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Subject:

Ecosystem services assessment in urban and peri-urban forests over West Africa to improve air quality: A case study of Mbao Classified Forest, Dakar (Senegal)

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DEDICATION

I dedicate this work to all those who believed in my abilities and backed me up during the initiation and completion of this master's degree. These are the ones although the list is not exhaustive:

- My biological family: my Father, my Mother, my Wife, my children, my brothers, and sisters.
- My professional family which made me what I have become today: a tireless defender of the global environment.
- My Spiritual Guide **MAOULANA CHEIKH IBRAHIMA NIASS (KAOLACK).**

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ABSTRACT

Urban trees provide numerous ecosystem services to city residents, including carbon storage and sequestration and air pollution removal. Improving urban air quality has also become one of the most pressing tasks facing policymakers worldwide. Estimation of urban tree aboveground biomass has traditionally been based on the use of allometric equations developed for forest trees. The particularity of this study is to use AI to perform these tasks with more accurate results. With Google Earth Engine (NDVI) our findings show that Mbao Forest biomass underwent a net regression from 1.5 Kg/ha in 1988 to 0.8 Kg/ha in 2018. The i-Tree Software showed that Mbao forest taking into account only trees, grossly sequestrated 1,506.43 metric tons of carbon per year with an associated value of CFAF15,547.8 thousand. The carbon stored is 7,892.17 metric tons corresponding to CFAF 813.91 million. Regarding air pollution control, the model estimates that 44,834.78 kg/year of pollutant has been removed from the atmosphere corresponding to CFAF 188,173.91 thousand. The results showed that the i-Tree Eco can be successfully applied to an African case study area to quantify ecosystem services benefits. The results were also beneficial in developing policies related to future green infrastructure applications in major African cities for ecosystem services.

Keywords: Ecosystem services; i-Tree Eco; urban forest; Mbao; Senegal.

RESUME

Les arbres fournissent de nombreux services écosystémiques aux citadins, notamment le stockage et la séquestration du carbone et la dépollution atmosphérique. L'amélioration de la qualité de l'air urbain est devenue une préoccupation majeure pour les décideurs politiques du monde entier. L'estimation de la biomasse aérienne a traditionnellement été basée sur l'utilisation d'équations allométriques développées pour les arbres forestiers. La particularité de cette étude est d'utiliser l'Intelligence Artificielle pour réaliser ces activités avec une grande précision. Google Earth Engine, confirme que la biomasse de la forêt de Mbao a subi une nette régression de 1,5 kg /ha en 1988 à 0,8 kg /ha en 2018. Le logiciel i-Tree montre que 1 506,43 tonnes de carbone sont séquestrées par an équivalent à 15 547 800 de FCFA. Le carbone stocké est de 7892,17 tonnes correspondant à 813,91 millions de FCFA. Concernant la dépollution de l'air, le modèle estime que 44 834,78 kg /an de polluant ont été retirés correspondant à 188 173 910 de FCFA. Les résultats permettent d'affirmer que i-Tree Eco utilisé depuis 2006 aux USA et en Europe peut être appliqué avec succès en Afrique pour quantifier les avantages des services écosystémiques. Pour l'élaboration de politiques liées aux infrastructures vertes dans les grandes villes d'Afrique, ces résultats peuvent être très bénéfiques.

Mots- Clés: Services écosystemiques; i-Tree Eco; forêts urbaines; Mbao; Senegal.

ACRONYMS AND ABBREVIATIONS

AGB : Above Ground Biomass

AI : Artificial Intelligence

ANACIM : National Agency of Civil Aviation and Meteorology

ANSD : Agence Nationale de la Statistique et de la Demographie (National Agency for Statistics and Demography)

BGB : Below Ground Biomass

CO2e : Carbon dioxide equivalent

CITEPA : Centre Interprofessionnel Technique d'Études de la Pollution Atmosphérique (Inter Professional Technical Center for Atmospheric Pollution Studies)

FAO : Food and Agriculture Organization

GEE : Google Earth Engine

GHG : Greenhouse Gases

ICRAF : International Centre for Research in Agroforestry

INDC : Intended Nationally Determined Contribution

ISFAR : Institut Superieur de Formation Agricole et Rurale

LEGS-Africa: Leadership, Gouvernance, Stratégies pour l'Afrique

NASA : National Aeronautics and Space Administration

NDC : Nationally Determined Contribution

NDVI : Normalized Difference Vegetation Index

Pg : A petagram is a decimal multiple of the base unit of mass in the International System of Units (SI) kilogram. 1 Pg = 10^{15} g = 10^{12} kg

SDG : Sustainable Development Goal

SENELEC : Société Nationale d'Électricité du Sénégal (Senegal National Electricity Company)

UAD : Universite Alioune Diop

UNEP : United Nations Environment Programme

VOC : Volatile Organic Compounds

WHO : World Health Organization

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1. INTRODUCTION

1.1. Background

Population growth in African cities has dramatically increased endemic precariousness. Thus, the urban forests that could solve a large number of these difficulties are destroyed in favor of dwellings and infrastructures less useful most of the time.

Urban forestry and greening offer a multitude of benefits to the inhabitants of towns and cities. According to Shackleton (2012), the developing world context around urban forestry debates seems to be poorly represented in the international peer-reviewed literature. The number of urban forestry-related publications has grown consistently in the recent past, such that urban forestry features as a prominent topic on the research agenda, especially in the so-called ‘developed world (Shackleton, 2012). But what is the status of the discipline elsewhere, such as in African countries?

Besides most of the studies use classic methods sometimes time-consuming and less accurate. Thus, in the 21st century, it is important to take advantage of the new tools (Artificial intelligence, deep learning) to work faster in terms of forestry over West Africa.

This study is divided into five chapters and the hierarchy is as follows:

(1) Chapter 1 introduces the topic with a general introduction of the subject, it displays the problem statement, the research question, and objectives of the research;

(2) Chapter 2 exposes the methods and materials used and the data collection scheme;

(3) Chapter 3; The results and discussions are presented in Chapter 3 and

(4) Ultimately, the conclusion and recommendations.

1.2. Literature review

The world urban population increased from 746 million people in 1950 to 4 billion in 2015 (more than a fivefold increase), and this growth is expected to continue in the coming decade with low- and middle-income countries projected to more than double and triple their urban populations, respectively, by 2050 (United Nations, 2016). Of the world's regions, Africa and Asia are urbanizing fastest: Africa had the highest urbanization rate of all the regions between1995 and 2015 (Borelli et al., 2018).

Total urban land amounts to 106 million hectares and Africa has only 7.3 million hectares. This world's urban tree cover had a slight but statistically significant decline (−0.2 %) between 2012 and 2017 (Nowak & Greenfield, 2020). According to FAO every year, Senegal experiences the loss of 40,000 ha of forest for the period 2005-2010 (CITEPA, 2015).

From the situation of the peri-urban forest, the classified forest of Mbao has gradually become an urban forest (Gueye et al., 2008). Thus, it is the object of envy from the villagers and real estate developers. Many infrastructures are established in that forest: water pumping station, toll highway, garbage transfer center, SENELEC dispatching Centre, parking of Henan Chine Company, SENEGALEX depot, etc. All these installations make it subject to encroachments and the risk of depletion that could compromise its existence.

In Senegal, urban dwellers have grown from 25% to 46% between 1960 and 2015 (ANSD, 2019). Besides, about a quarter of the Senegalese population lives in Dakar (23%). (Faye et al., 2018). Rapid urbanization brings a lot of environmental problems such as climate change due to the anthropogenic carbon dioxide (CO_2) emissions from the cities (Seto et al., 2014), air pollution (He et al., 2017), modification of local and regional climate (Zhou et al., 2014) and loss of natural habitats and biodiversity (Seto et al., 2014). It is showed that urban forests provide many ecological services, which offset urbanization caused deterioration of the environment (Nowak et al., 2014). Nevertheless, ecosystem services are often ignored because they are not well understood or quantified (Hönigová et al., 2012), and mostly the role of urban forests in atmospheric carbon dioxide reduction is poorly known (Ugle et al., 2010). Added to that, in Senegal, there is a need for more studies to quantify accurately each of the ecosystem benefits provided by urban forests and publish the scientific outputs.

Cities contribute to global anthropogenic carbon dioxide (CO_2) emissions by about 75% (Seto et al., 2014). It is estimated that exposure to pollutants causes around 2.1 million premature deaths per year worldwide (154 thousand in Europe) associated with cardiopulmonary disease (93%) and lung cancer (7%) (Silva et al., 2013).

Inhaling these particles reduces the average life expectancy in Europe by eight (8) months, four (4) months in Finland, and up to three (3) years in the most polluted areas (WHO, 2006).

Air pollution causes about 780,000 premature deaths per year in Africa, according to a modeling study by researchers at NASA (Bauer et al., 2019).

The absence of data relating to the monitoring of atmospheric pollution and the poor consideration of air quality in the transport and industry sectors led the Senegal government to set up a laboratory to monitor air atmospheric pollution: Air quality management center.

Thus, for the achievement of the Sustainable Development Goals by 2030, in particular SDG3 and SDG13, it is urgent to make advocacy for safeguarding this very important legacy, which constitutes by forests and related bodies.

A growing number of studies have identified and quantified various ecosystem services provided in an urban context (Soule, 2019; Ngom, 2011;) but some of them used AI (Koricho et al, 2020), hence, this makes the relevance of such study to promote the use of this indispensable tool in forestry and particularly in Africa.

1.3. Problem statement

Total global greenhouse gas (GHG) emissions continue to show a steady increase, reaching approximately 52.7 gigatons carbon dioxide equivalent (GtCO2e) in 2014 (UNEP, 2016).

Current projections predict that our emissions will grow up to 59 gigatons (Gt) in 2030 with a Business-as-Usual Scenario. However, the reasonable scenario for limiting warming below the dangerous threshold of 2 °C requires a drop in emissions, up to 42 GtCO2e in 2030 (UNEP, 2017).

Meanwhile, between 2015 and 2020, the rate of deforestation was estimated at 10 million hectares per year, down from 16 million hectares per year in the 1990s (Qin et al., 2021). The area of primary forest worldwide has decreased by over 80 million hectares since 1990 (FAO & UNEP, 2020).

Ecosystem services are the essence and the primary function of any forest stand. Urban forests have a structural value based on the tree itself and functional values based on the functions the tree performs (Nowak et al., 2012). Among these ecosystem services, particularly carbon sequestration and storage and air pollution removal are highlighted in this study.

These functions are closely related to the forest biomass so it is important to know the dynamics of this forest to propose some sound recommendations.

Forest biomass plays an important role in the sequestration of carbon dioxide from the atmosphere but the global forest biomass is declining at an alarming rate due to human activities (Misra et al., 2015). In West Africa, urban sprawl causes a depletion of the urban forest and leads to population diseases. The conversion of peri-urban forests into urban forests led to carbon gain (Moussa, 2019).

To rescue the world from global warming and climate change, the sustainable management of forests with the objectives of carbon sequestration is mandatory (Jaiswal et al., 2014). Since the forests having the same area may contain different amounts of forest biomass, the estimation of forest biomass is a difficult and time-consuming process (Houghton, 2005). So far, the planning of reforestation activities in many forest services in West Africa is based either on the aesthetics of the tree if it is urban plantations, or on the adaptive capacity of the tree species in the area where it is intended.

To limit global warming to a degree by 2030, it is advisable to take into account the most efficient species in terms of storage and sequestration in the planning of reforestation activities.

Air pollution is a significant problem globally that affects human health and well-being, ecosystem health, crops, climate, visibility, and man-made materials (Nowak et al., 2018). However, there has been an increasing interest in the quantification of carbon storage and sequestration by urban forests in both developing and developed countries (Brack, 2002). Thus, if we define ecosystem services as the components of urban forests that are directly enjoyed, consumed, or used to produce specific, measurable human benefits (Escobedo et al., 2011) it is indispensable to assess the nine major ecosystem services (Nowak et al., 2020).

The various ecosystem services provided by the forest are among others:

- Air pollution removal;
- Building energy use and emission;
- Carbon storage and sequestration;
- Food provisioning service;
- Oxygen production;
- Streamflow and water quality;
- Volatile organic compound emissions;
- Ultraviolet radiation;
- Wildlife habitat.

Nowadays Artificial Intelligence (AI) has become essential in biomass studies to increase the reliability of results. While it is true that a lot of work is being done in Africa and elsewhere for the quantification of biomass, carbon storage, and sequestration, air removal, the majority have used allometric equations. The purpose of this study is mostly to use AI to perform these tasks.

1.4. Research questions

The main research question is how to find the best way for advocating and monitoring towards urban forests in West Africa using AI.

Specifically, the study targeted the following research questions:

What is the behavior of the Mbao classified forest over the past thirty years? How carbon sequestration and air pollution removal can improve air quality in Dakar city? Finally, what is the monetary value of ecosystem services provided by Mbao Classified Forest using i-Tree Eco Software?

1.5. Hypotheses

This study attempt to reply at three hypotheses:

i. The Mbao classified forest biomass gradually decreases from 1988 to 2018.

ii. The removal of pollutant matters (CO, SO_2, NO_2, $PM_{2.5}$, PM_{10}) improves significantly the air quality in Dakar city.

iii. The monetary value of Mbao Classified Forest ecosystem services is greater than the income of the Dakar-Diamniadio toll highway over thirty years.

1.6. Research objectives

The ultimate aim of this thesis was to determine the structure and ecosystem services of urban forests in West Africa using AI.

The specific objectives of this study were to:

- Analyze the dynamic of Mbao Classified Forest in Dakar City for the period from 1988 to 2018;
- Estimate the carbon sequestered and stored and air pollution removal by Mbao urban forest;
- Develop a model to compute the ecosystem services value using i-Tree Eco software.

1.7. Definition of key concepts

Carbon dioxide equivalent (CO_2e): A way to place emissions of various radiative forcing agents on a common footing by accounting for their effect on climate. It describes, for a given mixture and amount of greenhouse gases, the amount of CO_2 that would have the same global warming ability, when measured over a specified period (UNEP, 2017).

Carbon sequestration: is the process of removing carbon from the atmosphere and depositing it in a reservoir (Nowak, 2020).

Nationally Determined Contribution (NDC): By its decision 1/CP.21, paragraph 22, the Conference of the Parties (COP) invited Parties to communicate their first NDC no later than when the Party submits its respective instrument of ratification, acceptance, approval, or accession of the Paris Agreement. In the same paragraph, the COP further stated that if a Party has communicated an INDC (Intended Nationally Determined Contribution) before joining the Agreement, that Party shall be considered to have satisfied the provision of decision 1/CP.21, paragraph 22, unless that Party decides otherwise (UNEP, 2017).

Above Ground Biomass (ABG): Aboveground tree biomass, for example, refers to the weight of that portion of the tree found above the ground surface, when oven-dried until a constant weight is reached. AGB includes stems, stumps, branches, bark, seeds, and foliage (Sar & Further, 2020)

Normalized Difference Vegetation Index (NDVI): is indicative of the abundance of photosynthetically active vegetation (Rouse et al., 1974)**.**

Google Earth Engine (GEE): Google Earth Engine (GEE) is a planetary-scale platform for Earth science data and analysis (Gorelick et al., 2017).

1.8. Urban Forestry in West Africa

Urban forestry in West Africa aims to set off positive examples of planning, design, management, and monitoring approaches that cities with diverse cultures, environmental and socio-economic contexts, sizes, forms, structures, and histories have implemented. In partnership with other sectors in Africa, it is to optimize the contribution of urban forests and green infrastructure to sustainable economic development, biodiversity conservation, and sustainable use, landscape restoration. In addition, combating desertification and sand encroachment, climate change mitigation and adaptation, building resilience, improved social cohesion, and increased public involvement and green jobs is the key role of West Africa urban forestry.

More specifically, the objectives of urban forestry are:

- to increase the resilience of cities to global/regional changes, biodiversity conservation and action against climate change and desertification and enhance green recovery;
- disseminating inspiring practices on the co-creation, maintenance, and management of urban forests and green public spaces networks;
- to allow the urban forest and green infrastructure actors and stakeholders in Africa to have a link towards the global World Forum on Urban Forests and the World Urban Forum;
- to support the SDG1, SDG2, SDG3, SDG13, SDG14, SDG15, SDG16, and the New Urban Agenda processes and optimizing actions related to urban ecosystems and green spaces;

Forest policies in Senegal constitute a disintegrated legacy of colonial practices in this area (Manga, 2018).

