Assessment of Aboveground Biomass-Vegetation Storage in Urban Centres Using Remote Sensing Technology

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Abstract: Urban centres have grown rapidly, expanding into areas that were previously used for agriculture or were occupied by natural vegetation such as forests. The development of human and productive activities has increased environmental degradation and pollution through greenhouse gas emissions, which further aggravates the aforementioned problems and increases the effects of climate change. One of the main pollutants is CO_2, which contributes to the warming of the earth's surface, but it can be removed from the atmosphere by vegetation and stored as biomass. In urban centres, the lack of vegetation cover directly affects the processes of air purification and carbon storage. This is why quantifying and monitoring the vegetation cover is crucial in urban environments. This monitoring can be done through remote sensing techniques supported by traditional processes such as data collection in the field. For this study, it was used satellite data from Sentinel 2 and data from an unmanned aerial vehicle (UAV). The obtained results indicate a scarce of vegetation cover within the urban centre.

1 INTRODUCTION

Nowadays, due to the increase in population and its productive and industrial activities, cities are the main sources of pollution and emission of greenhouse gases (Chen, 2015; Liang et al., 2017), which go directly to the atmosphere, affecting the environment. These gases threaten the health of living beings that inhabit a certain sector, but their effects expand globally (Manisalidis et al., 2020). According to data provided by the World Health Organization (Sivaramanan, 2014), there are around 3.7 million premature deaths due to air pollution, numbers that are continually increasing due to excess emissions from productive activities, industries and automobile circulation (Roser, 2021). Cities are among the main sources of emission of polluting gases such as CO_2, which is one of the main pollutants and generator of global warming (Sood & Vyas, 2017). That is why cities are also pioneers in finding ways to mitigate the damage and collateral effects caused by pollution (Chen, 2015).

To address the problem of the negative effects of polluting and greenhouse gas emissions, the use and implementation of urban green areas has been proposed as an alternative (Badach et al., 2020; Diener & Mudu, 2021), because vegetation purify the water, the air, sequester $C0_2$ from the atmosphere and release oxygen.

In continental Ecuador during the last decades there has been a strong decrease in plant cover, where different ecosystems have been affected, especially primary forests (González-Jaramillo et al., 2016), where not only is there complete deforestation, but practices of selective extraction of commercial species are carried out. Thus, near the populated areas, the pressure of demographic growth and the expansion of the urban area have generated the decrease and degradation of vegetal covers. One of these urban centres is the city of Loja, which in recent years has shown accelerated population growth due to the migration of people from rural to urban areas, thus triggering the expansion of the urban area and generating a considerable decrease in plant cover (Tello, 2012). The city of Loja currently does not have information on the vegetation cover within the

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city and previous reports such as INEC (2012), place the cantonal head well below the reference minimum threshold. For this reason, the objective of this research is to use data from remote sensors to determine the amount of existing vegetation cover in the urban area, specifically in the vegetation of the banks of the rivers and main parks of the city, this to estimate the accumulated biomass and therefore its carbon storage capacity.

2 STUDY AREA, MATERIALS AND METHODS

2.1 Study Area

The city of Loja is located in the south of the Republic of Ecuador at 2,100 m above sea level and has a land area of 5,757.14 ha. In addition, the city is crossed from south to north by two low-flow rivers (Malacatos and Zamora), both intersect downstream of the city to form the Jipiro River. In the urban centre there are 21 types of vegetation cover (Villa, 2009), among which are dominant tree species such as: arupo, cascarilla, molle and sauce llorón (Salix babylonica L.) (Alcaldía de Loja, 2015).

2.2 Materials and Methods

2.2.1 Satellite Data and Its Processing

In the present research work, Sentinel 2B images have been used at level 1C with 10m of spatial resolution, corresponding to the dates of 11/18/2017 and 07/31/2019. The satellite images were processed in QGIS 3.4.12, with the Semi-Automatic Classification Plugin (SCP) tool. To do this, a dark object correction is performed to reduce the haze effect in the image (Congedo, 2021), then cloud masking is applied to use only pixels free of contamination. With the valid pixels of the satellite images, the Normalized Difference Vegetation Index (NDVI) was calculated (Bhandari et al., 2012), where the NIR and RED band are used. Simultaneously, the delimitation of the vegetation cover of Loja city was carried out, for which the information available in Google Satellite was used, and which was obtained through the QGIS QuickMapServices complement.

