forest	6	146	0.8	11	48	401	74	4	192	6	773	172	37
	Cropland	10	124	1.1	9	14	77	70	13	54	1	633	219	37
	Grassland	1	0	NA	0	NA	107	NA	0	NA	7	NA	NA	NA
MSD-SE	Closed Forest	9	453	0.6	85	25	205	93	9	46	4	63	151	22
	Open Forest	7	129	1.4	28	171	209	190	8	55	1	250	121	26
	Cropland	2	115	2.6	52	24	34	226	13	NA	6	600	186	117
MSD-NW	Closed Forest	45	148	0.2	56	12	399	74	8	23	4	23	224	12
	Open Forest	24	64	0.3	33	31	476	165	8	50	3	50	200	16
	Cropland	35	65	1.8	36	18	104	89	10	21	1	63	264	8
	Grassland	1	4	NA	8	NA	0	NA	5	NA	NA	NA	180	NA
	Settlement	1	4	NA	4	NA	0	NA	9	NA	6	NA	140	NA
DSD-I	Closed Forest	1	85	5.0	54	NA	22	NA	5	NA	8	NA	391	NA
	Open Forest	9	52	0.8	37	24	29	53	7	47	8	57	267	19
	Cropland	4	41	1.2	12	122	436	323	7	103	2	130	250	29
	Settlement	1	0	NA	0	NA	817	NA	6	NA	1	NA	476	NA
DSD-F	Closed Forest	0	56	3.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Open Forest	11	44	0.5	29	NA	11	NA	6	NA	3	NA	215	NA
	Cropland	11	37	0.7	9	52	10	169	3	44	3	79	216	15
	Grassland	4	4	220	1	183	2	170	4	91	4	215	264	71
S	Closed Forest	0	65	1.3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Open Forest	12	48	0.5	17	57	140	91	6	26	2	58	279	19
	Cropland	9	36	1.2	8	54	2	75	5	186	2	67	242	26
	Grassland	36	44	0.4	14	72	6	627	3	64	5	69	226	19
SM	Closed Forest	3	41	3.7	62	27	8	152	8	123	2	380	209	81
	Open Forest	4	31	2.7	25	55	2	242	2	108	3	661	217	101
	Cropland	1	25	7.3	7	NA	0	NA	2	NA	6	NA	121	NA
	Grassland	3	4	255	21	398	2	360	3	194	1	50	177	172
UE	Closed Forest	15	268	0.4	86	99	915	176	5	36	1	38	279	40
	Open Forest	6	96	0.8	47	47	54	113	4	67	3	94	173	38
	Cropland	2	85	1.5	28	950	28	1275	7	850	1	850	164	43
Mangrove		2	18	19	8	378	0	NA	NA	NA	NA	NA	142	280

x̄ = Mean value, $Mg(CO_2\text{-e})$/hectare = $t(CO_2)$/ha; CI = 95-% Confidence Interval for the mean, ± %; WE = Wet evergreen; ME = Moist evergreen; MSD-SE = Moist Semi-deciduous South-East; MSD-NW = Moist Semi-deciduous North-West; DSD-I = Dry Semi-deciduous (Inner Zone); DSD-I = Dry Semi-deciduous (Fire Zone); S = Savannah; SM = Southern Marginal; UE = Upland Evergreen; * = Mean and confidence interval derived with LiDAR-based models; NA = Not sufficient field plot data available.

Table 4-9: The look-up table per the climatic zones

Zone	Land Use	Plots	AG* x	AG* CI	BG x	BG CI	Deadwood x	Deadwood CI	Litter x	Litter CI	Non-tree x	Non-tree CI	Soil x	Soil CI
Wet	Closed Forest	35	504	1.4	86	26	2729	54	9	19	2	41	328	13
	Open Forest	6	142	1.8	11	36	396	125	4	31	5	120	171	26
	Cropland	13	119	2.9	10	23	70	90	13	24	1	97	212	27
	Grassland	1	0	NA	0	NA	107	NA	0	NA	7	NA	NA	NA
Moist	Closed Forest	54	173	1.2	69	10	421	54	8	20	4	20	224	11
	Open Forest	31	69	1.1	35	23	463	125	9	33	2	45	201	15
	Cropland	37	68	2.1	33	19	96	90	9	25	2	46	244	8
	Grassland	1	5	NA	8	NA	0	NA	5	NA	NA	NA	180	NA
	Settlement	1	4	NA	5	NA	0	NA	9	NA	6	NA	140	NA
Dry	Closed Forest	1	69	9.4	54	NA	22	NA	5	NA	9	NA	391	NA
	Open Forest	20	65	1.0	31	43	16	84	7	30	5	46	230	11
	Cropland	15	47	1.2	9	40	44	321	4	36	2	55	219	11
	Grassland	4	38	NA	1	118	2	108	4	43	4	96	264	44
	Settlement	1	0	NA	817	NA	1	NA	NA	NA	NA	NA	NA	NA

x = Mean value, $Mg(CO_2\text{-e})$/hectare = $t(CO_2)$/ha; CI = 95-% Confidence Interval for the mean, ± %; Wet = Wet evergreen and Moist evergreen; Moist = Moist Semi-deciduous South-East and Moist Semi-deciduous North-West; Dry = Dry Semi-deciduous (Inner Zone), Dry Semi-deciduous (Fire Zone); S = Savannah. * = Mean and confidence interval derived with LiDAR-based models (5 % sample); NA = Not sufficient field plot data available.
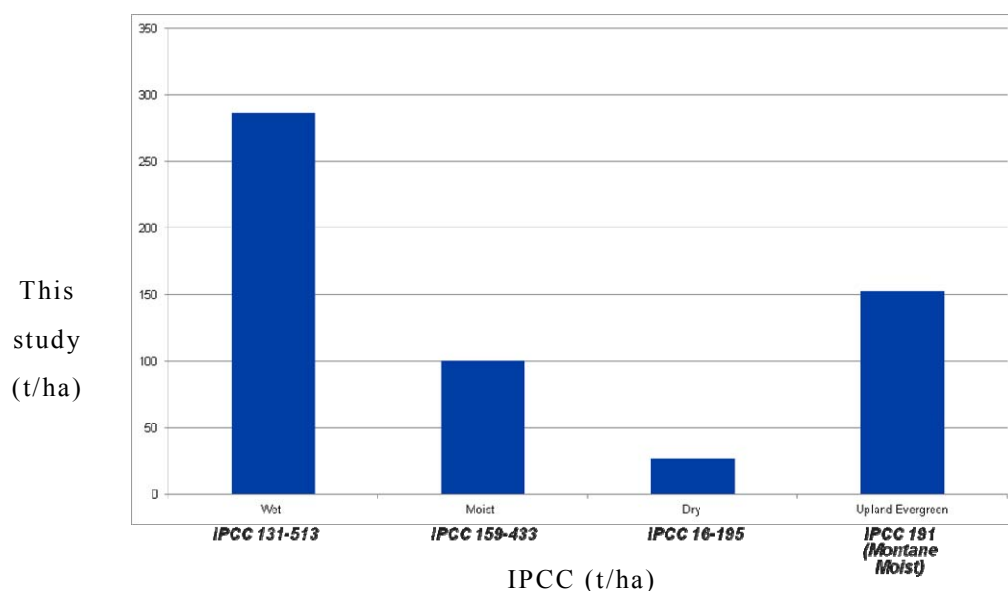
Figure 4-7: The average above-ground biomass values of the broad forest categories and the IPCC default value range expressed below the bars

The average biomass values were compared with the IPCC default range for naturally regenerated forests by broad categories (IPCC 2003). Mostly the averages fell within the reference range except in moist zone forests (Figure 4-7). The upland evergreen comparison was made with the montane moist forest default value.

Finally the conversion factor 44/12 are applied for conversion from carbon ton per hectare units to CO_2-equivalent Mg/ha for populating the final look-up table values. The carbon density maps were produced based on the stratification and look-up table values for the pilot areas (Figures 4-8, 4-9, 4-10, 4-11, 4-12, 4-13, 4-14).
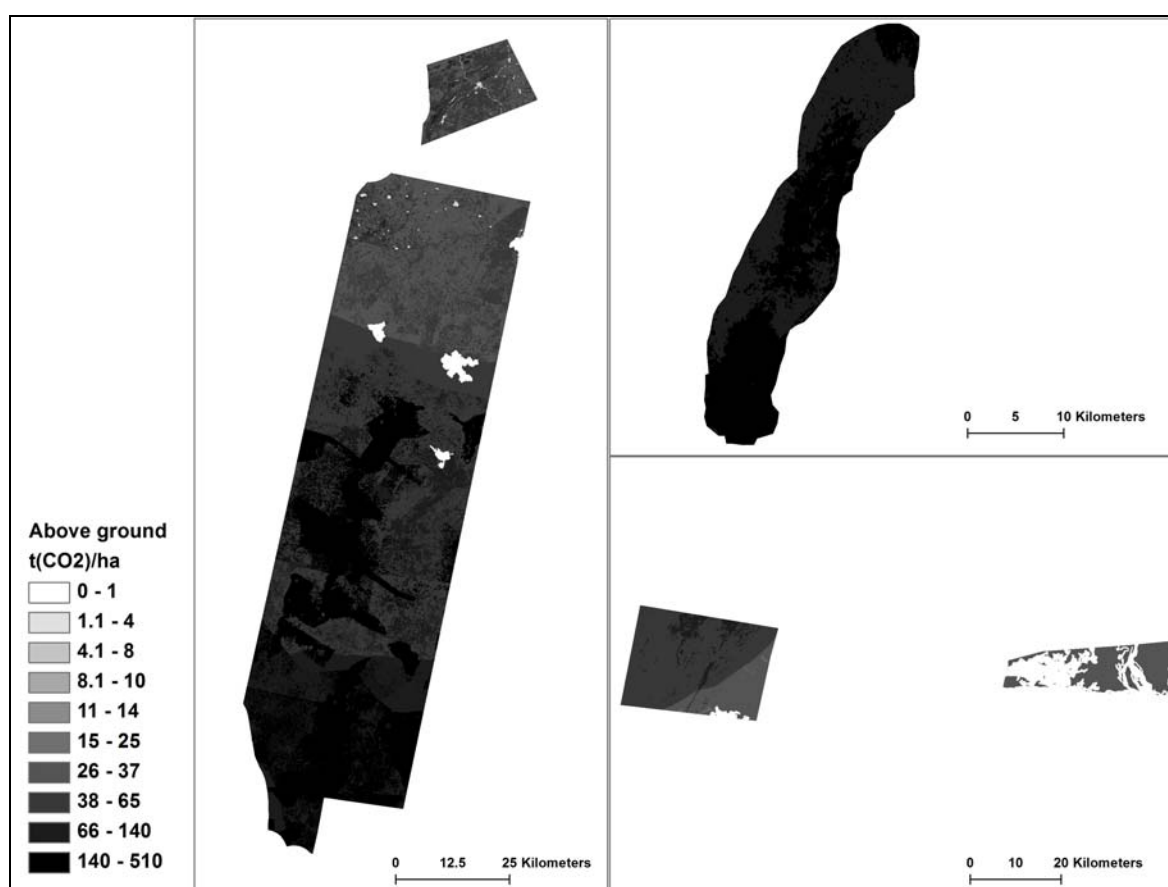
Figure 4-8: Aboveground carbon density map over the pilot areas based on the stratification and look-up table values
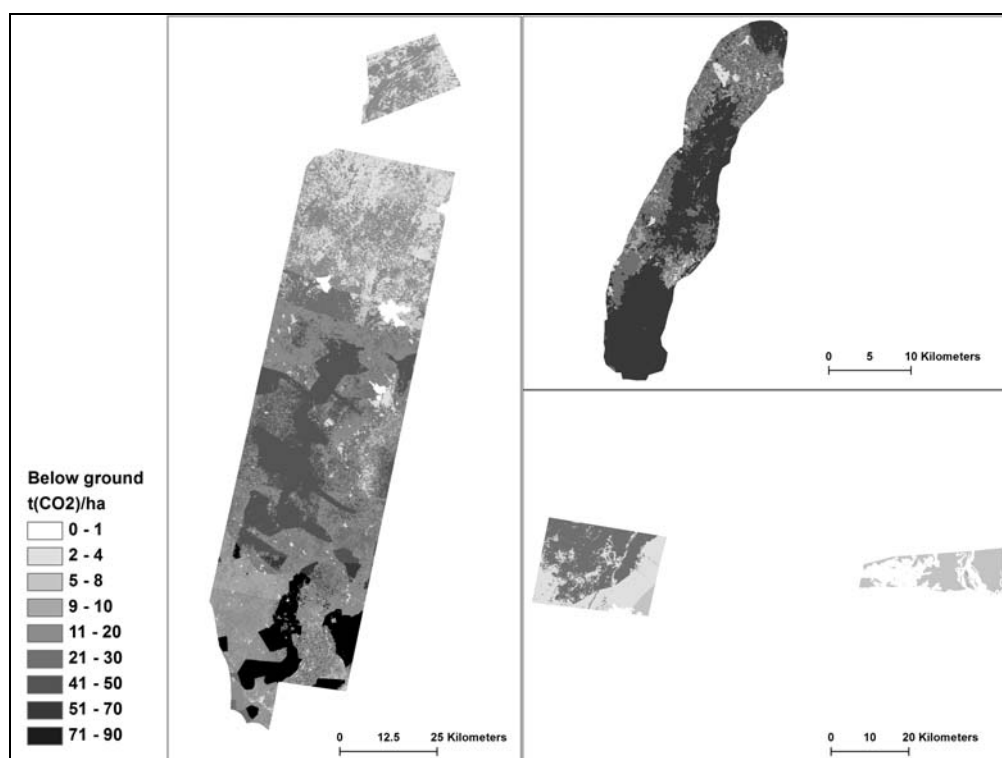
Figure 4-9: Belowground carbon density map over the pilot areas based on the stratification and look-up table values
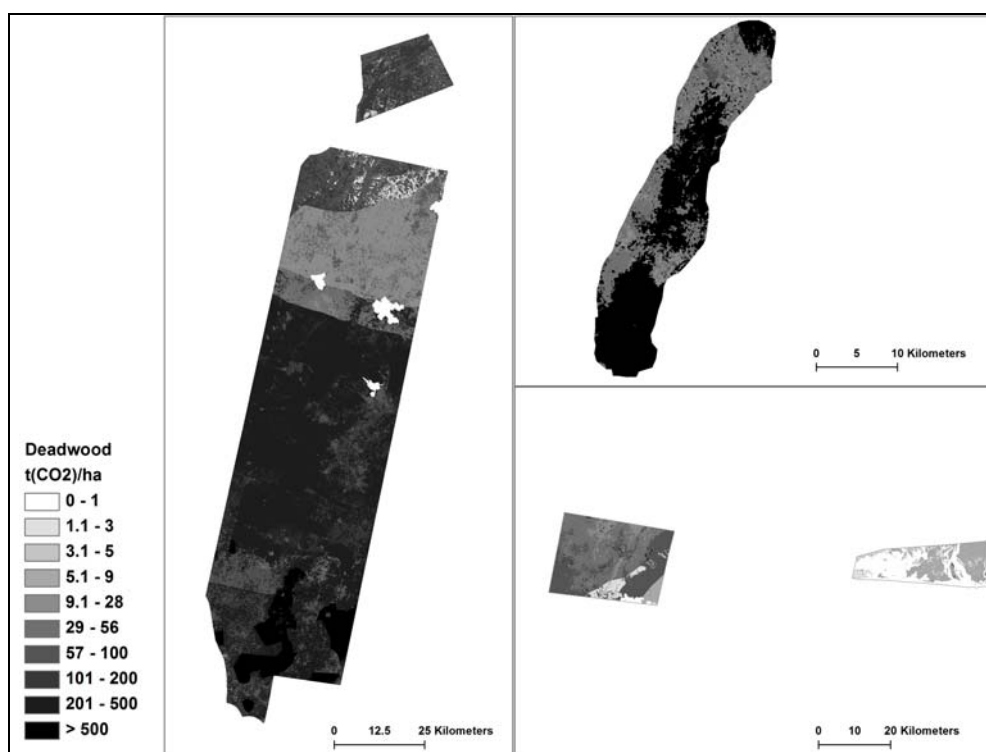
Figure 4-10: Deadwood carbon density map over the pilot areas based on the stratification and look-up table values
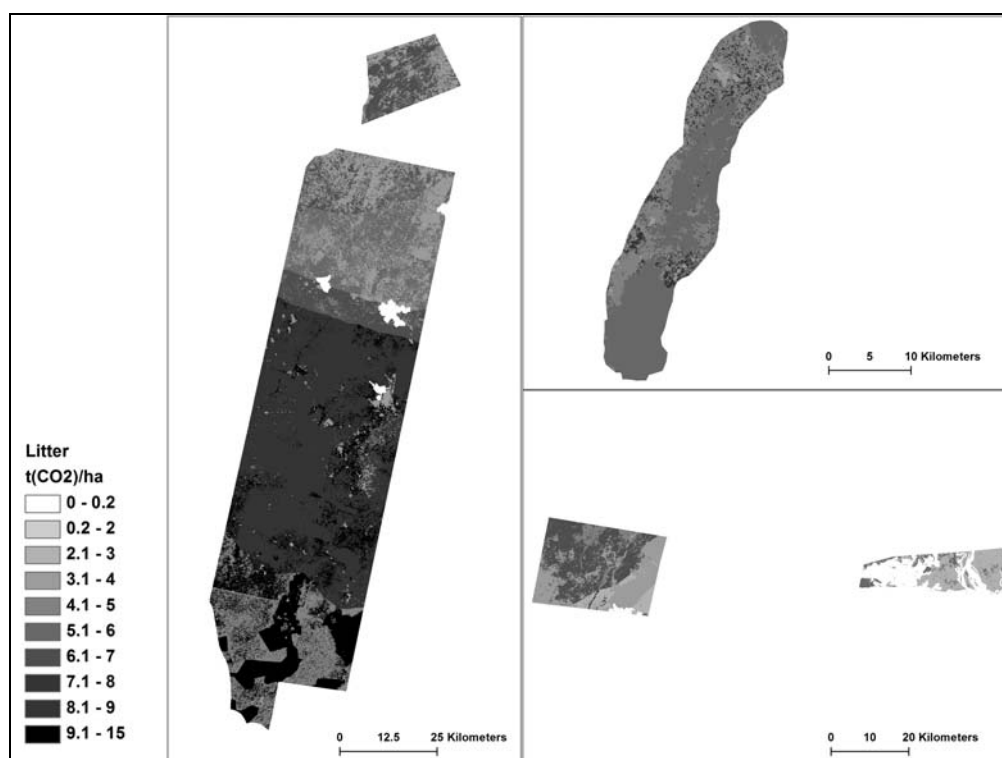
Figure 4-11: Litter carbon density map over the pilot areas based on the stratification and look-up table values
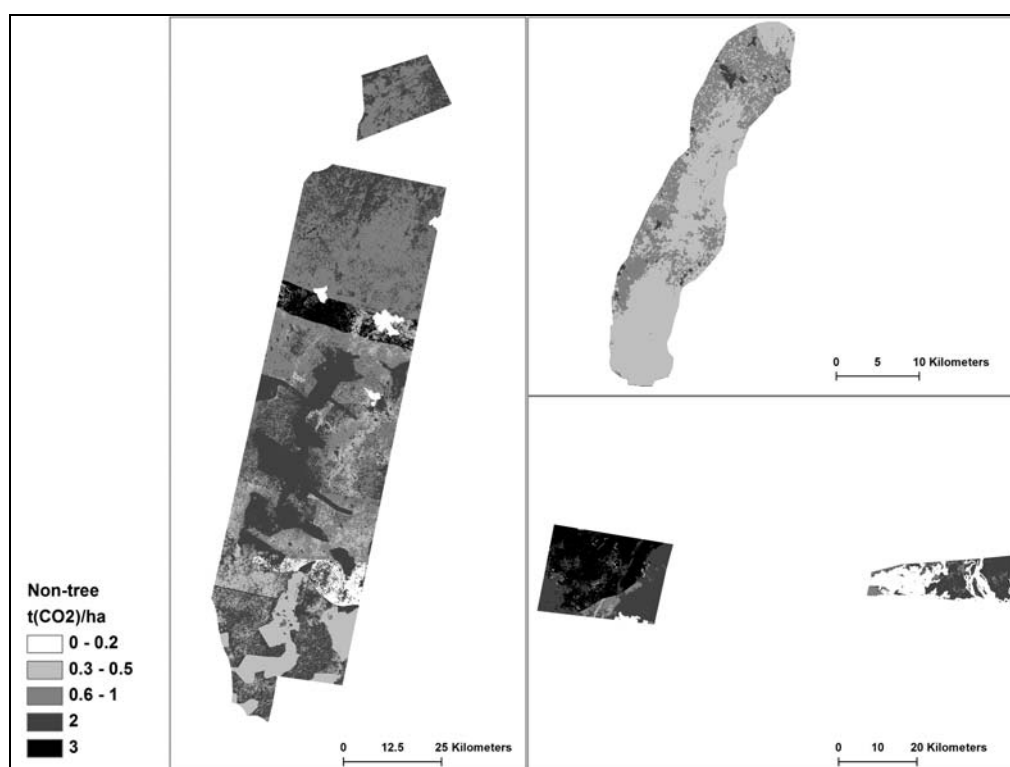
Figure 4-12: Non-tree carbon density map over the pilot areas based on the stratification and look-up table values
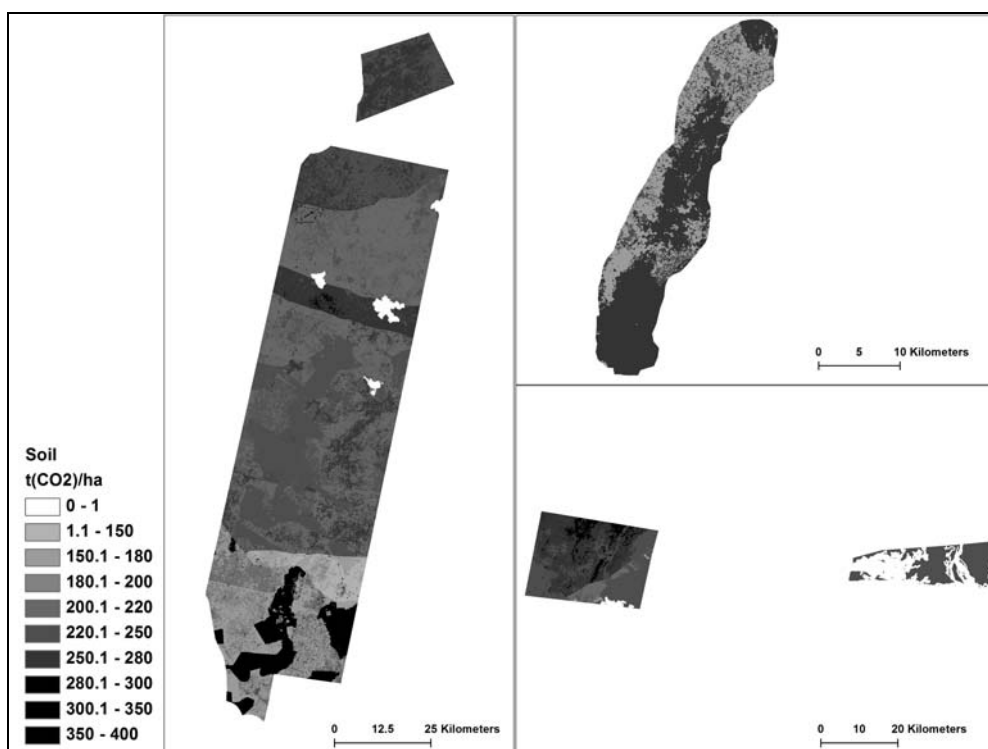
Figure 4-13: Soil carbon density map over the pilot areas based on the stratification and look-up table values
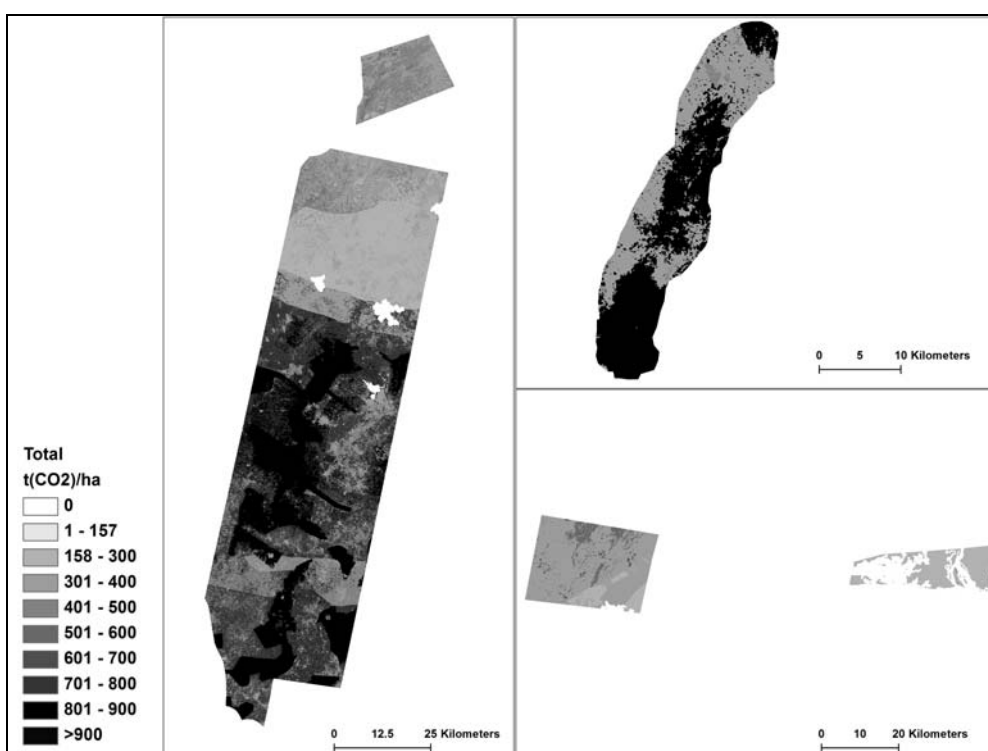
Figure 4-14: Total carbon density map (6 pools) over the pilot areas based on the stratification and look-up table values

4.1.9. Outputs

The task 14 outputs have been described in the Table 4-10.

Table 4-10: Outputs of Task 14

NO.	Item	Type	Where to Find
1	GIS dataset for the biomass field sample data	Data	GIS Server at RMSC
2	Carbon lookup table with biomass figures from field sample data for Ghana and the regional forest types	Document Lookup table XLS file	This Report GIS Server @ RMSC/ External HDD
3	A procedures manual for the sample selection process and the biomass measurement techniques	Document	Manual 5-1 Manual 5-2

4.1.10.   Conclusion

One team was expected to sample one plot cluster (with 3 plots) a day for all six carbon pools, but in practice it could be achieved only 1 plot a day in closed forests and up to 2 plots in more easily accessible terrain conditions.

It was found that in the dense canopy plots, GNSS receiving was remarkably poorer than in the open canopy areas. Most of the points inside the dense forest were not observed due to lack of reception of satellites.

In general, height measurements seem to improve the tree-level AGB estimate precision, but at the same time the risk for height measurement errors gets higher when the tree height exceeds 25 meters. That is why it is recommended to apply dbh-h based models in wet and dry zones when the tree height remains below 25 meters, if there is any uncertainty around the high measurement accuracies.

This time the mangrove forest pilot area was formed by two small patches and most of the plots were not visited due to reported inaccessibility reasons. A more

systematic sampling procedure should be targeted to coastal mangrove areas in the future.