Urban forestry in Dakar (Senegal) becomes relevant since 1903 when Governor Merlin decided to create a public garden and a nursery (test garden) in the Hann area. The area was 73 hectares. In 1908 this trial garden was transformed into the "Hann Forest station”.

In 1912, the new species introduction trials continue with a staff of 18 employees, a chief gardener, a foreman, and a manager. Then 8,500 coconut trees (*Cocos nucifera*) from Dahomey (now Benin), 3,500 *Eucalyptus camaldulensis*, and 1,500 Australian pine (*Casuarina equisetifolia*) were maintained in the park.

In 1933, fruit and forestry production was the main activity of the park. The paperbark tree (*Melaleuca leucadendron* L.) was introduced to reforest along the marshes where the environment is brackish. The arboretum was created in 1947. The purpose of this structure is to develop the local species of French West Africa, but also to acclimatize plants from all regions of the globe.

Regarding the classified forest of Mbao, it was erected as a reforestation area by a general decree taken on May 7, 1940, but its registration as State's land dates from November 1908. In 1917, when a water pumping station was established inside, the colonial administration decided to prohibit access to the populations and to proceed with reforestation of the area.

Begun in 1918 with *Casuarina equisetifolia*, the purposes of the tree plantations were to stabilize and protect the soil. Between 1940 and 1955, several other species were introduced into the forest: *Eucalyptus camaldulensis*, *Prosopis juliflora*, *Anacardium occidentale*, etc.

After the independence, these actions continued which allowed the realization of the coastal plantations of *Casuarina equisetifolia*, in the form of a discontinuous strip 200 to 500 m wide, from Cayar (Thiès) to Sag (Ndar-St Louis), over a length of 182 km.

In the rural area, peculiarly in the southern part of Senegal, the stand called "sacred woodland" is an excellent means to safeguard the forests around the villages.

Currently, with the rural exodus, the main urban centers of the country such as Dakar, Thiès, Ziguinchor, saw their populations rise increasingly to such an extent that the remnants of the forests, which bordered them were replaced by new dwellings without any development plan. In Dakar, the only remaining forest is an area of 700 ha wooded with cashew trees (*Anacardium occidentale* L.) and some local species such as *Faidherbia albida* (Kad), *Neocarya macrophylla*, *Adansonia digitata* (Baobab tree), *Maytenus senegalensis*, *Ximenia americana*, *Elaeis guineensis* (Palm Kernel Oil): Mbao Classified Forest.

2. RESEARCH METHODOLOGY

2.1. Study area

Covering an area of around 1000 ha when it was created in 1908, Mbao Classified Forest covers now only 720 ha. It is located in Dakar region West of Senegal, between 17 ° 10 and 17 ° 32 LW and 14 ° 53 and 14 ° 35 LN. The classified forest of Mbao, located in the department of Pikine, has been set up as a reforestation area for soil fixing and conservation objectives. The classified forest of Mbao is limited to the North by the traditional villages of Bourne, Darou Misseth, and Médina Kell, to the South by Petit Mbao and Grand Mbao, to the East by Kamb and Keur Mbaye Fall, and to the West by the National Road N °1 and the Petit Mbao and Fass Mbao road.

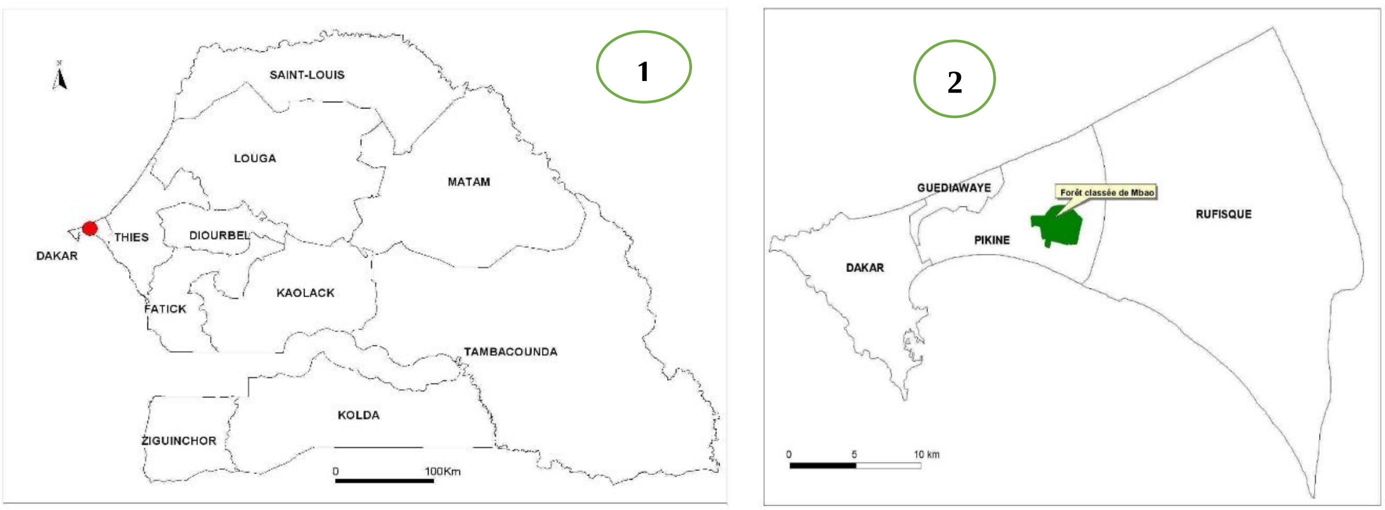

Figure 1: Localization of the study area in Senegal and Dakar region respectively 1 and 2

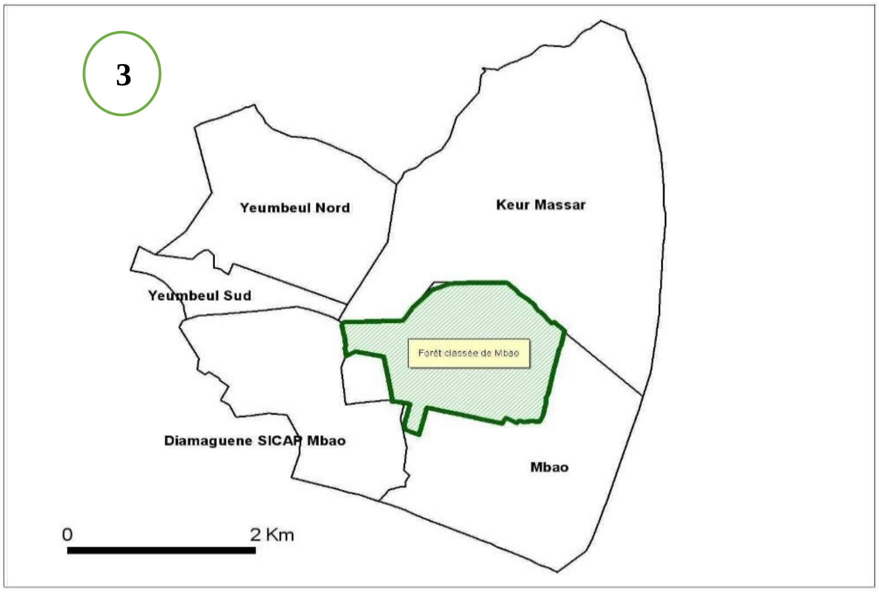

Figure 2: Localization of the study area in Pikine Departement (PAFCM, 2008)

2.1.1. Temperature and Rainfall of Dakar

Based on data from 1984 to 2018 collected by the National Agency of Civil Aviation and Meteorology (ANACIM), the monthly mean rainfall, minimum, maximum temperature of Dakar between 1984 and 2018 period are shown in Figure 2. The average monthly mean minimum and maximum temperature in Dakar are 21.9°C and 27.9°C from 1984 to 2018. The average monthly rainfall and minimum and maximum temperature are shown in Figure 2.

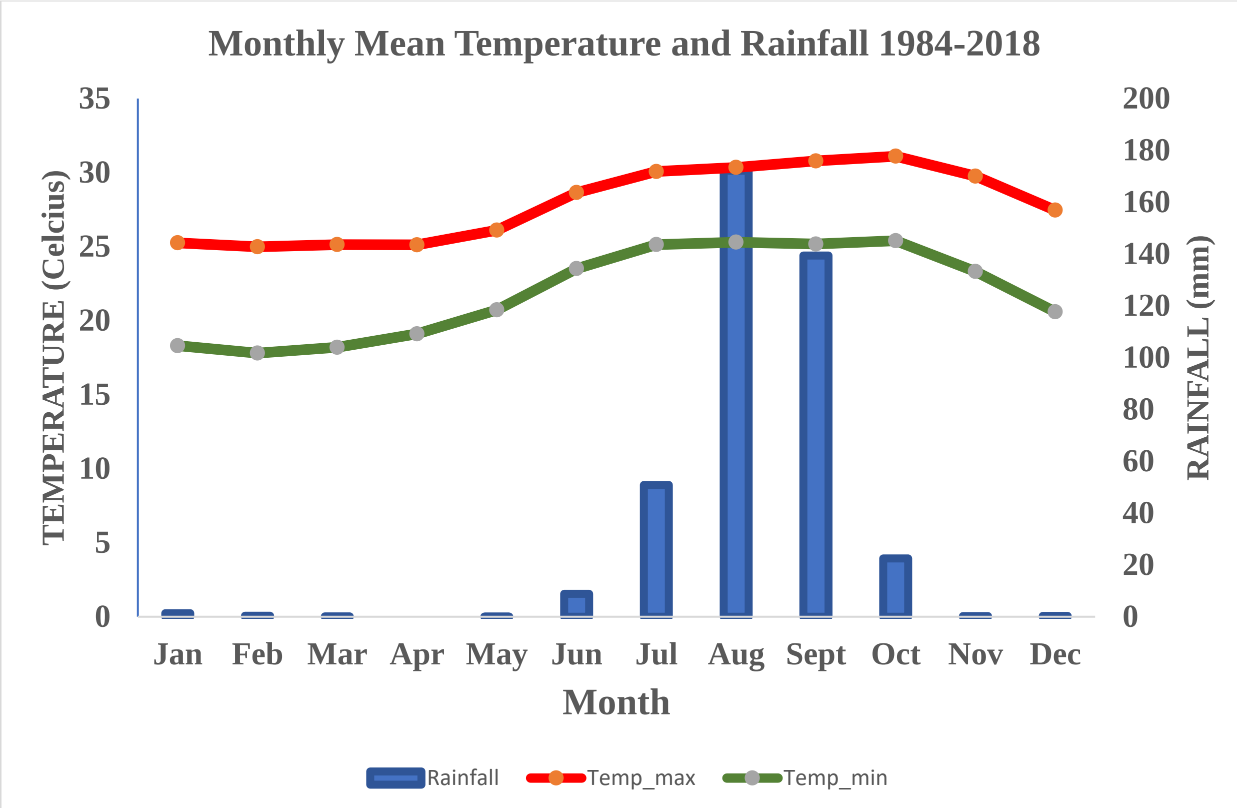

Figure 3: Monthly mean temperature and rainfall between 1984-2018

The rainfall is distributed from July to October in a normal year with the maximum in August which is less than 200 mm on average.

Regarding the temperature, the analysis of the graph shows that:

1. The highest temperatures are between June and November and can reach 31°C which corresponds to the hot period.

2. The lowest temperatures are recorded from December to April with the influence of the maritime trade winds from the Azores High.

Through the analysis of the monthly average temperatures from 1984 to 2018, we observe a contrasting thermal regime that alternates between a cool period from December to April and a hot period from July to October, corresponding respectively to a dry season and a rainy season.

2.1.2. Humidity and evaporation

The mean monthly humidity and evaporation are shown below:

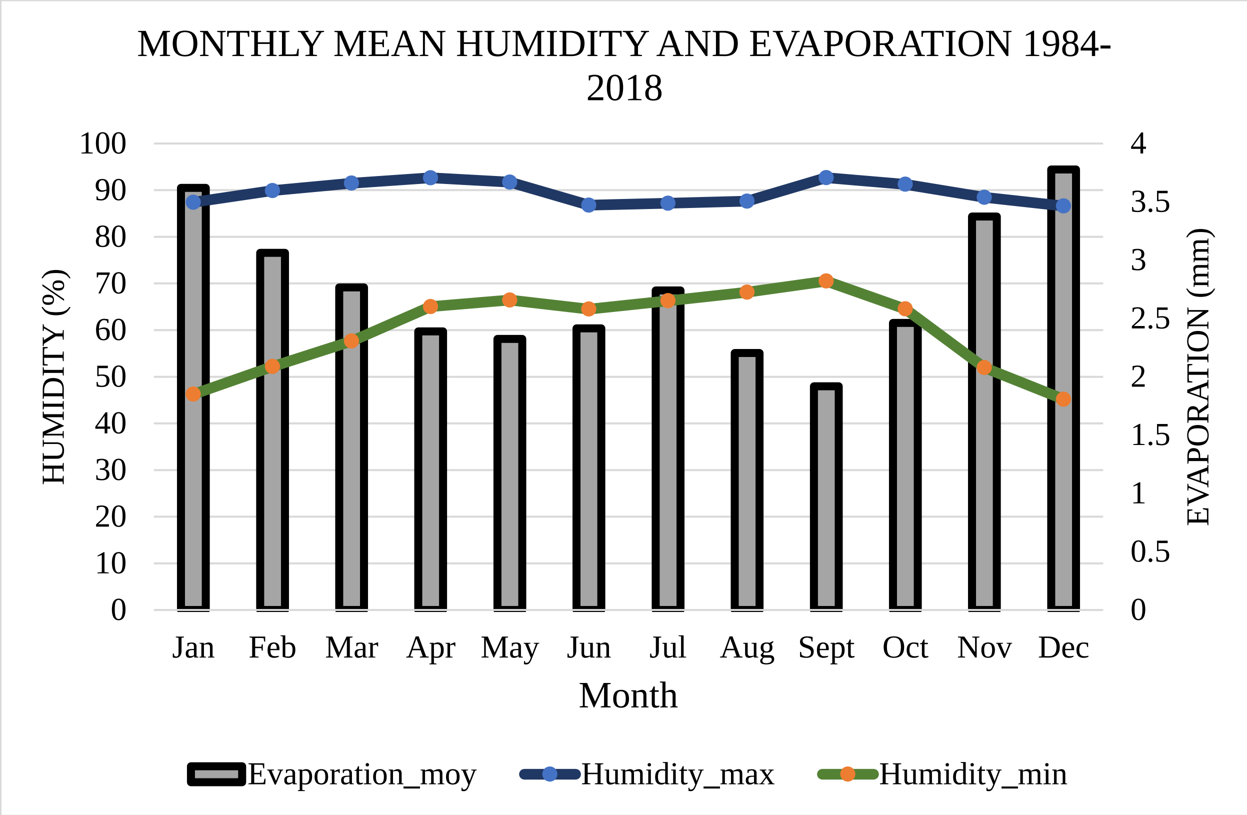

Figure 4: Monthly mean humidity and evaporation 1984-2018

This graph shows that relative humidity is high throughout the year. The maximum is reached in September with 92.6%; the minimum is recorded in December with 45.18%. This abundance of atmospheric humidity is due to the maritime trade winds from the Azores High, which blows during the dry season bringing a certain humidity.

The lowest value of ETP is noted in September (1.91). It is high the rest of the year with a high of 3.77 in October.