Subsequently, the amount of AGB was estimated using the equation proposed by (Das & Singh, 2016), as can be seen in Equation (1), where the previously estimated NDVI value intervenes. From the calculated AGB it was possible to estimate the amount of stored carbon (C).

$$AGB = 324.2 * NDVI_{mean} + 14.18 \quad (1)$$

Where:
AGB corresponds to Above Ground Biomass
$NDVI_{mean}$ corresponds to NDVI mean value

To estimate the amount of carbon stored (C), the obtained AGB value is multiplied by a factor of 0.5, which will give the mean AGB value.

2.2.2 Aerial Photographs Obtained with UAV and Their Processing

Having a relatively large land area (5,757.14 ha), it is not possible to cover the entire study area by UAV flights. For this reason, 4 areas within the city were selected for data collection (La Argelia, Parque Lineal, Parque Recreacional Jipiro and Kartodromo). In each zone, between 9 and 11 ground control points (GCP) were placed, whose coordinates were obtained with the help of a differential global positioning system (GPS). Plots were also established within each zone, in Argelia 5 plots were placed, in the Parque Lineal 6 plots were placed, in the Jipiro zone 5 plots and the Kartodromo zone 6 plots were placed.

Regarding the technical characteristics of the overflights, a UAV Mapper platform with a 24.24 megapixel fixed focal camera, known as Ricoh GR III, was used. The flight was executed considering a double grid, with a horizontal and lateral overlap of 80%. The UAV flew over at a height of 110 m with a speed of 18 m/s.

The obtained aerial photographs were processed in the Pix4D software using photogrammetric techniques, generating point clouds and orthomosaics for each zone. From the 3D point clouds using the FUSION 3.7 tool, digital terrain models (DTM) and digital surface models (DSM) were generated. From these data, an individual tree classification was obtained (Iizuka et al., 2018; Wilkes et al., 2018), and the variables of tree height (H) and diameter at breast level (DBH) were derived (da Silva Scaranello et al., 2012; González-Jaramillo et al., 2018). The derived data are required for the estimation of aerial biomass in the allometric equation proposed by Chave et al. (2005), as can be seen in Equation 2. The amount of carbon stored is considered to be half the value obtained from AGB.

$$AGB = 0.0776\left(\rho_{\omega} D^2 H\right)^{0.940} \quad (2)$$

Where:
AGB corresponds to Above Ground Biomass
D corresponds to chest height diameter
H corresponds to overall height
$\rho\omega$ corresponds to wood density

For the wood density, reference values have been taken based on the species present in the research area. The assumed value was 0.59 gr/cm3 based on the species reported by Tello (2016).

2.2.3 Vegetation Measurements

The measurement of the vegetation was carried out within the plots selected for the survey by means of UAV. For this, a diametric tape and a hypsometer model Vertex 5 of the HAGLOF brand were used. For this purpose, there were measured only trees. The position of each tree is obtained from high-resolution satellite images. In the field, the variables to be measured correspond to tree height (H) and diameter at breast height (D).

3 RESULTS AND DISCUSSION

3.1 Total Estimation of Biomass and Carbon through Satellite Images in the City of Loja

Through the digitization of high-resolution satellite data, a total of 86.38 ha of vegetation cover was obtained in the city of Loja, where 59.01 ha correspond to vegetation cover on riverbanks and 27.37 ha correspond to parks. The total area obtained represents 1.48% of the total territorial extension of the area occupied by the city. Figure 1 shows the process, where the vegetation has been delimited. This process was done using high resolution satellite images using the QGIS QuickMapServices plugin.