The highest AGC densities were found in closed forest in wet evergreen, moist evergreen and south-eastern moist-semi-deciduous zones, reaching up to 455 carbon dioxide equivalent tons per hectare, $t(CO_2)/ha$, 511 $t(CO_2)/ha$, and 453 $t(CO_2)/ha$, respectively. Depending on the ecological zone, the BGC-AGC ratio varies considerably. In wet zone forestland the plot-level mean BGC-AGC ratios varies from 0.06 to 0.18, in moist zone forestland from 0.19 to 0.52, in dry zone forestland from 0.23 to 0.73 and in mangrove forest it is 0.46. The root-shoot ratio (BGB:AGB) depends on, e.g. the climatic zone, tree species composition and volume.

Deadwood in large quantities was discovered in moist evergreen plots, most likely due to trees felled on the cocoa farms admitted to expand into the forest reserves and palm pruning residues of palm trees in off-reserve areas. The highest mean soil carbon densities in forestland are again found in Wet (341 tCO2/ha) and Moist Evergreen (324 tCO2/ha) zones.

The carbon density values are characterized with very high local variation. The plot-based mean values are generated with a very low number of field plots for 9 ecological zones mangroves and 4 land use categories, which is also the most important factor to the low-precision. The LiDAR model-based AGC helps to produce an unbiased mean estimate with much higher precision.

4.2. Task 15: LiDAR Survey and 3D Structural Analysis

4.2.1. Introduction

Optical remote-sensing does not capture information from below dense canopy covers. This results in a saturation effect which leads to underestimation of biomass in areas with high above-ground biomass concentrations. The problem does not affect LiDAR which can penetrate even through a closed canopy cover to return information from ground-level.

The LiDAR-assisted multisource programmes (LAMP) for carbon stock assessments usually rely on 5-10 % LiDAR transect sample field plot measurements and wall-to-wall satellite datasets over the project area. Implementation of a LAMP approach helps to lower the required field sampling intensity and LiDAR data provides a prior information basis for objective and efficient field plot sampling. Besides it allows generation of numerous extra biomass sample plots called as surrogate sample plots with help of regression models relying on LiDAR metrics for different broad forest types.

4.2.2. LiDAR sample planning

In the western pilot area the reference strip location was randomly sampled and three systematic strips from north-east to south-west were generated accordingly. These LiDAR strips with 1-km width and additional 100 m buffers were expected to provide an unbiased sample of the broad ecological forest types and other land use types existing within the study area.

The systematic LiDAR strip sampling design was verified against the LU classification data. Disregarding the ecological zones, the systematic LiDAR sample design captures different LU classes over the pilot area efficiently (Sah et al. 2012, Annex 4-2A). The same applies to closed and open canopy forest classes when different ecological zones are studied independently. Only within the DSD-I zone the 0.8 percents sampling rate for closed forests, remain remarkably below the average prevalence ratio of 4.9 % percents for this zone (Figure 4-15).
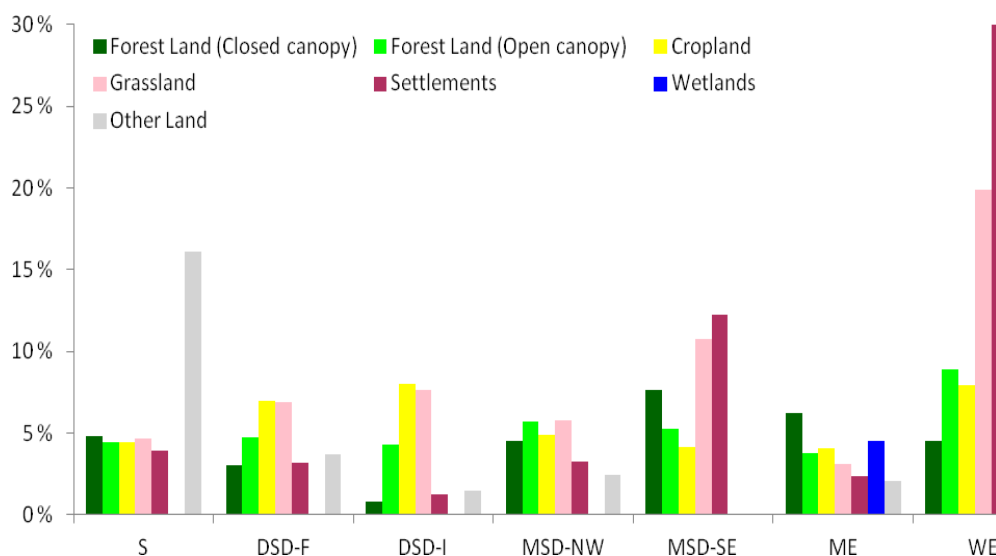
Figure 4-15: Proportional LiDAR Sampling Intensity per LU class

In the upland evergreen zone (Atiwa) a similar systematic LiDAR strip sampling approach was followed. The small southern margin and mangrove sample areas were decided by hearing local experts.

4.2.3. LiDAR acquisition and pre-processing

The airborne laser-scanning pilot campaign was carried out between from 12th December 2011 until 2nd January 2012. The LiDAR acquisition specifications, meetings memos and progress reports related to the external service provider are compiled in Annex 4-2B. There were resources secured for acquiring airborne laser scanning data for 864km2 land coverage, summing up to approximately 5% of the total pilot area (Table 4-11). Laser-scanning altitude was specified to be maintained constant at 1300m AGL (Above Ground Level) with FOV (Field-of-View) of 27 degrees to meet the minimum pulse density requirement of 1-2 returns per square meter. In average, this implied a swath width of 644 m and with a minimum 30-50 % side-overlap between 3-4 parallel transects. LiDAR acquisition parameters are found in Table 4-11.

Table 4-11: LiDAR acquisition parameters

Total Coverage	864 km^2
Aerial Platform	Fixed wing aircraft
Flying altitude, above-ground level (AGL)	1300 m / +-100 m
Flying speed	120 knots
Sensor	Leica ALS50-II
Sensor pulse rate	81.100 kHz
Sensor scan speed	47.6 Hz
Nominal outgoing pulse density, at ground level	2 returns / m ^{2}
Scan Field-of-View	27 degrees
Swath width, at ground level	644 m
Beam footprint, at ground level	31 cm / e^2

4.2.4. Quality control

The LiDAR data was delivered as .las -standard format, classified by vendor to three classes: default, ground and error. LiDAR data in raw format is a three-dimensional point cloud, which quality was checked in terms of gaps in data, classification, point density and spacing. More generally, the data was checked to see whether it met the specifications and was suitable for further analysis. The detailed procedure is described in Manual 5-3.

4.2.5. Post-processing steps

Further processing of LiDAR data included the calculation of a Digital Terrain Model (DTM) from the ground returns and conversion of height coordinates for vegetation returns from absolute elevation into distance-to-ground using the DTM. The removal of flight line overlaps from the raw data was not applied due to relatively small scanner opening angle, 27 degrees. Overlaps are problematic in a case where an area is scanned with a large opening angle, the edges of each flight

line thus having a small angle of incidence. When an area is not scanned close-to-nadir, edges of a flight line might not be comparable to other dataset.

The quality of digital terrain model and thus the precision of LiDAR -derived forest height depend on success of ground returns classification. In forests with high canopy closure and dense ground vegetation layer only a few observations penetrate to actual ground level, and the hits from lower branches are easily interpreted as ground returns in classification procedure. This was noted during visual checking of raw LiDAR files, and a reclassification process was applied to data. However the corrections applied rely on the same number of ground returns, and the new ground level mean height error compared to one classified by vendor was at sub-meter accuracy. Thus the original classification was used.

For the task 15 outputs, LiDAR derived forest height data and canopy closure data were calculated from the height-normalized LiDAR files. Forest canopy height model (CHM) was acquired simply by extracting the maximum value of 2 x 2 meter grid. This grid was further processed by applying a median filter to fill possible pixels with no data values and to smoothen the image. Final output was given in raster (tiff) format with 32 bit radiometric resolution (Figure 4-16).

The canopy closure data was calculated as a ratio of first and only -pulse returns above 5 meters (high-vegetation returns) to all first and only -pulse returns. A 20 x 20 meters grid was considered to be appropriate resolution to represent canopy information. Output of canopy closure analysis was also given in raster tiff-format (Figure 4-17).
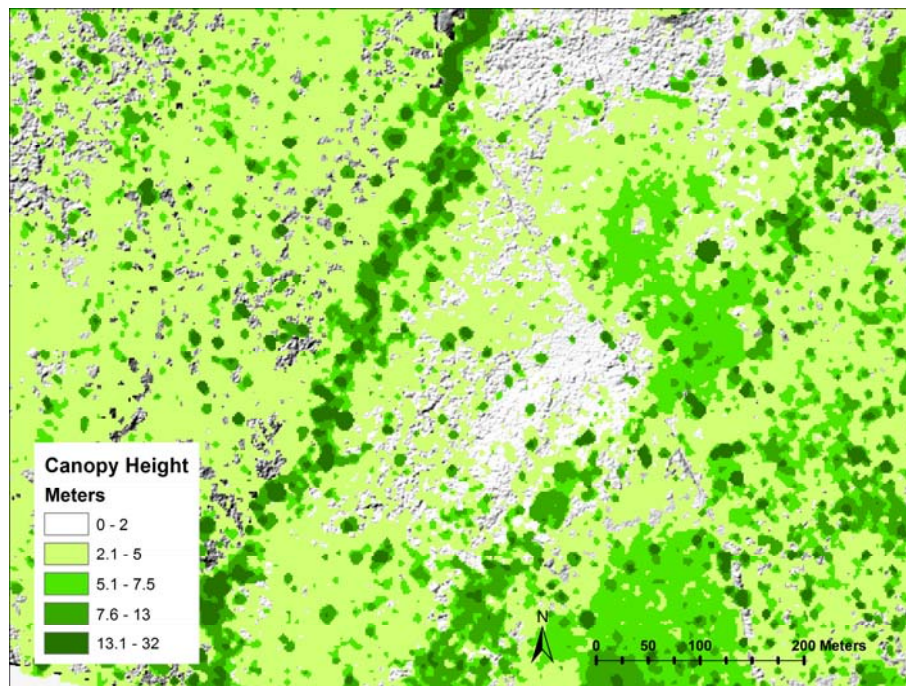
Figure 4-16: Canopy height model
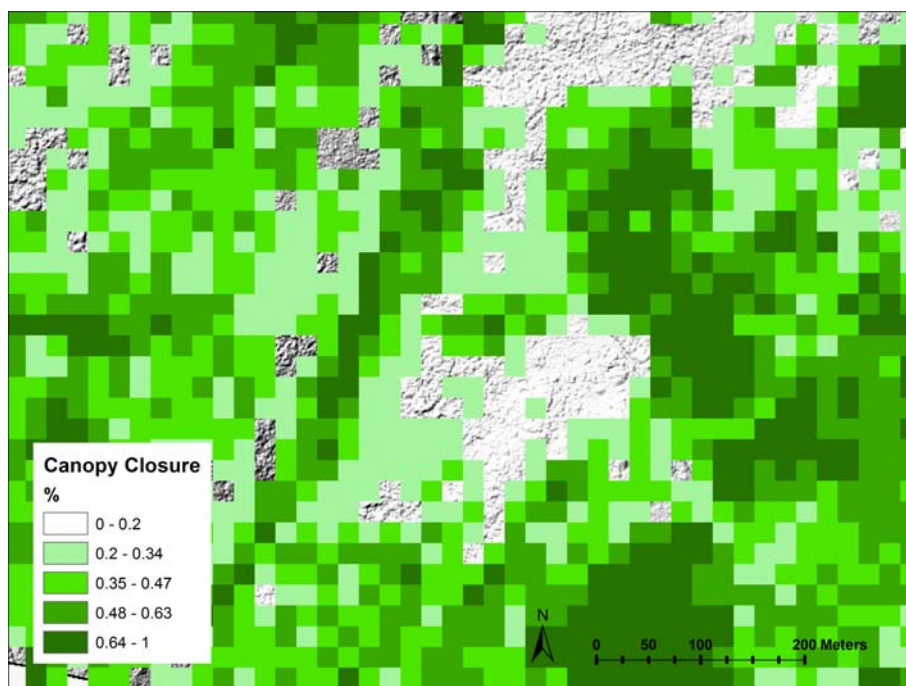
Figure 4-17: Canopy closure map

4.2.6. LiDAR model generation for the study area

From the pre-processed LiDAR, 24 features were calculated keeping the high-vegetation threshold in 5 meters and ground-returns threshold in 1 meter. The features are described in Table 4-12 and in detail by Junttila et al. (2010). They include different height percentiles for the first-pulse and last-pulse returns, mean height of first-pulse returns above 5 meters, standard deviation for first-pulse returns, ratio between first-pulse returns from below 1 meter and all first-pulse returns, ratio between last-pulse returns from below 1 meter and all last- pulse returns. All features were calculated to a total of 254 available field sample plots, 400sqm in area. Due to sometimes poor GNSS signal, the measured position was not available and was then estimated. If no GNSS measurements were available, the positions recorded with handheld -GPS device were used.

Table 4-12: LiDAR features

Feature nr	Explanation
1..10	Height of the 10%, 20%, 30% … 100% percentile for first pulse points.
11..20	Height of the 10%, 20%, 30% … 100% percentile for last pulse points.
27	Mean height of first pulse high vegetation points (points over highveg_threshold m).
28	Standard deviation of first pulse heights.
29	The ratio of the below vegetation first pulse points (points under ground_threshold m) and all first pulse points.
30	The ratio of the below vegetation last pulse points (points under ground_threshold m) and all last pulse points.

The only dependent variable estimated was above ground carbon (tons/ha). There is also a strong statistical correlation between above-ground and belowground carbon pool. For dead-wood carbon (tons/ha), litter carbon (tons/ha), non-tree carbon (tons/ha) and soil carbon (tons/ha) it is not meaningful to build a regression model from LiDAR data.

Modelling was started by applying a linear regression using all field sample plots. The variance through the whole dataset was though too large, producing a high level of error. Thus the plot dataset was divided to three categories according to vegetation types; dry zone, semideciduous and wet zones as shown. In further division for more precise vegetation zones the number of plots decreased too much for reliable analysis. It was noted that plots in closed forest separately gave a better response than an average model including all land use classes. Thus for zones dry and semideciduous, two models were applied; one for closed forest class and an average for remaining land use classes. The closed forest class was defined as equal to or more than 60 % canopy closure, calculated from LiDAR data. For wet evergreen zone in the South, a model applying all plots together worked better than separate model for closed forest. Thus the whole dataset was used to build an average model in this area.

From the three separate plot datasets, plots having measured height lower than 5 meters were removed based on definition of forest. A correlation analysis was performed between pool of 30 possible predictor LiDAR features and dependent variables. From these images, outliers were manually detected and then checked against LiDAR data and comments to find an explanation. The outliers are listed in Table 4-13. Predictor variables were manually selected based on which gave the highest correlation; these were LiDAR 90th percentile, mean height of vegetation first pulse returns, and ratio between first-pulse returns from below 1 meter and all first-pulse returns. The leave-one-out cross-validation described by Kangas and Maltamo (2006) was applied to models for verification.

Table 4-13: Outliers removed from LiDAR models

ID	Justification
155	Difference between LiDAR -and field measured height over 30 meters.
156	Difference between LiDAR -and field measured height over 30 meters.
199	Difference between LiDAR -and field measured height over 30 meters.
128	Difference between LiDAR -and field measured height over 30 meters.
304	Difference between LiDAR -and field measured height over 30 meters.
333	Difference between LiDAR -and field measured height over 30 meters.
334	Difference between LiDAR -and field measured height over 30 meters.

132	Only handheld GPS measurements available.
312	Only handheld GPS measurements available.
319	Only handheld GPS measurements available.
338	Only handheld GPS measurements available.

4.2.7. LiDAR modelling

The validation results for selected regression models showed high RMSEs at the field-plot level, ranging from 62 % for AGC in wet evergreen zone up to 89% for moist-semideciduous zone (Table 4-14, Table 4-15; Selected independent variables: Mean height of first pulse high vegetation points (points over 5 m);Table 4-16, Table 4-15). No significant bias was present. Below-ground carbon estimation showed more error, especially in Moist-semideciduous zone, but performed well in model for closed forest. Model summaries for above-ground carbon and below-ground carbon are given in following tables, separately for each zone and for class closed forest.

Table 4-14: LiDAR model summary for dry forest zone (applies to open forest and croplands)

Variable	Mean of estimates	Standard deviation of estimates	Mean of reference plots	Standard deviation of reference plots	RMSE	Relative RMSE (%)	Bias	Relative bias (%)
Validation against original plots (400 m² plot size)								
Total above-ground carbon (t/ha)	13.02	10.03	12.9	14.6	10.7	0.82	-0.1	-0.00

Selected independent variables: Standard deviation of first pulse heights.

Table 4-15: LiDAR model summary for wet evergreen forest zone

Variable	Mean of estimates	Standard deviation of estimates	Mean of reference plots	Standard deviation of reference plots	RMSE	Relative RMSE (%)	Bias	Relative bias (%)
Validation against original plots (400 m² plot size)								
Total above-ground carbon (t/ha)	90.5	85.12	91.2	99.3	57.0	0.62	0.67	0.00

Selected independent variables: Mean height of first pulse high vegetation points (points over 5m).

Table 4-16: LiDAR model summary for semideciduous forest zone (applies to open forest and croplands)

Variable	Mean of estimates	Standard deviation of estimates	Mean of reference plots	Standard deviation of reference plots	RMSE	Relative RMSE (%)	Bias	Relative bias (%)
Validation against original plots (400 m² plot size)								
Total above-ground carbon (t/ha)	41.6	27.8	41.5	45.8	37.1	0.89	-0.06	-0.00

Selected independent variables: Mean height of first pulse high vegetation points (points over 5 m).

Table 4-17: LiDAR model summary for closed forest applied in all ecological zones

Variable	Mean of estimates	Standard deviation of estimates	Mean of reference plots	Standard deviation of reference plots	RMSE	Relative RMSE (%)	Bias	Relative bias (%)
Validation against original plots (400 m² plot size)								
Total above-ground carbon (t/ha)	91.65	76.0	91.6	97.0	62.63	0.68	-0.01	-0.00

Selected independent variables: Height of the 90% percentile for first pulse points, height of the 90% percentile for last pulse points, mean height of first pulse high vegetation points (points over 5 m), standard deviation of first pulse heights.

4.2.8. Outputs

The task 15 outputs are listed in Table 4-18.

Table 4-18: Outputs of Task 15

NO.	Item	Type	Where to Find
1	LiDAR derived forest height data and canopy closure data	Raster .tiff 32 bit	GIS Server @RMSC/ External HDD
2	Regression equations between the field sample data	Model configuration .xml file + Document	This report GIS Server @ RMSC/ External HDD

4.2.9. Conclusion

The applied LiDAR-assisted inventory approach for carbon stock assessments relied on the 5 % LiDAR transect sample. Implementation of a LiDAR-based modelling approach helps to reduce field sampling intensity, once the approach allows generation of numerous extra biomass sample plots called as surrogate sample plots with help of regression models relying on LiDAR metrics for different broad forest types (strata). LiDAR data provides a prior information basis for objective and efficient field plot sampling.

Once forests are with high canopy closure and dense ground vegetation layer only a few observations penetrate to actual ground level, and the hits from lower branches are easily interpreted as ground returns in classification procedure. The classification correction procedure was applied to remove this effect in estimation. Accurate LiDAR derived forest height data and canopy closure data was delivered as the outputs of the task 15.

4.3. Task 16: Undertake Carbon Inventory for the Total National Forest Resource Area

4.3.1. Technical approach

The look-up table values developed in Task 14 have been extrapolated to derive raster maps for 6 carbon pools and total terrestrial carbon density over Ghana (Figure 4-18, 4-19 4-20, 4-21, 4-22, 4-23, 4-24). The country is stratified based on 9 ecological zones and 4 land use categories, namely closed forest, open forest, cropland and other land uses. The other land use category was applied, because there is not a representative number of a plot sample for the remaining land uses on all the ecological zones. The reference values for all the 6 pools were computed as a weighted mean of grassland and settlement lookup table values with the following equation

$$\bar{x} = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i},$$

where $\underline{x}_i$ are plot measurement derived carbon density values and ω_i are weights. The proportions between the land uses (grassland and settlement) with collected plot data in the pilot area were applied as weights.

Above ground t(CO2)/ha

☐	0 - 1	▨	14.1 - 25
☐	1.1 - 4	▨	25.1 - 35
☐	4.1 - 8	▨	35.1 - 75
▨	8.1 - 10	■	75.1 - 250
▨	10.1 - 14	■	250.1 - 510
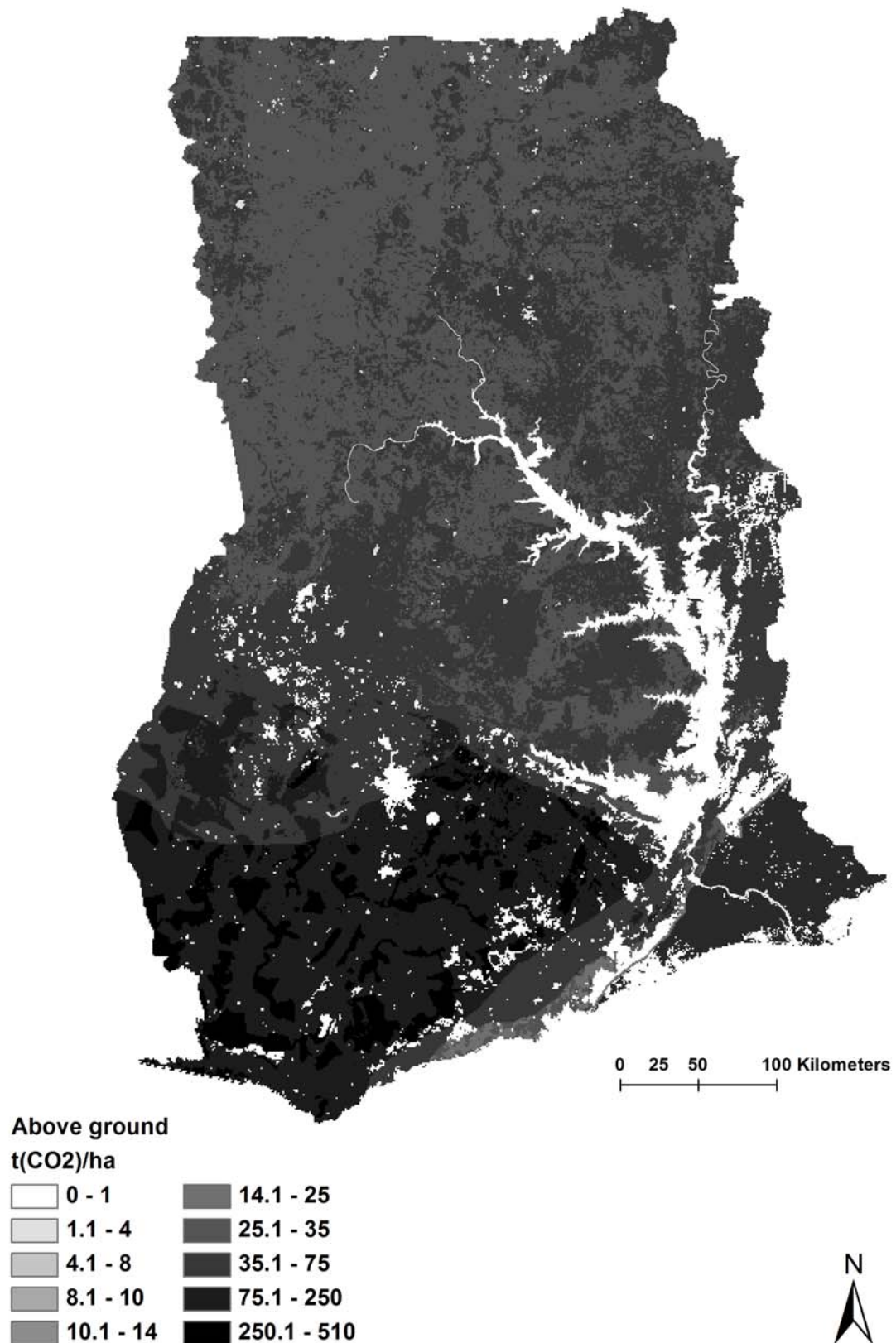
Figure 4-18: Aboveground carbon density map

Below ground

t(CO2)/ha

☐ 0 - 1	
☐ 2 - 4	■ 21 - 30
☐ 5 - 8	■ 41 - 50
☐ 9 - 10	■ 51 - 70
■ 11 - 20	■ 71 - 90
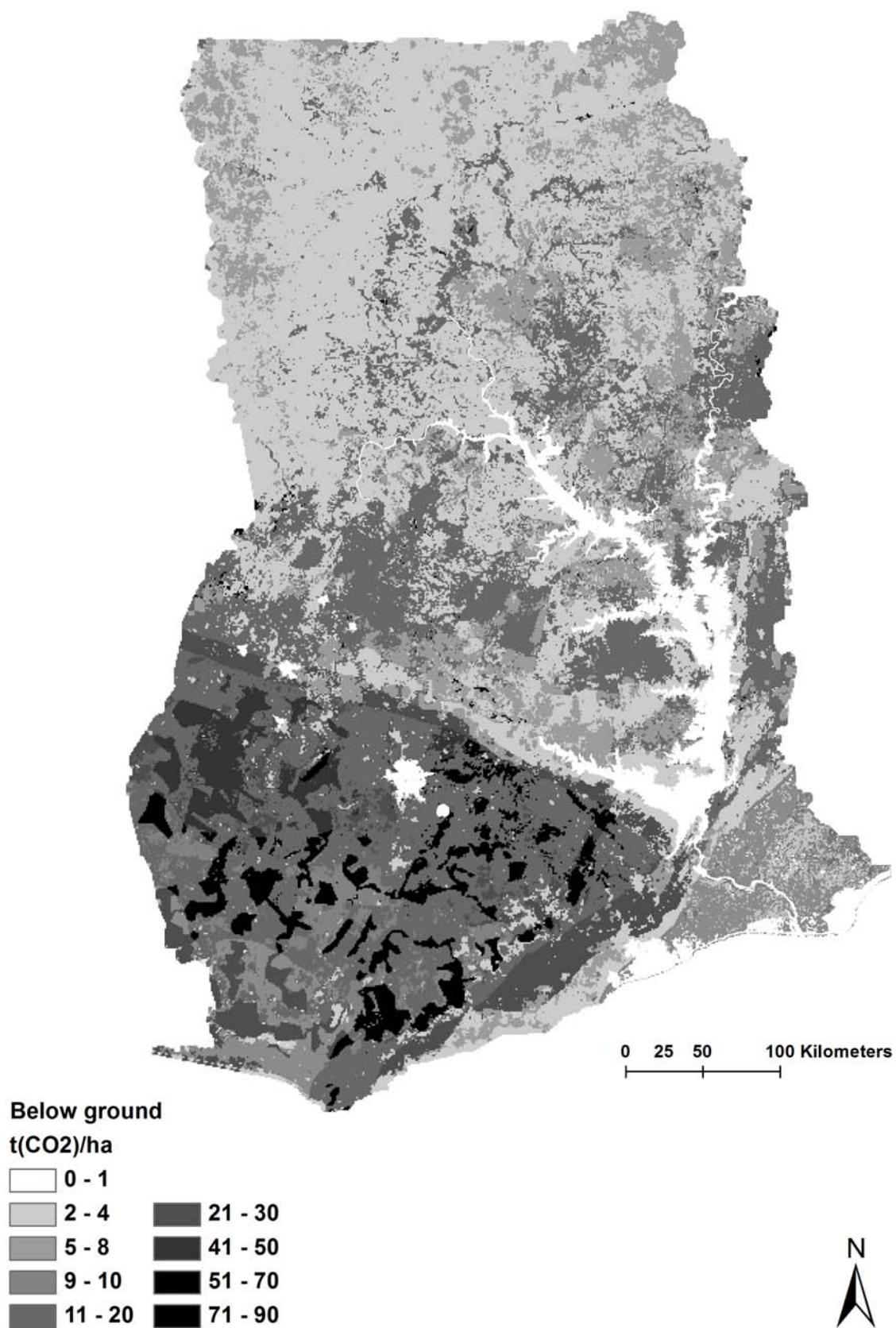
Figure 4-19: Belowground carbon density map