2.1.3 Insolation and wind speed

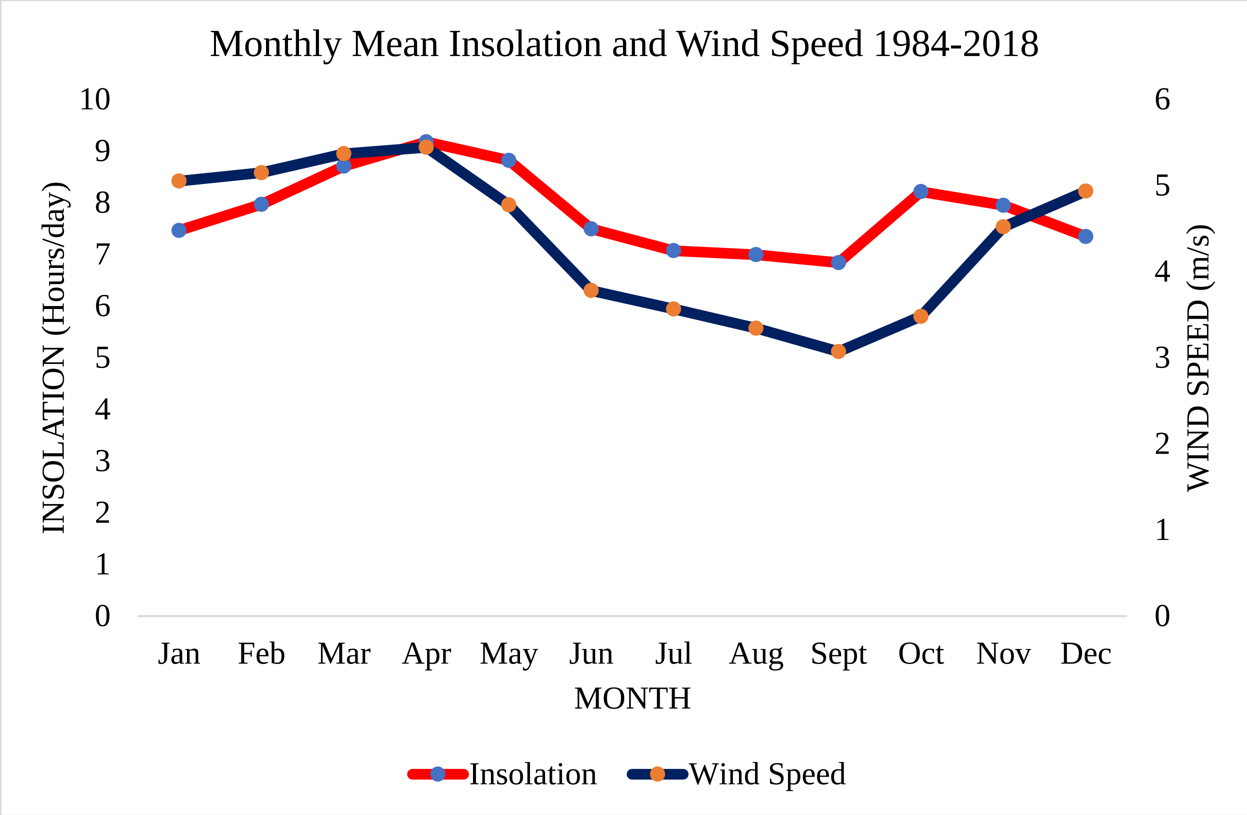

Figure 5: Monthly mean insolation and wind speed 1984-2018

The duration of the insolation is relatively long with a maximum in April of 9.17 hours per day. The minimum is observed in September with 6.84 hours per day. This is very profitable for plants in the context of photosynthesis but also carbon sequestration.

Examination of the graph below of average wind speed reveals two dominant orientations during the year:

1. From November to May the maritime trade winds blow with a certain regularity. These are north to northwesterly winds. Their slightly cool and humid character gives relative clemency to the climate of the peninsula during this period.

2. From June to September the wind speed is relatively stable, not reaching 4 ms^{-1}. These are southerly to southwesterly and southeasterly winds that correspond to the monsoon originating from the trade winds from Saint Helena High.

2.2. MATERIALS AND METHODS

2.2.1. Urban Forests Dynamics Assessment

2.2.1.1. Forest inventory

The mission of the Forest Inventory is to produce reliable forest inventories and stand growth models so that natural resource management is informed by credible information on forest conditions (Omule, 2015).

The Mbao classified forest is a restoration perimeter so there is no significant stratification but just a mixture of reforestation and natural species. Therefore, for this inventory, we have opted for a sampling rate of **0.5%.**

The forest area is 720 ha and the area to survey is 3.60 ha or 36000 m^2.

The area of a plot in the i-Tree Eco inventory is 407 m^2 with a radius of 11.16 meters.

The number of plots is $\frac{36000}{407}$ = **90 plots**.

The area of influence of a plot is obtained by making $\frac{720}{90}$ = 8 ha or 80,000m^2.

The distance between the plot centers is $\sqrt{80000}$ = 282 m.

The UTM coordinates are used to materialize the plots.

This part was made using ArcView and Google Earth. A point grid (center of plots) is developed from the calculated distance between the centers of the plot which is equal to the square root of the area of influence of a plot. This grid is overlaid on the plot map for locating the plots and plot centers on the ground.

The results are as follows on Google Earth and ArcView.

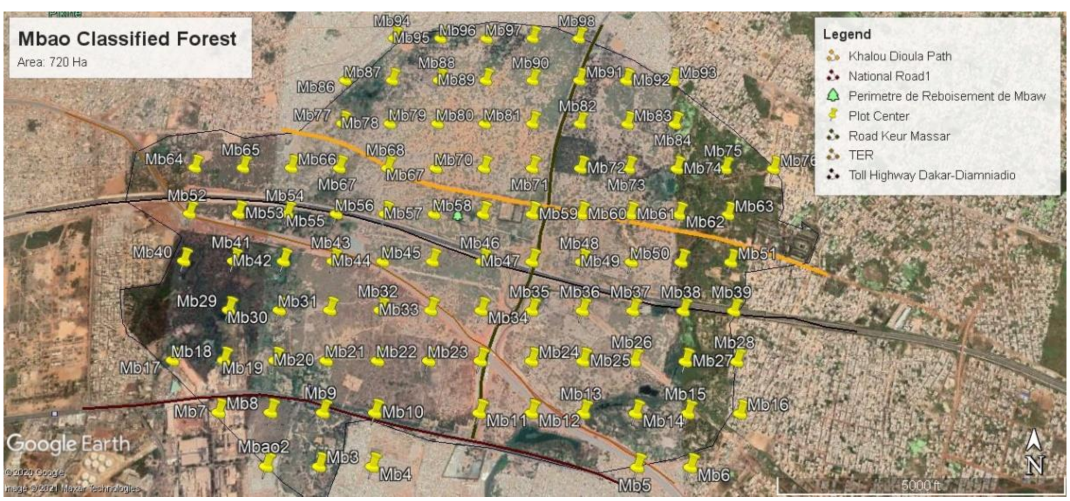

Figure 6: Map of Mbao forest with the plot centers

- **How to make the grid of points**

First, you have to determine the pitch, that is, the distance between the plots.

Knowing the area of the plot and the number of plots, we can determine the area of influence of the plot.

Area of influence of the plot = 720 ha / 90 = 8 ha = 80,000 m^2.

Knowing the area, we look for the step by taking the square root of the area of influence which represents the side of this area.

Side of the area = $\sqrt{80{,}000}$ = 282 m.

This means that the plot centers are 282 m apart.

At the points serving as the boundary of the forest area:

- Find the maximum latitude and the maximum longitude.
- Progress from minimum latitude to maximum latitude in intervals of 282 m
- Progress from minimum longitude to maximum in intervals of 282 m
- The intersection between latitude and a longitude constitutes a point of this grid or a plot center.

- **Data processing and analysis**

To estimate carbon sequestered and stored by Mbao urban forests in Dakar we used two methods: The allometric model and the i-tree model (Objective 4)

For the allometric model, the Above Ground Biomass (AGB) of remnant trees was estimated. Based on the model, the appropriate predictors (Height, Diameter, or woody) density was used to calculate the carbon sequestered and stored over the land areas.

AGB (Kg/tree) = Volume of tree (m^3) x Wood density (Kg/m^3) (Jaiswal et al., 2014)

or $= \pi r^2 H$ **(m^3) x Wood density (Kg/m^3)**

or $= \frac{(GBH)2}{4\pi}$ **x H x Wood density (Kg/m^3)**

Where, r = radius of the tree (in m) = GBH/2π;

H = Height of the tree (in m);

GBH= Girth at Breast Height.

African Wood Density Database (http://apps.worldagroforestry.org/treesandmarkets/wood/) or (http://db.worldagroforestry.org/wd)

The Below Ground Biomass was calculated by multiplying the **Above Ground Biomass (AGB) by 0.26** (Macdicken, 2015) factors as the root: shoot ratio (Nowak and Crane, 2002).

Below Ground Biomass (BGB) kg/tree or ton/tree = Above Ground Biomass (AGB) kg/tree or ton/tree x 0.26. (BGB= AGB X 0.26)

Total Biomass (TB) = Above Ground Biomass + Below Ground Biomass. As it was assumed that 50 % of vegetative biomass was carbon (Westlake, 1966) thus the total biomass was converted to total stored carbon by multiplying by 0.5 (Nowak and Crane, 2002).

The plots all have a radius of 11.16 m; which means that their surface is 407 m^2.

By applying the formula: **Carbon stored * 10000/407**; the carbon values are obtained in $Kgha^{-1}$.

Other approaches have been developed by FAO and which allow the estimation of wood carbon. However, we made our choice on the method used by the USDA Forest Service, which was more suited to the needs of our study. Microsoft Excel was used to do the calculations.

COMPUTATION OF THE VOLUME: $V = \frac{1}{4\pi} fC^2$ HT; f = 0.65 (Shape coefficient); HT=height total

V = 0,05172524 C^2 HT; (C et HT) are in meter

Understanding forest biomass dynamics is crucial for carbon and environmental monitoring, especially in the context of climate change. (Nguyen et al., 2020).

2.2.1.2. Determination of Normalized Difference Vegetation Index (NDVI)

NDVI has been widely used in the quantification of biomass, leaf phenology, and net primary production (Buitenwerf et al., 2015), and remote sensing vegetation indices are required to be not significantly affected by abiotic factors for monitoring vegetation activity (Kong et al., 2017).

The normalized difference vegetation index (NDVI), (Equation 1) is the ratio of the difference between the near-infrared band (NIR) and the red band (R) and the sum of these two bands (Rouse Jr *et al.*, 1974).

$$NDVI = \frac{NIR-RED}{NIR+RED}$$ Equation (1)

Where NIR is the reflectance in the near-infrared band and RED is the reflectance in the visible red band. The NDVI algorithm takes advantage of the fact that green vegetation reflects less visible light and more NIR, while sparse or less green vegetation reflects a greater portion of the visible and less near-IR. NDVI combines these reflectance characteristics in a ratio so it is an index related to photosynthetic capacity. The range of values obtained is between −1 and +1. Only positive values correspond to vegetated zones; the higher the index, the greater the chlorophyll content of the target (Tengberg et al., 2014).

There are several ways to calculate NDVI. However, in recent years with the development of Artificial Intelligence, Google Earth Engine (GEE) has become an essential tool for remote sensing. GEE is a powerful geospatial tool to create complex custom analysis but requires some programming knowledge. It supports both JavaScript and Python (Gorelick et al., 2017)

GEE is a Remote Sensing Archive with petabytes of data in one location, a cloud-based geospatial processing platform for executing large-scale data analysis. The Data Catalog contains:

- 200 public datasets;
- 4000 new images every day;
- 5 million images;
- 5 petabytes of data (1 petabyte = 1,000 terabytes= 1,000,000 gigabytes).

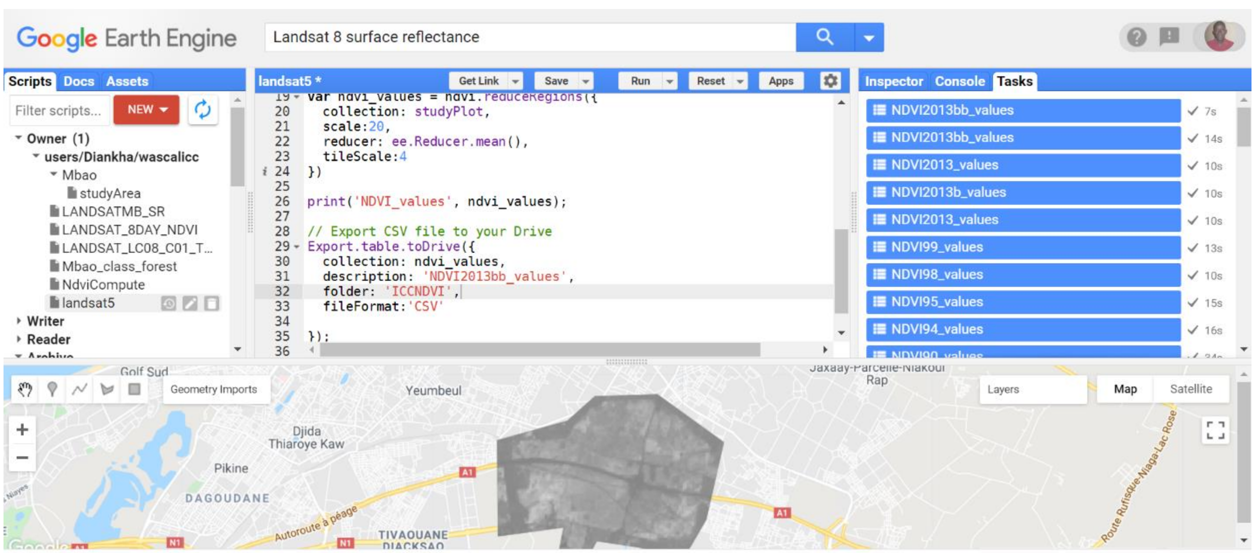

Figure 7: Application Programming Interface (API) of GEE

To achieve the dynamics of Mbao forest Landsat 5, Landsat 7, and Landsat 8 are combined:

- Landsat 5 from 1988 – 1998, NIR = Band 4 and Red = Band 3
- Landsat 7 from 1999 – 2012, NIR = Band 4 and Red = Band 3
- Landsat 8 from 2013 – 2018, NIR = Band 5 and Red = Band 4

Landsat 8, launched as the Landsat Data Continuity Mission on February 11, 2013, contains the push-broom Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). OLI collects data with a spatial resolution of 30 meters in the visible, near-IR, and SWIR wavelength regions, and a 15-meter panchromatic band, which provides data compatible with products from previous missions. (U.S. Geological Survey, 2018).

To compute NDVI using Google Earth Engine Editor it is possible to follow four steps:

1- Import the image collection surface reflectance for the study area using this code;

```
Imports (4 entries)
▸ var studyArea: Polygon, 13 vertices
▸ var geometry: Point (-17.33, 14.76)
▸ var studyPlot: Table users/Diankha/studyPlot
▸ var imageCollection: (Deprecated) ImageCollection "USGS Landsat 8 Surface Reflectance T…
 // import of Landsat 5  surface reflectance image collection
var landsat8SR = ee.ImageCollection('LANDSAT/LC08/C01/T1_SR')
                  .filterDate('2021-01-01', '2021-02-10')
                  .filterBounds(studyArea)
                  .sort('CLOUD_COVER')
                  .first()
                  .clip(studyArea);
```

2- Compute the NDVI using one of these two javascript codes below

```
// Define a function that will add an NDVI band to the Sentinel image.
var addNDVI = function(image) {
  var ndvi1 = image.normalizedDifference(['B8', 'B4']).rename('NDVI1');
  var nir = image.select('B8');
  var red = image.select('B4');
  var ndvi2 = nir.subtract(red).divide(nir.add(red)).rename('NDVI2');
  return image.addBands([ndvi1, ndvi2]);
};
```

3- Add the reducer output

```
// Add reducer output to the features in the collection
var ndvi_values = ndvi.reduceRegions({
  collection: studyPlot,
  scale:20,
  reducer: ee.Reducer.mean(),
  tileScale:4
})
```

4- Print the value and send them to Google Drive

```
// Export CSV file to your Drive
Export.table.toDrive({
  collection: ndvi_values,
  description: 'NDVI2013bb_values',
  folder: 'ICCNDVI',
  fileFormat:'CSV'

});
```

Before this, all the points of your study area should be converted into a shapefile using ArcGis or QGis.

In the case of sentinel, Band 8 is NIR, and Band 4 stands as the red band.

The regression model is created using R software with its IDE RStudio.

2.2.2. Determination of ecosystem service values using i-tree Eco software

2.2.2.1. Presentation of i-Tree

i-Tree Eco version 6 is a flexible software application designed to use data collected in the field from single trees, complete inventories, or randomly located plots throughout a study area along with local hourly air pollution and meteorological data to quantify forest structure, environmental effects, and value to communities (Nowak, 2020). Designed and developed by the U.S. Department of Agriculture, Forest Service, and several partner organizations (www. itreetools. org), the i-Tree Eco assesses urban forest structure and consequent ecosystem services and value (Selmi et al., 2016). Eco v6 is a model that uses tree measurements and other data to estimate ecosystem services and structural characteristics of urban or rural forests.