Figure 2 shows the delimitation of the city of Loja, where through the Senstinel 2B satellite images the NDVI values have been calculated for the study dates (years 2017 and 2019). The images used for the comparison correspond to different months (July and November), this due to the high level of cloud cover in the area, for which it was not possible to have images for the same month.

For the estimation of AGB and C through the use of satellite images, only the total area of existing vegetation cover on the riverbanks and city parks has been taken into consideration, which was estimated and mentioned in this section (Figure 1). In the satellite image corresponding to 11/18/2017, a total of 12,797.31 Tn of AGB and 6,398.66 Tn of C were obtained. In the satellite image corresponding to 07/31/2019, a total of 13,474.46 Tn was obtained of AGB and 6737.23 tons of C.

Figure 1: Figure 1: Delimitation of vegetation cover in the city of Loja.

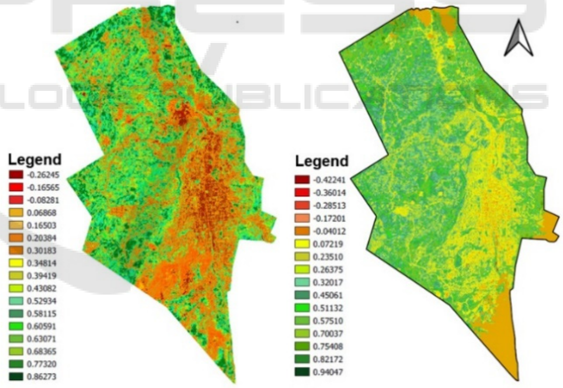

Figure 2: Normalized Difference Vegetation Index (NDVI); a) November 11, 2017, b) July 31, 2019.

3.2 Total Estimation of Biomass and Carbon using UAV in the City of Loja

The processed data from the 4 selected areas made it possible to obtain the initial data for the development of the study. For this, the photographs were processed with the Pix4D software. Figure 3 shows the delimitation of one of the sites and the distribution of the GCPs used in the processing.

From the photographs obtained by each site, products such as the point cloud and orthophotos are obtained (Figure 4), which will serve for subsequent analysis. From the point cloud, it is possible to determine the DTMs and DSMs that were the basis for the individual tree detection and the subsequent processing for the AGB estimation.

Figure 3: Delimitation of the zones in the urban area in the city of Loja and installation of the GCPs. This area corresponds to Jipiro.

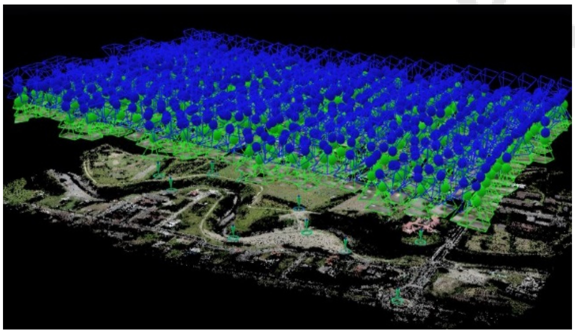

Figure 4: Cloud of points in the Argelia area

Table 1 shows the values obtained for each zone according to the detection of individual trees, from which the height of each tree, DBH and AGB values were estimated. In this case, the mean values are presented.

Table 2 shows the area that represents each of the study zones and the values obtained for each zone for AGB and for C. The estimate for each of the zones consists of adding all the trees present in the zone. Conventionally, average values are given in Tn/ha, but in this case the AGB content is presented for an entire area. With subsequent calculations, the mean values can be obtained and represented in a conventional manner with a distribution per ha (Table 3).

Table 1: Values obtained at individual tree level and its parameters.

	N° of trees	H (m)	DBH (cm)	AGB (Tn)
Zones		Mean	Mean	Mean
Argelia	524	27,23	106,90	18,95
Parque Lineal	432	19,00	51,01	2,80
Jipiro	995	20,53	60,01	4,31
Kartodromo	1136	18,72	49,61	2,61

Table 2: Study zones with total coverage and estimation of AGB and C expressed in Tn.