Figure 4-20: Deadwood carbon density map
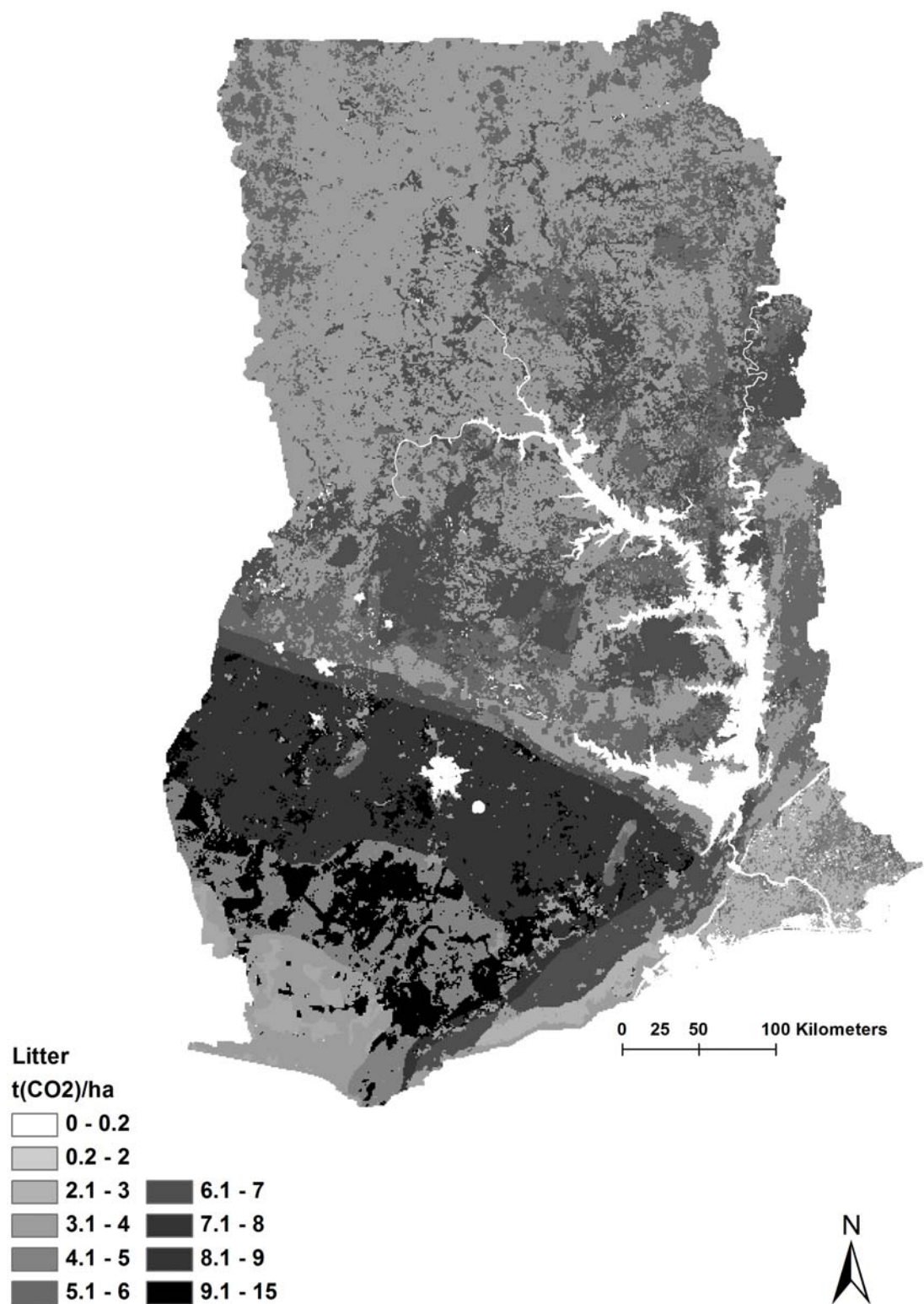
Figure 4-21: Litter carbon density map

Non-tree

t(CO2)/ha

☐ 0 - 0.6	
▨ 0.6 - 1	▨ 4.1 - 5
▨ 1.1 - 3	▨ 5.1 - 6
▨ 3.1 - 4	■ 6.1 - 8
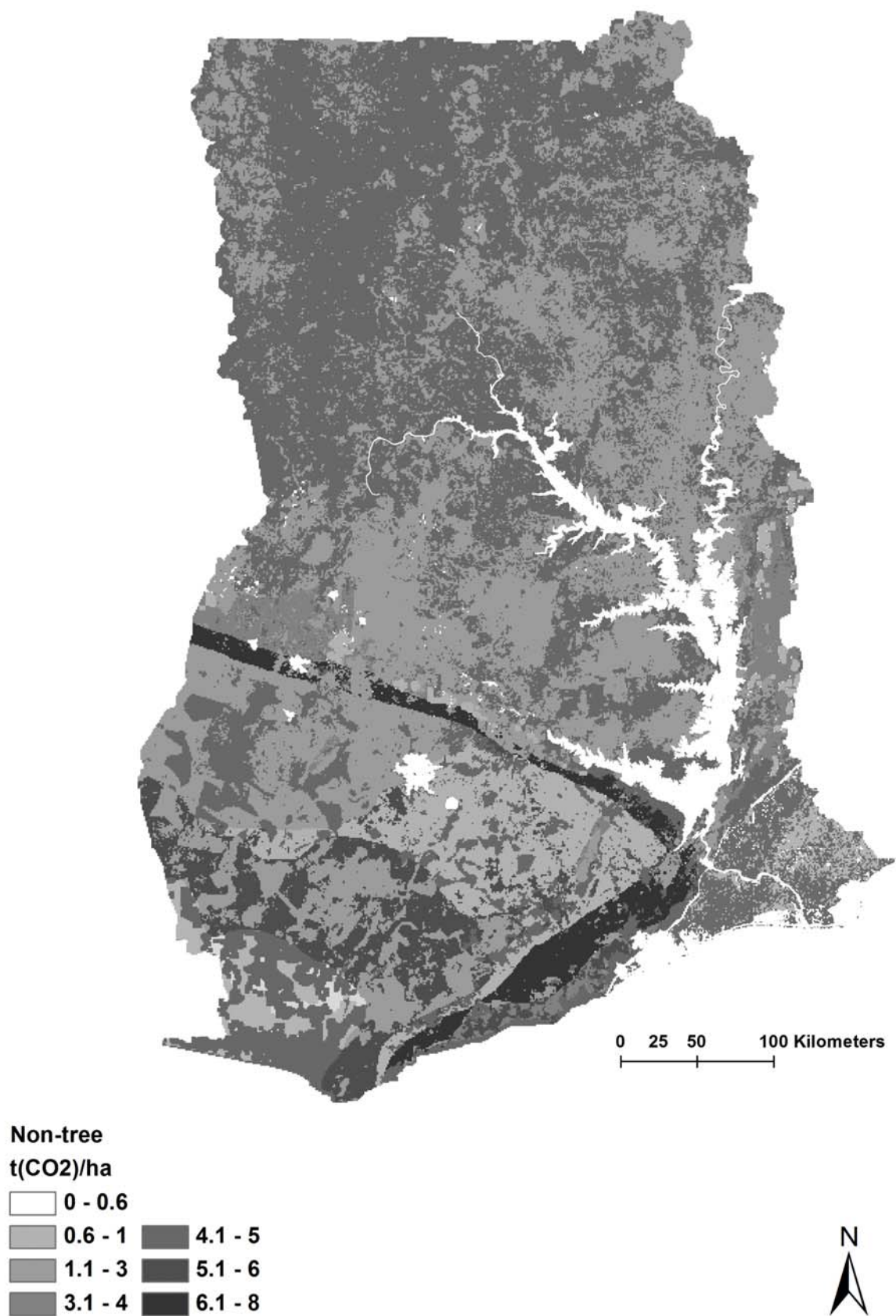
Figure 4-22: Non-tree carbon density map

Soil

t(CO2)/ha

▢ 0 - 1	
▢ 1.1 - 150	
▢ 150.1 - 180	▨ 250.1 - 280
▨ 180.1 - 200	■ 280.1 - 300
▨ 200.1 - 220	■ 300.1 - 350
▨ 220.1 - 250	■ 350.1 - 480
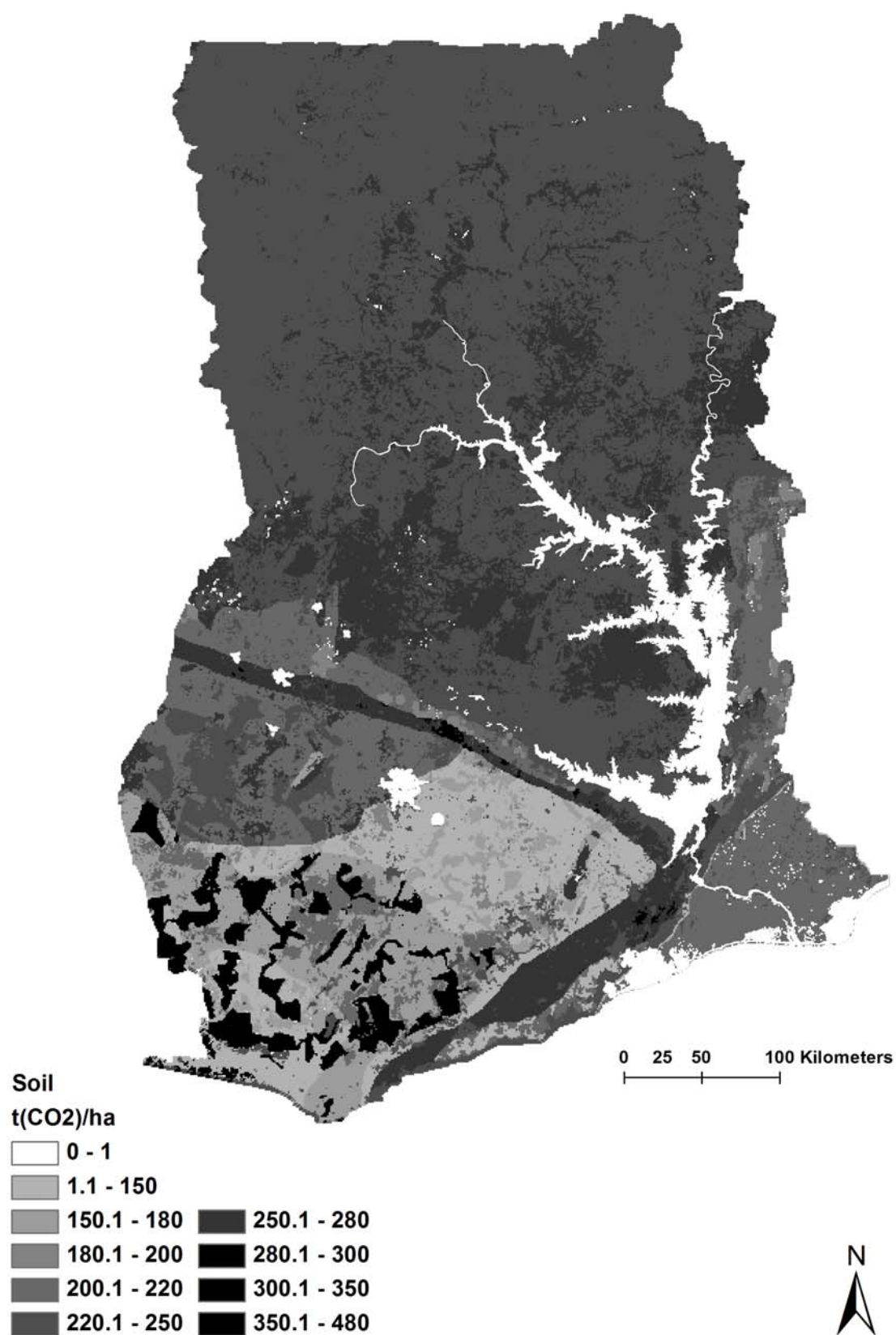
Figure 4-23: Soil carbon density map

Total
t(CO2)/ha

- 0 - 1
- 1.1 - 200
- 200.1 - 300
- 300.1 - 400
- 400.1 - 500
- 500.1 - 600
- 600.1 - 700
- 700.1 - 800
- 800.1 - 900
- >1600
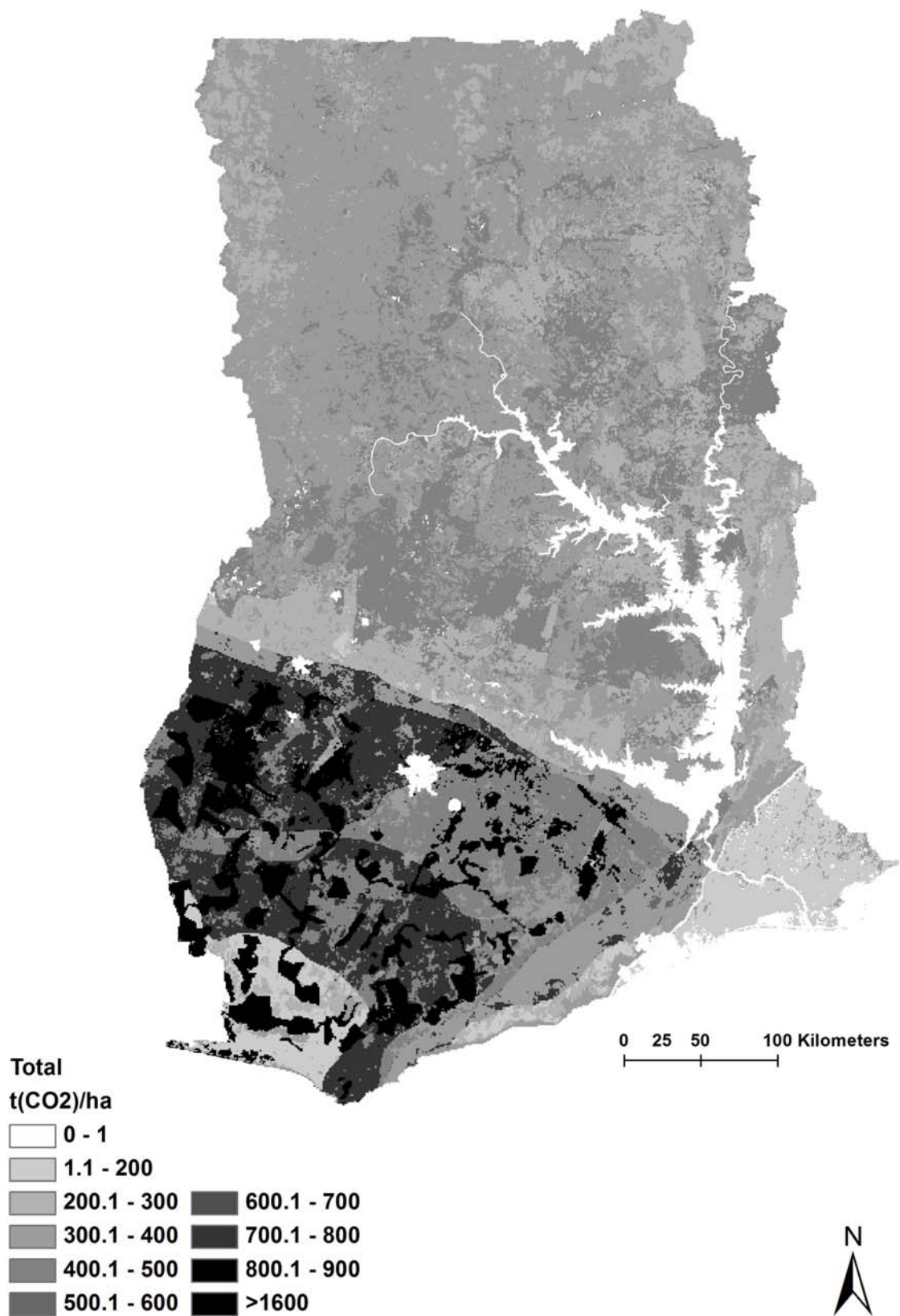
Figure 4-24: Total carbon density map (6 pools)

4.3.2. Comparison with biomass map of Ghana (2008/2009)

When Ghana joined the REDD+ Readiness process in 2009, the country was lacking sufficient data on biomass at national, regional or district levels. In an effort to fill this gap, the Ghana Carbon Map Project was initiated in December 2009, as a joint initiative of the NCRC, the Katoomba Group's West Africa Incubator for Ecosystem Services, Oxford University, and FCG. Technical support and guidance was provided by the JPL, NASA, and specific biomass data was openly contributed by multiple scientists, research institutions, government agencies, and students of national and international affiliation. Specifically, the project aimed to create the first national biomass map of Ghana in an effort to determine biomass ranges and distribution across the country (Asare et al. 2012).

Ghana's carbon map was built through two parallel work-streams that were eventually merged to produce the final map. The first process focused on generating a draft national biomass map, based upon the layering of multiple types of remote sensing imagery and data (Figure 4-25).
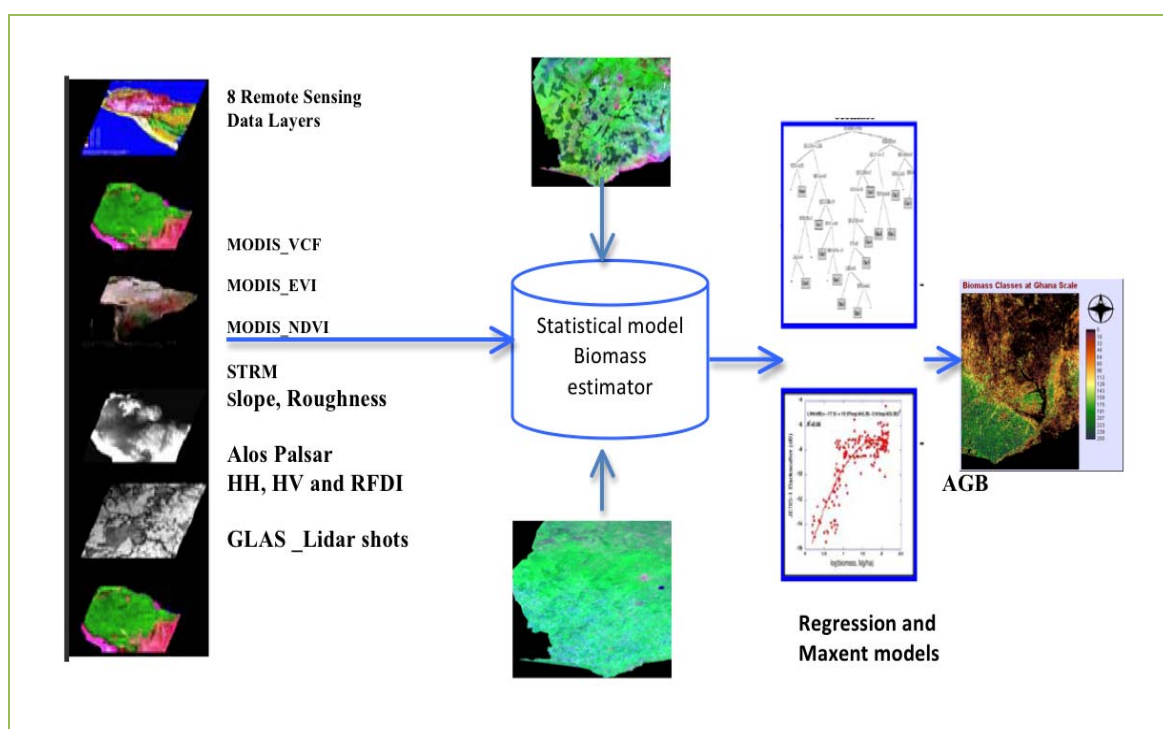
Figure 4-25: Integrative approach to map biomass distribution at 250 m resolution

Concurrent with the mapping work, a dataset was assembled of existing sampled biomass carbon stock datasets from across the country, and then supplemented by targeted field sampling of biomass (1-hectare plots) to fill remaining gaps in terms of underrepresented land use types and geographic regions. The draft biomass map was then calibrated using the sampled biomass carbon stock dataset and a maximum entropy analysis was conducted to produce a final version of the map. The final map shows above-ground carbon at 250m resolution (Figure 4-26).
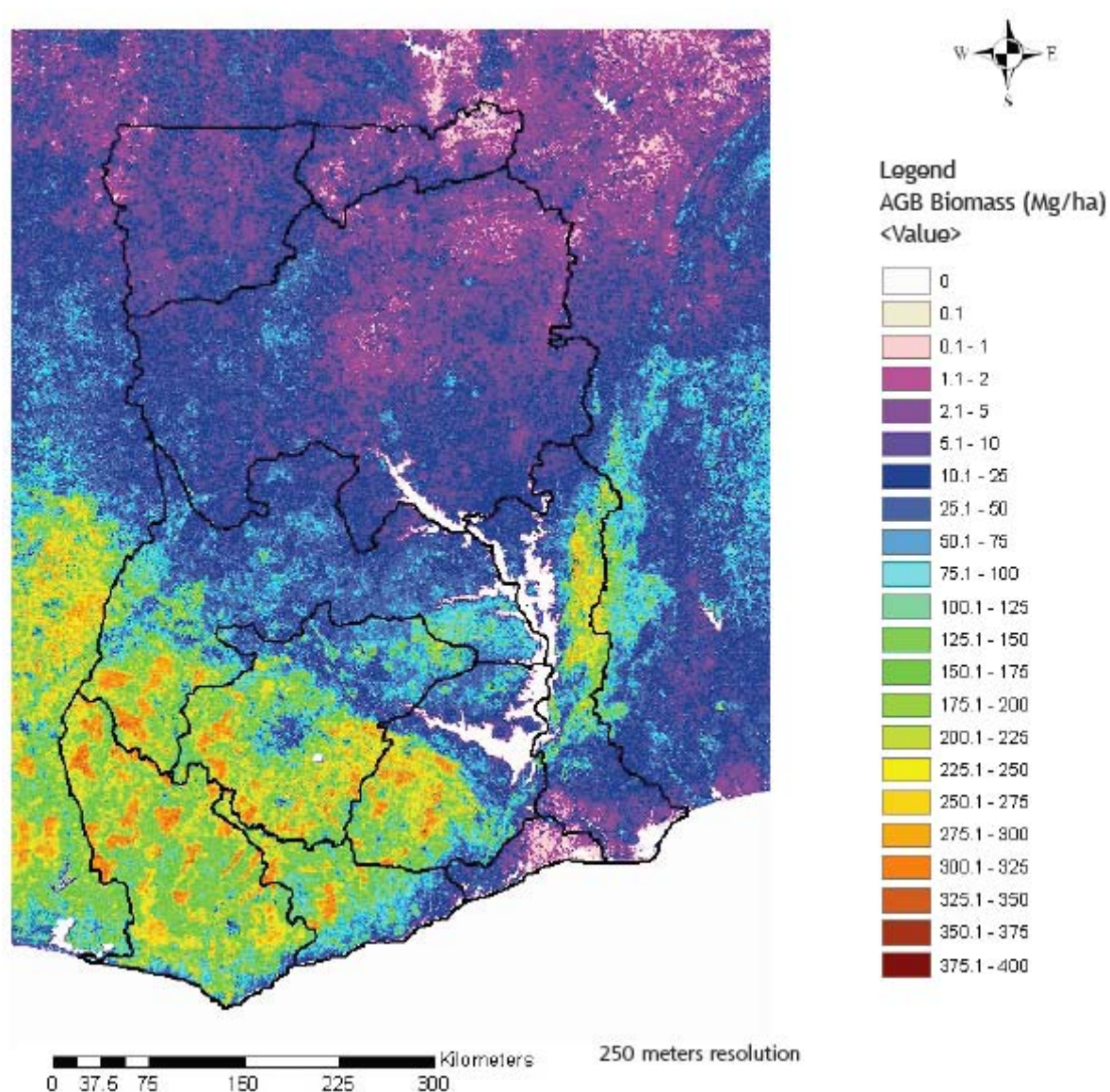
Figure 4-26: The Biomass Map of Ghana (2008/2009) showing biomass figures in tons/ha (Asare et al. 2012)

The Biomass Map of Ghana (2008/2009) was validated against LiDAR-based above-ground biomass estimates. The information on land use and ecological zone was extracted for each cell using the majority to define the strata of a cell. For each 250 m x 250 m cell, the pixel value of the biomass map was extracted as well as the mean value of the LiDAR-based biomass estimates with a resolution of 20 meters x 20 meters. The cells with LiDAR coverage higher than 75 per cents were included in the assessment.

Accuracy analysis was carried out by strata. All cells belonging to a stratum were considered for the assessment of this particular stratum. Both biomass values (biomass map values versus LiDAR-based estimates) were compared for each cell, and validation statistics were calculated. If there are less than 30 cells in a stratum, validation results have not been calculated for that stratum.

When comparing the overall pixel-level (250 m x 250 m) statistics between the biomass mean values of the Biomass Map of Ghana (2008/2009) and the aggregated LiDAR-based estimates (reference), the Biomass Map values are remarkable overestimated for forestland and croplands. As an exception, the mean biomass pixel values of these two maps are converging for closed forests of the wet evergreen (difference of 9.8 %), moist evergreen (difference of 1.6 %) and Moist Semi-deciduous SE (difference of 8.9 %) zones. The Biomass Map authors have identified the risk for bias as a potential issue, as well, and recognised the need for correction of this bias. The observed bias may be associated to some extent with the sample design, field data quality and applied aboveground biomass models, but a more detailed methodological description and used field plot data needs to be analysed to conclude the primary source of the bias.

4.3.3. National plot-based sampling intensity

The plot data collected from the pilot area was used to estimate the required number of plots, in case of the national-level plot-based C-stock assessment approach for all 6 forest carbon pools. The following formula was applied

$$n = \frac{(N \times s)^2}{\dfrac{N^2 \times E^2}{t^2} + N \times s^2}$$

where E is allowable error of the carbon stock (MgCO2-e/hectare), t is the sample statistic from the t-distribution for 95 per the cent confidence level (2 in this case), N is the number of sample units in the population (number of plot-sized units), and s is a standard deviation estimate of the stratum (MgCO2-e/hectare). The estimated plot-based sampling intensities are discovered to meet the desired precision at national level in forestland, cropland and grassland (Table 4-19). Up to 6000 plots (20 x 20 meter) are needed to achieve 10-% precision for plot-based above-ground, belowground, litter and non-tree, carbon assessment in forestland at the national level. The required number plots for the same precision of soil carbon is about one fifth of that amount and a five times higher figure to estimate deadwood carbon with the same precision. A bit lower plot number of plots is likely needed to estimate aboveground (3800), belowground (< 2100), litter (< 1600), non-tree carbon (< 3300) and soil (< 270) carbon stock in croplands. A remarkably higher number of plots would be required for deadwood carbon stock assessment.