Eco is a complete package that provides:

- Sampling and data collection protocols - For plot-based sample projects, total population estimates, and standard error of estimates are calculated based on sampling protocols. For complete inventories, eco calculates values for each tree.
- Flexible data collection options - Use the mobile data collection system with web-enabled smartphones and tablets, or traditional paper sheets.
- Automated processing - A central computing engine that makes estimates of the forest effects based on peer-reviewed scientific equations to predict environmental and economic benefits.
- Reports - Summary reports that include charts, tables, and a written report.

2.2.2.2. How i-Tree Eco software works

Tree measurements and field data are entered into the Eco application either by webform or by manual data entry; they are merged with local preprocessed hourly weather and air pollution concentration data. These data allow the model to calculate structural and functional information using a series of scientific equations or algorithms (Nowak et al., 1998).

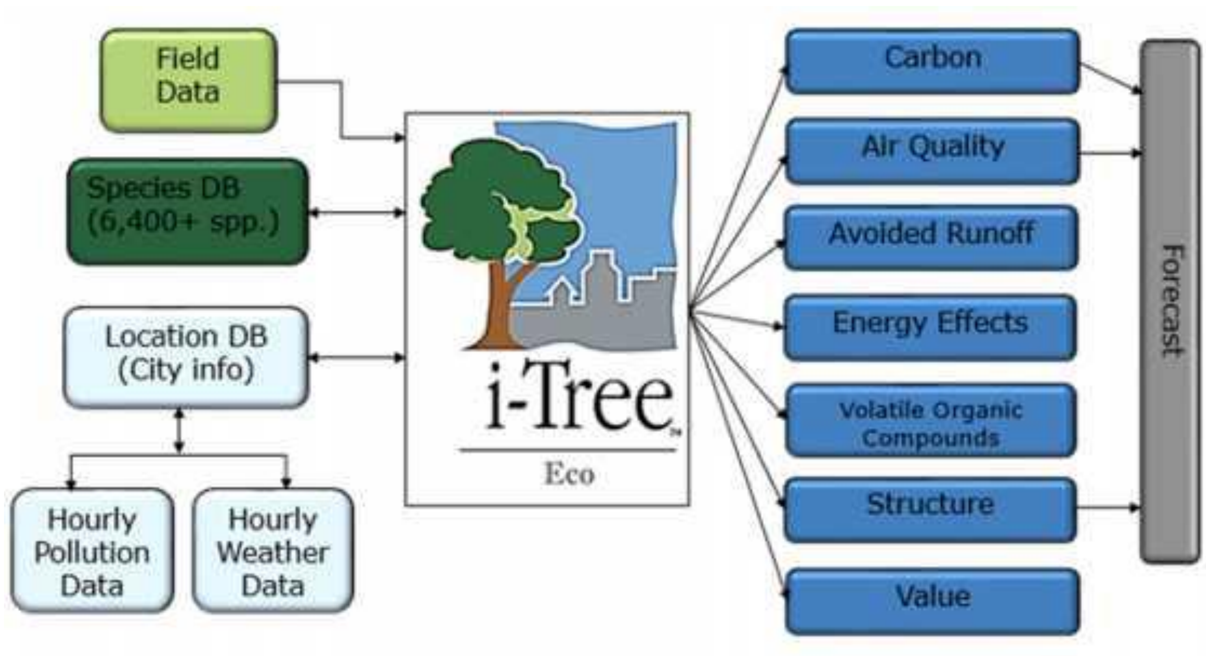

Figure 8: Operating principle of i-Tree eco (source: i-Tree factsheet)

Depending on your project configuration i-Tree Eco is currently designed to provide estimates of:

- Urban forest structure - Species composition, number of trees, tree density, tree health, etc.
- Pollution reduction - Hourly amount of pollution removed by the urban forest, and associated percent air quality improvement throughout a year. Pollution removal is calculated for ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide, and particulate matter 2.5 (<2.5 microns).
- Public health impacts – Health incidence reduction and economic benefit based on the effect of trees on air quality improvement for the United States only.
- Carbon - Total carbon stored and net carbon annually sequestered by the urban forest.

- Energy Effects - Effects of trees on building energy use and consequent effects on carbon dioxide emissions from power plants.
- Avoided runoff - Yearly avoided runoff attributed to trees summarized by tree species or strata.
- Forecasting - Models tree and forest growth over time; considers factors like mortality rates, tree planting inputs, pest and disease impacts, and storm effects. Some ecosystem services including carbon and pollution benefits are also forecasted.
- VOCs - Hourly urban forest volatile organic compound emissions and the relative impact of tree species on net ozone and carbon monoxide formation throughout the year.
- Values - Compensatory value of the forest, as well as the estimated economic value of ecosystem services.
- Potential pest impacts - based on host susceptibility, pest/disease range, and tree structural value.

To be able to work with i-Tree, it is required to send the pollution and rainfall parameters via the i-Tree database. It may take up to 6 months for the software to be updated in your study area.

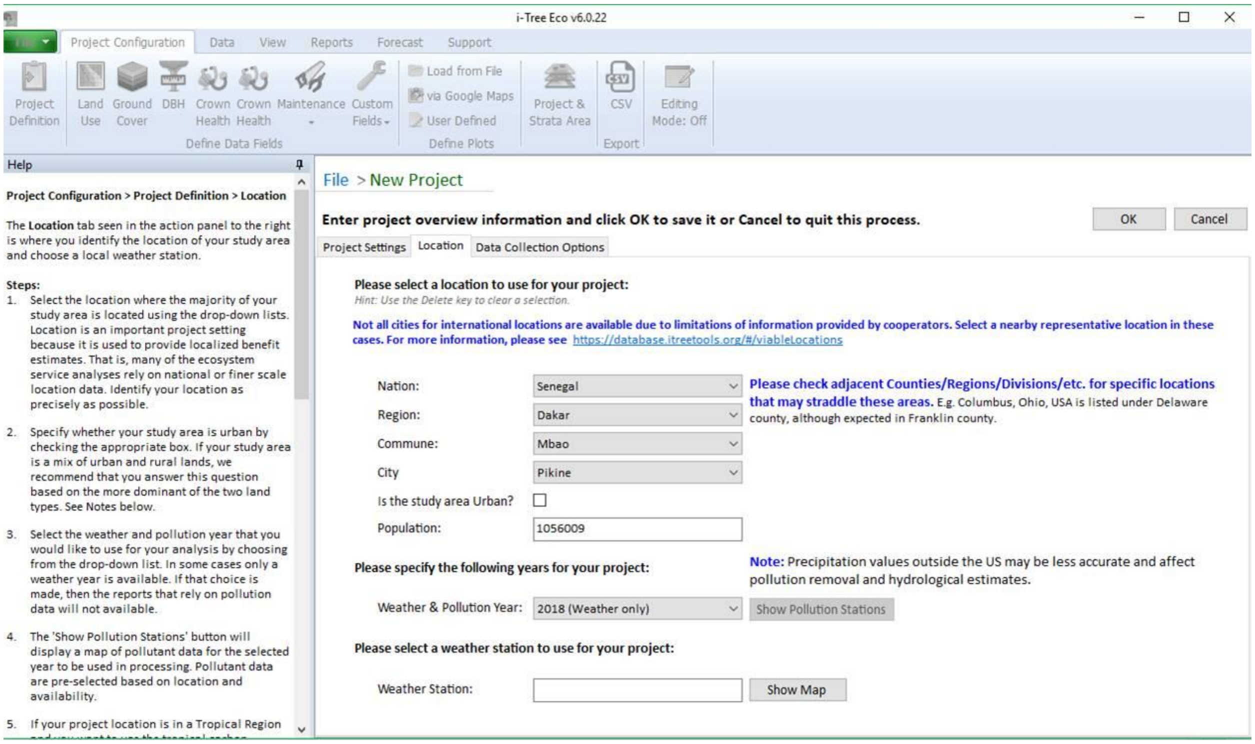

Figure 9: i-Tree Eco Software updated in Senegal

Applied for the first time in West Africa since its release in August 2006 according to our research, i-Tree Eco is a powerful tool to assesses urban forest structure and consequent ecosystem services and value. Around the world, i-Tree Eco has been implemented in several countries. The map below shows the locations where i-Tree Eco has been used.

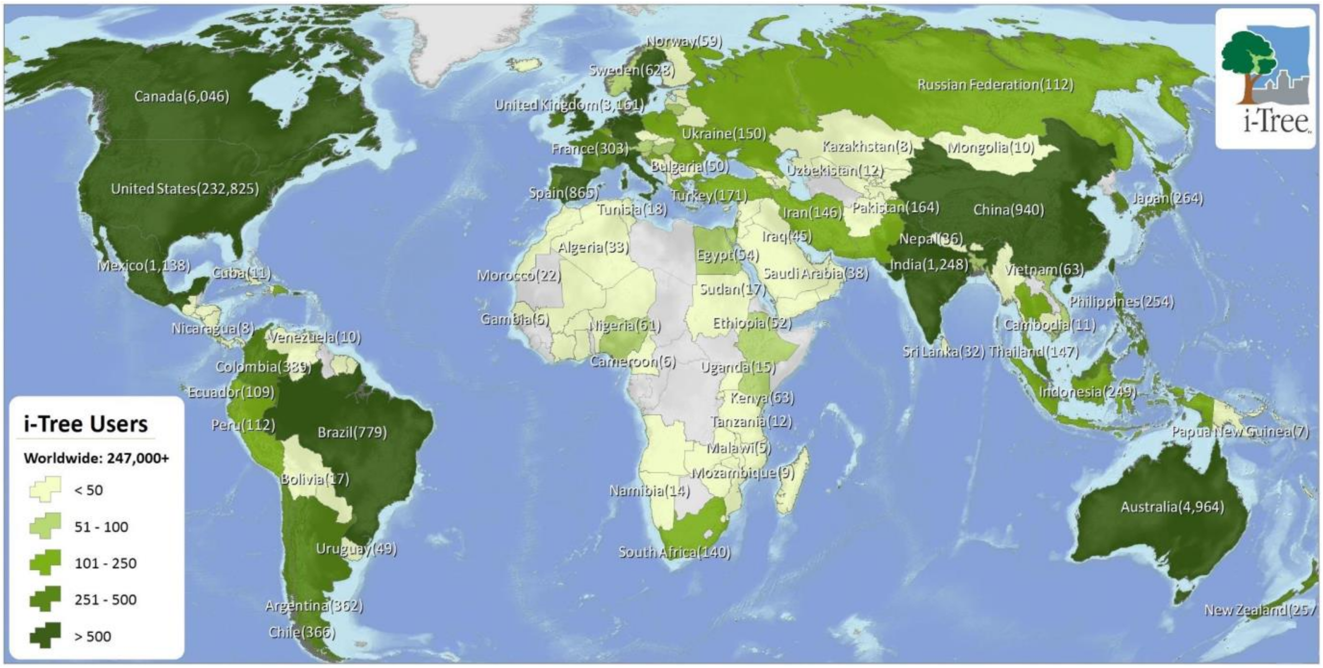

Figure 10: Locations where i-Tree is implemented (Source: Prof. Nowak presentation WFUF, 2018)

The study area remains Mbao classified forest described in chapter 3 above.

2.2.2.3. Methodology for i-Tree

For international projects like this study, the manager needs to submit pollution data, rainfall data, and species to the i-Tree database. This database has at least 7,100 species. The validation of the data can take up to six months. For this project, the data were submitted on June 30, 2020, and the i-Tree Eco software was updated in Senegal on March 3, 2021, i.e., nine months almost after the submission.

In this study, a total of 91 sample plots (0.5 % of the forest) have established by using a simple random sampling method. Concerning the sample plot size, the standard plot size for an Eco analysis is a 0.1-acre circular plot with a radius of 11.16 m or 0.0407 hectares. The diameters of all identified trees were measured at breast height (1.3 m above ground) using a diameter tape (5 m length). The height of all sampling trees was measured by clinometer but some of them were estimated based on our field experience.

To collect the data, it is possible to use either the Mobile Data Collector or the paper form.

The Mobile Data Collector functionality is not an app that you have to download from a store, it's a web-based inventory data collection form. This means that the only requirement is a device with a web browser that is HTML5 compatible (i-Tree Eco, 2020).

i-Tree Eco offers paper forms for collecting data in the field which provides a simple, inexpensive method of recording data.

To perform i-Tree Software we have to follow at least six steps:

1- Set up the project configuration;

2- Create a spreadsheet recording all the trees surveyed with their parameters (D.B.H, total height, crown width, etc.);

3- Import the spreadsheet in i-Tree clicking on the tree in the dashboard and the import button;

4- Match the spreadsheet and the i-Tree Eco features;

5- Check the data after the match;

6- Submit data for processing;

7- Go to report to retrieve your results.

(https://www.youtube.com/watch?v=aooEeOy5wb4&t=290s)

In this study, the paper forms were used to collect the data, and the crew was composed by:

- A Water and Forests engineer, pointer,
- Two Water and Forestry engineers, identifiers or meters;
- A ranger helping in the delimitation of the plots;
- A driver to drop off team members.

The duration of the fieldwork is from January 18, 2021, to January 31, 2021.

After collecting the data, it is now time to send it to the i-tree server following the above procedure by external data or another available way. The results were retrieved and the time depends on the size of the project and the number of projects on the queue to be processed.

The main objectives of this study are carbon storage and sequestration and air pollution removal.

Figure 11: Crew of inventory for Mbao forest (© Diankha, 2021)

- **Carbon sequestration and storage**

Carbon storage is the amount of carbon bound up in the above-ground and below-ground parts of woody vegetation. To calculate current carbon storage, biomass for each tree was calculated using equations from the literature and measured tree data. Open-grown, maintained trees tend to have less biomass than predicted by forest-derived biomass equations (Mcpherson et al., 1994). To adjust for this difference, biomass results for open-grown urban trees were multiplied by 0.8. No adjustment was made for trees found in natural stand conditions. Tree dry-weight biomass was converted to stored carbon by multiplying by 0.5.

Carbon sequestration is the removal of carbon dioxide from the air by plants. To estimate the gross amount of carbon sequestered annually, average diameter growth from the appropriate genera and diameter class and tree condition was added to the existing tree diameter (year x) to estimate tree diameter and carbon storage in year x+1.

Carbon storage and carbon sequestration values are based on estimated or customized local carbon values. For international reports that do not have local values, estimates are based on the carbon value for the United States (U.S. Environmental Protection Agency 2015, Interagency Working Group on Social Cost of Carbon 2015) and converted to local currency with user-defined exchange rates.

For this analysis, carbon storage and carbon sequestration values are calculated based on CFAF103,123 per metric ton. (i-Tree Eco report, 2021).

- **Air Pollution Removal**

Pollution removal is calculated for ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide, and particulate matter less than 2.5 microns. Particulate matter less than 10 microns (PM_{10}) is another significant air pollutant. Given that i-Tree Eco analyzes particulate matter less than 2.5 microns ($PM_{2.5}$) which is a subset of PM_{10}, PM_{10} has not been included in this analysis. $PM_{2.5}$ is generally more relevant in discussions concerning air pollution's effects on human health.

Air pollution removal estimates are derived from calculated hourly tree-canopy resistances for ozone, and sulfur and nitrogen dioxides based on a hybrid of big-leaf and multi-layer canopy deposition models (Baldocchi et al., 1988; Baldocchi et al., 1987). As the removal of carbon monoxide and particulate matter by vegetation is not directly related to transpiration, removal rates (deposition velocities) for these pollutants were based on average measured values from the literature ((Bidwell & Fraser, 1972; Lovett, 1994) that were adjusted depending on leaf phenology and leaf area. Particulate removal incorporated a 50 percent resuspension rate of particles back to the atmosphere (Zinke, 1967). Recent updates (2011) to air quality modeling are based on improved leaf area index simulations, weather and pollution processing and interpolation, and updated pollutant monetary values (Nowak et al., 2014; Nowak et al., 2018; Hirabayashi et al., 2012).

Trees remove $PM_{2.5}$ when particulate matter is deposited on leaf surfaces (Nowak et al., 2013). This deposited $PM_{2.5}$ can be resuspended to the atmosphere or removed during rain events and dissolved or transferred to the soil. This combination of events can lead to positive or negative pollution removal and value depending on various atmospheric factors. Generally, $PM_{2.5}$ removal is positive with positive benefits. However, there are some cases when net removal is negative or resuspended particles lead to increased pollution concentrations and negative values. During some months (e.g., with no rain), trees resuspend more particles than they remove.

