LiDAR-Assisted Multi-source Program (LAMP) for FRA Nepal

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LiDAR (Light Detecting and Ranging) is an active remote sensing technology which provides precise 3D information of the terrain and vegetation. LiDAR pulse density from 0.5 to 2 returns per square meter is sufficient for forest inventory applications in general cases. It is also possible to assess vegetation height and density directly from LiDAR data. Accurate and high-resolution mapping of biomass and carbon density requires tree level field sample plot data and biomass models to calibrate statistical models based on LiDAR pulse data properties.

LiDAR-Assisted Multi-source Program (LAMP) is a branch of science which integrates LiDAR data with satellite imagery, and field data for estimating forest resources, biomass and carbon stocks. Therefore, it complies with the requirements of REDD+ in measuring, reporting and verification (MRV) of forest resources. ArboLiDAR method, developed by Arbonaut Ltd. in Finland, is an example of the newest LAMP method. ArboLiDAR is being implemented in Forest Resource Assessment (FRA) Project in Nepal in which Arbonaut is a consortium member. Arbonaut's LAMP methods have already been successfully implemented in Laos, Finland, and Sweden for similar studies.

In LAMP method, the LiDAR returns can be captured by systematic strips or by random blocks. Various weight functions can be used to calculate the right method for selecting strips or blocks for laser scanning. The weight can be based on a land use or forest type. Forest types with high internal variability are given higher weight. The bias aroused by weighting is removed in the estimation process by inverse weighting of the corresponding estimates.

In the ongoing Forest Resource Assessment, laser scanning was done in blocks because of the challenging physiographic characteristics. Nepal is aligned along the Himalayas and it is highly anisotropic, so parallel strips are prone to directional bias. Nevertheless, the most important reason using blocks was that the probability to get more forest plots are lower using the strip method than using blocks while intended long strips fall often to non-forested areas. The blocks were designed based on the stratification from a Landsat based forest classification by Dr. Anup Joshi. The weight function was calculated for every block. The flight lines were designed to cover the blocks (5 km x 10 km) wall-to-wall. LiDAR scanning mission also included additional 20 blocks covering 100,000 hectares in Terai Arc Landscape (TAL) area supported by WWF (USA, Finland and Nepal) and ITC/ICIMOD biomass sites in Gorkha and Chitawan covering 137,000 hectares.

Field plots were sampled using systematic cluster sampling in Terai and Siwaliks. Each block contains six clusters, and eight plots in each cluster. The plots are in two parallel columns which are stretched from North to South and in four rows which are set from East to West. The distance between the two columns is 300 m. The distance between rows is 300 m in Terai and 150 m in Siwaliks. The distance between cluster centres in East to West rows is 3333 m and in North to South columns 2500 m. A cir-