Table 4-19: Estimated plot-based sampling intensities to meet the desired precision at national level in forest land, cropland and grassland

Aboveground Carbon	Wet			Moist					Dry		
Desired precision (%)	Closed Forest	Open Forest	Cropland	Closed Forest	Open Forest	Cropland	Grassland	Settlement	Closed Forest	Open Forest	Cropland
10	296	68	63	261	701	1372	-	-	-	343	298
15	132	30	28	116	312	610	-	-	-	152	132
20	74	17	16	65	175	343	-	-	-	86	74
25	47	11	10	42	112	220	-	-	-	55	48
30	33	8	7	29	78	152	-	-	-	38	33

	Sothern Margin				Mangrove	Upland Evergen			TOTAL		
Desired precision (%)	Closed Forest	Open Forest	Cropland	Grassland		Closed Forest	Open Forest	Cropland	Closed Forest	Open Forest	Cropland
10	68	74	-	77	106	659	626	203	1284	1812	1935
15	30	33	-	34	47	293	279	90	571	806	860
20	17	19	-	19	27	165	157	51	321	453	484
25	11	12	-	12	17	106	100	33	206	290	310
30	8	8	-	9	12	73	70	23	143	202	215

Belowground Carbon	Wet			Moist					Dry		
Desired precision (%)	Closed Forest	Open Forest	Cropland	Closed Forest	Open Forest	Cropland	Grassland	Settlement	Closed Forest	Open Forest	Cropland
10	242	83	70	57	168	133	-	-	-	379	248
15	107	37	31	25	75	59	-	-	-	168	110
20	60	21	17	14	42	33	-	-	-	95	62

25	39	13	11	9	27	21	-	-	-	61	40
30	27	9	8	6	19	15	-	-	-	42	28

	Sothern Margin			Mangrove	Upland Evergen			TOTAL		
Desired precision (%)	Closed Forest	Open Forest	Cropland	Grassland		Closed Forest	Open Forest	Cropland	Closed Forest	Open Forest	Cropland
10	5	1122	-	1030	73	14	81	579	317	1832	1030
15	2	499	-	458	33	6	36	257	141	814	458
20	1	281	-	258	18	4	20	145	79	458	258
25	1	180	-	165	12	2	13	93	51	293	165
30	1	125	-	115	8	2	9	64	35	204	115

Deadwood Carbon	Wet			Moist					Dry		
Desired precision (%)	Closed Forest	Open Forest	Cropland	Closed Forest	Open Forest	Cropland	Grassland	Settlement	Closed Forest	Open Forest	Cropland
10	1464	206	434	1661	5050	3150	-	-	-	1455	16095
15	651	92	193	738	2244	1400	-	-	-	647	7158
20	366	52	108	415	1263	788	-	-	-	364	4027
25	234	33	69	266	808	504	-	-	-	233	2578
30	163	23	48	185	561	350	-	-	-	162	1790

	Sothern Margin			Mangrove	Upland Evergen			TOTAL		
Desired precision (%)	Closed Forest	Open Forest	Cropland	Grassland		Closed Forest	Open Forest	Cropland	Closed Forest	Open Forest	Cropland
10	155	1009	-	849	-	4015	465	799	7296	8185	20478
15	69	449	-	377	-	1793	207	355	3251	3638	9106
20	39	252	-	212	-	1010	117	200	1830	2047	5123
25	25	162	-	136	-	647	75	128	1172	1310	3279
30	17	112	-	94	-	449	52	89	814	910	2277

Litter Carbon	Wet			Moist					Dry		
Desired precision (%)	Closed Forest	Open Forest	Cropland	Closed Forest	Open Forest	Cropland	Grassland	Settlement	Closed Forest	Open Forest	Cropland
10	280	943	81	188	277	186	-	-	-	130	188
15	124	419	36	84	123	83	-	-	-	58	83
20	70	236	20	47	69	47	-	-	-	32	47
25	45	151	13	30	44	30	-	-	-	21	30
30	31	105	9	21	31	21	-	-	-	14	21

	Sothern Margin			Mangrove	Upland Evergen			TOTAL		
Desired precision (%)	Closed Forest	Open Forest	Cropland	Grassland		Closed Forest	Open Forest	Cropland	Closed Forest	Open Forest	Cropland
10	95	62	-	281	-	158	150	355	721	1562	809

15	42	27	-	125	-	70	67	158	320	694	360
20	24	15	-	70	-	39	38	89	180	391	202
25	15	10	-	45	-	25	24	57	115	250	130
30	11	7	-	31	-	18	17	39	80	174	90

Nontree Carbon	Wet			Moist					Dry		
Desired precision (%)	Closed Forest	Open Forest	Cropland	Closed Forest	Open Forest	Cropland	Grassland	Settlement	Closed Forest	Open Forest	Cropland
10	393	300	196	214	548	568	-	-	-	399	374
15	175	133	87	95	243	252	-	-	-	177	166
20	98	75	49	53	137	142	-	-	-	100	93
25	63	48	31	34	88	91	-	-	-	64	60
30	44	33	22	24	61	63	-	-	-	44	42

	Sothern Margin			Mangrove	Upland Evergen			TOTAL		
Desired precision (%)	Closed Forest	Open Forest	Cropland	Grassland	Closed Forest	Open Forest	Cropland	Closed Forest	Open Forest	Cropland
10	75	237	-	24	-	173	326	512	855	1810	1649
15	33	105	-	11	-	77	145	227	380	804	733
20	19	59	-	6	-	43	82	128	214	452	412
25	12	38	-	4	-	28	52	82	137	290	264
30	8	26	-	3	-	19	36	57	95	201	183

Soil Carbon	Wet			Moist					Dry		
Desired precision (%)	Closed Forest	Open Forest	Cropland	Closed Forest	Open Forest	Cropland	Grassland	Settlement	Closed Forest	Open Forest	Cropland
10	59	36	92	63	69	23	-	-	-	24	19
15	26	16	41	28	31	10	-	-	-	11	9
20	15	9	23	16	17	6	-	-	-	6	5
25	9	6	15	10	11	4	-	-	-	4	3
30	7	4	10	7	8	3	-	-	-	3	2

	Sothern Margin			Mangrove	Upland Evergen			TOTAL		
Desired precision (%)	Closed Forest	Open Forest	Cropland	Grassland	Closed Forest	Open Forest	Cropland	Closed Forest	Open Forest	Cropland
10	42	66	-	192	39	213	52	1	377	246	135
15	19	29	-	85	17	95	23	0	168	109	60
20	11	16	-	48	10	53	13	0	94	61	34
25	7	10	-	31	6	34	8	0	60	39	22
30	5	7	-	21	4	24	6	0	42	27	15

4.3.4. Outputs

The task 16 outputs are listed in Table 4-20.

Table 4-20: Outputs of Task 16

NO.	Item	Type	Where to Find
1	GIS dataset of the forest resource baseline with attributions for total carbon (tCO$_2$)/ha and the carbon components	Data	GIS Server @RMSC/ External HDD
2	A procedure manual and any software tools for converting from the biomass lookup tables and regression equations to carbon stocks	Document	This report Manual 5-4

4.3.5. Conclusion

The national carbon density map in raster format for 6 pools and total carbon have been produced based on the look-up table values generated in Task 14 and the ecozone/land use stratification. Nationwide field sample data needs to be collected for assessing validity of the look-up table C-stock mean values generated in the pilot area inventory.

5. Capacity Building

5.1. Task 17: Installation of GIS Software for Forest Resource Management, Image Processing Software for Remotely Sensed Data Together With Hardware and Peripherals

5.1.1. Procured Equipment

All required Hardware such as servers, workstations, printers etc, and software such as ArcGIS and ERDAS software that had been identified in Task 5 were procured. Detailed List of Hardware and Software are mentioned in Table 5-1 and Table 5-2.

Table 5-1: List of Hardware & Non-GIS Software

Item No.	Item Description	Quantity			
		Accra	Kumasi	Regional & District Office	Total
1	WorkStation used for Digital Photogrammetric, GIS and Mapping Workstation (and for Digital Editing)	0	8	8	16
2	Fire wall	0	1	0	1
3	Router	0	1	0	1
4	Switch Hub	0	1	0	1
5	GIS Server	0	1	0	1
6	Database Server	0	1	0	1
7	Web Server	0	1	0	1
8	KVM Switch	0	1	0	1
9	Display	0	1	0	1
10	Backup External Hard disk	0	8	8	16
11	DLT (Digital Linear Tape) Device	0	1	0	1
12	Plotter	0	1	0	1
13	Uninterruptible Power Supply (UPS)	0	3	0	3
14	Digital Camera with GPS	0	4	0	4
15	Projector	1	1	0	2
16	Notebook computer	1	4	0	5
17	Video Camera	0	4	0	4
24	Software used for GPS analysis	0	1	0	1

		Accra	Kumasi	Regional & District Office	Total
29	Software for Map symbolization (Adobe Illustrator (Latest version))	1	0	0	1
30	Image Editing Software (Adobe Photoshop (Latest version)(Creative Suite)	1	0	0	1
31	WorkStation used for Digital Photogrammetric (and for Digital Editing)	1	0	0	1
32	Personal Computer used for GIS and Map Symbolization (and Digital Editing)	1	0	0	1
33	External Hard disk for Workstation	1	0	0	1
34	Printer	1	0	0	1
35	Larger format printer & Scanner	0	1	0	1
36	Uninterruptible Power Supply (UPS)	2	0	0	2

Table 5-2: List of GIS Software

Item No.	Item Description	Quantity			
		Accra	Kumasi	Regional & District Office	Total
18	Software for Web Based GIS (ArcGIS10ServerBasicEnterprise)	0	1	0	1
19	Software for GIS (ArcGISDesktop10(ArcEditor))	0	2	0	2
20	Software for GIS (ArcGISDesktop10(ArcView)) + Spacial & 3D	0	4	8	12
21	Software for GIS (ArcView + Spacial & 3D new floating license)	5	0	0	5
28	Software for GIS (ArcGIS Desktop) (ArcInfo latest version) + 3 extensions	1	0	0	1
22	Software for SAR Imaging (ERDASRadarMappingSuite2011)	0	1	0	1
23	Image processing software (ERDASIMAGINE2011-Professional)	0	4	0	4
25	Software for Aerial triangulation and Mapping (LPS CORE)	1	0	0	1
26	Software for Mapping (Micro station latest version)	1	0	0	1
27	Stereoscopic monitor (3D) (Planar SD2620W) + TopoMouse	1	0	0	1

Note: Item Number 21 Installation Arrangements 3 CERGIS and 2 FCG

5.1.2. Forest Inventory System Overview
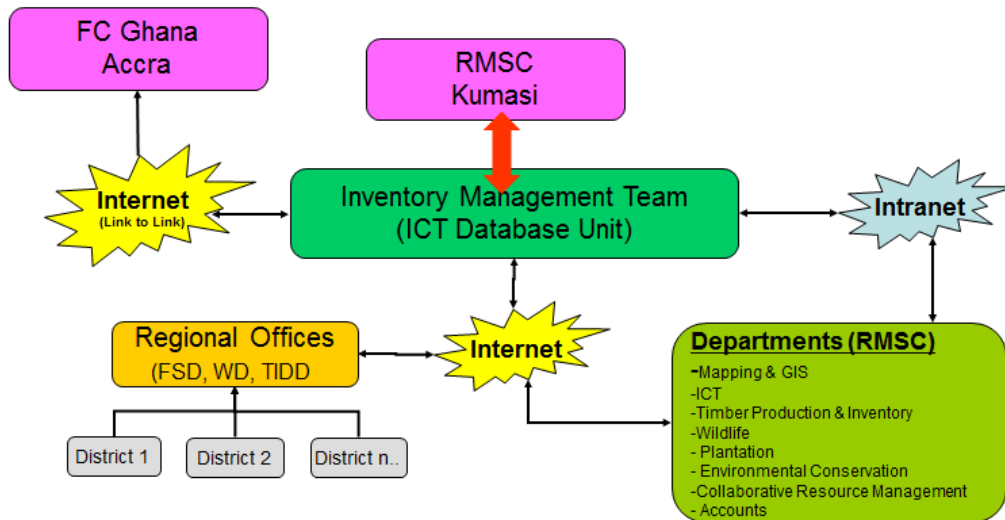
Figure 5-1: Forest Inventory System Connectivity Model

Figure 5-1 shows the Forest Inventory System Connectivity model. The GIS database will be residing inside Resource Management Support Center (RMSC) ICT Server room and other departments of Forestry commission will be accessing the data through Intranet. Departments which are far by distance are also be connected through secure high speed virtual private network (VPN). The overall forest inventory system is described in Figure 5-2.
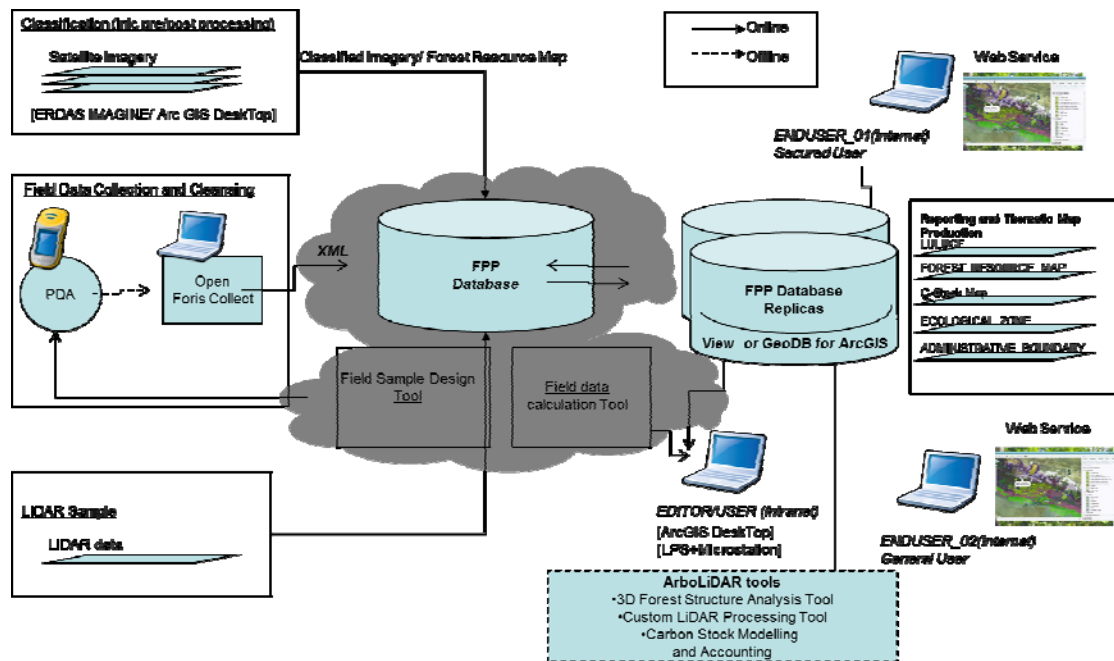
Figure 5-2: Forest Inventory System Overview

5.1.3. Set-up and Installation

5.1.3.1.   Set-up

All Hardware/Software were installed in the designated place/ office in either in Accra or Kumasi, which are mentioned in Table 5-1 and Table 5-2. Hardware and software installation manuals (Manual 7- System Administrators Manual – Hardware/Software Installation Manual) were prepared and handed over to FC Ghana.

5.1.3.2.   Server Framework

Server connectivity for Forest Inventory System of Forest Preservation Programme is illustrated in Figure 5-3.
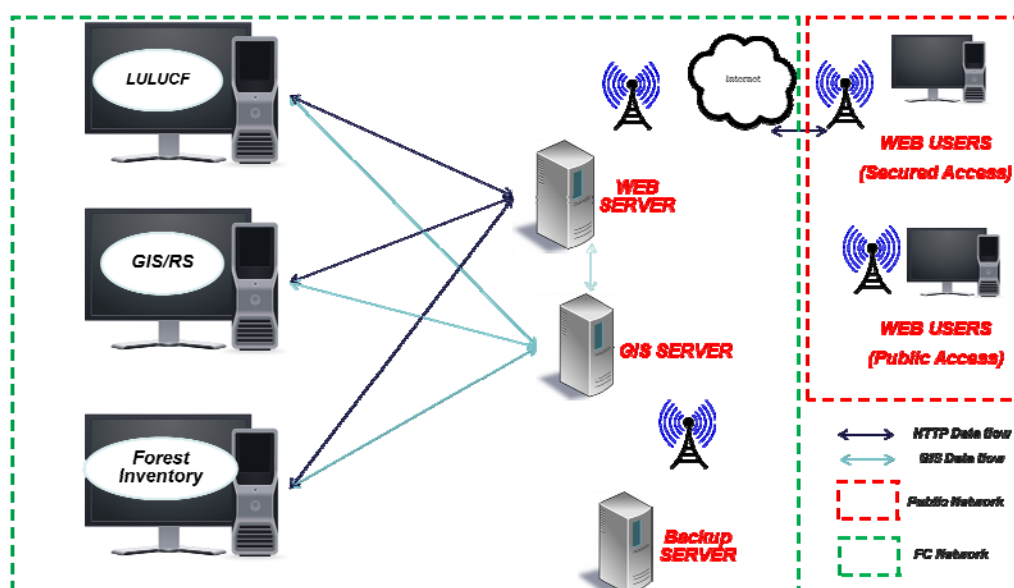
Figure 5-3: Server connectivity Framework

Figure 5-3 shows the schematic representation of the servers' locations and their connectivity within FC Ghana for Forestry Preservation Programme (FPP).

5.1.3.3.   GIS Server

Resource Management Support Centre (RMSC) hosts the main Database/GIS server which has all the GIS data, Forest Inventory data and spatial database. The schematic representation of GIS Server is shown in Figure 5-4.
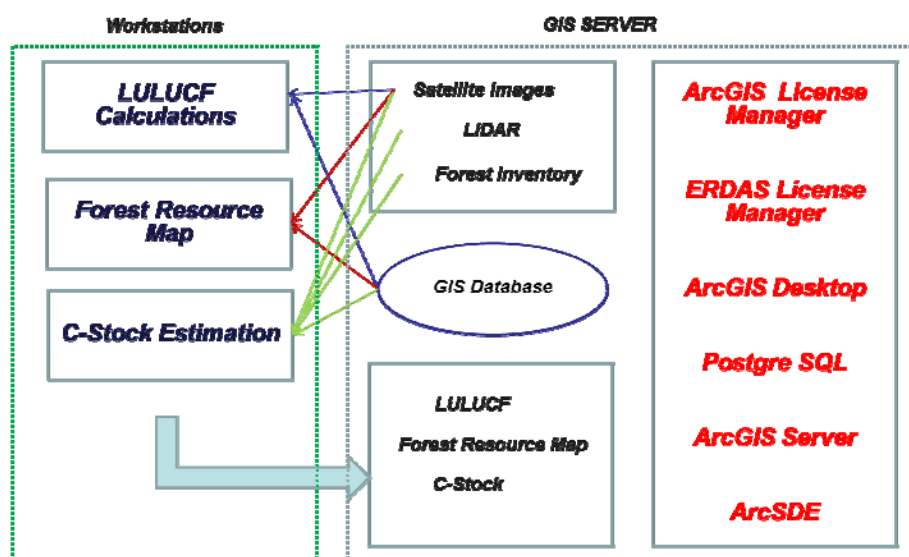
Figure 5-4: Schematic representation of GIS Server

GIS server has (i) RAW Data like satellite image, LiDAR and also Field Plot data (ii) Result Data which are processed using different processing tools for each data. (iii) Software for processing and also license for workstations. The data flow shows in Figure 5-4 that data are read by workstations for processing and then the results are transferred back to server.

5.1.3.4.   Web Server

The Web server has spatial data being served to the public or within FCG for data sharing through web browsers. It also hosts the website for FPP related activities. The customized software for FPP is hosted on this web server which can be accessed through the web address http://www.fcforestinfo.gov.gh.
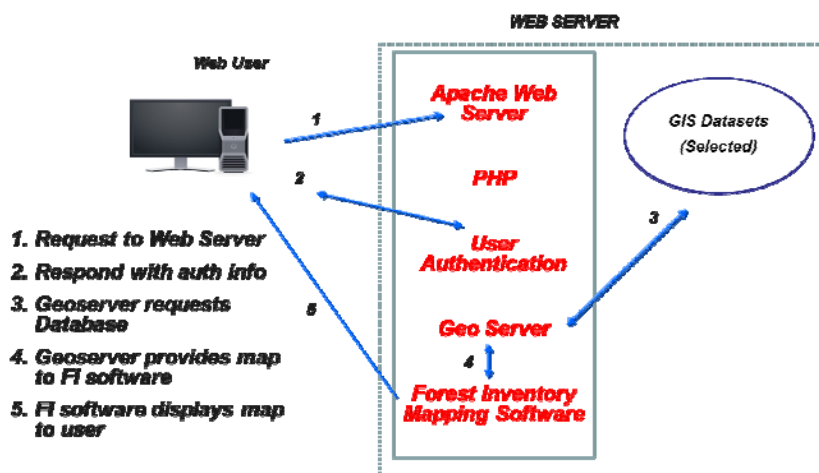
Figure 5-5: Web Server data flow

The data flow for the Web server is shown in Figure 5-5. Web Server hosts the website on Apache HTTP Web Server which comes as part of BitNami WAPP Stack server.

The data flow starts with the user entering the web address on the browser then, ii) The Apache HTTP Server will ask for user authentication (Optional for certain pages only or else skips to step 4), iii) User enters the credentials and then the server verifies it, iv) Page requests maps from GeoServer and internally prepares the map for display from GIS Data hosted on GeoServer v) Forest inventory software then displays the map to user on the web browser.

Using the Web server and WebGIS portal has been created for publishing the data and information. The forest inventory user manual (Manual 8) for FCG user and general public user, can guide the user to browse the data. The portal is also used for data sharing with stakeholders through data clearing house (Manual 7, attachment 7-1) managed by the system administrator.

5.1.3.5.   Backup Server

The Backup Server has been placed in Accra which is a replica of the Database/GIS server. The backup policy is devised by the Forestry Commission ICT and the backup

will be done regularly by ICT according to the backup schedule. Minimum requirement of Backup is complete backup every month and incremental backup every week and archival of at least 2 years data.
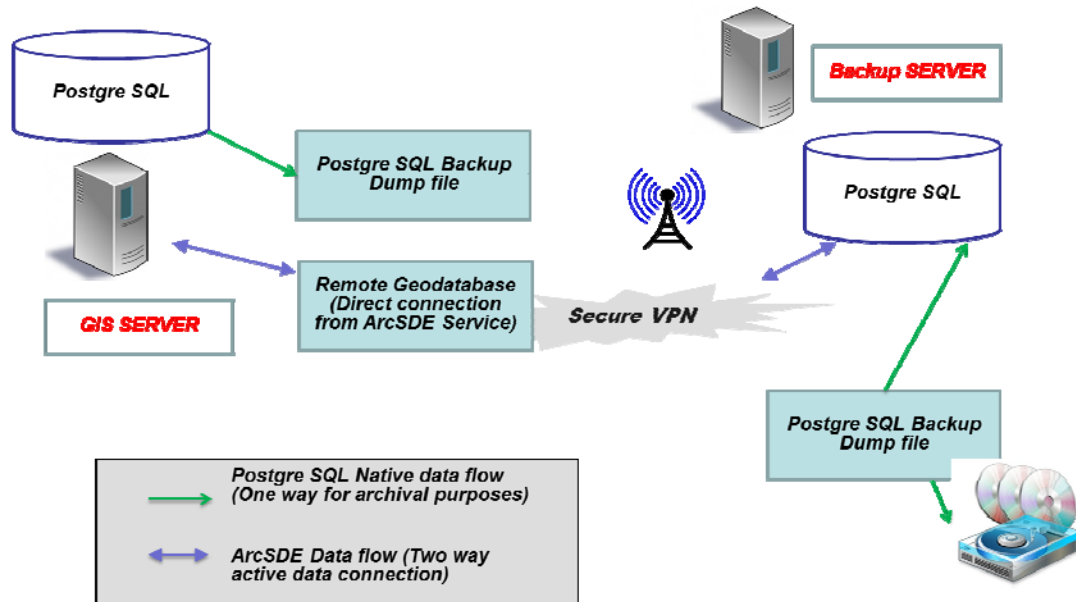
Figure 5-6: Backup Server data flow

The data flow diagram for the Backup server is shown in Figure 5-6. This figure explains that the GIS Server (Kumasi) and Backup server (Accra) are connected through VPN. The GIS Server has direct replica Geodatabase on the Backup server through ArcSDE Service. Apart from this, the postgre SQL backup dump files are transferred to Backup server and then this dump file is restored in Backup Server to make replica and also is archived in disks.

The RMSC servers (GIS Server & Backup Server) and FCG Headquarters server (Backup Server) are connected through the high speed VPN connections over secure Internet. The workstations at RMSC are connected locally through physical Local Area Network (LAN) connections to main Database/GIS Servers. So the licenses are communicated respective to their connectivity and so are the data transfer between workstations and server.

5.1.3.6.   Installation

All installations were completed with supervision of FC Ghana ICT staff. The installation steps for the servers and workstations which included main Software such as ArcGIS Desktop and ERDAS IMAGINE are described in the following sub chapters. The Server room was renovated for handling the servers in better way. The server racks with appropriate air conditioning systems were also installed to keep the servers cool and running 24x7. Detailed Installation Manuals are provided in Manual 7 – System Administrator's Manual – Hardware / Software Installation Manual.

(1) Installation of GIS/DB Server

The GIS server hardware was appropriately fixed in the server racks in server room. The operating system Windows 2008 Server Enterprise Edition was installed on the server. The server is also joined to existing domain "FCGHANA.ORG" local area network. The server is named as "GISSERVER.FCGHANA.ORG" with the following IP-address

LAN: 192.168.3.55

WAN/VPN IP: 10.5.91.240

Public IP: 197.253.69.27

(2) Installation of Web Server

The Web server hardware was appropriately fixed in the racks. The operating system Windows 2008 Server Enterprise Edition was installed on the server. This server is also joined to existing domain "FCGHANA.ORG". The server is named as "WEB_SERVER.FCGHANA.ORG" with the following IP-address

LAN: 192.168.3.3

WAN/VPN IP: 10.5.91.241

Public IP: 197.253.69.27

(3) Installation of Backup Server

The Backup server hardware was appropriately placed in ICT, FCG Headquarters Accra. The operating system Windows 2008 Server Enterprise Edition was installed on the server. This server is joined to existing domain in ICT Accra "FCGHANA.ORG". The server is named as "FPP_Server.FCGHANA.ORG" with the following IP-address

WAN/VPN IP: 10.5.40.23

(4) Installation of Workstations

Each of the workstations must be connected locally to the GIS server in RMSC or to FPP Server in Accra for the licensing. They can be connected locally through Local Area Network (LAN) or through Virtual Private Networking (VPN).

Install the software in the workstations as explained in Manual 7 – System Administrator's Manual – Hardware/Software Installation Manual and configure to access license from GIS/DB server which also acts as License Server.

5.1.4. Outputs

The outputs of Task 17 are mentioned in Table 5-3.

Table 5-3: Outputs of Task 17

NO.	Item	Type	Where to Find
1	Hardware and software deployment	HW/SW	Respective locations as mentioned table 5-1 and 5-2 of this report.
2	Installation Guide and Manuals	Document	Manual 7 – System Administrators Manual (Hardware / Software Manual) Manual 8- FIS user Manual
3	Software Licenses	Files	GIS Server @ RMSC/ FPP_Server @ FCG,HQ

5.2. Task 18: Deployment of All Equipment for Carbon Stock Assessment for Field Survey

5.2.1. Procured Equipment

All required survey (forest inventory) equipments such as PDA, GPS, tree measurement tools etc, that were identified in Task5 have been procured. Detailed List of equipment is mentioned in Table 5-4.

Table 5-4: List of Survey Equipment

Item No.	Item Description	Quantity		
		Accra	Kumasi	Total
1	PDA	0	4	4
2	GPS (Handheld)	5	25	30
3	GPS Receiver (Rover)	0	2	2
4	GPS Receiver (BASE station)	0	2	2
5	Caliper used to measure tree diameter	0	7	7
6	Caliper used to measure tree diameter (Tree diameters > 90 cm)	0	7	7
7	Diameter tapes	0	7	7
8	Hypsometer	0	6	6
9	Densiometer	0	6	6
10	Linear tape	0	7	7
11	Loggers tape	0	7	7
12	Compass/Clinometer	0	6	6
13	Compass	0	10	10
14	Soil Auger	0	6	6
15	Core Sampler	0	6	6
16	Ladder	0	4	4
17	Tent	0	35	35
18	Sleeping Bag/Bed	0	35	35
19	Generator	0	3	3
20	Infrared Spectrophotometer	0	1	1

5.2.2. Deployment

All equipments have been installed in the designated place/ office in Accra/ Kumasi. The designated places are mentioned in Table 5-4. The equipments were deployed to the Survey teams for field work. After the completion of the survey work, all the equipments have been stored at designated offices for future use.