Resuspension can also lead to increased overall $PM_{2.5}$ concentrations if the boundary layer conditions are lower during net resuspension periods than during net removal periods. Since the pollution removal value is based on the change in pollution concentration, it is possible to have situations when trees remove $PM_{2.5}$ but increase concentrations and thus have negative values during periods of positive overall removal. These events are not common but can happen.

For reports in the United States, the default air pollution removal value is calculated based on the local incidence of adverse health effects and national median externality costs. The number of adverse health effects and associated economic value is calculated for ozone, sulfur dioxide, nitrogen dioxide, and particulate matter less than 2.5 microns using data from the U.S. Environmental Protection Agency's Environmental Benefits Mapping and Analysis Program (BenMAP) (Nowak et al., 2014). The model uses a damage-function approach that is based on the local change in pollution concentration and population. National median externality costs were used to calculate the value of carbon monoxide removal (Murray et al., 1994).

For international reports, user-defined local pollution values are used. For international reports that do not have local values, estimates are based on either European median externality values (Van Essen et al., 2011) or BenMAP regression equations (Nowak et al., 2014) that incorporate user-defined population estimates. Values are then converted to local currency with user-defined exchange rates.

For this analysis, pollution removal value is calculated based on the prices of CFAF882,693 per metric ton (carbon monoxide), CFAF6,214,762 per metric ton (ozone), CFAF6,214,762 per metric ton (nitrogen dioxide), CFAF1,521,475 per metric ton (sulfur dioxide), CFAF4,149,311 per metric ton (particulate matter less than 2.5 microns).

- **Oxygen production**

The amount of oxygen produced is estimated from carbon sequestration based on atomic weights: net O_2 release (kg/yr) = net C sequestration (kg/yr) × 32/12. To estimate the net carbon sequestration rate, the amount of carbon sequestered as a result of tree growth is reduced by the amount lost resulting from tree mortality. Thus, net carbon sequestration and net annual oxygen production of the urban forest account for decomposition (Nowak et al., 2007). For complete inventory projects, oxygen production is estimated from gross carbon sequestration and does not account for decomposition.

- **Avoided Runoff**

Annual avoided surface runoff is calculated based on rainfall interception by vegetation, specifically the difference between annual runoff with and without vegetation. Although tree leaves, branches, and bark may intercept precipitation and thus mitigate surface runoff, only the precipitation intercepted by leaves is accounted for in this analysis.

The value of avoided runoff is based on estimated or user-defined local values. For international reports that do not have local values, the national average value for the United States is utilized and converted to local currency with user-defined exchange rates. The U.S. value of avoided runoff is based on the U.S. Forest Service's Community Tree Guide Series (McPherson et al., 1999).

For this analysis, avoided runoff value is calculated based on the price of CFAF1,294.87 per m^3.

3.RESULTS AND DISCUSSION

3.1. Results

Due to accessibility issues, 51 plots could be inventoried out of the 90 planned.

Figure 12: Plots surveyed in Mbao Classified Forest

3.1.1. Forest dynamics

The study sampled 418 stems with DBH ≥ 2.54 cm (1 inch) (Nowak, 2020) that belong to 10 families and 18 species. About 51 sample plots covering 20,757 m^2 were measured. Table1 presents the families and species recorded during the stocktaking.

Table 1: List of species surveyed

Num	Family name	Species	
		Scientific name	**Common name**
1	Anacardiaceae	*Anacardium occidentale* **L.**	Cashew
2	Arecaceae	*Borassus aethiopum* Mart.	African Fan Palm
3	Bombacaceae	*Adansonia digitata* L.	baobab tree
4	Celastraceae	*Maytenus senegalensis* (Lam.) Exell	spike thorn
5	Casuarinaceae	*Casuarina equisetifolia* L.	Australian pine
6	Fabaceae	*Tamarindus indica* L.	tamarind
7	Meliaceae	*Azadirachta indica* A. Juss.	Neem Tree
		Khaya senegalensis (Desr.) A. Juss.	Senegal Mahogany
8	Fabaceae	*Senegalia ataxacantha* (DC.) Kyal. & Boatwr.	flame thorn
		Senegalia macrostachya (Rchb. ex DC.) Kyal. & Boatwr. (2013)	
		Senegalia mellifera (Vahl) L.A.Silva & J.Freitas, 2014	Blackthorn acacia
		Vachellia nilotica (L.) P.J.H.Hurter & Mabb	Gum Arabic tree
		Faidherbia albida (Del.) Chev.	Faidherbia
		Prosopis juliflora (Sw.) DC.	Mesquite
9	Moraceae	*Ficus benjamina* L.	
10	Myrtaceae	*Eucalyptus camaldulensis*	Redgum eucalyptus

		Dehnh.	
		Melaleuca leucadendra (L.) L.	Paper Bark Tree
11	Balanitaceae	*Balanites aegyptiaca* (L.) Del.	Balanites

The data processing allows us to have the above-ground biomass, the below-ground biomass, and the total biomass.

The table below shows the result for all species (Kg/ha).

Table 2.: Results for all species combined

PARAMETER	QUANTITY
Number of stems/ha	204.902
Volume (m3)/ha	47.311
Above Ground Biomass (Kg/ha)	30.193
Below Ground Biomass (Kg/ha)	7.85
Total Biomass (Kg/ha)	38.043
Carbon stored (Kg/ha)	19.022
Tree cover (%)	13.46%

The number of stems combined per hectare is 204.902. However, four major species preponderate in this urban forest. Some of them are indigenous species and the rest are exotic:

- *Anacardium occidentale;*
- *Eucalyptus camaldulensis;*
- *Casuarina equisetifolia;*
- *Faidherbia albida.*

3.1.1.1. Description of the major species

Knowledge of its species is essential to assess the quantity of CO_2 stored by each of them.

- ***Anacardium occidentale* L.**

The cashew tree (*Anacardium occidentale* L.) is an angiosperm of the dicotyledonous class, the order Sapindales, and the family Anacardiaceae that contains 73 genera and about 600 species.

The genus *Anacardium* contains eight species native to tropical America, of which *Anacardium occidentale* L. is the most important in economic terms (Tandjiekpon, 2005). It is variously called a cashew, cashew apple, or apple cashew.

The cashew tree is native to northeastern Brazil and the Caribbean (Arbonnier, 2000). It was discovered by the Portuguese who introduced it to their colonies in Africa and Asia (Lacroix, 2003). The cashew tree is a plant that has great hardiness. It can grow on very poor soils and under very varied climatic conditions. In its original range, it can reach up to 20 meters high and its trunk can reach one meter in diameter (up to the breast, either 1.3 or 1.5 m high, depending on the country). Branches are extremely sensitive to fire, and when branches are destroyed by fire, it takes many years for the tree to rebuild its crown, especially as the tree is old. The wood is resistant to termites, useful in boat building, but charcoal is little appreciated because it crackles due to its balsam content (Goudiaby, 2014). The lifespan of the tree is around 30 years (Lautié et al., 2019).

Table 3:The features of Anacardium occidentale L.

PARAMETER	QUANTITY
Number of stems/ha	139.02
Volume (m^3)/ha	18.9227
Above Ground Biomass (Kg/ha)	7.75832
Below Ground Biomass (Kg/ha)	2.01716
Total Biomass (Kg/ha)	9.77549
Carbon stored Kg/ha	4.88774
Tree cover (%)	9.8%

- ***Casuarina equisetifolia* L.**

The genus *Casuarina* included a group of about 80 species of trees and shrubs native to the southern hemisphere and particularly from Australia and the coasts of South Asia, as well as in the Pacific Islands.

Casuarina was introduced to Africa in the 1930s, notably in Egypt and around 1948 in Senegal where the first reforestation of the *equisetifolia* species was carried out especially on the coastal dunes of Cape Verde.

Casuarina equisetifolia L. is located in a wide range of habitats, from the wetland to the desert, from the coastline to the top of the mountain, and from the temperate cold regions to the warm and humid tropical regions. The species *Casuarina equisetifolia* is a relatively weeping bear tree that can reach a height of up to thirty (30) meters, its crown is irregular in shape, rather ovoidal. File wood is often characterized by a well-mesh wood on a quarter like that of the Chenas (Quercus), isolated pores without the porous zone, and parenchyma in many tangential lines, invisible to the naked eyes.

The longevity is low, 30 to 50 years. Its growth is very rapid during the first 20 years. Beyond this age, it gradually decreases.

Table 4: The characteristics of Casuarina equisetifolia L.

PARAMETER	QUANTITY
Number of stems/ha	11.7647
Volume (m^3/ha)	3.80984
Above Ground Biomass (Kg/ha)	3.16217
Below Ground Biomass (Kg/ha)	0.82216
Total Biomass (Kg/ha)	3.98433
Carbon stored (Kg/ha)	1.99216
Tree Cover (%)	0.86%

- ***Eucalyptus camaldulensis*** Dehnh.

The *Eucalyptus camaldulensis* Dehnh, introduced to Senegal in 1863 (Adam, 1956), has acclimatized well. However, provenance tests revealed phenotypic variability from station to station and found that each climatic zone corresponded to a source that was distinguished by its growth and survival rate.

The first world conference on *Eucalyptus*, held in Rome in 1956, highlighted the global importance of this genus.

Eucalyptus belongs to the Myrtaceae family. It is a very plastic genus and has about 600 species including *camaldulensis*.

Eucalyptus camaldulensis Dehnh. is an evergreen tree, with a slender port reaching 12 to 20 m at a generally straight and more or less whitish barrel, with narrow tops with drooping branches and little supply.

The bark is smooth and creamy-white, scaly, flaking in irregular gray, brown, or brown scales with a reddish slice turning brown.

The age of operation varies from 6 to 10 years depending on the targets (perch, firewood, poles, carbonization). In its country of origin, *Eucalyptus* wood is red, with a dense texture; hard enough and easy to work. It usually takes polished wood (FAO, 1982).

In Burkina Faso, Mali, Cabo Verde, and Senegal *Eucalyptus* are used as lumber wood. The lifespan of *Eucalyptus* is over 200 years (Rica et al., 1993).

Table 5: The features of Eucalyptus camaldulensis Dehnh.

PARAMETER	QUANTITY
Number of stems /ha	32.8431
Volume (m^3)/ha	13.2328
Above Ground Biomass (Kg/ha)	12.9681
Below Ground Biomass (Kg/ha)	3.37172
Total Biomass Kg/ha	16.3399
Carbon stored Kg/ha	8.16993
Tree cover (%)	1.27%

- ***Faidherbia albida* (Del.) Chev.**

This indigenous tree is found in virtually all of Africa. Its natural range extends throughout dry tropical Africa, the Middle East, and Arabia, from 270 m below sea level in Palestine to 2500 m in Sudan (Wickens, 1969). It has been introduced to India, Pakistan, Nepal, Peru, Cyprus, Cape Verde, and Ascension Island. Its taproot deeply penetrates the soil (up to 15 m deep and sometimes 40 m) makes it very resistant to drought. It feeds in deep water tables and does not compete with crops. Due to its size, the wood is used locally for canoes, mortars, doors, and light carpentry, but it is susceptible to attack by borers (Acacia & Sud, 1934).

Table 6: The features of Faidherbia albida (Del.) Chev.

PARAMETER	QUANTITY
Number of stems/ha	5.39216
Volume (m^3)/ha	3.12965
Above Ground Biomass (Kg/ha)	1.7839
Below Ground Biomass (Kg/ha)	0.46381
Total Biomass (Kg/ha)	2.24772
Carbon stored (Kg/ha)	1.12386
Tree Cover (%)	0.31%

3.1.1.2. Tree Characteristics of the Urban Forest

The urban forest of Mbao has around 145,391 trees with a tree cover of 89.2 %. The three most common species are *Anacardium occidentale* (67.2 %), *Eucalyptus camaldulensis* (16.0%), and *Casuarina equisetifolia* (5.7%)

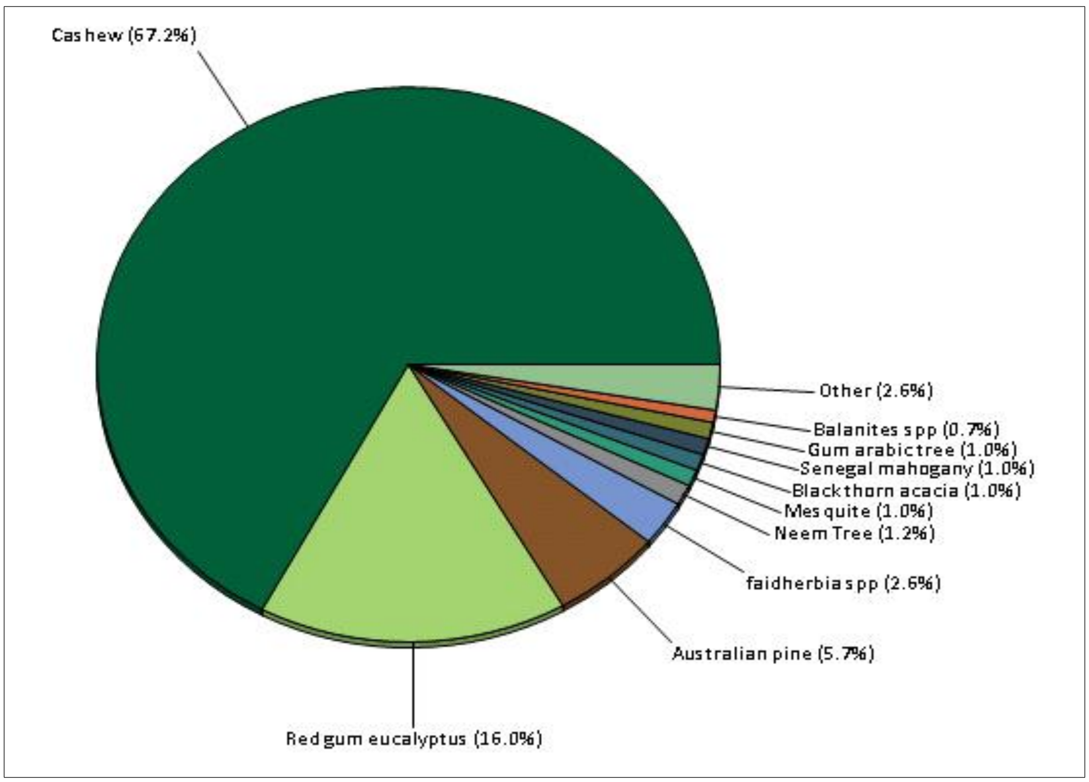

Figure 13: Tree species composition in Mbao Classified Forest (source: i-Tree report 2021)

- **Stems distribution by Diameter at Breast High (DBH)**

Most of the stems have a diameter between 15.2 and 30.5 centimeters followed by 7.6-15.2cm. The stems with DBH greater than 106.7 centimeters are almost non-existent. (cf. Figure 8).

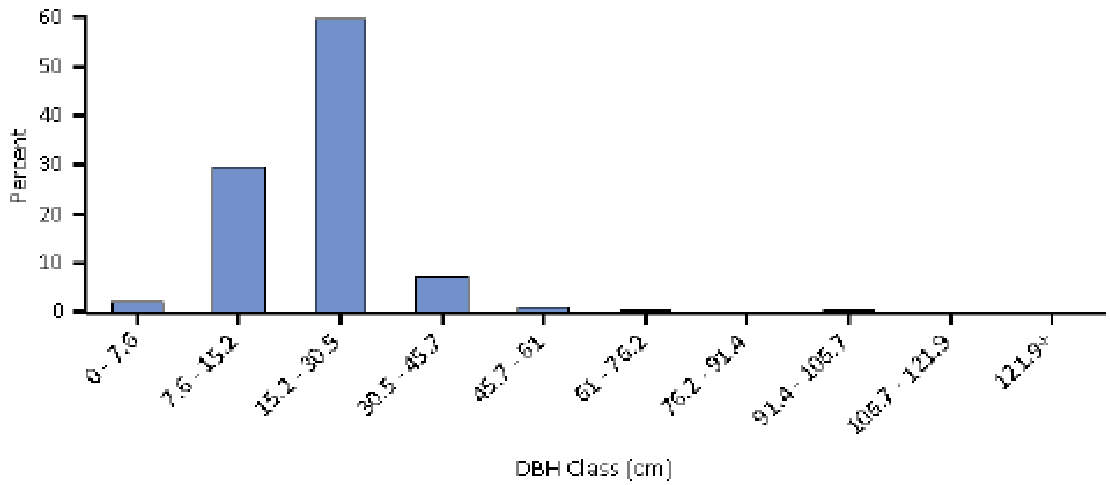

Figure 14: Percent of tree population by diameter class (DBH- stem diameter at 1.37 meters)

- **Species distribution by native origin**

In Mbao Forest, about 2 % of the trees are species native to Africa. Most of the trees have an origin from North & South America (68 % of the trees) (cf. Figure 9).