Zones	Area (ha)	AGB (Tn)	C (Tn)
Argelia	20,35	630,08	316,30
Parque Lineal	7,49	145,45	73,83
Jipiro	16,72	433,67	219,19
Kartodromo	25,53	233,24	119,43
Total		1442,44	728,75

Table 3: AGB vales per each zone expressed in Mg ha^{-1}.

Zones	AGB (Mg $\mathbf{ha^{-1}}$)
Argelia	30,96
Parque Lineal	19,41
Jipiro	25,94
Kartodromo	9,20

The total estimated AGB on the riverbanks that cross the city and its parks was 2,864.34 Tn. Of the totals mentioned, 1,442.44 Tn of AGB were estimated in the areas where data were obtained, while for the areas where survey were not performed with the UAV, 1,421.90 Tn of AGB were estimated for an area of 62.47 ha.

The validation of data taken in the field was carried out for the H and DBH variables for a total of 54 trees, which were distributed in the plots and included trees of different heights (from 9 to 25 m), obtaining a higher r^2 value of 94%. These values represent the error introduced in the measurement and the error estimated by taking the data with the UAV, where, being a passive sensor, it cannot penetrate the foliage of the vegetation or herbs or shrubs existing at the foot of the recorded tree.

In order to compare the results of the two methodologies corresponding to the use of satellite images and data from a UAV, work has been done at the plot level. In the results obtained at this level, the data obtained by UAV in the Argelia area, the plot that yielded a greater amount of AGB was plot 5, with 53.73 Tn of AGB. In the Parque Lineal zone, the plot that yielded the greatest amount of AGB was plot 5, with 22.33 Tn of AGB. In the Jipiro zone, plot 3 was the one that yielded a greater amount of AGB, with 62.36 Tn of AGB, and in the Kartodromo zone, plot 1 was the one that yielded a greater quantity of AGB, with 7.15 Tn of AGB.

On the other hand, in the satellite images in the Argelia area, the plot that showed the highest value of AGB was plot 5, with 55.14 Tn of AGB. In the Parque Lineal area, in the 2019 satellite image, the highest AGB value was obtained in plot 1, with 57.41 Tn of AGB, and in the 2017 image in plot 2, with 67.43 Tn of AGB. In the Jipiro area, in both satellite images, the plot with the highest amount of AGB was plot 2, with 87.20 Tn of AGB in the 2019 satellite image, and with 73.05 Tn of AGB in the 2017 satellite image. Finally, in the Kartodormo area in both satellite images, the highest value of AGB calculated was found in plot 5, with 78.18 Tn of AGB, recorded in the 2019 satellite image, and with 62.27 Tn of AGB in the satellite image of 2017.

The results obtained by plots reflect an evident difference between the used methodologies. For this analysis, the results were calculated as a percentage, considering the AGB variable for this purpose. Thus, from a total of 22 plots, it was obtained that only 4 plots presented a percentage difference between methods of less than 51%; of these 4 plots, 2 showed values of difference less than 7%. While of the other 18 plots with values greater than 51%, 5 plots presented a percentage difference greater than 93%.

4 CONCLUSIONS

Based on the methodologies applied through the use of remote sensing data, it is partially possible to obtain estimates of aboveground biomass. This is due to the fact that the results obtained through the use of satellite images reflect oversaturated values, while the estimation through the use of UAV presents values based on detection at the individual tree level, using the parameters of H, DBH and mean values of the wood density.

The city of Loja has a low vegetation cover in their urban area. As can be verified in the results presented, the largest amount of vegetation exists on the banks of the rivers. While in the parks where the largest number of people and vehicles are concentrated, the vegetation cover is low.

UAV technology allows products such as point clouds to be obtained, as well as high-resolution orthophotos. These GCP-assisted data can have very good accuracies, which can be comparable with data obtained with much more expensive platforms such as those from LiDAR (Wilkes et al., 2018; Chen et al., 2016). This lowers costs, and allows investigations and monitoring to be carried out, especially in small areas, where financial resources are limited.

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