5.2.3. Outputs

The outputs of Task 18 are mentioned in Table 5-5.

Table 5-5: Outputs of Task 18

NO.	Item	Type	Where to Find
1	Hardware and Forest Inventory Equipments deployment	HW	Respective locations as mentioned in Table 5-4 of this report

5.3. Training in GIS/Image Processing and LiDAR / Forest Inventory and Biomass Estimation

5.3.1. Training Overall

Two weeks formal training programme was conducted under to capacity building; Task 19, 20 and 21. There were three groups; namely GIS/GPS Group (Task 19), Remote Sensing (RS) Group (Task 20) and Forest Inventory (FI) Group (Task 21), of trainees selected from various departments of FCG. The list of the trainees was provided by FCG in advance. The training manuals were prepared and delivered before the start of training so that trainees had opportunity to study it in advance.

The training programme was divided into two parts namely:

(i) General introduction conducted for all trainees

(ii) Practical training conducted by separating the trainees into three specific groups; GIS/GPS, RS and FI

The first two days were allocated for the first section followed by remaining time for the second section. Training for the handheld GPS was conducted during the first two weeks; but GNSS (Global Navigation Satellite System) training could not be conducted because of delay in delivery of equipments (Trimble Base and Rover). The GNSS training was conducted from 10 to 12 April, 2012 after renting Trimble GNSS (one Base and one Rover) equipments from K. N. University of Science and Technology, Kumasi.

The training was evaluated by the trainees at the end of the two weeks formal training.

5.3.2. Training Schedule

Duration: 2 weeks (March 28 to April 6 and April 10 to 12, 2012)
Venue: Wood Industries Training Centre (WITC), Kumasi, Ghana
Session 1: 9.00am-10.30 am. Session 2: 10.30am-0.00pm. Session 3: 1.30pm-3.00pm.
Session 4: 3.00pm
The session details are mentioned in Table 5-6 and Table 5-7.

Table 5-6: Summarised Training Time Table

Group	Session	28-Mar	29-Mar	30-Mar	31-Mar	2-Apr	3-Apr	4-Apr	5-Apr
RS	1	RS 01	RS 03	Rec 01	Classification 01	SAR 01	Project 01	Project 02	Project 03
	2	GIS 01	RS P01	Rec 02	Classification 02	SAR 02			
	3	FI 01	FI 02	Basic function	Model Maker	SAR 03			
	4	RS 02	GIS 02	Enhancement		Map Composition			
GIS/ GPS	1	RS 01	RS 03	Data Roaming	Data Editing	Logical Operator and Map Overlay	Project 01	Project 02	GIS Presentation
	2	GIS 01	RS P01	Data Query					GPS installation and operation (in house)
	3	FI 01	FI 02	Creation and extracting new layers	Data Management (Quality & Accuracy)	Data Conversion			
	4	RS 02	GIS 02		Basics of Database & PostGry server	Map Composition			
FI	1	RS 01	RS 03	Practical Training					
	2	GIS 01	RS P01						
	3	FI 01	FI 02						
	4	RS 02	GIS 02						

Table 5-7: Detail of General Sessions for Day 1 and 2

Session	Title	Lecturer
RS 01	Introduction of Remote Sensing	M. Yoshimura
RS 02	Remote Sensing Basics	M. Yoshimura
RS 03	Image Analysis of Remote Sensing	M. Yoshimura
RS P01	Introduction to ERDAS IMAGINE	A.K. Sah
GPS	GPS installation and operation	R. Jha
GIS 01	Basic Concept & Principle of GIS and GPS	B.P. Sah/ S. Senthil
GIS 02	a) GIS Data & Database	B.P. Sah/ Rodolfo
	b) Introduction of ArcGIS/ ArcView	"
FI 01	Introduction of Forestry and Forest Management	H. Jarno
FI 02	Introduction of Forest Inventory	H. Jarno
	Essence of Biomass Estimation - Theory	Dr. Bredu (CSIR)
	Essence of Biomass Estimation - Practicals	Dr. Foli and Dr. Bredu (CSIR)

Figure 5-7: General Lecture to all participants

5.3.3. Opening Ceremony

As part of the training and Field Inventory to be carried out, an official opening ceremony was held on the 2nd of April 2012 at WITC Akyawkrom. The essence was to educate all participants, Forestry Commission officials and all stake holders on the importance of the training and Field work. Below is the program line up for the training opening Ceremony.

Time	**Activity**	**Person**
10.00am	Opening Prayer	Thomas Gyambrah
10.05am	Introduction of Dignitaries, Guests and Participants	
10.10am	Welcome Address	Mr. K Lumor
10.15am	Overview of the FPP Programme	Mr. E. Obiaw
10.20am	Address by PASCO Representative	Dr.B.P.Sah
10.30am	Address by FCG Stakeholders/ Invited Guests (FORIG/Soil Research Institute/CERGIS)	
10.40am	CE's Address	
10.50am	Closing Remarks	Mr. E. Obiaw

Figure 5-8: Opening Ceremony

5.3.4. Assigned Members

11 international consultants/ experts were assigned for conducting trainings as mentioned in Table 5 8.

Table 5-8: List of Assigned Members

NO.	Position	Name	Remarks
1	Project Manager	Dr. Bhuwneshwar Prasad Sah	Lecturer for GIS
2	Forest Inventory Expert	Mr. Jarno Hämäläinen	Lecturer / Trainer for FI
3	Remote Sensing Expert	Mr. Awadh Kishor Sah	Lecturer / Trainer for RS
4	GIS Expert	Rodolfo Palencia, Jr.	Trainer for GIS
5	GIS Specialist	Mr. Selvaraj Senthil	Trainer for GIS System administrator
6	Biomass/ C-Stock Specialist	Mr. Olli Isotupa	Trainer for FI
7	3D Forest Structure Processing Specialist	Mr. Juha Hartikainen	Trainer for FI
8	Remote Sensing Specialist	Dr. Mitsunori Yoshimura	Lecturer for RS
9	Field Survey (Topo) Specialist	Dr. Raghunath Jha	Trainer for GPS
10	System Design Support	Mr. Yuzuru Kikuchi	
11	Coordinator	Ms. Kubo Nami	

5.4. Task 19: Training in GIS Forest Resource Management Software

5.4.1. GIS/ GPS Group

Formal training was conducted from 28th March 2012 to 6th April 2012 for selected GIS/ GPS Group of staff mainly from Remote Sensing/GIS and Cartographic sections of various departments and regional and district offices of FCG. After two days of general introductory joint lecture sessions for all groups of trainees, the GIS/ GPS Group was selected based on their interest and training need evaluation. The sessions were categorized in three categories; i) learning about GIS analysis (ESRI ArcGIS version 10.0) and functions, ii) practicing the data input and analysis considering forest inventory system and (iii) Handheld GPS observation and GNSS introductory lectures. Each category included various sessions of involved GIS/ GPS Group trainees.

Altogether 7 trainees participated in the GIS/ GPS Group practical sessions and pre-training questionnaire survey revealed that all of them had some working experience with ArcGIS Software (mostly on previous versions). This helped during the practicing with ArcGIS. A printed manual with the functions of ArcGIS included in practice was provided to trainees in advance to start of sessions. Practical sessions were structured as follows:

i)   Briefing about the session followed by demonstration to trainees.
ii)   Practice of session tasks by trainees.
iii)   Presentation about tasks results by trainee and group discussion.

The trainees showed good motivation. From the training evaluation as shown in Figure 5-9, it is reflected that trainees had responded well in terms of the gain in applicability of GIS for forest inventory system and related analysis during their job related to FPP.

The GPS-GNSS training was conducted from 10 to 12 April, 2012 using Trimble GNSS base, Rover sets, peripherals and Trimble Business Center software.
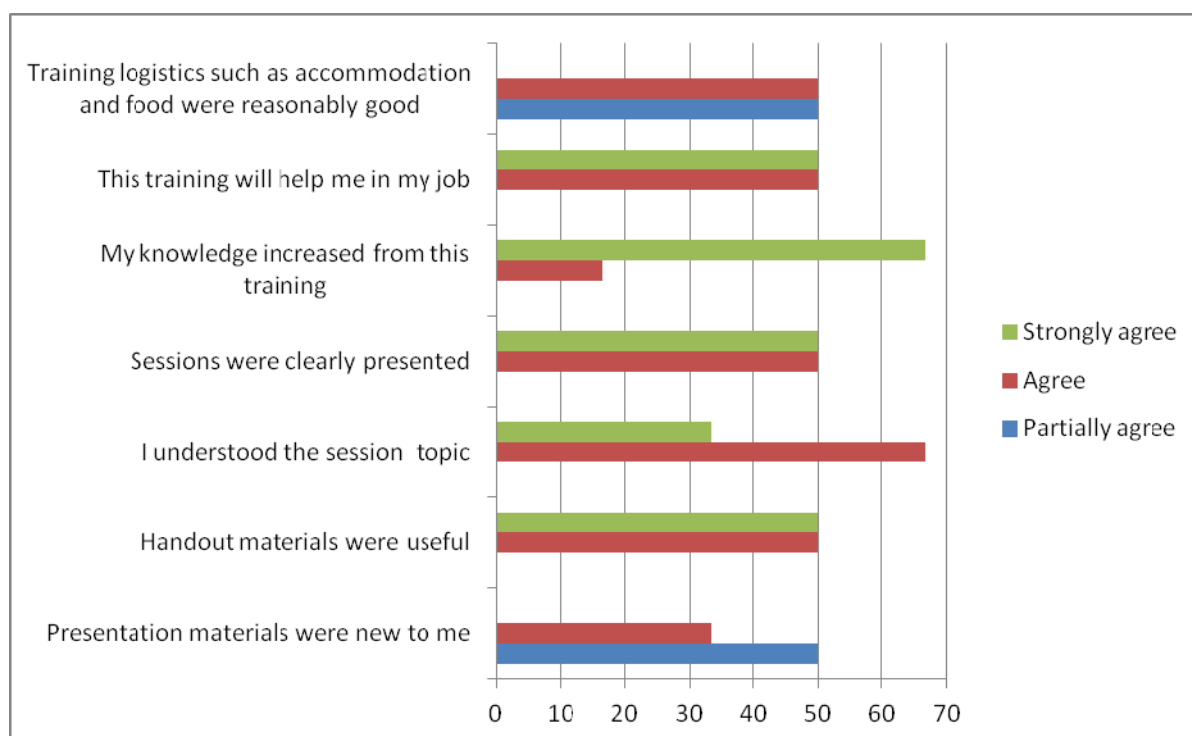
Figure 5-9: Result of Training Evaluation for GIS/GPS Group

Figure 5-10: GIS/ GPS Group

5.4.2. System Administration and Database Group

Formal training was conducted from 28th March 2012 to 6th April 2012 for GIS and system administrator group with a group of 16 trainees which included 3 trainees from various ICT department of FC Ghana. Although this group was not identified in the Inception Report, this was formed because it is important for FC Ghana to have staffs trained specially for managing the web-GIS system that will be developed for FPP. Practical sessions which were conducted included sessions for maintenance of system and database using PostgreSQL server.

Based on the pre-training questionnaire, it was understood that one of them has used GIS software before, while for others it was new for them. Also they are strong in Microsoft SQL Server and MS-Access databases. They were also strong in networking and IIS webservers.

Since the training was planned to be a on the job simulation. The training started with setting up a small network hub using the trainee's laptop and a desktop computer simulating the database server. Trainees were installing the postgre SQL server on their own machines and also on the database server. They learnt the different configuration options while they installed. After that there was simulation of remote server as one of the trainee's laptop. They were trained to connect to remote database, create and edit permission and also backing up to remote servers and restoring them were practiced.

Trainees were curious to learn, motivated and driven to solve the problems as team work. They discussed and coordinated well coming up with alternate solutions with different efficiency levels.

From the post training evaluation, we understood that most of trainees agree that they understood the topic well, and their knowledge has increased in the training, also it will help them in their job. The general comment is about new presentation material because GIS domain is new to those ICT staffs and they were quickly learning the GIS geodatabases and GIS basics too.
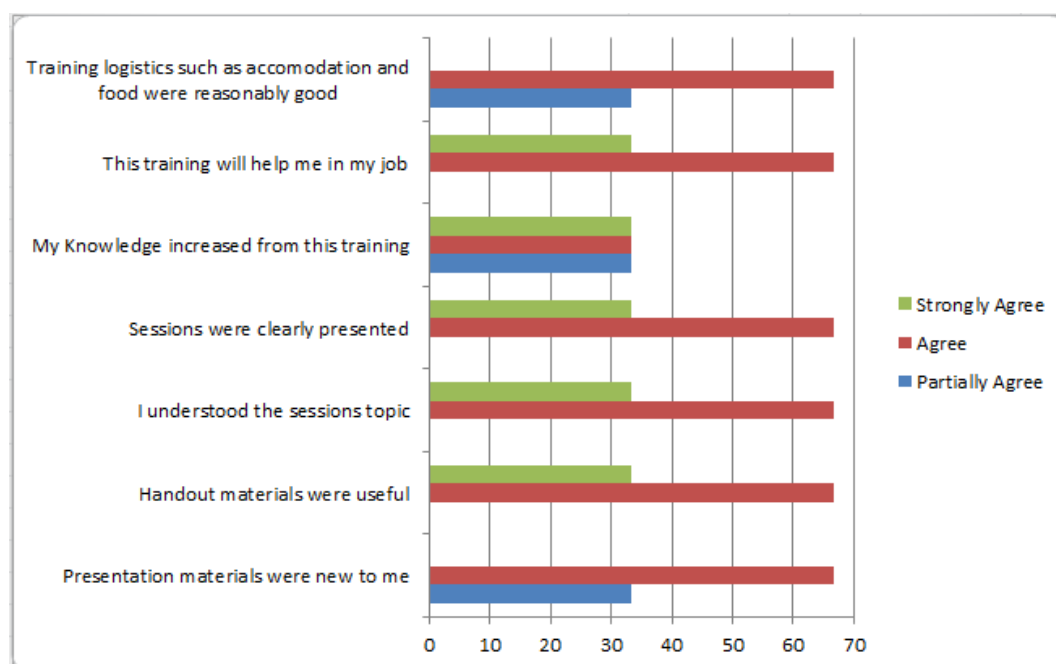
Figure 5-11: Result of Training Evaluation for System Administration and Database Group

Figure 5-12: System Administration and Database Group

5.4.3. Follow up Hands-on Exercises for Forest Inventory System

The follow up training titled "Forest Inventory System: System Configuration & Database Management Hands-on Exercises" for the GIS group and also mainly concentrating on the System admininstrators group. The training was conducted during October 2012 for about 1 week. The training involved team of 7 members which involved GIS group, System administrators from ICT, RMSC and also from ICT, FCG Head Quarters.

The topics covered during the "Forest Inventory System: System Configuration & Database Management Hands-on Exercises" are described in Table 5-9.

Table 5-9: Forest Inventory System: System Configuration & Database Management Hands-on Exercise

Day	Date	Time	Session	Instructor
1	Mon 15 Oct 2012	9:00 - 10:30	System Overview	Mr. Senthil Selvaraj
		10:30 - 12:00	Web Server Stack Installation	-do-
		12:00 - 13:00	-- LUNCH BREAK --	
		13:00 - 15:00	Installing PostGRE & PostgreSQL Remote Access	-do-
		15:00 - 17:00	-do-	-do-
2	Tue 16 Oct 2012	9:00 - 10:30	ArcGIS SDE Installation	-do-
		10:30 - 12:00	Creating SDE Geodatabase	-do-
		12:00 - 13:00	-- LUNCH BREAK --	

		13:00 - 15:00	Client access to SDE	-do-
		15:00 - 17:00	Populating Data to SDE Geodatabase	-do-
3	Wed 17 Oct 2012	9:00 - 10:30	GeoServer Installation	-do-
		10:30 - 12:00	Managing Data in GeoServer	-do-
		12:00 - 13:00	-- LUNCH BREAK --	
		13:00 - 15:00	Managing Data in GeoServer	-do-
		15:00 - 17:00	Configuring GeoServer public & local access	-do-
4	Thu 18 Oct 2012	9:00 - 10:30	Installing WebGIS Portal	-do-
		10:30 - 12:00	Configuring webGIS Portal	-do-
		12:00 - 13:00	-- LUNCH BREAK --	
		13:00 - 15:00	Modifying data at WebGIS Portal	-do-
		15:00 - 17:00	-do-	-do-
5	Fri 19 Oct 2012	9:00 - 10:30	Installing & Configuring Client Authentication software	-do-
		10:30 - 12:00	Managing Client Authentication	-do-
		12:00 - 13:00	-- LUNCH BREAK --	
		13:00 - 15:00	Testing GIS Data authentication	-do-
		15:00 - 17:00	Recommendation for Domain Name	All

The list of Participants for the "Forest Inventory System: System Configuration & Database Management Hands-on Exercises" are mentioned in Table 5-10.

Table 5-10: System Configuration & Database Management Hands-on Exercises Participants Table

No	Name	Station	Designation
1	David Baidoo	RMSC, Kumasi	GIS Officer
2	Lawrance Akpalu	RMSC, Kumasi	Asst Manager RS/GIS
3	George Rockson Odame	RMSC, Kumasi	Manager ICT
4	Daniel Mensah	RMSC, Kumasi	IT Technician
5	Daniel Agyei	ICT, Accra	Asst. Network Administrator
6	Albert Appiah	ICT, Accra	IT Officer
7	Ebo Darko	ICT, Accra	Network Administrator

The hands-on exercise helped the system administrators and GIS administrators to understand the forest inventory system and its data flow. It also helped the participants to know about the different configuration to maintain the system effectively.

The detailed manuals for installation and also for configuration are included in Manual 7 – System Administrator's Manual – Hardware / Software Installation.

The participants showed interest in learning and they have performed well on exercises. There were also technical discussions and clarifications during the training to enhance their knowledge and also to know the concepts of the system better.
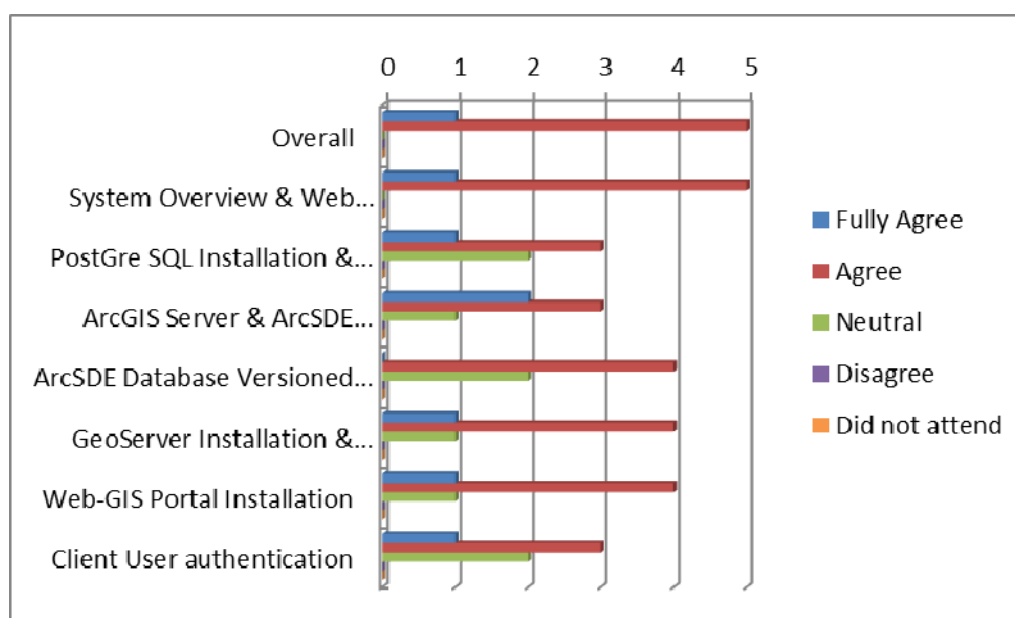
Figure 5-13: Hands-on Exercise participants feedback

The Figure 5-13 shows that the participants have understood the topics well. Following this training, the participants uploaded the actual data to the System.

5.4.4. Outputs

The outputs of Task 19 are mentioned in Table 5-11.

Table 5-11: Outputs of Task 19

NO.	Item	Type	Where to Find
1	Training Manuals	Document	Manual 9 Manual 7

5.5. Task 20: Training in Image Processing Software for ALOS and Other Satellite Imagery for Forest Resource Mapping and Change Detection- Including Both Optical and SAR Imagery and LiDAR

5.5.1. Remote Sensing (RS) Group

Formal training was conducted from 28th March to 6th April, 2012. First two days, lecture sessions were introduced to all participants. And, then practical sessions related to RS were carried out to the participants of RS Group. These sessions were categorized in two groups; i) learning about ERDAS IMAGINE (version 11.0) functions, and ii) practicing the image processing considering LULUCF. Each category included various sessions; of involved RS Group trainees.

Altogether 6 trainees participated in the RS practical sessions and pre-training questionnaire survey revealed as 5 of them had some working experience with ERDAS IMAGINE Software (mostly on previous versions). This helped during the practicing with Erdas Imagine. A printed manual with the functions of ERDAS IMAGINE included in practice was provided to trainees in advance to start of sessions. Practical sessions were structured as follows:

i)   Briefing about the session followed by demonstration to trainees.

ii)   Practice of session tasks by trainees.

iii)   Presentation about tasks results by trainee and group discussion.

During the training, the trainees showed good motivation and willingness to learn about ERDAS IMAGINE functions as well as processing steps of LULUCF. Moreover, as it is revealed from their training evaluation response, most of them have marked as 'Agree' regarding 'Handout material were useful' and 'I understood the session topic' and however, 'Partially-agree' to 'Sessions were clearly presented'. This might be because the presentations (demonstrations) were yet to be followed by practice, which increased their confidence. Overall, the trainees made best efforts in practicing the image processing techniques and in future, they need to give continuity to this in order to upgrade the level.
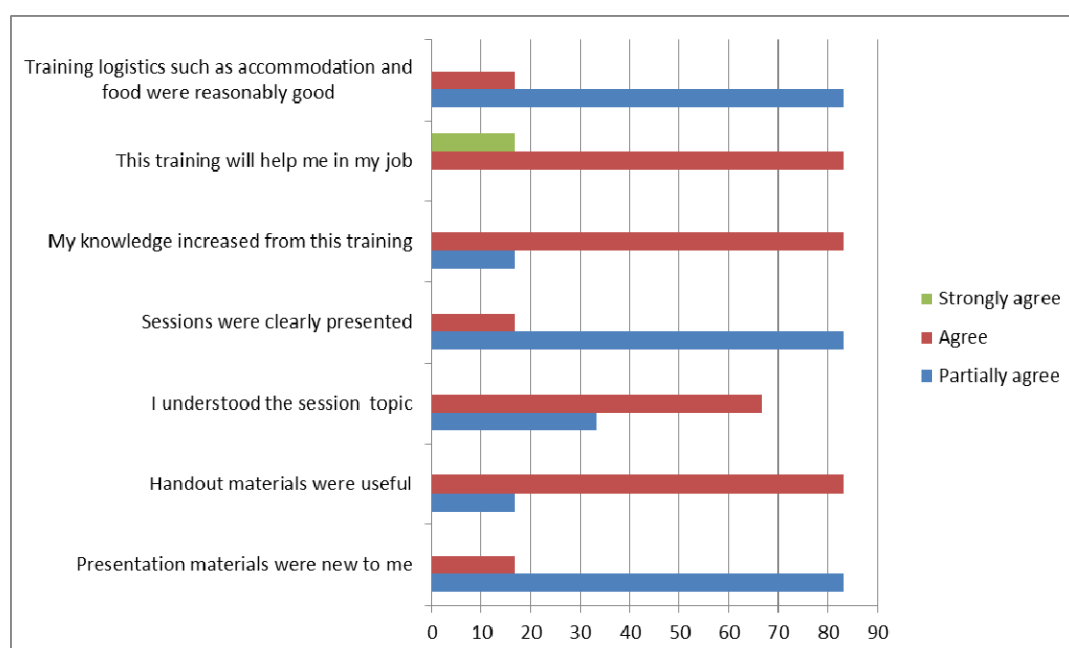
Figure 5-14: Result of Training Evaluation for RS Group

Three days LPS (software for stereo imagery processing for 3D and 2D features extraction) training was conducted in March, 2013 using users guide and training Manual (Manual 10).

Figure 5-15: Remote Sensing Group

5.5.2. LiDAR Data Pre-processing

An introduction lecture was given by the forest inventory expert about the LiDAR data pre-processing steps to 4 survey and mapping unit staffs at RMSC in Kumasi in May 4th, 2012. The lecture offered an overview of the LiDAR data properties, quality control and the following pre-processing steps. A software demonstration regarding to LiDAR 3D properties and visualisation options with FugroViewer was provided. The lecture material is found in Manual 11.

5.5.3. Outputs

The outputs of Task 20 are mentioned in Table 5-12.

Table 5-12: Outputs of Task 20

NO.	Item	Type	Where to Find
1	Training Manuals	Document	Manual 11 Manual 10

5.6. Task 21: Training on Forest Inventory Survey and Biomass Estimation

Formal training was conducted from 28th March to 6th April, 2012. For the first two days the lectures were presented to all the participants and there were given two forest inventory specific lectures (Annex 5-6A and 5-6B). For the following two days of practical training, the trainees were introduced to the tree diameter and height measurements and also the use of field PDA. The Forest Inventory (FI) Group also visited FORIG where the soil sampling technique was demonstrated.

From 2nd to 5th April, 2012 the FI Group moved to Bobiri Forest for more practical training. The trainees practiced laying out the field sample plot, measuring forest inventory data and also some basic use of the GPS. After basic training, trainees practiced in groups and underwent the whole sample plot measuring and data recording procedure. Data was recorded for all the forest carbon pools, namely tally trees, juvenile trees, seedlings and shrubs, standing dead wood, downed dead wood, non-tree biomass, litter and soil following the procedures described in Manual 5-2.

The FI Group consisted of 20 trainees and for the most part they showed enthusiasm and were motivated to learn the use of new equipment and procedures. Pre-training questionnaire survey prevailed that the trainees had some knowledge about forest inventory. Almost every trainee had experience from diameter measurements and about half of them had done height measurements before. In practical training the trainees succeeded well with diameter measurements, but height measurements revealed to be more complicated, especially in the case of leaning trees. Training evaluating response suggests that the training was helpful, understandable and has increased trainees knowledge. The majority of trainees also felt that the handout materials were useful and partially agreed that the training logistics were on a reasonably good level.