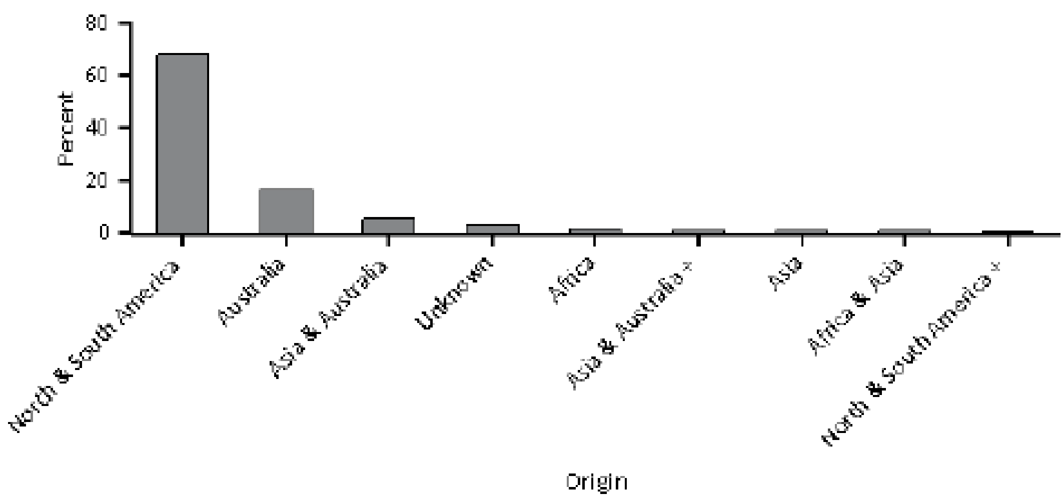

Figure 15: Percent of live tree population by area of native origin

- **Stems distribution of the four dominant species**

The figure shows that *Anacardium occidentale* L. has the greatest number of stems, this confirms that the zone is a reforestation perimeter since *Anacardium occidentale* is exotic. It is followed by *Eucalyptus camaldulensis* and *Casuarina equisetifolia*. Aboriginal species like *Faidherbia albida* are under-representation.

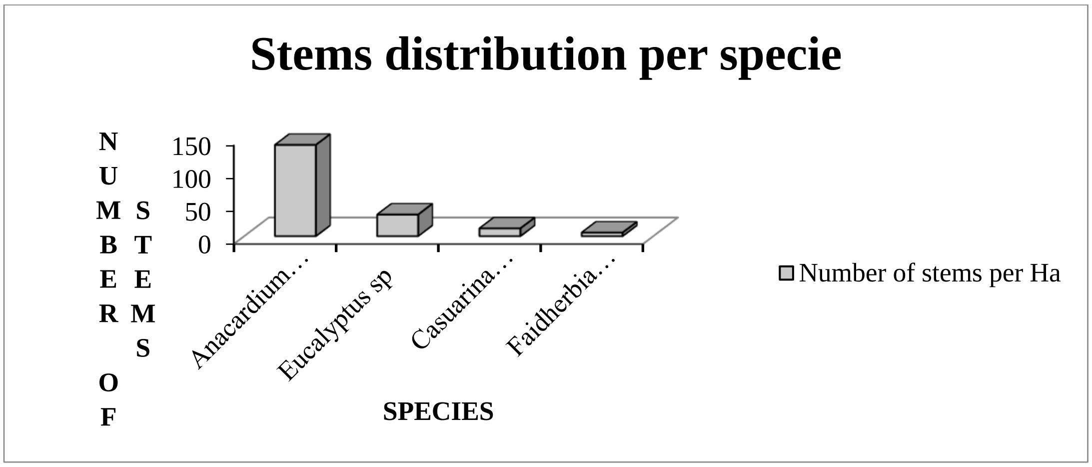

Figure 16: Stems for the four major species

- **The volume of wood distribution of the four dominant species**

The following figure shows that even if *Anacardium* has a greater volume than *Eucalyptus*, the biomass of the latter is more important due to its high density (*Eucalyptus* density = 0.8, *Anacardium* density = 0.44). Therefore, in carbon storage, *Eucalyptus* is a species of choice.
Apart from the competition that *Eucalyptus* exercises on other species, it must consider when it comes to carbon sequestration because of its lifespan (> 200 years).

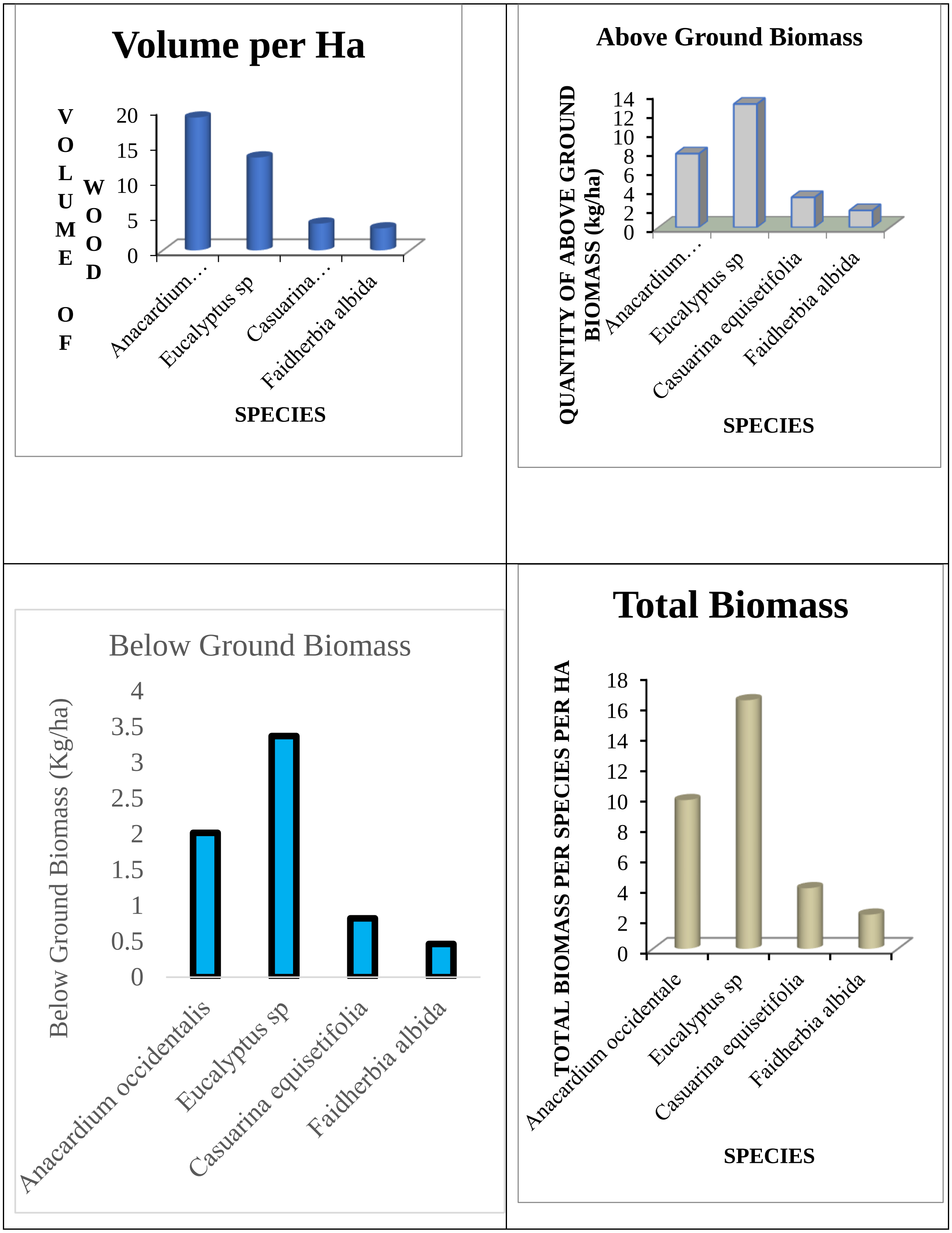

Figure 17: Volume, AGB, BGB, and total Biomass for major species

- **Carbon stored**

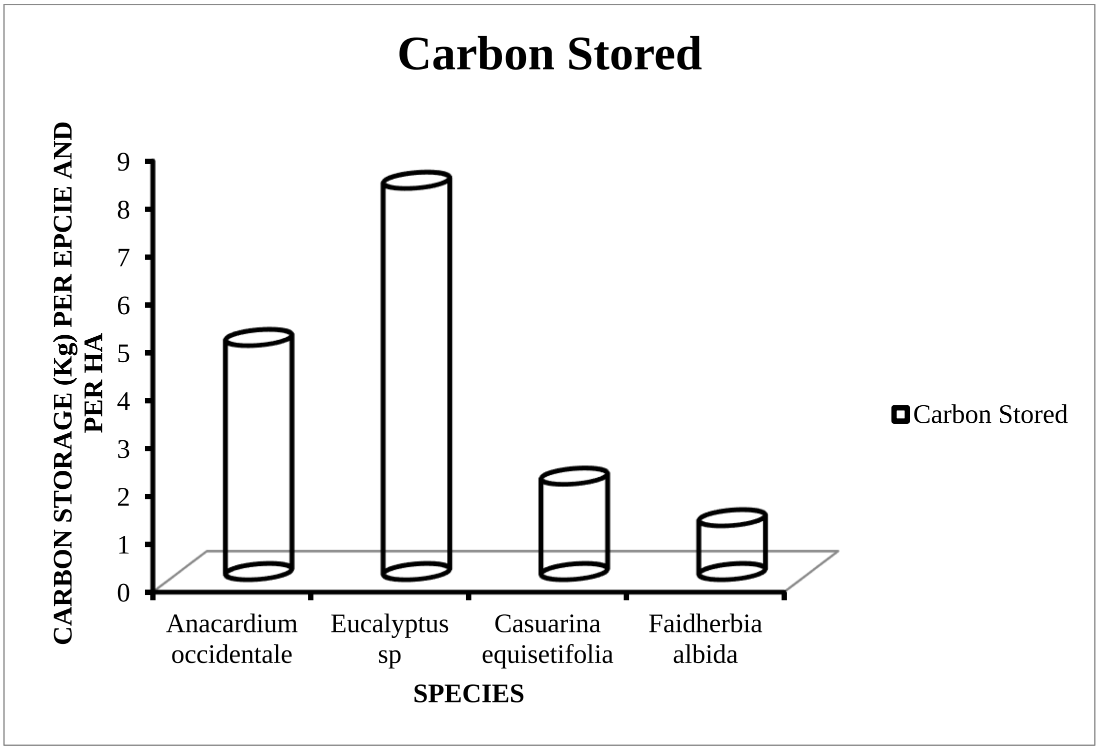

Figure 18: Carbon stored by Mbao major species

From January 1st, 2021 to February 10, 2021, using the forest inventory and the Google Earth Engine computation the following values were obtained. In table 7 the average values of biomass and NDVI are listed.

Table 7: NDVI and AGB of the surveyed plots

num	x	y	NDVI	AGB($Kgha^{-1}$)
1	248841	1631803	0.457582	3.404582
2	248559	1632085	0.494603	0.50092
3	248841	1632085	0.635408	7.31095

4	249123	1632085	0.405582	0.155344
5	249405	1632085	0.556549	3.163511
6	249687	1632085	0.20641	2.664363
7	249969	1632085	0.315591	0.519741
8	250251	1632085	0.319227	0.057183
9	250533	1632085	0.377855	2.159232
10	248559	1632367	0.549676	0.85949
11	248841	1632367	0.355916	0.111962
12	249405	1632367	0.340684	0.698379
13	249687	1632367	0.298399	0.308969
14	249969	1632367	0.254388	0.517528
15	250251	1632367	0.42229	0.541588
16	250533	1632367	0.476758	2.495665
17	249123	1632649	0.384441	0.547178
18	249405	1632649	0.439004	0.038312
19	249687	1632649	0.681047	0.305229
20	250815	1632649	0.458297	0.150227
21	247995	1632931	0.243804	5.978465
22	248277	1632931	0.147052	0.891155
23	248559	1632931	0.589015	9.290705
24	248841	1632931	0.542565	2.915419
25	249123	1632931	0.36604	0.850906
26	249969	1632931	0.689256	0.443229
27	247995	1633213	0.338468	1.761268
28	248277	1633213	0.537068	0.778214
29	248559	1633213	0.460106	1.336509
30	248841	1633213	0.598582	0.707798
31	249123	1633213	0.29755	0.352686

32	249405	1633213	0.2578	0.586981
33	249687	1633213	0.371893	2.065759
34	249969	1633213	0.399665	1.017465
35	250251	1633213	0.499743	0.370063
36	250533	1633213	0.47806	0.326705
37	248841	1633495	0.466527	0.278492
38	249123	1633495	0.406897	0.916726
39	249405	1633495	0.284499	0.144851
40	249687	1633495	0.343347	0.717946
41	249969	1633495	0.364028	1.543348
42	250251	1633495	0.520645	4.119342
43	250533	1633495	0.433798	0.770658
44	250815	1633495	0.305281	0.466062
45	248841	1633777	0.613105	6.743225
46	249123	1633777	0.508497	0.69343
47	249405	1633777	0.473735	1.026507
48	249687	1633777	0.454321	1.947208
49	249969	1633777	0.436346	0.32135
50	250251	1633777	0.466837	1.031652
51	250533	1633777	0.565798	0.092669

The regression model made it possible to establish a relationship between biomass and NDVI by assuming that all things being equal. Thus, the following table gives the values of the regression.

Coefficient	Value
Intercept	-0.3859
Slope	4.4165
P-value	0.0553
R^2	0.07292

Thus, the equation below allows calculating the average biomass during the same period (January, 1st to February 10) knowing the average NDVI using GEE.

Biomass = - 0.3859 + 4.4165 NDVI

The study period is used to calculate the mean NDVI for each year from 1988 to 2018 and the equation above to compute the Aboveground Biomass. The table below resumes the different values.

Table 8: Mean NDVI and Aboveground Biomass from 1988 to 2018

Year	**Mean NDVI**	**Aboveground Biomass** (Kg/ha)
1988	0.4362354	1.54073365
1989	0.45363465	1.61757744
1990	0.4159384	1.45109194
1992	0.40050239	1.3829188
1994	0.207302	0.52964927
1995	0.23653952	0.65877678
1998	0.24581765	0.69975363
1999	0.49260825	1.78970432
2000	0.26239797	0.77298065
2001	0.4065525	1.40963912
2002	0.42811586	1.50487368
2003	0.3376492	1.10532771
2004	0.36023724	1.20508776
2005	0.28110469	0.85559886
2006	0.33061245	1.07424987
2007	0.32933096	1.0685902
2008	0.2297427	0.62875862

2009	0.34858126	1.15360914
2010	0.31414412	1.0015175
2011	0.36212927	1.21344393
2012	0.2831544	0.86465142
2013	0.27052444	0.80887117
2014	0.40190328	1.38910582
2015	0.30629753	0.96686304
2016	0.33357741	1.08734462
2017	0.34807966	1.15139384
2018	0.28471436	0.87154096

It is important to note that although there is a decrease in AGB over the period, it has not been homogeneous as shown in the graph below. (Cf. Figure 19).