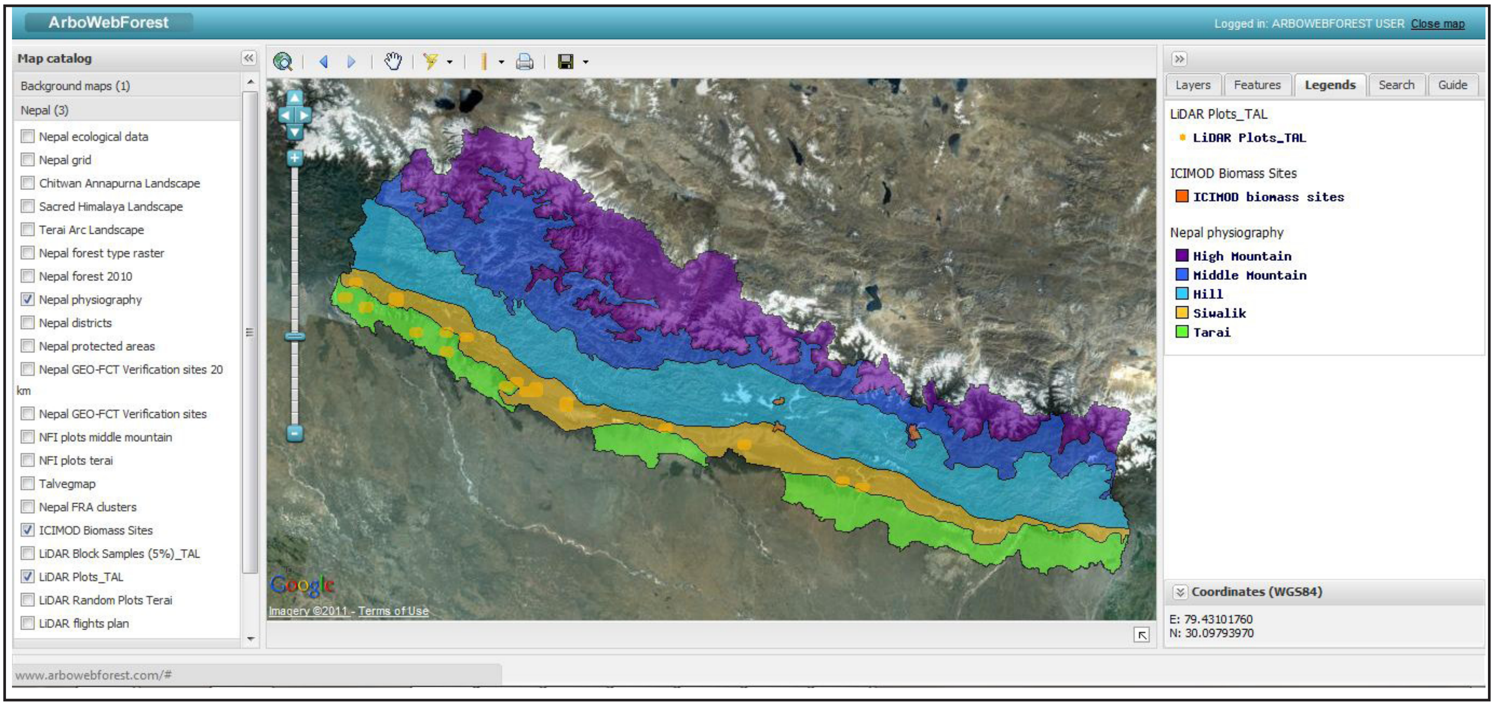

Figure 2 *LiDAR plots and ICIMOD Biomass Sites in ArboWebForest Web-GIS*

cular plot with radius of 12.62 m, equivalent of an area of 500 m^2, was designed to collect plot and tree level characteristics. All trees above the diameter of 5 cm at the breast height were measured within the radius of the plot. In addition to the systematic, some random plots were also collected from Terai. The reason for the random plots collection was to verify the sample-specific accuracy. Independent plot verification is very important to prove scientifically that carbon estimates are reliable.

Once results from LAMP method are verified within the blocks they will be cross-verified with National Forest Inventory (NFI) plots which are located outside the LiDAR blocks. FRA can use models based on forest parameters, for example carbon models for wall-to-wall estimates. This will make FRA estimates more accurate in high spatial resolution – and allow for attaining Tier-3 in REDD+ MRV. The high quality of results is guaranteed by the mathematical consistency that is required for the estimates. This will convince international authorities and donors for the reproducibility and dependability of the MRV process in Nepal. LAMP results from the two watersheds will be compared with the community monitoring results that ICIMOD has implemented. This is an important step in REDD+ in Nepal to verify participatory community monitoring with advanced remote sensing based monitoring, thereby integrating both approaches is important to reach the highest tier level. Highly accurate data means high compensations in REDD+ scheme due to a better reliability of the assessed amount of measured carbon stocks in forests.

The importance of the LAMP method lies in accurate estimation of biomass and carbon stocks. The traditional optical satellite images and Synthetic Aperture Radar (SAR) based monitoring are affected by saturation problem due to the lack of their capacity to reach ground from vegetation canopy. A strong correlation between the signal and biomass is crucial in measuring any other forest indices, for example tree volume. There is strong correlation between LiDAR (i.e. pulse height and vegetation point density) and biomass as long as some pulses reach the ground. But with both optical and SAR satellite instruments this correlation becomes flat when stem volume reaches a certain threshold (e.g. 150 m^3/ha). Due to this saturation effect estimations based on optical imagery may lead to significant underestimation of carbon stock in areas with high above-ground biomass concentrations (e.g. >200 m^3).

Training and capacity building are integral part of the FRA project. Once data have been processed and the results verified, appropriate documentation and training material will be produced. The materials will be used to train other stakeholders. Arbonaut has developed New Inventory Method (NIM) to involve stakeholders in processing and capacity building. NIM is inherent approach in most of the ArboLidar service for FRA, REDD+ and in developing countries in general, but also for all public forest organizations. Stakeholder can be involved in different phases of the processing. Some parts of the ArboLiDAR suite, such as ArboWebForest, already are – and will remain – free, since they are used on as a Software as a Service (SaaS) principle. ArboWebForest is an Open Source and internet based environment for monitoring national forest inventory, and REDD+ data. It maintains results on cloud servers, with background images coming from Google Maps. It supports mobile access from GPS devices and Android mobile phones. ArboWebForest requires only a web browser and an internet connection – no license fees are required. FRA data remains safe even if nobody uses or maintains it. This would be a great advantage for Nepal for effective monitoring of the results from the FRA Nepal project in the future.

NFI-Sample Units Design

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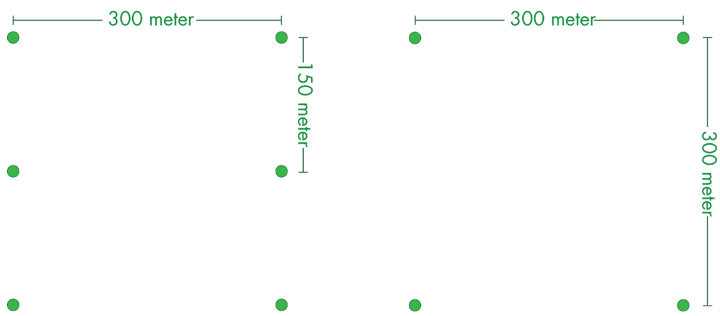
Nepal is a relatively small country covering 147,480 km^2 of land area. Topographically it can be divided into five physoigraphic zones from south to north. It is a diverse country with complex geomorphology, landform and climate within a short span in width. About three quarters of the Country's topography is rugged and fragile.In this context, the sampling unit is designed as a concentric circular sample plot (CCSP). The use of CCSP in forest inventory aims at increasing the accuracy of the measurement and sampling intensity of large trees, and simultaneously at saving time.

For the Hilly Region, including Siwaliks, there are six sample plots per one cluster. For the Terai physiographic zone (including the Inner Terai as shown in the Figure 3), there are four sample plots per one cluster. The reason for different sampling design in the Terai region is that Terai region is relatively flat. Variation of forests is much less in the Terai region, because elevation does not attribute to the changes in the ecotypes. Therefore, larger distance between plots is required for efficiency.



(a) Hilly Region (b) Terai/Inner Terai Region

Figure 3 *Clusters in (a) Hilly and (b) Terai/Inner Terai Regions*