The forest inventory training report is found in Annex 5-6C.
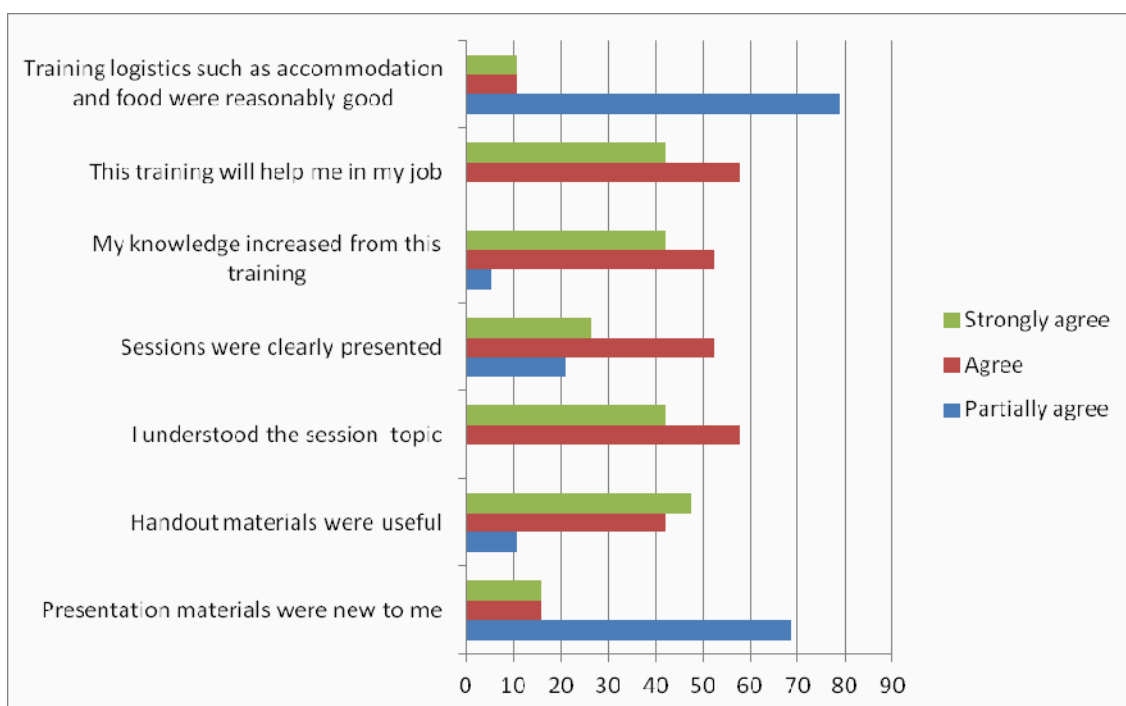
Figure 5-16: Result of Training Evaluation for Forest Inventory Group

Figure 5-17: Forest Inventory Group

Table 5-13: List of Participants of Formal Training

NB: Attendance, 1 = Present, 0 = Absent

No.	Name/ Position	Region	Group	28-Mar Wed	29-Mar Thu	30-Mar Fri	31-Mar Sat	2-Apr Mon	3-Apr Tue	4-Apr Wed	5-Apr Thu
1	Charity Appiah, RMSC	Ashanti	GIS	1	1	1	1	1	1	1	1
2	Edward Owusu Ansah, WITC	Ashanti	GIS	1	1	1	1	1	1	1	1
3	Emmanuel Opoku, RMSC	Ashanti	GIS	1	1	1	1	1	1	1	1
4	George Rockson Odame, RMSC	Ashanti	GIS	1	1	1	1	1	1	1	1
5	Emmanuella Ntiamoah Sarpong, RMSC	Ashanti	GIS	0	1	0	0	1	1	1	1
6	Solomon N. Mamah, RMSC	Ashanti	GIS	0	0	1	1	1	1	1	1
7	Godwin Agyemang, FSD	Brong Ahafo	GIS	1	1	1	1	1	1	1	1
8	Theresa Adjaye, Wildlife Division	Greater Accra	GIS	1	1	1	1	1	1	1	1
9	Daniel Agyei, FSD, HQ	Greater Accra	GIS	1	1	1	1	1	1	1	1
10	David Baidoo, RMSC	Ashanti	RS	1	1	1	1	1	1	1	1
11	Lawrence Atsu Akpalu, RMSC	Ashanti	RS	1	1	1	0	1	1	1	1
12	Christopher Ihejirika, RMSC	Ashanti	RS	1	1	1	1	1	1	1	1
13	Benjamin Antepim, FSD	Brong Ahafo	RS	1	1	1	0	1	1	1	1
14	Benjamin Torgbor, FSD, HQ	Greater Accra	RS	1	1	1	1	1	1	1	1
15	Sylvia Acquah-Payne, RUDAN Eng. Ltd	Greater Accra	RS	1	1	1	1	1	1	1	1
16	Raymond Votere, RMSC	Ashanti	FI	1	1	1	1	1	1	1	1
17	Alfred Yabepone, FSD	Ashanti	FI	1	1	1	1	0	1	1	1
18	Adu Sarpong Emmanuel, RMSC	Ashanti	FI	0	0	0	0	1	1	1	1
19	Yaa Konadu Pokuaa, RMSC	Ashanti	FI	0	1	0	0	1	1	1	1
20	John Atinga Parker, BIMU-Wildlife Divisi	Brong Ahafo	FI	1	1	1	1	1	1	1	1
21	Mary Nyadia, FSD	Brong Ahafo	FI	1	1	1	1	1	1	1	1
22	Ali Abdallah Seidu, FSD	Brong Ahafo	FI	1	1	1	1	1	1	1	1
23	Rita Mintah, FSD	Brong Ahafo	FI	1	1	1	1	1	1	1	1
24	George Agbenowoshie, FSD	Brong Ahafo	FI	1	1	1	1	1	1	1	1
25	Oteng Agyekum Maxwell, FSD	Eastern	FI	1	1	1	1	1	1	1	1
26	Isaac Kofi Gyekye, FSD	Eastern	FI	1	1	1	1	1	1	1	1
27	Dominic Oteng Attebare, FSD, HQ	Greater Accra	FI	1	1	1	1	1	1	1	1
28	Thomas Yaw Gyambrah, FSD, HQ	Greater Accra	FI	1	1	1	1	1	1	1	1
29	Dickson Agyemang, Wildlife Division	Greater Accra	FI	0	0	0	1	0	1	1	1
30	Emmanuel Ampomah, RUDAN Eng. Ltd	Greater Accra	FI	1	1	1	1	1	1	1	1
31	Owusu Ameyaw, FSD	Northern	FI	1	1	1	1	1	1	1	1
32	Linda Asumah Zury, FSD	Volta	FI	1	1	1	1	1	1	1	1
33	Kwame Oteng Awuah, FSD	Western	FI	1	0	1	1	1	1	1	1
34	Frank Ankrah, FSD	Western	FI	1	1	1	1	1	1	1	1
35	Kwasi Frimpong, FSD	Western	FI	1	1	1	1	1	1	1	1
36	Ishmael Boakye Agyemang, FSD	Western	FI	1	1	1	1	1	1	1	1
37	James Osei Gyimah, FSD	Western	FI	1	1	1	1	1	1	1	1
38	Alexander Asum, FSD	Western	FI	0	0	0	1	0	1	1	1

5.6.1. Task 21: C-Stock Computation Hands-on Exercises

The C-Stock Computation Hands-on Exercises –programme was organised for 6 participants at RMSC Survey and Mapping unit from 15th October to 19th October in 2012. The participants gained hands-on experience on computing plot-level carbon stocks in MS Excel, pre-processing LiDAR data with open source tools and modelling carbon stocks with ArboLiDAR forest inventory tools and field sample plot, LiDAR and ALOS AVNIR satellite data. On the final day of the ArboLiDAR training the participants were divided into two groups in order to carry out a group work applying the knowledge and exercise of the previous days. Both groups kept a presentation and their results were discussed together with rest of the class and instructors.

Figure 5-18: C-stock hands-on computation exercises

Table 5-14: A group members in hands-on exercises

No	Name	Station	Designation	Remarks
1	Oteng Awuah	FSD, Dunkwa	Asst. District Manager	Team leader, Inventory
2	Raymond Votere	RMSC, Kumasi	Asst. District Manager	Team leader, Inventory
3	Sarpong Emmanuel	RMSC, Kumasi	Asst. District Manager	Team leader, Inventory
4	Atinga John Parker	WD, Goaso	Asst. District Manager	Team leader, Inventory
5	Evans Opoku Appiah	Intern RMSC	INTERN	Background knowledge in Stratistics
6	Emmanuel Opoku	RMSC, Kumasi	ICT Manager	Data management and storage, RMSC
7	Emmanuel Donkor	RMSC, Kumasi	Survey Officer	Team leader, Inventory
8	Kofi Affum-Baffoe	RMSC, Kumasi	Manager Production	
9	Yakubu Mohammed	RMSC, Kumasi	Manager RS/GIS	
10	Samuel Ayesu	RMSC, Kumasi	Asst Manager / Env. Conservation	

Training evaluation responses suggest that the participants were satisfied with the overall success and quality of training (Figure 5-19). All the sessions were found to be useful and the provided materials were appropriate (Figure 5-20). The participants wished that subsequent workshop courses of this subject matter would be organized periodically to provide them with more practice time to fully grasp the concepts.

How would you rate the overall success and quality of this course?
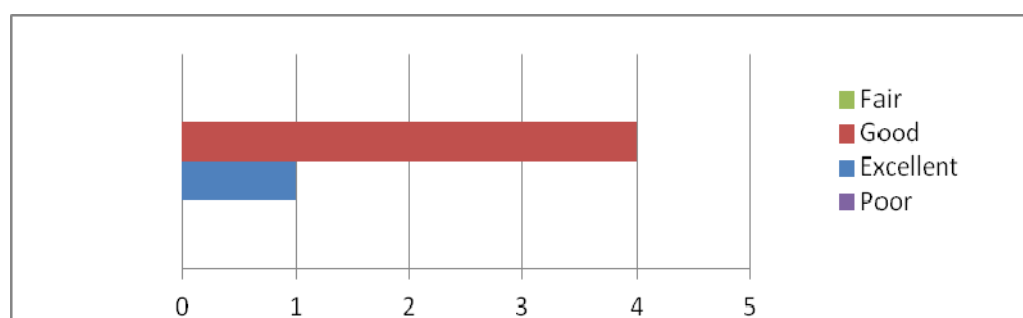
Figure 5-19: Result of Hands-on Exercise Evaluation for C-stock modeling sessions
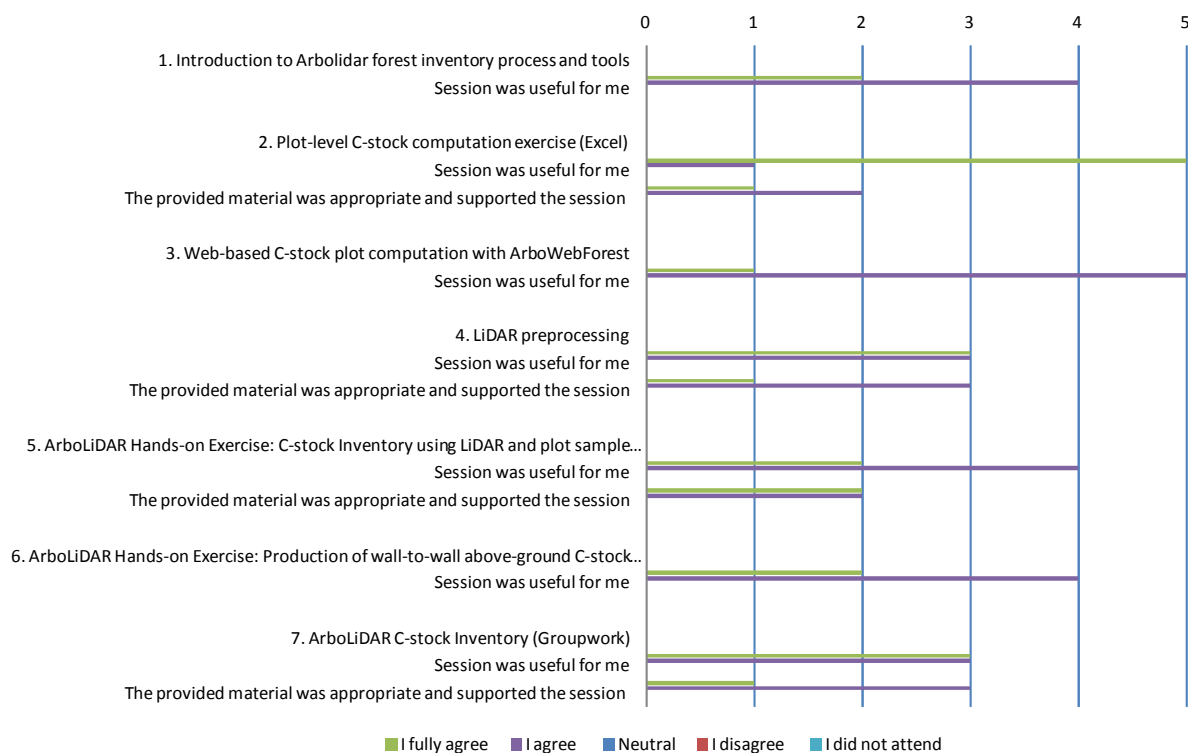
Figure 5-20: Result of Hands-on Exercise Evaluation for C-stock modeling sessions

The following hands-on exercise documents are included as annexes:

- Time table (Annex 5-6D)
- Presentation slides: Introduction to ArboLiDAR Forest Inventory Process and Tools (Annex 5-6E)
- Field plot data calculation exercise and formulas (Annex 5-6F)
- Presentation slides: ArboWebForest plot sampling and aggregation (Annex 5-6G)
- Group exercise description (Annex 5-6H)
- Evaluation form for C-stock Computation Hands-on Exercises (Annex 5-6I)
- Report on C-Stock computation hands-on exercises (Annex 5-6J)

5.6.2. Outputs

The outputs of Task 21 are mentioned in Table 5-15.

Table 5-15: Outputs of Task 21

NO.	Item	Type	Where to Find
1	Training Manuals	Document	Manual 5 Manual 6 Annex Chapter 5

5.7.   Conclusion

The Hardware and Software which were acquired in this project were deployed to respective locations. The software installation and hardware installation were done by vendor and service provider with supervision from PASCO ICT staff member and also FCG ICT Staff members. After the deployment of the HW/SW and FI equipment, Training were conducted with 3 different groups as i) Remote Sensing ii) GIS/GPS iii) Forestry Inventory group for field inventory and Biomass estimation. The participants were showing great interest and learned them and used in for different job roles they were in the organization. The follow-up training was provided to these groups again to enhance their knowledge and also perform better. Each of the training were provided with handout and detailed manuals. These documents will help them to practice their training later on their own. These manuals are delivered along with this report.

Various tasks processed data and output results were saved in GIS Server in Kumasi. Backup server has been setup with regular backup schedules followed by FCG ICT Administrators. Well devised online data sharing protocol was created with (i) main GIS server, (ii) WebGIS sever and (iii) Backup server. Selected data were published on WebGIS portal for data and information sharing with stakeholders. FCG must devise a data sharing policy to share the data online and also to stake holders.

6. Forest Resource Inventory 1st Year Update (2012)

After discussion with FCG, it was decided that only selected area of about 24,233km^2 in the Northwest region of Ghana should be used for forest resource mapping for 1st year update. Furthermore a smaller area of about 9,352km^2 within the selected area should be used for forest inventory and biomass field survey. It was argued that the baseline LU and forest resource map at national level of year 2010 will not change much within this short period of time. Thus the tasks 22 to 25 were conducted using the selected areas only as shown in Figure 6-1, not at national level.
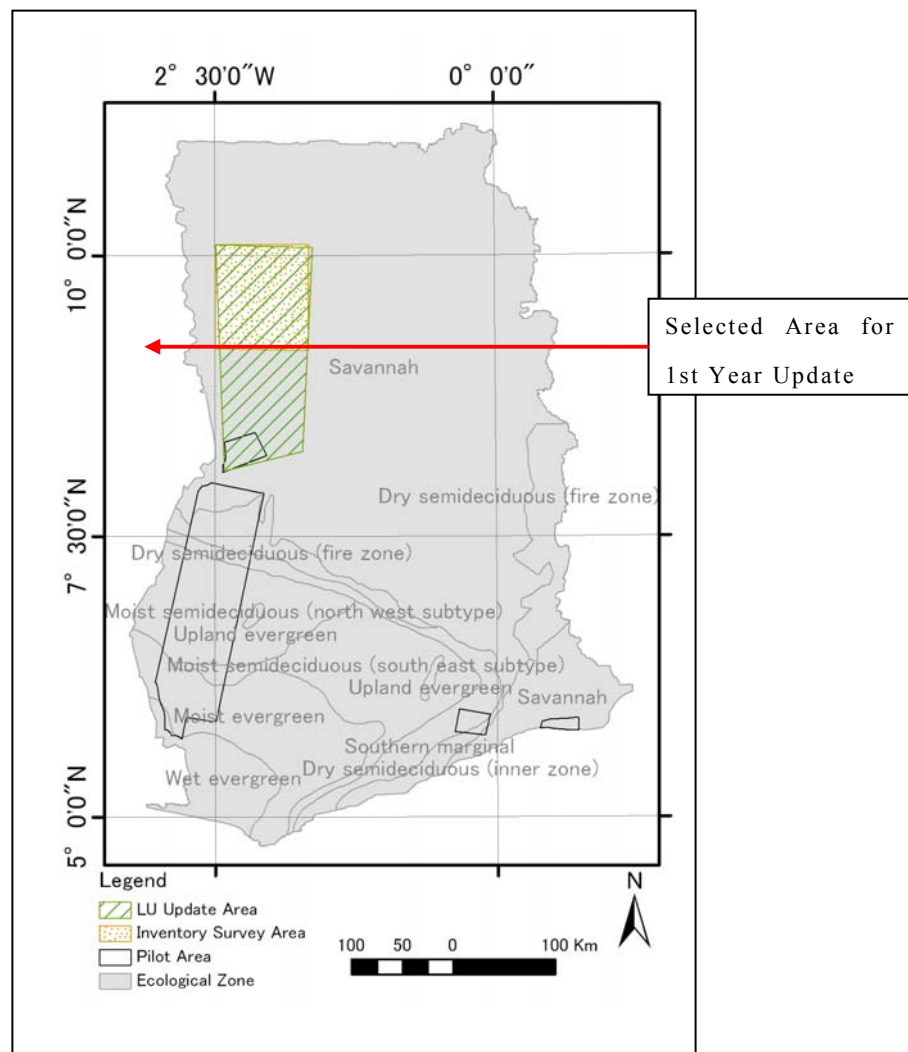
Figure 6-1: Selected Area for 1st Year Update

6.1. Task 22: Oversee the Selection of Satellite Image1y to Allow Updating of Forest Resource Maps for the Forest Reserves and Extrapolate to the National Scale

6.1.1. Introduction

This task was to liaise with nominated FCG staff to select the satellite scene as part to create the updated forest resource maps for the forest reserve areas and extrapolate to the national scale. All the activities were conducted by FCG staff under the supervision of Consultants.

6.1.2. Study Area

For this analysis, after discussion with Client, FC Ghana, it was decided to include the area of around 24,233km^2, covering part of Mole and Bui National park and the forest reserves such as Kani Kani, Laboni, Yakombo lying in between these two national parks. The Study area, with coverage of satellite scenes, is presented in Figure 6-2.
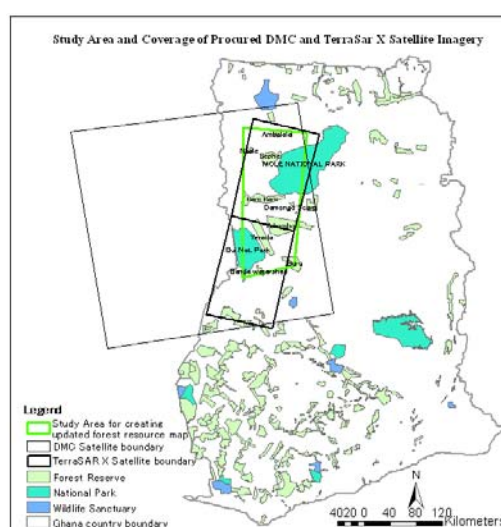
Figure 6-2: Study Area and Coverage of Procured DMC and TerraSAR-X Imagery

6.1.3. Procured Satellite Imagery

For this Task, two kinds of Satellite imageries were procured:

(1) Disaster Monitoring Constellation (DMC) satellite data (1 scene): The procured scene of DMC was composite covering relatively larger area, approximately 108,990km^2. This is optical satellite imagery with 22m spatial resolution.

(2) TerraSAR-X: It is a side-looking X-band Synthetic Aperture Radar (SAR) based on active phased array antenna technology. It has capability of acquiring data in different modes and the procured dataset was of ScanSAR mode. Azimuth resolution of ScanSAR data is 18.25m.

The detail of procured images is provided in Table 6-1 below:

Table 6-1: List of Procured Satellite Data for Updating Forest Resource Map

SN	Satellite Data	Product Information	Quantity (scenes)	Acquisition Date
1	DMC	**Multispectral: 3bands with 22m pixel; Processing Level: L1T; Product Format: GeoTIFF.**	1	2012/12/6
2	TerraSAR-X	**HH and VV Mode: 1bands with 18.25m pixel; Product Format: GeoTIFF**	4 (2HH, 2VV)	2013/1/13

6.1.4. Outputs

Table 6-2 shows the outputs of Task 22.

Table 6-2: Outputs of Task 22

NO.	Item	Type	Where to Find
1	Selected list of satellite imagery (DMC and TerraSAR-X) for Study area	document	This Report

6.1.5. Conclusion

It remained quite satisfactory that the most recent dated Satellite data of DMC and TerraSarX could be found in Archive. The FCG staff found to be well versed in selection procedure of quality satellite imagery from available archive.

6.2.   Task 23: Oversee the Image Processing and Forest Resource Mapping Update With Respect to the 2010 Baseline

6.2.1. Introduction

The image analysis of DMC imagery of 2012 and subsequently creating the forest resource map and Land Use Change (LUC) analysis between 2010 epoch and 2012 all works were carried out by FCG staff under the supervision of Consultant team members. Mainly following works were carried out:

- Collection of Ground Truth (GT) data
- Classification of 2012 Ortho-rectified image (DMC) using GT data as reference.
- Accuracy Assessment of the classified image.
- Comparison of the 2012 classified image with 2010 classified image and then producing the change map.

6.2.2. Ground Truthing and Verification

The ground truthing and verification process involved the Planning, Execution, and Processing stages. The planning was done by the FCG staff considering diversity of features and a fairly distribution of selected points across the area of interest. The included planned route was between Kumasi in the Ashanti Region and Sooma in the

Northern Region. A well planned out work ensured an easy execution by the FCG staff.

In the execution stage, satellite maps, GPS, GPS Camera, and writing materials for documentation were used. On arriving at a point of interest, its location coordinates were determined using the GPS ensuring the accuracy is within acceptable range (4m). Simultaneously, the photos were taken in 4-directions; North, East, South and West. The existing land use and other information such as topography were noted down. This activity was well performed by the FCG staff having a prior knowledge of the various types of Land Use (LU) classes.

The processing stage involved downloading the waypoints from the GPS and GPS Camera for further analysis.

6.2.3. Land Use Classification

The data collected from the field by the FCG Staff was used divided into two datasets. The first set as Ground Truthing (GT) and the other set as Ground Verification (GV). The Ortho-rectified image, DMC 2012, was used to create the updated forest resource map. The involved FCG staff performed the supervised classification on the image using the GT points as references. Similar, methodology as of Task 8 was adopted in the classification. Six classes were used in the classification; namely Forest Land, Cropland, Grassland, Settlements, Wetlands, and Other Land. The used DMC satellite image and classified image are presented in Figure 6-3:
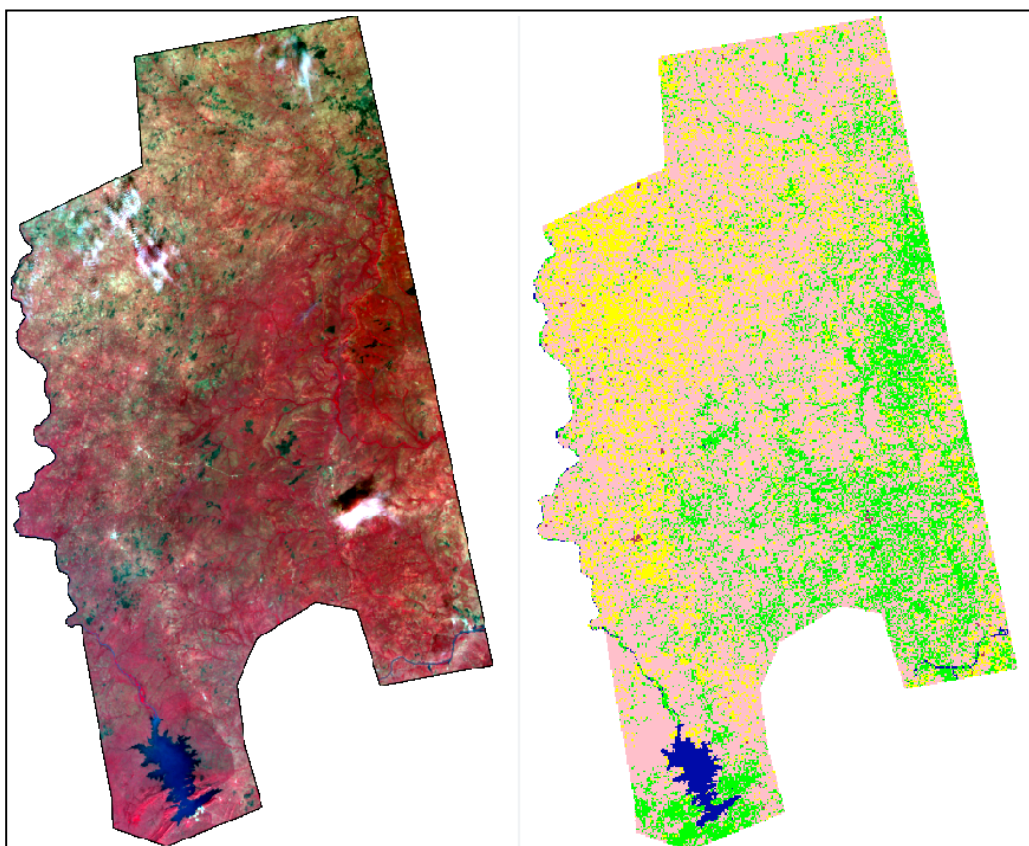
Figure 6-3: a) Ortho-rectified DMC image of 2012 b) Forest Resource Map from DMC 2012

6.2.4. Accuracy Assessment

With the shorter field survey, FCG staff could take the record 10 points as GV. With those points the classification result from DMC was tried to verify as part of assessing the accuracy and below is the result, refer to Figure 6-4. And, out of 10 checked points, 6 were found correctly classified.

```
ACCURACY TOTALS
---------------

                 Class  Reference      Classified      Number  Producers       Users
                 Name     Totals          Totals      Correct   Accuracy    Accuracy
            ----------  ---------      ----------      -------  ---------    ---------
                             0               0            0        ---          ---
          Forest Land        5               3            3      60.00%      100.00%
            Crop Land        1               2            1     100.00%       50.00%
           Grass Land        1               4            1     100.00%       25.00%
           Settlement        1               0            0        ---          ---
             Wet Land        2               1            1      50.00%      100.00%

               Totals       10              10            6

Overall Classification Accuracy =        60.00%

                ----- End of Accuracy Totals -----


KAPPA (K^) STATISTICS
---------------------

Overall Kappa Statistics = 0.4805

Conditional Kappa for each Category.
-------------------------------------

     Class Name              Kappa
     ----------              -----
                            0.0000
    Forest Land             1.0000
      Crop Land             0.4444
     Grass Land             0.1667
     Settlement             0.0000
       Wet Land             1.0000

            ----- End of Kappa Statistics -----
```

Figure 6-4: Accuracy Assessment of LU Map

6.2.5. Tiling of LU and Ortho-rectified Image

Tiling of the LU as well as ortho-rectified image was done in accordance with 1:100,000 index map in Erdas Imagine employing similar procedure as adopted for Task 8. The whole analyzed area was covered by 16 map sheets. The map layout for each 16 tiled LU image along with background data was compiled in ArcGIS at 1:100,000 scale, which as saved as MXD and exported as PDF format. In the layout of ortho-rectified image, the displayed combination of image file as R, G, and B is Layer_1, Layer_2, and Layer_3, respectively, which are Near-InfraRed, Red, and Green bands in case of DMC 2012.

6.2.6. Processing of TerraSAR-X Satellite Data

TerraSAR-X ScanSAR imagery was used to establish a correlation with DMC image. For this, the procured 2 scenes of HH and VV each were processed using Erdas Imagine Software mainly for following steps:

1. Radiometric Terrain Correction
2. Radar Speckle Suppression (Image Filtering)
3. Creating Indices Image

4. Layer Stack
5. Interpretation of TerraSAR-X (ScanSAR)

The layer stack was carried out using the Filtered (Mean）HH image, Filtered (Mean) VV image, and HH-VV to one image file as 1, 2, and 3 bands. The detail of all above processing steps is presented in manual 2.

6.2.7. Outputs

Table 6-3 shows the outputs of Task 23.