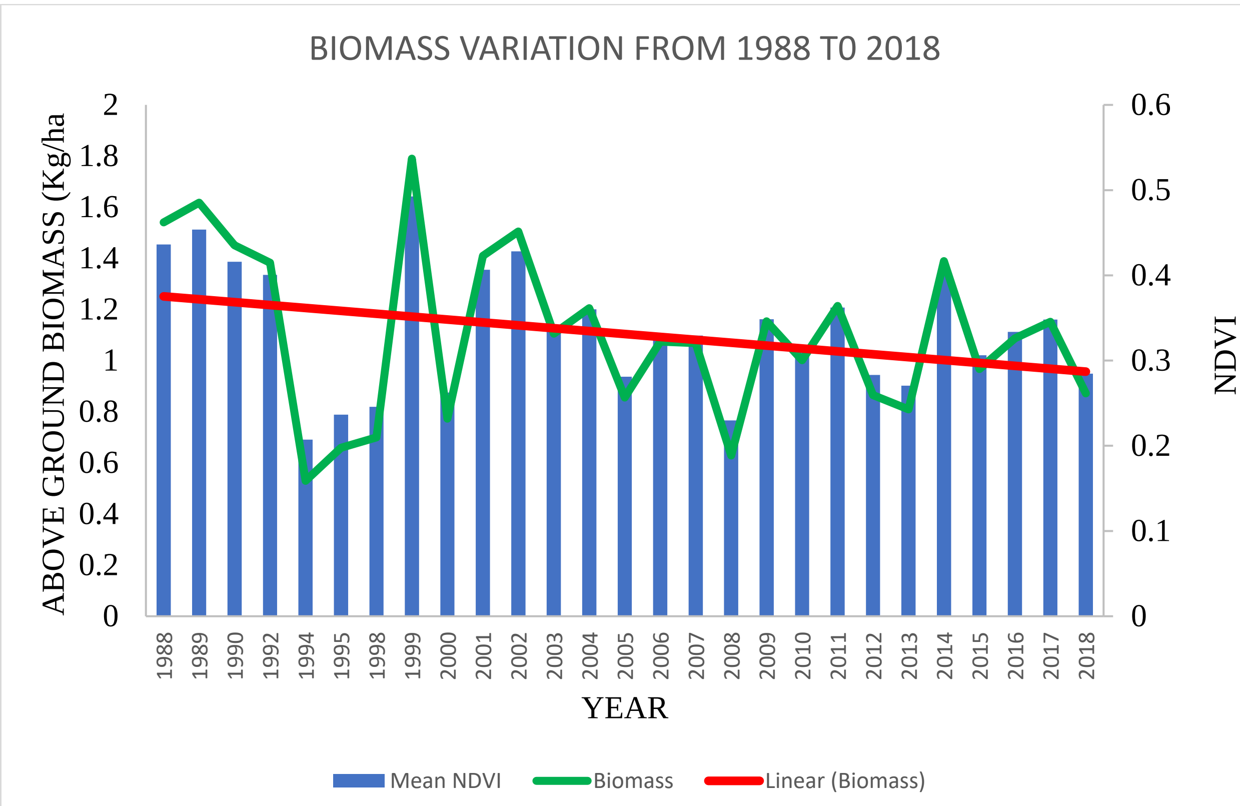

Figure 19: Trend of the biomass variation between 1988 to 2018

3.1.2. Ecosystem services assessment

3.1.2.1. Carbon sequestration and storage

Climate change is an issue of global concern. Urban trees can help mitigate climate change by sequestering atmospheric carbon (from carbon dioxide) in tissues and by altering energy use in buildings, and consequently altering carbon dioxide emissions from fossil-fuel-based power sources (Abdollahi et al., 2020).

Trees reduce the amount of carbon in the atmosphere by sequestering carbon in new growth every year. The amount of carbon annually sequestered is increased with the size and health of the trees. The gross sequestration of Mbao Classified Forest trees is about **1,506.43 metric tons** of carbon per year (2.09 metric tons/ha) with an associated value of **CFAF 15,547.8 thousand**.

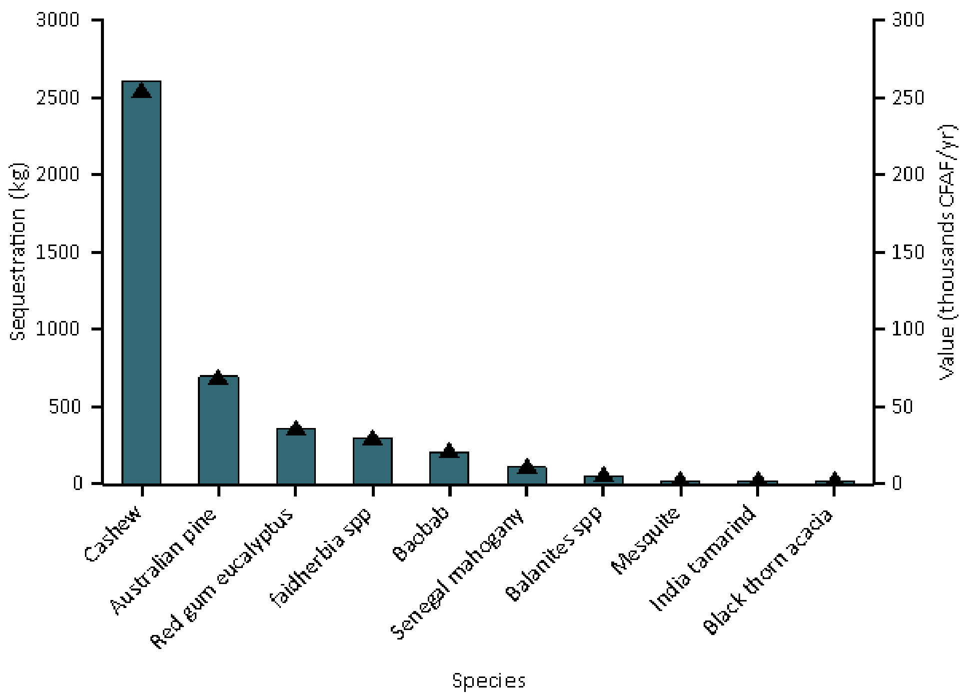

Figure 20: Estimated annual gross carbon sequestration (points) and value (bars) for urban tree species with the greatest sequestration

Carbon storage is another way trees can influence global climate change. As a tree grows, it stores more carbon by holding it in its accumulated tissue. As a tree dies and decays, it releases much of the stored carbon back into the atmosphere. Thus, carbon storage is an indication of the amount of carbon that can be released if trees are allowed to die and decompose. Maintaining healthy trees will keep the carbon stored in trees, but tree maintenance can contribute to carbon emissions

(Nowak et al., 2002). When a tree dies, using the wood in long-term wood products, to heat buildings, or to produce energy will help reduce carbon emissions from wood decomposition or fossil fuel or wood-based power plants.

Trees in Mbao Forest are estimated to store **7,892.17 metric tons (10.96 T/Ha)** of carbon (CFAF 813.91 million). Of the species sampled, *Anacardium occidentale* stores and sequesters the most carbon (approximately 40.2% of the total carbon stored and 58.5% of all sequestered carbon.)

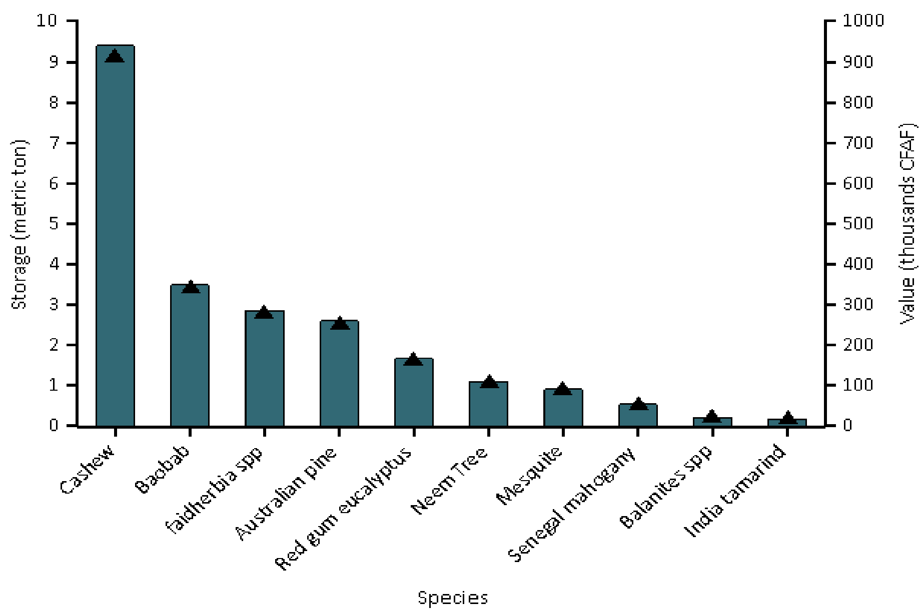

Figure 21: Estimated carbon storage(points) and values (bars) for urban species with the greatest storage

3.1.2.2. Air Pollution Removal by Urban Trees

Poor air quality is a common problem in many urban areas. It can lead to decreased human health, damage to landscape materials and ecosystem processes, and reduced visibility. The urban forest can help improve air quality by reducing air temperature, directly removing pollutants from the air, and reducing energy consumption in buildings, which consequently reduces air pollutant emissions from the power sources. Trees also emit volatile organic compounds that can contribute to ozone formation. However, integrative studies have revealed that an increase in tree cover leads to reduced ozone formation (Dwyer & Nowak, 2000).

Pollution removal by trees in Mbao Forest Senegal was estimated using field data and recent available pollution and weather data available. Pollution removal was greatest for ozone (Figure 22). It is estimated that trees remove 44,834.78 kg per year (62.27 kg/ha) of air pollution (ozone (O_3), carbon monoxide (CO), nitrogen dioxide (NO_2), particulate matter less than 2.5 microns ($PM_{2.5}$), and sulfur dioxide (SO_2) per year with an associated value of CFAF 188,173.91 thousand/year.

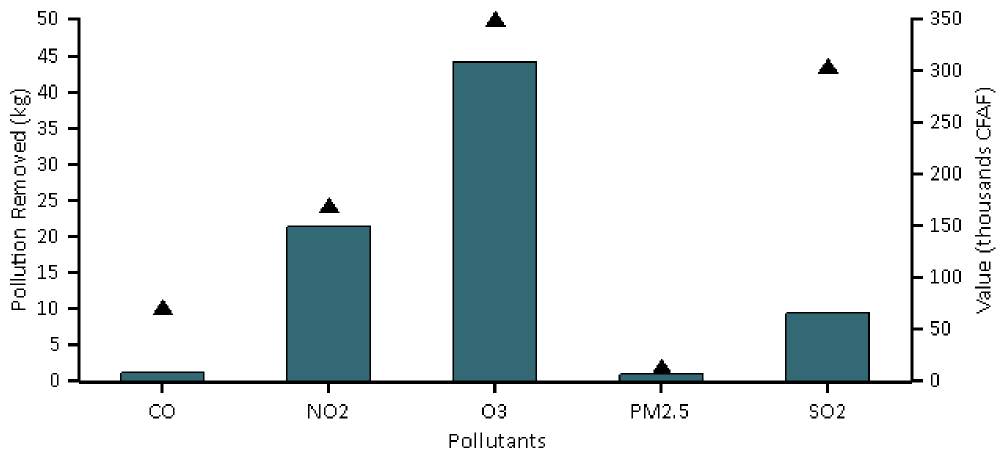

Figure 22: Annual pollution removal (points) and value (bars) by urban trees of Mbao

In 2021, trees in Mbao Forest Senegal emitted an estimated 42,086.95 kilograms of volatile organic compounds (VOCs) (15,850.43 kilograms of isoprene and 26,250.43 kilograms of monoterpenes). Emissions vary among species based on species characteristics (e.g., some genera such as oaks are high isoprene emitters) and the amount of leaf biomass. Eighty- six percent (86%) of the urban forest's VOC emissions were from *Anacardium occidentale* L. and *Eucalyptus camaldulensis* Dehnh. These VOCs are precursor chemicals to ozone formation.

3.1.2.3. Oxygen production

Oxygen production is one of the most commonly cited benefits of urban trees. The annual oxygen production of a tree is directly related to the amount of carbon sequestered by the tree, which is tied to the accumulation of tree biomass.

Trees in Mbao Forest Senegal are estimated to produce 4,017.39 metric tons of oxygen per year.

However, this tree benefit is relatively insignificant because of the large and relatively stable amount of oxygen in the atmosphere and extensive production by aquatic systems. Our atmosphere has an enormous reserve of oxygen. If all fossil fuel reserves, all trees, and all organic matter in soils were burned, atmospheric oxygen would only drop a few percent (Broecker, 1970).

Species	*Oxygen (kilogram)*	*Gross Carbon (kilogram/yr)*	*Number of Trees*	*Leaf Area (hectare)*
Anacardium occidentale	6,757.54	2,534.08	281	4.18
Casuarina equisetifolia	1,808.86	678.32	24	0.13
Eucalyptus camaldulensis	942.94	353.60	67	0.37
Faidherbia albida	761.92	285.72	11	0.06
Adansonia digitata	544.62	204.23	2	0.02
Maytenus senegalensis	284.12	106.54	4	0.13
Balanites aegyptiaca	129.54	48.58	3	0.00
Prosopis juliflora	64.70	24.26	4	0.03
Tamarindus indica	57.42	21.53	1	0.00
Acacia nilotica	50.45	18.92	4	0.01
Maytenus senegalensis	39.33	14.75	2	0.00
Melaleuca leucadendron	37.45	14.04	3	0.04
Ficus benjamina	27.80	10.42	1	0.00
Azadirachta indica	19.85	7.44	5	0.15
Acacia senegal	16.10	6.04	4	0.05
Acacia macrostachya	5.40	2.03	2	0.00

3.1.2.4. Avoided Runoff

Surface runoff can be a cause for concern in many urban areas as it can contribute to pollution to streams, wetlands, rivers, lakes, and oceans. During precipitation events, some portion of the precipitation is intercepted by vegetation (trees and shrubs) while the other portion reaches the ground. The portion of the precipitation that reaches the ground and does not infiltrate into the soil becomes surface runoff (Hirabayashi et al., 2012). In urban areas, the large extent of impervious surfaces increases the amount of surface runoff.

Urban trees and shrubs, however, are beneficial in reducing surface runoff. Trees and shrubs intercept precipitation, while their root systems promote infiltration and storage in the soil. The trees and shrubs of Mbao Forest Senegal help to reduce runoff by an estimated 21,982.6 cubic meters a year with an associated value of CFAF 8,410.25 thousand. Avoided runoff is estimated based on local weather from the user-designated weather station. In Mbao Forest Senegal, the total annual precipitation in 2012 was 31.6 centimeters.

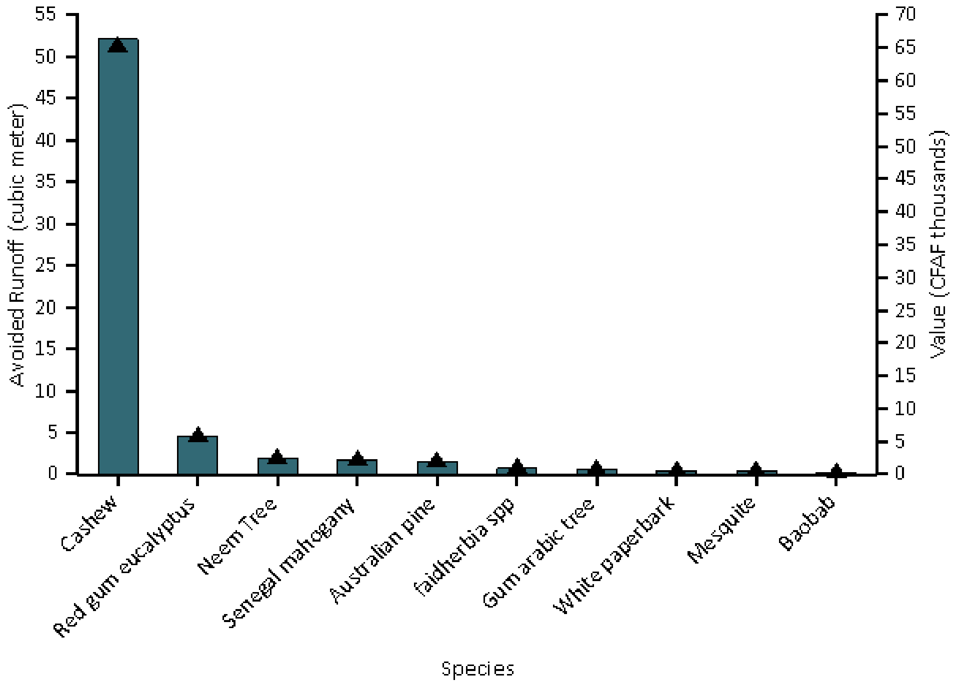

Figure 23: Avoided runoff (points) and value (bars) for species with the greatest overall impact on runoff

3.1.3. Comparison between Mbao ecosystem service values and the toll highway Dakar-Diamniadio turnover during a year

The Dakar-Diamniadio toll highway was born out of the Senegal State desire to improve urban mobility within the metropolitan of Dakar. Its construction required a total area estimated at 432,000 m^2 in urban areas and 444,000 m^2 in rural areas (LEGS-Africa, 2020). The toll highway is like a “knife stuck in the throat of the Mbao classified forest” and cuts it from West to East into two entities with different evolutions.