Table 6-3: Outputs of Task 23

NO.	Item	Type	Where to Find
1	Report on the success of the Task undertaken by FCG staff	Document	This Report
2	Recommendations for further training/support	Document	This Report
3	Processed and classified imagery in the agreed GIS ready formats	Document	External HDD/GIS Server at RMSC, Kumasi

6.2.8. Conclusion

FCG staff undertook the works actively. The participated staff had good knowledge of Remote Sensing as well as the functions of Erdas Imagine Software. Thus, in future they will be able to carry out such work themselves confidently. However, refresher training should be arranged time to time to keep the staff up to date.

6.3. Task 24: Oversee Forest Inventory and Biomass Field Survey

6.3.1. Planning Forest Inventory and Biomass Field Survey

The land use map produced during the 1st Year Update phase was used as a basis in defining strata for preparing a field plot sample plan. The LU raster product was converted into a vector polygon file format and forestland compartments (closed and open forest classes) with a smaller size than 1-hectare were filtered out. The stratified Simple Random Sampling (SRS) approach was applied to define locations for total 12 sample plots for the selected area (Figure 6-5) for forest inventory and biomass field survey.
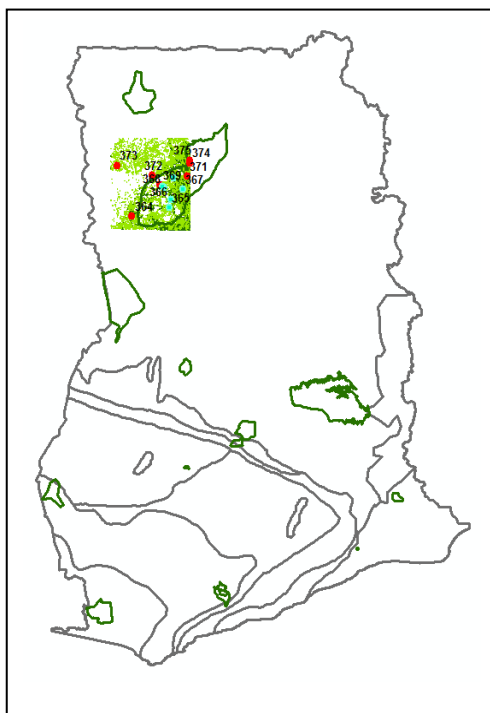
Figure 6-5: Location for Forest Inventory/Biomass field survey for 1st Year Update
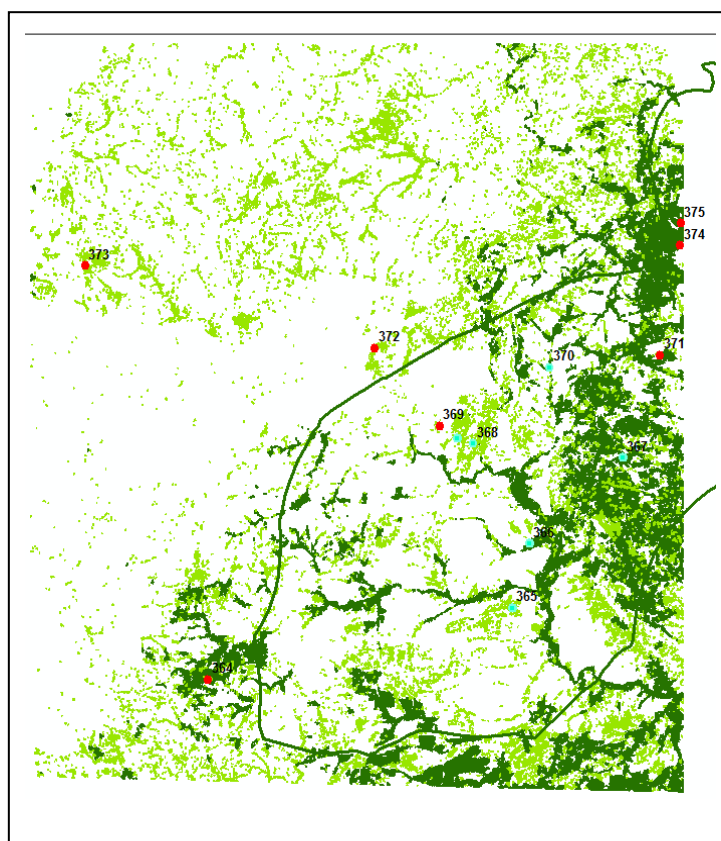
Figure 6-6: Planned (red) and enumerated (light-blue) sample plots located inside and outside the boundary of Mole National Park (green)

6.3.2. Field work

The 1st[t] year update field work was conducted in March 1st and 2nd in 2013 under supervision by one of the consultant expert staff. Before heading to field the team leaders and some team members received refreshment training in Kumasi for measuring tree heights, distances and point of measurement diameters with help of the LaserAce hypsometers. The update AWF mobile client version (vers. 2.0) was installed for all the Trimble Nomad handheld devices to facilitate the future digital data collection activities.

Total 6 plots located inside the Mole National Park were enumerated by two teams during the period of two days. Each team consisted of five core members following the role division described in the field manual (Manual 5-2) and the two teams members are indicated in Table 6-4: 1st Year Update Forest Inventory Team Members. The litter, non-tree and soil samples were collected by the teams under supervision of the Soil Research Institution expert (Mr. Gabriel Quansah).

The teams had not carried electronic balances to field for measuring fresh weights for total litter and non-tree sub-plot samples. They relied on a manual procedure by separating approximately a half of the mixed fresh litter samples from two-subplots into bags in most of the cases, except at plot 369, where only approximately one fourth of the litter sample was taken to the laboratory. Downed deadwood particles were enumerated, even though some of them are missing the decomposition classification, and carbon fractions for these particles were derived in the soil analysis lab. The deadwood density analysis was carried out by FORIG as earlier. Soil bulk density samples for plots 368 and 369 were not taken from field to the laboratory analysis.

Table 6-4: 1st Year Update Forest Inventory Team Members

TEAM ONE

NO.	NAME	RANK	STATION
1	VOTERE RAYMOND	ADM	RMSC
2	SUALIHU ABDUL JALEEL	ATTACHEE	RMSC
3	CHRISTOPHER IHERIGAH	ATTACHEE	RMSC
4	OSEI KOFI JOHN	F/G	RMSC
5	THOMAS OWUSU	F/G	RMSC
6	YAW NJKRUMAH	F/G	RMSC
7	RICHMOND ODURO	NSP	RMSC
8	ALEX K. YEBOAH	DRIVER	RMSC
9	TWUMASI ANKRAH JUSTICE	DRIVER	RMSC

TEAM TWO

NO.	NAME	RANK	STATION
1	OTENG AWUAH KWAME	ADM	DUNKWA
2	EMMANUEL DONKOR	MAPPING OFFICER	RMSC

3	EVANS OPOKU	ATTACHEE	RMSC
4	PHILLIP AMANKWAAH	ATTACHEE	RMSC
5	FRANCIS ADDAI	F/G	RMSC
6	KWABENA OTENG	F/G	RMSC
7	KWESI PINKRAH	F/G	RMSC
8	GEORGE OSEI KWADWO	NSP	RMSC
9	KWABENA JAMES	DRIVER	RMSC
10	KWAME AFRIFAH	DRIVER	RMSC

6.3.3. Data cleansing and analysis

Data was collected on paper field sheets and was entered into the Open Foris Collect for data cleansing under supervision of Emmanuel Opoku at RMSC. The cleansed plot data was exported in xml-format into the calculation spreadsheet template in MS Excel and uploaded for the AWF plot calculation. The enumerated field data can be found in Annex 6-3A. The selected allometric regression models (See Chapter 4.1.7) were adopted for tree-level above-ground and below-ground biomass stock computation for the 1st year update plots. The laboratory physical and chemical analysis results were received from the Soil Research Institute to compute litter, non-tree and soil carbon stocks. The results were computed by the team formed by Emmanuel Opoku, Emmanuel Donkor, Kwame Oteng and Samuel Ayesu under supervision of the Consultant team expert. The plot results are shown in Table 6-5.

Table 6-5: Plot-level carbon stock (t/ha) results of the 1st year update (*only downed deadwood due to lack of wood densities, **approximate division of total sample in the field)

Plot ID	Team Leader	Above-ground C	Below-ground C	Deadwood	Litter C	Non-tree C	Soil C
365	Raymond Votere	21.3	6.4	32.9	1.3	0.47	41.5
366	Raymond Votere	2.3	1.2	5	1.7	0.03	24.5

367	Raymond Votere	13.1	7.7	9.6	1.9	0.36	40.9
368	Kwame Oteng	25.2	5.8	2.0	0.6*	0	NA
369	Kwame Oteng	8.4	9.3	0	1.7*	0	NA
370	Kwame Oteng	6.7	5.5	4.5	1.6	0.13	16.6
	Average	12.9	6.0	9.0	1.5	0.17	30.9
	Standard deviation	8.8	2.7	12.1	0.5	0.2	12.4

6.3.4. Outputs

The task 24 outputs are described in the Table 6-6.

Table 6-6: Outputs of Task 24

NO.	Item	Type	Where to Find
1	Report on the success of the task undertaken by the FCG staff	Report	This Report
2	Recommendations for further training / support	Report	This Report
3	Field data results	Report Data	This Report GIS Server at RMSC

6.3.5. Conclusion

6.3.5.1. GNSS data collection and processing

The GNSS team staffs at FCG-RMSC were taking care of the equipments nicely. All the equipments were in good shape and working condition. Batteries were charged regularly. The data collection of GNNS from the sample field plots by FCG-RMSC staff was done efficiently in a static mode without handling the survey controller. They could centre and level the GPS on base station, connect the cables with antenna

and receiver, and log the data. They could also efficiently connect a rover to antenna and set on the mountings and log the data from the rovers. GPS Survey field book were filled properly, however it was on the loose paper. GNSS had problem to capture the data under deep forest. It was not required; however it would be advisable to use Survey Controller to know the status of the satellites and PDOP.

The GNSS team could download the data from receivers to the computer without any difficulty. During data processing they were consulting with consultant frequently. Initially the FCG-RMSC staffs were calculating the position using the available height without considering difference between the orthogonal and ellipsoidal heights. They were also using the Global Geoid model (Earth Geoid Model (EGM96)) developed by NASA, without knowing what would be output height. The consultant explained the theoretical background and then they were able to process the data correctly by taking account of these issues.

It has been recommended that at least three staffs should be involved in the GNSS work. A 15 days training should be organised to enhance the theoretical background and advance uses of GPS/GNSS. Hard binding field book should be used during the filed work.

6.3.6. Forest Inventory Survey

The inventory teams that participated in the 1st year update field work have gained solid routines for all the introduced measurement instruments and workflow. The FCG staff has also achieved good results for implementing the standard formulas for computing the carbon densities for 6 pools at plot-level.

Once the sample plot planning has been completed carefully taking necessary resource and working environment constraints (e.g sparse road network) into consideration, the plan must be followed except in cases when the planned plots are found completely inaccessible in the prevailing field conditions. In those cases, we recommend to skip the inaccessible plots and save efforts for reaching the other plots. It is important to get prepared for field mission well in advance and check that all the necessary instruments and accessories are in a normal condition, accessible and fully charged by the time of field mission departure.

Another important notation is that all the required measurement variables should be measured carefully with the proper instruments and field data inserted rigorously

into the field forms. Following the digital data collection will help to avoid text misinterpretations, to avoid unnecessary delays with the data entry and to go through the data cleansing already in the field conditions before leaving the inventory site. It is recommended to have a dedicated person to carry out data cleansing in the field.

During the 1st year update task the forest inventory team members expressed their interest and need for more practice with non-tree, litter and soil sample extraction techniques as most of the time SRI staff performed these sampling. It is recommended that FCG/RMSC should make necessary arrangements for the future soil carbon stock assessment and monitoring purposes to offer an opportunity for practicing FCG/RMSC staff. Furthermore, refresher training should be organised time to time on deriving a statistically sound field sample plan, enumeration of the sampling plots and taking the sample for laboratory analysis, biomass/C-stock calculation and others.

6.4. Task 25: Oversee the Process to Update Forest Resources and Change Datasets, and the Simulation of Future Forest Using Updated Input Data

6.4.1. Introduction

In this Task, works of Land Use Change (LUC) analysis and creation of forest conversion risk map were carried out by FCG staff under the supervision of consultant.

6.4.2. Land Use Change Map

Before creating the change map, the pixel resolution of LU image of 2012 was re-sampled to 30m that is similar to that of 2010. The Land Use Change (LUC) was

done using the matrix union. The result is presented in Figure 6-7 along with is conversion matrix with area in (Hectare, Ha) in Table 6-7.
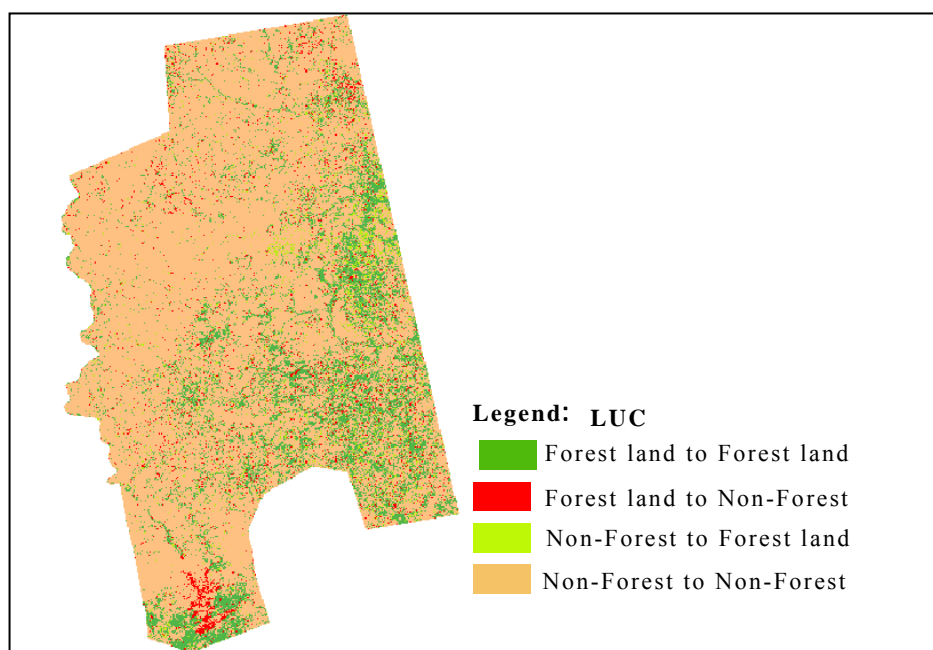
Figure 6-7: Land Use Change (LUC) (2010 – 2012)

Table 6-7: Land Use Conversion Matrix 2010 -2012

2012 \ 2010	Forest land	Cropland	Grassland	Settlements	Wetlands	Other land	Total LU Area in 2010 (Ha)
Forest land	357,852.6	15,111.5	62,256.2	85.1	9,876.2	2.3	**445,183.8**
Cropland	7,656.2	215,160.5	70,664.6	527.5	3,052.7	98.2	**297,159.7**
Grassland	78,678.4	152,508.4	1,423,517.3	399.2	13,443.3	107.3	**1,668,653.8**
Settlements	103.5	304.3	306.6	4,922.1	3.8	0.0	**5,640.3**
Wetlands	203.0	260.3	293.8	0.2	4,647.2	0.0	**5,404.4**
Other land	200.9	133.0	904.3	3.0	24.9	0.0	**1,266.1**
Total LU Area in 2012 (Ha)	**444,694.5**	**383,477.9**	**1,557,942.8**	**5,936.9**	**31,048.2**	**207.7**	**2,423,308.1**
Net LU Change Area (Ha)	*-489.3*	*86,318.3*	*-110,711.0*	*296.6*	*25,643.8*	*-1,058.4*	

Figure 6-7 and Table 6-7 show that there is slight to and from conversion of Forest land. Moreover, during these two year period, one of reason of LU conversion is due to construction of Bui Dam. The net change in Forest land is only -489.1Ha (that is, about 0.1% of its area in 2010), which may be considered as minor one.

The LUC image was tiled in accordance with 1:100,000 index maps in Erdas Imagine employing similar procedure as adopted for Task 8. The analyzed area was located in 16 map sheets. Their map layout was compiled in ArcGIS at 1:100,000 scale

including background data such as settlements, road, and output was prepared in MXD and PDF format.

6.4.3. Forest Conversion Risk Map

Risk map was produced showing the forestland which is at high risk and which is at less risk. For this, the same conversion risk factors along with classifying criteria; those were decided in the meeting among the involved stake holders (FCG, FORIG, RUDAN, and FPP) on 19th July, 2012 (refer to Annex 2-4A for detail); were used.

Buffers were created for Towns/Settlements and Roads with slope of the surface created using the DEM. Results of the buffers and slope with its table displayed in Figure 6-8.

Town/Settlement

Town_All

	FID	Shape	C_Weight	F_Weight	BuffDis_Km	Product
▶	0	Polygon	1	0.5	>10	0.5
	1	Polygon	2	0.5	5 - 10	1
	2	Polygon	3	0.5	0 - 5	1.5

Road Network

road_final   X

	FID	Shape	C_Weight	F_Weight	BuffDis_Km	Product
▶	0	Polygon	1	0.3	>10	0.3
	1	Polygon	2	0.3	5 - 10	0.6
	2	Polygon	3	0.3	0 - 5	0.9

Slope

slope_clip

	FID	Shape *	C_WEIGHT	F_WEIGHT	Slop_Perct	Product
▶	0	Polygon	0.2	2	20-40	0.4
	1	Polygon	0.2	3	0-20	0.6
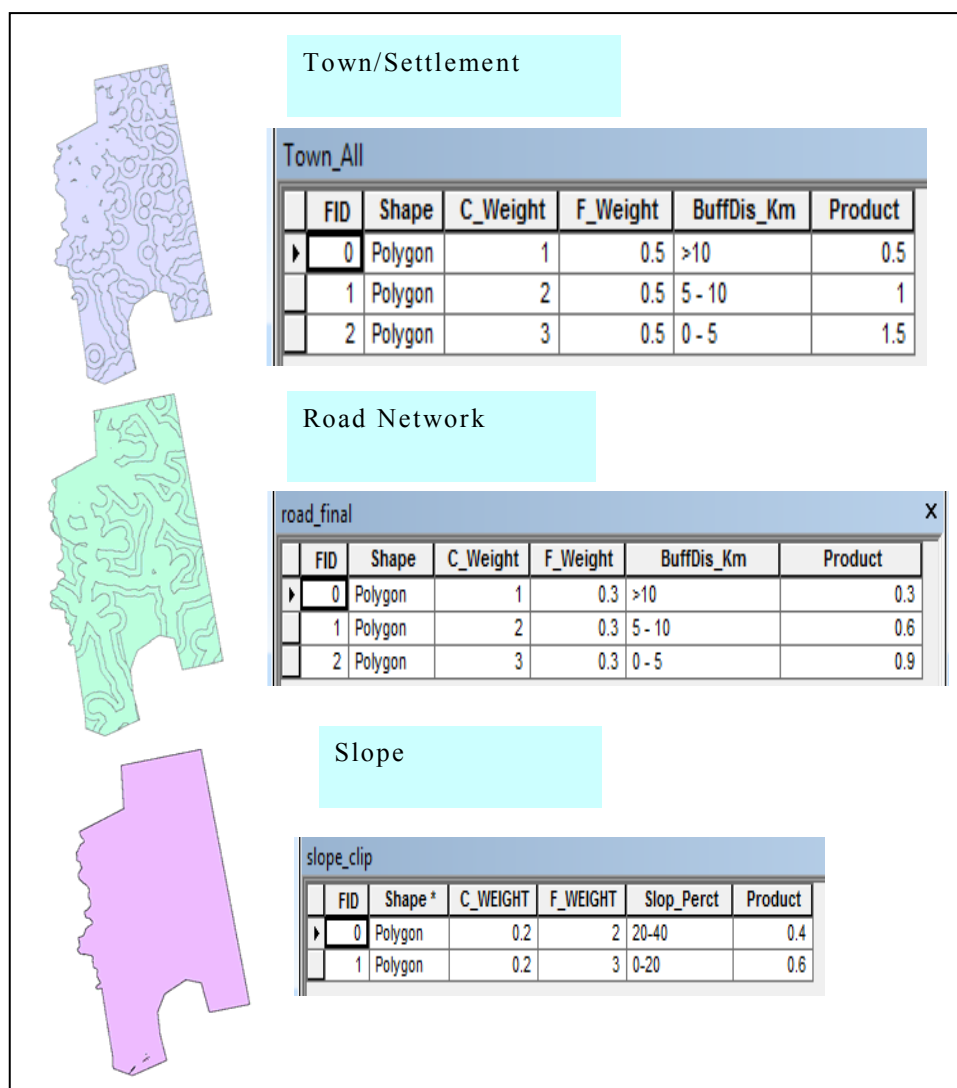
Figure 6-8: Created Buffers of Settlements, Road, and Slope

By overlaying the buffered result of above risk factors; Settlements, Road, and Slope, the forest conversion risk map was created, refer to Figure 6-9 below:
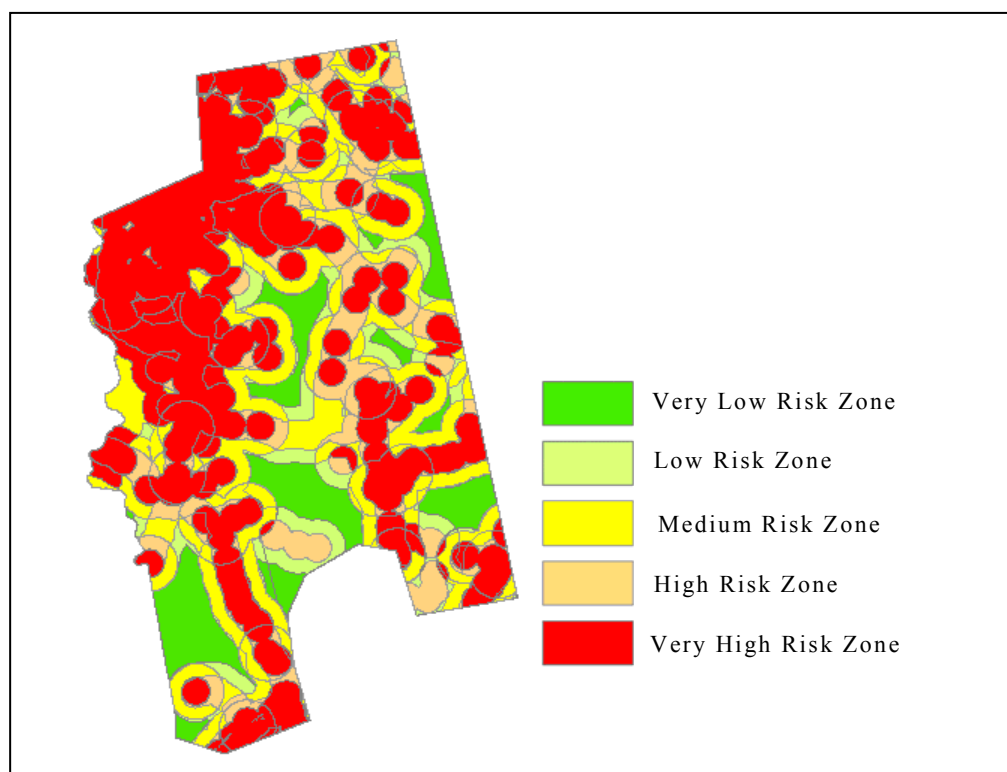
Figure 6-9: Conversion Risk Map in the Analyzed Area

The level of risk was categorized in to 5 following the similar class interval criteria that ware adopted in Task 10. Thus, the areas having highest accumulated risk after overlay of all three risk factors were included in Very High Risk zone and lowest in Very Low Risk Zones. The result of classified risk area was similar to that achieved for 2010.

The above conversion risk map was overlaid on to the forest land of 2012 to know the conversion risk within the forest land. And, the result is presented in Figure 2-31, which reveals that significant of forest land in the analyzed area, is under 'High Risk Zone' to 'Very High Risk Zone'.
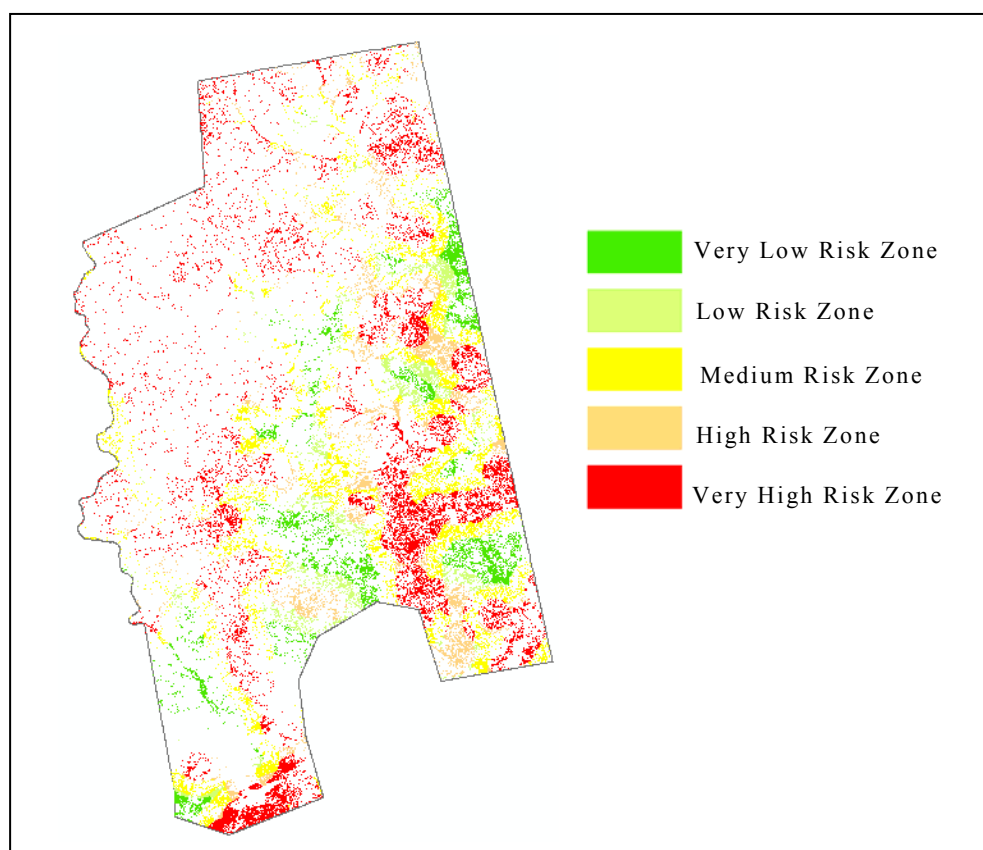
Figure 6-10: Resulted Conversion Risk Map within the Forest Land of 2012

6.4.4. Outputs

Table 6-8 shows the outputs of Task 25.

Table 6-8: Outputs of Task 25

NO.	Item	Type	Where to Find
1	Report on the success of the Task undertaken by FCG staff	Document	This Report
2	Recommendations for further training/support	Document	This Report
3	Updated resource database and forecast model	Document	External HDD/ GIS server at RMSC

6.4.5. Conclusion

This task involved more technical discussion since participants were already well versed in the use of the Erdas Imagine and ArcGIS Software. Thus, in future they will be able to carry out such work themselves confidently. However, a well planned refresher training is recommended to keep the staff up to date for recent developments in application of Remote Sensing and GIS for forestry.

6.5. Task 26: Conduct a Seminar and Workshop to Inform Al the Relevant Stakeholders and Organisations of the Aims and Outcome of the Project

6.5.1. Task Overview

One day workshop and one day seminar were conducted to inform the concern parties and stakeholders about the outcome and result of the consultancy services. The workshop was internal and organised for the FCG staff, while seminar was for all other relevant stakeholders.

6.5.2. Workshop

The workshop was organised by FCG in collaboration with consultant on March 5, 2013 at Wood Industry Training Center (WITC), Kumasi. The title of the workshop was "Presentation and Discussion of the Draft Result at the Expanded Executive Management Team (EMT) Meeting". The EMT is below the FCG board, who govern day to day business of FCG. As it was expanded EMT, there were other FCG staff, such as district managers, national park managers, regional directors, who participated in the workshop. The list of participants is given in Annex 6-5A and the programme of the workshop in Annex 6-5B. As it can be seen in the programme,

there were three part namely; opening and welcome, technical presentation and group discussion. The first was conducted by FCG-RMSC, second by consultant and last one by EMT. In the opening remarks, Chief Executive, who chaired the workshop, mentioned that FPP was one of the most successful programmes undertaken by FCG. During the recent briefing of FCG activities to MLNR minister, FPP was also briefed and received enthusiastic remarks from the minister. So he asked participants to pay attention during technical presentation and grasp it so that we can present them to various stakeholders with confidence. After the opening remarks three presentations were made, the first one was overview of the FPP presented by FCG followed by two presentations, one each from FORIG and SRI. The detail of the presentations is given in Annex 6-5C.

During the technical sessions, the resulted data, analysis outputs and results were presented by the consultant team. There were 5 presentations; namely mapping historical LU and LUC at national level LULUCF, pilot area forest resource mapping, study area forest inventory and biomass estimation, capacity building including forest inventory system and 1st year update. The detail of the presentation is given in Annex 6-5D.

The floor was opened for question and answer and comments after the technical presentation. There were couple of questions and clarifications on the allometric model, biomass estimation and LULUCF.

(a) For above ground and below ground there are 5 and 6 models respectively followed by ecological base models. The question was which model was used out of so many models and what was the error? Furthermore, selected or all tree destructive sample data were used in modelling or not and how about the savannah? Also it was suggested that one model for the Ghana should be used.

It was clarified that all the collected data, including from savannah, were used for modelling. In the process of modelling the R2 and RMSE were produced for evaluation and selection of models those suits for particular condition of ecological zone. Furthermore models were produced by inputting different combinations of input variables (diameter, height and density) so that in future appropriate model can be used based on the available data. For input data of density, the average of bottom, middle and top of steam and branches density was taken. For the height, it has good

correlation with biomass. Regarding the use of one standard model for whole Ghana, it was clarified that it would not be good idea. Appropriate model for different vegetation or forest type gives better estimation.

(b) Comparison of estimated biomass with other institutions value, such as IPCC default value was performed or not and issue of overestimation deadwood biomass and colour and grid size of the biomass distribution output map were raised. Furthermore, the biomass calculation for different tree types such as teak, cocoa, etc. should also be considered.

It was clarified that these issues will be addressed before the seminar presentation. Regarding the biomass estimation of teak, cocoa, etc. it was clarified that there was not such provision in the scope of work; however the data and model produced could be useful for future work on these areas.

(c) There were couple of question about the definition of forest and other land use categories.

It was clarified that, these were defined by FCG within the IPCC definition.

(d) There were some questions and clarification demanded on the input data in simulation of the deforestation risk.

It was clarified that the consultant together with FCG expert team selected the best data available from secondary source, which could be used for simulation despite of knowing that these data were not sufficient to do so. And it was suggested that recent socioeconomic and livelihood survey should be conducted in and around the forested area to make such simulation.

After the technical presentations, group discussion was organised by EMT to evaluate and discuss the presented data, analysis output and results. There were four groups one each to discuss on (i) national level LULUCF, (ii) pilot area forest resource mapping and inventory survey, (iii) biomass/c-stock estimation and (iv) prospect of trading under REDD+ mechanism and data sharing and implication on

forest management policy and ongoing and future forest programmes. The outcome of the discussion were presented by the EMT as given in the Annex 6-5E.

At the end of workshop, director of RMSC thanked the consultant for presenting the data, analysed output and results, which were appreciated by the EMT. Further he thanked the participants for active participation and critically evaluating the outputs and results during the group discussion and presented their report. Finally the chair closed the workshop.

6.5.3. Seminar

The seminar was organised by FCG in collaboration with consultant on March 12, 2013 at FCG auditorium, Accra. The title of the workshop was "Presentation of the Mapping Results of the State of Forest and Carbon Stock in Ghana". Besides the EMT member, most of the participants were invited from various stakeholders. The list of participants is given in Annex 6-5F and the programme of the workshop in Annex 6-5G.

As it can be seen in the programme, there were two sessions; opening and presentation of resources. Both sessions were chaired by Nana Ohene Wontumi II, Member of FCG Board. During the first session welcome address (Annex 6-5H) was delivered by Chief Executive of FCG followed by two statements by representatives of Minister from Minister for Environment, Science, Technology and Innovation (MESTI) followed by Japanese Ambassador. The opening was concluded by the keynote speech by representative of Minister from Ministry of Lands and Natural Resources (MLNR). The speakers were highlighted the importance of forestry for socioeconomic and ecosystem services to the society and added that recently recognised value of forest for carbon sequestering, thus emphasised on the need of forest conservation. MESTI representative talked about green growth and sustainable development and MESTI effort to achieve them, such as Environmental Protection Agency (EPA) is preparing environmental policy where role of natural resource for carbon capturing will be highlighted and recognised as services, which might lead to payment for environmental services. For this purpose coordinated approach is needed from EPA and FCG. Furthermore, representative from Japanese embassy highlighted

the utilisation of the output and results from FPP and sustainability of the developed system and continuation of work based on the acquired knowhow from FPP.

During the keynote speech, MLNR representative thanked Japanese government and mentioned that one year after handing over of HW/SW, Data and Vehicles to the former minister, now he is eagerly waiting to see the output and results produced by utilising them, which is going to be presented shortly in second session. He mentioned two important issues those are going to be addressed during the presentation, namely (i) output will provide baseline forest information and forestland change trend will reveal if carbon-sequestering is reducing the carbon-emission and (ii) national plantation programme, which was running for several years now, is adding any value to the quality of forest and forestry sector job creation. The output and results will have impact on new forest and wildlife policy and working document such as forest master plan. Finally he thanked PASCO consultant, for successfully completing all tasks on time, and FCG staff who were assigned to collaborate with them to get technical knowhow for future work.

The second session was started with overview of FPP and declaration of main output and resulted resources from the consultancy services. It was followed by two presentations and one demonstration from the consultants, where national level LU and LUC and pilot area detailed forest resource mapping, forest inventory and biomass/C-stock estimation and available MM&FI capability of FCG were presented followed by online demonstration of available data, analysis output and results. The session was concluded by presentation from FCG on issues and way forward. The presented materials are given in Annex 6-5I.

After second session, the floor was opened for questions and clarifications. Some of the questions and clarifications presented hereafter.

(a) Clarification on the Ground Truthing (GT) and Ground Verification (GV): There was question about the different number of GT and GV. The GTs were collected to train the image processing for extraction of LU while GV were used for verifying the resulted LU map on ground so that necessary correction could be made if there is misclassification. There were set technical specification for collection of minimum number of GT and GV, however effort were made to collect maximum possible number to enhance the accuracy of classification.

(b) On the comment of the forest land deforestation and degradation were not mapped, it was clarified that in the matter of fact it was mapped. For example there is further stratification of forest land in open and close forest, which showed the

trend of both forest types over last 20 years (1990 to 2010) time. Form this trend; it can be easily interpreted about the issue of deforestation and degradation.

(c) On the question about expansion of forest land over time was result of natural regeneration or plantation. The answer was that there is no plantation and natural forest classes in the classification scheme, thus difficult to answer; however the data can easily be used to extract it. For example, by overlaying the polygon of plantation area on the LU map, plantation and natural forest could be segregated and trend can be analysed for these two categories of forest land.

(d) After congratulating the consultant and FCG staff for excellent work, the questioner asked about the mapping status of rubber plantation as huge swath of open forest land or other land use type is being converted into rubber plantation, which is having clear cut felling cycle. It was clarified that being an IPCC definition based LU mapping, such issue had been already defined and taken care of into the definition of six LU types.

(e) On the query on the opening access to available data and outputs, FCG clarified that FCG is now custodian of data and will prepare necessary mechanism to share them with all stakeholder with due procedure.

(f) There was confusion about the way forward presented by FCG as it suggested continuous training for the FCG staff for utilisation of resources. It was clarified that this was not the case, but the trained FCG staff will continue to train more FCG staff about the utilisation of available resource and further analysis and implementation of similar work.

(g) On the question of increment of forest land mainly from conversion of close forest to open forest, it was explained that the analysis showed close forest is decreasing, open forest is increasing and in totality the forest land is increasing, thus it was not the case. There are six categories of LU and complex (6 by 6: 36 conversion possibilities) change had been going on spatially. Thus it is difficult to conclude that the increment of forest land was just conversion of close forest to open forest.

(h) There was issue on the classification of some of the cropland, such as fruit orchard (citrus) and palm plantation into forest land. It was clarified that (i) there might be some classification error, which was given into accuracy assessment (overall accuracy is about 84%) and (ii) during the GV it was found that there were tree on the farm and if it meets the criteria of forest land definition then such land could be classified as forestland.

(i) EPA wants to authenticate the data and output so that it can be reported to 3rd national communication. Furthermore, FCG should consider to include EPA staff in capacity building activities as they are also engaging on similar kind of work.

After the floor discussion, the chairman had delivered the concluding remark (Annex 6-5J) before closing the workshop.

6.5.4. Outputs

Table 6-9 shows the outputs of Task 26.

Table 6-9: Outputs of Task 26

NO.	Item	Type	Where to Find
1	Report on the seminar and workshop and feedback from the participants	Report	This Report Annex Chapter 6

6.5.5. Conclusion

One day workshop and one day seminar was conducted on March 5 and March 12, 2013 respectively. The events were organised by EMT of FCG in collaboration with the consultant. The workshop was organised with two key objectives namely; (i) informing data, analysis output and results of consultancy services to FCG staffs followed by (ii) evaluation of data, analysis output and results. Based on the evaluation report, the consultant took necessary measures to finalise them for presentation during the seminar. The seminar was organised to inform the data, analysis output and results to the all stakeholders. The key objectives were, announce the status of forest cover and carbon-stock in Ghana and availability of data, analysis output and results those could be shared online with the potential users.

7. Concluding Remarks

7.1. Mapping Historical Land Use and Forest Resource Change Assessment

Wall-to-Wall LU and LUC were mapped using UNFCC/IPCC-LULUCF classes for 3 epochs; 2010, 2000, and 1990; covering whole Ghana. Medium (for 1990 and 2000; Landsat) and high (for 2010 ALOS-AVNIR-2) resolution satellite imagery were used as source data for this forest resource mapping. The overall accuracy of 2010 LU map as was 83.87%, which is quite satisfactory. While using these LU maps the context and definition of land use categories should always be taken into account for any interpretation and analysis.

The extracted Forest Land Crown Cover (CC) classification from the satellite images of 2010 epoch was further stratified using REZ, PDU and LMS layers to generate Baseline Forest Resource Map of Ghana, which is having detail information regarding forest status. It is expected that such information will play a vital role in monitoring of Forest Land use and Biomass/C-stock status in future.

The forest conversion risk map was created considering the available secondary data, such as Settlements, Road, and Slope, which were considered as main driving factors for human activities within the forest land. The risk map shows majority of forest land is under very high risk zone meaning these are closer to settlement and road, and have gentle slope. In such forest land, greatest degree of human activity is possible. However, inputted geophysical and geopolitical/socioeconomic data are not sufficient to draw a concrete conclusion. Thus, primary data on geopolitical/socioeconomic, such as social services and livelihood of people, living in and around forest land, should be incorporated for simulating various scenario based risk maps, which may provide a realistic scenario about the conversion risk. In order to address the conversion risk, appropriate policy measures, in terms of strategic development plan and provision of social services, could be extracted from such simulated risk maps.

The trend of forest coverage change showed total area of forest land in Ghana is increasing over last 20 year time; however such increment is coming from open

forest as close forest is in decreasing trend. Thus, it can be reasonably concluded that the issue of Ghanaian forest in not deforestation, but forest degradation in totality. It demands further close analysis of forest land for its crown cover based geospatial distribution and quality of forest land for providing not only socioeconomic but ecosystem services as well. Furthermore, it would be desirable to extend the data to firm a clue for building the base line of biomass estimates with more sound analysis of socioeconomic consideration.

7.2. Pilot Area Forest Resource Mapping

ALOS-PRISM together with ALOS-AVNIR-2 satellite imagery data proved to be effective to derive 1:50,000 Forest Resource mapping quickly. However, for cloudy areas, some secondary source data, such as Google earth map was referred. The extracted features were compiled into a seamless geo-database. The compiled data were used for cartographic map composition. First an index map was prepared showing all 42 maps sheets followed by composing individual map sheets/tiles (ESRI MXD format) and printing into softcopy (PDF file format). If the Geodatabase is updated with new features, it will automatically reflect in the MXD file. Then print out should be taken from MXD file and a new set of PDF file should be created.

Due to lack of GEOID model of Pilot Area, orthometric height could not be derived from ellipsoidal height of the GCP. The ellipsoidal height was used for AT of ALOS PRISM images and universal GOEID (EGM96) was used to create contour and spot heights. For LiDAR data acquisition and GNSS survey for field plot sampling, ellipsoidal height were used, which served the purpose of tree height extraction from the relative height of DTM. However, it is recommended that Survey and Mapping Division of Ghana, should work in the direction to create an accurate Geoid model of the country for future use.

7.3. **Study Area Biomass Inventory**

Regarding the enumeration of field plot sampling sites, one team was expected to sample one plot cluster a day for all six carbon pools, but in practice it could be achieved only one plot a day in closed forests and up to two plots in a more easily accessible terrain. It was found that in the dense canopy plots, the GNSS receiving was somewhat poorer than in the open canopy areas. Most of the points inside the dense forest were not observed due to lack of reception of satellites. This time the mangrove forest pilot area was formed by two small patches and most of the plots were not visited due to reported inaccessibility reasons. A more systematic sampling procedure should be targeted to coastal mangrove areas in the future. For belowground biomass, stumps of the harvested trees should be included in future. Regarding litter pool, there may be some degree of chances or variation over the different seasons, so monitoring permanent sample plots may assist in modeling this dynamics.

The highest above-ground biomass/C-stock concentrations were found in closed forest located in wet evergreen, moist evergreen and moist-semideciduous south-east zones. Deadwood in large quantities was discovered in Moist Evergreen plots due to trees felled on the cocoa farms admitted to expand into the forest reserves and palm pruning residues of palm trees in off-reserve areas.

The applied LiDAR-Assisted inventory approach for carbon stock assessments relied on the 5 % LiDAR transect sample. Implementation of a LAMP approach helped to lower necessary field sampling intensity and LiDAR data provides a prior information basis for objective and efficient field plot sampling. Besides, it allowed to generate number of extra biomass sample plots, called as surrogate sample plots, with the help of regression models relying on LiDAR metrics for different broad forest types (strata).

However there is some difficulty of LiDAR pulse penetration in some cases of dense forest. Once in forests with high canopy closure and dense ground vegetation layer, only a few observations penetrate to actual ground level, and the LiDAR hits from lower branches were easily interpreted as ground returns in classification procedure. The classification correction procedure was applied to remove such error. Accurate LiDAR derived forest height data and canopy closure data was delivered.

A look-up table for C-stock average values was generated from the pilot area inventory survey and biomass estimation and extrapolated at national level. It is advisable to conduct nationwide sample plot to assess the validity of the look-up table.

7.4. Capacity Building

After acquisition of necessary Data, HW/SW and Forest Inventory Equipments, installation of HW/SW and deployment of forestry inventory equipments, all required trainings (both handout and on-the-job) were conducted to build the FCG capacity and capability for MM&FI. Trainings were conducted for several groups; namely GIS/GPS, System Administrator and Database, RS, LiDAR Data Processing, Forest Inventory Survey, Biomass/C-stock Estimation and GNSS; of FCG staff who engaged in various types of data collections, input and analysis followed by devising FIS. During the training and data collection and processing, all necessary manuals were prepared and delivered, which can be used for future reference as well.

Well devised online data sharing protocol was created that comprise (i) main GIS server, (ii) WebGIS sever and (iii) Backup server. All the collected, processed and resulted output data and results were compiled into database on the GIS server. Selected data were published on WebGIS portal for data and information sharing with stakeholders. The main GIS server and WebGIS server are located in RMSC, Kumasi while the backup server located at FCG headquarter Accra. The backup sever secures data by taking backup on regular (defined with standard practices) basis.

7.5. Forest Resource Inventory 1st Year Update (2012)

Most recent Satellite data; for both optical and SAR; from DMC and TerraSAR-X satellites respectively, were found in archive, thus imagery selection process

conducted smoothly by FCG staff under the supervision of consultant team expert. The participated staff had good knowledge of RS as well as the functions of Erdas Imagine. Thus, in future they will be able to carry out such work themselves confidently. The image processing related activities, such as GT, classification, GV, accuracy assessment, were conducted with the help of manuals as well as occasionally consultation with consultant team expert.

For data updating and management of geodatabase, the ICT team were found to be well versed; however the RS and GIS team were seeking consultation quite often. Also, there is in sufficient number of staff currently manning the RS and GIS division of RMSC. It would be advisable to have required number of RS and GIS staff to maintain and update the LU maps and the FIS. Also provision of short term training to enhance their capability, specifically on database architect and management and geospatial analysis, should be considered. Refresher training should be organised occasionally on remote sensing and GIS.

Regarding field inventory survey and biomass estimation three groups of FCG staff (GNSS/GIS, Inventory Survey and LiDAR assisted biomass/c-stock estimation) were involved for collection, inputting and analysing the data to obtained output and results.

The GNSS/GIS team handle and maintain the equipments in order. Static mode of GNSS was used to collect the field plot sampling location without using survey controller (as it is not must). The team could download the data from receivers to the computer efficiently; however data processing part is not so efficient. There were some shortcomings, such as calculating the position using the available height without considering the orthogonal and ellipsoidal heights. For instance as per instruction Global Geoid model developed by NASA, Earth Geoid Model (EGM96), should not be used as all GCPs in Pilot Area are in ellipsoidal height. Furthermore, there is only two staffs; one each at the office and filed work; are involved in the GNSS data collection and processing. In order to enhance the capability and knowhow of GNSS/GIS team, it would be desirable to increase the number of staff. Also a short term training should be organised for GNSS team tailored to theoretical as well as practical aspect of earth science and topographic surveying and data processing.

The inventory team conducted sampling designing of field sample location and plan using necessary software environment. Once the sample plot design planning has been completed in the office the implementation plan was prepared for field work. Necessary logistics were arranged for mobilisation according to the set plan. In the

field, it was found that the members were performing their role as it should be. After the completion of filed work the data input and processing for biomass/c-stock estimation were accomplished successfully. However some of the staff member consulted each other and some times with consultants, who were supervising them, for some critical issues. Furthermore, during the field work there was incidence of changing the sampling plan due accessibility problem, which should be avoided. Also some minor corrections were needed for collecting samples of all soil, litter, non-tree and deadwood and use of instruments. It is advisable that the forest inventory team members should be provided with refresher training time to time and orientation before starting future sampling and biomass/c-stock estimation. Regarding the LiDAR data processing exercise, it was found that FCG staff could handle it using the manual; however there is lack of sufficient theoretical knowledge of application of LiDAR in forestry. Thus it is recommended that month long customised training on LiDAR application in forestry should be provided to key FCG staff.

One day workshop and one day seminar were organised by FCG in collaboration with the consultant. The workshop was organised with two key objectives namely; (i) informing data, analysis output and results of consultancy services to FCG staffs followed by (ii) evaluation of data, analysis output and results. Based on the evaluation report, the consultant took necessary measures to finalise them for presentation during the seminar. Seminar was organised to inform the data, analysis output and results to the all stakeholders. The key objectives were, announce the status of forest cover and carbon-stock in Ghana and availability of data, analysis output and results those could be shared online with the potential users.

7.6. Way Forward

■ **Utilisation of the Data and Analysis Output and Results**

There are two main types of resources, namely (i) data and (ii) analysis output and results. For data, it can be further categorised into; (a) data collected from secondary source, (b) primary data in original form and (c) processed and collated data ready to be used. Similarly, the analysis output and results can be also further categorised

into (a) analysis resulted into output data (e.g. LU, LUC, Carbon map, Carbon look-up table, etc.) and (b) analysis report and manuals.

-   As specified in TOR, the resources were produced mainly for monitoring of the forest land both in terms of its quantity (area extent) and quality (health of the forest for ecosystem and related services). As demonstrated during the 1st year updating activities; where LU of year 2010 (baseline map) and recent satellite imagery of year 2012 were used; a time frame based monitoring for forest land change assessment can be devised for sustainable use of forest land and harness REDD+ benefits.

-   Historical time series mapping of LU showed that forest land area has increased; however there is significant conversion of closed forest into open forest. Thus, Ghana is having forest degradation problem, which will have serious implication on its potential to provide ecosystem and socioeconomic services. This will help FCG management to devise necessary policy measures to address it.

-   Original raw and processed and collated data and analysis outs can be used for various study and research oriented activities by targeting the specific problem (both technical and policy related issues) of sustainable forest management.

-   There should be a decision about which carbon pools are to be included in scope of the REDD+ monitoring activities. The selection criteria can be based on the criteria, such as available resources, existing data sources, feasibility and magnitude of potential changes in the pool due to deforestation and degradation processes.

■   **Limitations of the Methodology and Accuracy**

The LU classification was conducted in accordance with IPCC 6 LU types. Some of the agro-forestry and other commercial crops (cocoa, rubber, palm, fruits, etc.) could have been easily classified with open forest based on the definition of IPCC forest land. However, by superimposing cocoa/tree plantation sites on the developed LULUCF map may provide information on contribution of these vegetation to open forest cover. This will enable FCG to differentiate cocoa and rubber in the classification of other Land Use categories.

The accuracy of the LU classification is about 84%, which should be taken into account while interpreting the result. The speculation of overestimation of open forest might be due to the inclusion of cocoa farms with tree as open forest.

Under FPP, the MCS focus on the pilot area located in South-west to the mid-portion of the country and that the pilot areas did not capture areas such as Central and Upper Regions of Ghana. This gives the C-stock estimation with known accuracy only for pilot area. The accuracy for the county level C-stock estimation could not be known, thus need validation. Thus, as an important way-forward, it is suggested that the temporary sample plot coverage is extended over the entire country.

As it has been demonstrated, the model-based inventory approach relying on a 1-5-% LiDAR sample helps to reduce the required number of temporary sample plots to one tenth in comparison to a pure plot-based approach to meet the 10-percent precision in above-ground and below-ground carbon stocks. Permanent sample plots (PSPs) are needed to collect systematically growth, mortality, regeneration and carbon stock change data for different forest types. If the plots those measured in the past as part of PSP scheme, can positioned precisely in the field, it will be worth of considering reviving this. Relatively, large PSPs (at minimum 1 hectare size) allow reliable independent quality assessment of the nationwide carbon stock maps which are produced though modeling approaches using field plot data and remote sensing data (LiDAR-sample data, wall-to-wall satellite optical or radar data). Even up to 50 PSPs spread over the entire country can provide a good basis for that.

■ **Implication of the Results on Other Ongoing Initiative**

Some of the important implications are listed below:

- Based on the land use change trend, the ongoing initiatives should be revisited. For example, priority should be given to address the forest degradation as the impact of degradation on general health of forest and loss of biodiversity is very sever and some time irreversible.

- Revisiting the 600 one-hectare permanent sample plots and expanding the measurements parameters so that it could be used for carbon stocks estimation in addition to forest growth monitoring.

- For human resource capacity building related initiatives should be revisited to accommodate and take advantages of carbon stock assessment and computation all six carbon pools. For this a systematic programme should be designed.

- The forest inventory and c-stock pilot area covers only south-west and small patch in the central region of the country. Expansion of the plots to cover all parts of

Ghana and in this regard, identify synergies with other initiative in the country such as by the German and Italians.

-        Initiation for incorporating the carbon stock fund in regular activities so that different land use stands and cover. e.g. Teak stand, Rubber stand , Cocoa etc could be covered for C-stock inventory survey.

-        Initiation to accommodate the deforestation risk simulation work in one of the on going forest management activities by considering the impact of different drivers of deforestation/ degradation (agriculture, wildfire, demography, socio-economic activities, etc.) to inform policy and planning.

■   **Capacity Gap to be Addressed**

-        Online forest inventory system is running at RMSC with backup facility at FCG headquarter. The RMSC's IT section facility is not sufficient, specifically in terms of continuity in power supply. The necessary provision of uninterruptible power supply (UPS), which can sustain over 10 hours, and a stand by generator should be considered

-        Data storage: There should be provision of HD with sufficient space for future data storage at IT section of RMSC.

-        The number of staff working in GIS/Remote Sensing section at RMSC is not sufficient. Furthermore, a short terms diploma training is desirable specifically on LiDAR data processing and biomass/C-stock estimation for all 6 pools to enhance the underlying theoretical and technical background and estimation procedure.

-        Allocation of resource should also be considered for the provision of field logistics for inventory survey, specifically campaign gear that suits the local micro-climatic condition of different ecological zone.

-        It is also suggested that there should be a systematic capacity-building programme designed and implemented. There should be an extensive pool of capable staffs and other supporting resources in the districts to carry field plot campaigns under RMSC coordination and supervision. Decentralization will improve feasibility of the field measurement activities in relation to the potential REDD+ benefits.

References

Bouyoucos, G. J. 1962. Hydrometer method improved for making particle size analysis of soils. Agronomy Journal 54: 464 – 465.

Garcia, M., Riaño, D., Chuvieco, E., & Danson, F.M. (2010). Estimating biomass carbon stocks for Mediterranean forest in central Spain using LiDAR height and intensity data. *Remote Sensing of Environment, 114,* 816-830.

Gautam, B., Tokola, T., Hämäläinen, J., Gunia, M., Peuhkurinen, J., Parviainen, H., & Sah, B. (2010). Integration of airborne LiDAR, satellite imagery, and field measurements using a two-phase sampling method for forest biomass estimation in tropical forests. In B. Gautam (Ed.), *International Symposium on "Benefiting from Earth Observation".* 4 - 6 October 2010, Kathmandu, Nepal. (pp. 1-7)

Haralick, R. M., Shanmugam, K., & Dinstein, I. (1973). Textural features for image classification. *IEEE Transactions on Systems, Man and Cybernetics, 3,* 610-621.

Junttila, V., Kauranne, T., & Leppänen, V. (2010). Estimation of Forest Stand Parameters from Airborne Laser Scanning Using Calibrated Plot Databases. *Forest Science, 56,* 257-270.

Junttila, V., Maltamo, M., & Kauranne, T. (2008). Sparse Bayesian Estimation of Forest Stand Characteristics from Airborne Laser Scanning. *Forest Science, 54,* 543-552.

Kangas, A., & Maltamo, M. (2006). *Forest inventory methodology and applications.* Dordrecht, The Netherlands: Springer.

Blake, G. R. and Hartge, K. H. 1986. Bulk Density. In: A. Klute, 2nd ed., Methods of Soil Analysis, Part I. Physical and Mineralogical Methods: Agronomy Monograph no. 9: 363-375.

Nelson, D. W. and Sommers, L. W. 1982. Total carbon, organic carbon and organic matter. In: Page, A. L., R. H. Miller, and D. R. Keeney. (eds.). Method of Soil Analysis. 2. Chemical and Microbiological Properties. Agronomy 9: 301 – 312.

Sah, B. P., Hämäläinen, J. M., Sah, A. K., Honji, K., Foli, E. G., and Awudi, C.: THE USE OF SATELLITE IMAGERY TO GUIDE FIELD PLOT SAMPLING SCHEME FOR BIOMASS ESTIMATION IN GHANAIAN FOREST, ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., I-4, 221-226, doi:10.5194/isprsannals-I-4-221-2012, 2012