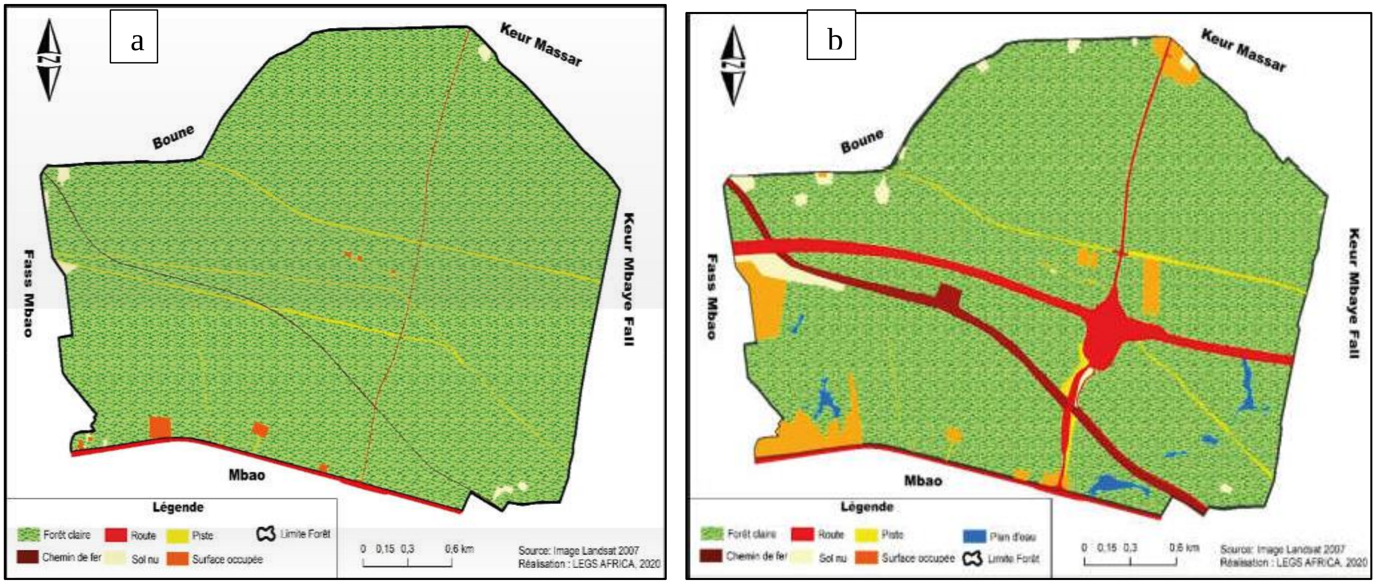

Figure 24: Mbao forest land use in 2007 (a) and 2020 (b) Source: LEGS-Africa, 2020

The entry into service of the toll highway significantly reduced the duration of journeys opening up to urbanization the areas around the classified forest. Even if the economic benefits are significant, the destruction of part of Dakar's main green lung deserves a comparison between the turnover of this infrastructure and the loss of ecosystem services to have better decision-making in future projects.

Table 9: SECAA cash flow analysis in 2019

Designation	**Expected** **M(million) CFAF HT**	**Real** **M(million) CFAF HT**
Operating revenue	107,324	143,757
Business Operating Expense	36,652	56,526
Additional investment	0	8,539

Source: SECAA SA cited by LEGS-Africa (2020)

The toll highway named “Autoroute de l'Avenir”, delivered in 2013 in its phase 1, displaced more than 41,000 people, caused the downgrading of part of the Mbao classified forest out of fifty-five (55) hectares, crossed flood zones among others.

SECAA – “Société Eiffage de la Concession de l'Avenir Autoroute” is in charge of operation for a period of thirty (30) years. It ends on November 30, 2039.

On an investment cost of CFAF 138 billion, the subsidy from the State of Senegal amounts to CFAF 77.6 billion. Eiffage's private financing contribution is only CFAF 61 billion. Better, it is important to specify that Eiffage only invested CFAF 20.8 billion in equity, the rest of its financial contribution being supported by private partners, in particular banks (Kane, E. H et al., 2020).

According to a study by LEGS-Africa published in November 2020, on a turnover of CFAF143,757 million, operating expenses of CFAF 56,526 million, taxes and duties of CFAF 28,021 million, a payroll of CFAF 5,100 million, the profit was CFAF 10,677 million. The overall budget of the toll highway establishment represents CFAF 380.2 billion.

So, it is easy to understand that the monetary value of carbon sequestration in 2021 (CFAF15,547.8 thousand), and that of air pollution removal (CFAF188,173.91 thousand) are not greater than the annual turnover of operating the highway. But if it comes to take account into the nine ecosystem service values the amount will be very important. So, the question to ask: is it relevant to destroy an urban forest to pass a toll highway even if it is obvious that all the parameters are not taken into account for the two variables.

3.2. Discussion

3.2.1. Forest dynamics

About the forest composition, large-diameter trees are not important and this fact demonstrates the reforestation and regeneration efforts undertaken by managers.

Urban forests are composed of a mix of native and exotic tree species. Thus, urban forests often have a tree diversity that is higher than surrounding native landscapes. Increased tree diversity can minimize the overall impact or destruction by a species-specific insect or disease, but it can also pose a risk to native plants if some of the exotic species are invasive plants that can potentially out-compete and displace native species. Invasive plant species are often characterized by their vigor, ability to adapt, reproductive capacity, and general lack of natural enemies. These abilities enable them to displace native plants and make them a threat to natural areas.

The regression model between the Above Ground biomass and the NDVI gives a relatively low R^2 ($R^2 = 0.07292$). The result is consistent with Morel et al. (2012) with $R^2 = 0.06$ in "Monitoring aboveground biomass in Sabah, Malaysia".

Using satellites like NOAA-AVHRR, SPOT, and MODIS, the Ecological Monitoring Center

(CSE) in Senegal found a regression line **Biomass = 11750 * NDVI - 3120** in 2011 with a correlation coefficient R = 0.87.(CSE, 2011). This is not consistent with our results.

Although these results do not correspond to ours, it should be noted that none of these studies used Google Earth Engine. If we know the precision with which, Artificial Intelligence, and more precisely the algorithms carry out their calculations, it would be interesting to resume these manipulations with Google Earth Engine.

In 1988 we had a biomass density equal to 1.5 Kg/ha while in 2018 the quantity of biomass fell to 0.8 Kg/ha, i.e., a decrease of 46.66%. The biomass is decreasing between 1988 and 2018.

This may be due to traditional healers who, according to Gueye (2015), harness trees with 47% followed by shrubs at 33% and lianas at 20%. The road infrastructure development contributes to a loss of the vegetation cover because the toll highway establishment required the declassification of 35 ha (Gueye et al., 2008). And it is consistent with Hansen et al. (2013) who found a global forest loss (2.3 million square kilometers) and gain (0.8 million square kilometers) from 2000 to 2012 at a Landsat spatial resolution of 30 meters, due to forest degradation. The tropics were the only climate domain to exhibit a trend, with forest loss increasing by 2101 square kilometers per year. The forest monitoring deficit linked to the staffing problems of the Forest Service can lead to the biomass decreasing because of the illegal logging about eucalyptus plantations by local populations.

These results are consistent with a previous inventory done by Ngom (2010) who, during a stratified stocktaking with 8 classes found average biomass of 8269.98 Kg/ha in 2010 due to illegal loggers. Likewise, Qin Y. et al. (2021) found that the net AGB loss of the Brazilian Amazon was three times smaller in 2019 than in 2015. During 2010–2019, it had a cumulative gross loss of 4.45 Pg C against a gross gain of 3.78 Pg C, resulting in a net AGB loss of 0.67 Pg C causing by forest degradation.

This approach for spatially and temporally estimating AGB dynamics at a land management scale, using single-date forest inventory plots and an annual Landsat time series (1988–2018) can be particularly useful in forest regions where only single-date and sparse inventory data are available. This can aid forest managers and policymakers in measuring and reporting on forest biomass changes, especially in developing countries, because with Google Earth Engine the most archive imagery is free of access.

In terms of urban forestry, the finding since the colonial period has been that the criterion for choosing reforestation species has not changed. This planning is based on the aesthetic qualities of the species and its adaptability to the area where it will be planted in most cases.

It is important to include the ability to sequester carbon in the selection criteria, especially in the context of climate change. This involves determining the density of all our indigenous species. Important work is being done in this area by ICRAF (International Centre for Research in Agroforestry), but in Senegal, the National Forestry Research Center (CNRF) should invest in it to fill the information gap concerning the density of our local species.

The National Agency for Statistics and Demography (ANSD) indicates that “the area covered by forests in Senegal decreased from 8.7 million hectares in 2005 to 8.5 million hectares in 2010, i.e. decrease of 2.3% corresponding to an average loss of 40,000 hectares per year. For the sustainable supply of wood fuel to the country, forest management began to emerge in the 1980s. The duration of a management plan is between ten and twenty years. According to decree n ° 27149 of 12/31/2018 setting the organizational arrangements for the 2019 logging campaign, Senegal has 48 forests developed for charcoal production, including 16 for Tamba, Kolda 11, Sédhiou 3, Kaolack 6, Kaffrine 5 and finally Fatick, which has 7 managed forests. Using this tool would allow the forest service to better monitor these forest areas to make more appropriate decisions. According to Arbonnier and Faye (1988), the basal surface of the stems reaching the maturity for charring remains relatively stable beyond 8 years under conditions comparable to the station conditions of Koumpentoum. Therefore, the majority of these forests have an 8 years rotation and should be comprehensively assessed after each rotation. For monitoring the evolution of forests over time, NDVI could be a less expensive alternative since the images are currently easily accessible and free of charge using Google Earth Engine.

In charcoal forest management, the forest is first divided into blocks and each block is divided into plots. For a rotation of eight (08) years, the block is divided into eight plots. In year 1 of implementation, 50% of the woody potential is exploited. It is in the ninth year that the operators will go back to cut 50% of the remaining potential. Thus, the harvested species has sixteen (16) years to reconstitute itself and therefore the sustainability of the forest is ensured.

The use of this method would make it possible to follow the evolution of the plot and give the alert in case that the reconstitution of the plant cover is not sufficient. This activity is really important in West African as forests are made up mainly of indigenous species whose silviculture is not yet well mastered (Combretum *glutinosum*, *Terminalia macroptera*, *Anogeissus leiocarpus, Terminalia avicennioides Guill. & Perr, etc.)*.

In terms of forest management, in most cases, there are production series intended for exploitation and protection series to preserve sensitive areas (around ponds, watersheds, etc.). Determination of biomass using NDVI allows quantification of the value of the protection series, which was often greatly underestimated during assessments compared to the series of production.

3.2.2. Ecosystem services

This study provided the quantity of the carbon stored and sequestered by urban trees but also explores the ability of public trees to improve air quality in Dakar city through the Mbao urban forest.

Thus the i-Tree model has shown that the quantity of CO_2 sequestered annually is 2.09 metric tons of carbon per hectare with an associated value of CFAF 21 594.16. Carbon sequestration is the process of removing carbon from the atmosphere and storing it in a physical element (Nowak, 2020). Trees absorb carbon dioxide during photosynthesis, storing carbon, use it for growth, and producing oxygen as a byproduct of photosynthesis. According to Nowak et al. (2012), as trees grow, they store more carbon by holding it in their accumulated tissues (roots, stems, branches, and leaves). Hence, the younger the stand, the greater the sequestration.

Trees and plants, for example, absorb carbon dioxide, release oxygen and store the carbon. It is a scientific fact that atmospheric concentrations of carbon dioxide can be lowered by reducing emissions or by taking carbon dioxide out of the atmosphere and storing it in inter-terrestrial, oceanic, or freshwater aquatic ecosystems.

The objective is to demonstrate that by converting intact forest property into financial capital it is feasible to protect the physical forest entity and provide incentives for sustainable forest management and sustainable livelihoods (Minott & Kolb, 2020).

Carbon sequestration is the most viable method of ending the rapid degeneration of our natural resources by linking multiple stakeholder interests with the goals of reducing CO_2 in the atmosphere and thus reducing the rapid rate of deforestation. If the carbon payment were zero, then the timber values would predominate, as has been the case historically. However, once annual payments are being received for carbon, the harvest and payment for timber would mean the loss of payments received for the carbon sequestration services (Sedjo, 2001).

The benefits of carbon sequestration activities are typically estimating in the amount of carbon sequestered, the number of tons of carbon sequestered indefinitely, or the number of tons of carbon sequestered for a while, e.g., for one year. More accurately, the benefits of carbon sequestration are the future damages are avoided by reducing the amount of atmospheric carbon.

However, the monetary value of the sequestered carbon is difficult to estimate hence the relevance of i-Tree software. The Kyoto Protocol recognizes forestry as an acceptable carbon sequestration vehicle, and forestry offers possibilities for significant carbon influence. Likewise, the use of forestry does not require the development of any new science or technologies. Societies know how to plant and manage fast-growing forests, and societies know where fast-growing forests will thrive and where they will not (Sedjo, 2001).

The Kyoto Protocol and the United Nations Framework Convention on Climate Change's (UNFCCC) strong emphasis on incorporating carbon market mechanisms as a method in reducing greenhouse gas (GHG) emissions.

The amount of carbon sequestered in Mbao is due to the young trees because the DBH between 15.2 cm and 30.5 cm are more important in the forest. In addition, the toll highway crosses the forest from West to East where at least 50.000 vehicles are recorded every day causing a lot of pollution. This value (2.09 ton metric per hectare per year) is greater than the value found in Toronto, Canada (0.73 metric tons/ha/ year), in New York (0.48 metric tons/ha/ year), in Washington, DC (0.92 metric tons/ha/ year), in Los Angeles (0.36 metric tons/ha/year) and Morgantown WV (1.17 metric tons/ha/year) according to the i-Tree Eco report (2021).

The carbon stored in Mbao is 7,892.17 metric tons of carbon (10.96 metric tons/hectare) which corresponds to CFAF 813.91 million. Storage depends on the diameter of the tree but also on its density. In Mbao we see that there is a predominance of medium diameters, implying a relatively low storage capacity.

In some forestry activities, the major carbon pools are found in large quantities of live biomass, dead biomass, and wood products (Minott, 2004). Knowledge of the carbon stored by forests is important because it guides the carbon market. Hence, carbon transfers or trading would have as a by-product the generation of financial transfers, usually from developed to developing countries.

This amount of carbon is less than the carbon stored in Toronto (17.4 metric tons/ha), in Atlanta

(35.7 metric tons/ha), in Morgantown WV (37.7 metric tons/ha) but higher than the carbon found in Los Angeles (9.4 metric tons/ha), in Phoenix (2.9 metric tons /year), and Jersey City (5.0 metric tons/ ha). (Nowak and Crane, 2002).

Likewise, air pollution removal by Mbao is around 44,834.78 kg/year (62.27 kg/ha/year) is greater than the pollutant removed in Syracuse NY (15.2 kg/ha/year), in Baltimore, MD (18.6 kg/ha/year), in Chicago, IL (15.7 kg/ha/year) and in Morgantown, WV (29.2 kg/ha/year) according to Nowak et al. (2012). It is less than the amount removed in Adama City, Ethiopia (14,087.45 kg/ha/year) (Koricho et al., 2020).

Mbao air removal is greater than the pollutant removed for Strasbourg, France (11.26 kg/ ha/ year) (Selmi et al., 2016). The major pollutants are CO (carbon monoxide), O_3 (ozone), NO_2 (Nitrogen Dioxide), SO_3 (Sulphur Dioxide), $PM_{2.5}$ (Particles matter less than 2.5 micrometers). Hence pollution removal is calculated for ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide, and particulate matter less than 2.5 microns. PM_{10} has not been included in this analysis. $PM_{2.5}$ which is a subset of PM_{10} is generally more relevant in discussions concerning air pollution's effects on human health. However, pollution can also affect plant health and functions. For example, ozone is considered harmful to plants as it affects tree growth, photosynthesis and accelerates the senescence of leaves (Ashmore, 2005; Anav et al., 2015). The total removal of main air pollutants by urban trees in the recreational zone of Guangzhou (China) was 23kg/ha/year (Jim & Chen, 2008).

Most of these values are less than the value of Mbao. Hence, it is important to jot down that all these studies have been done in the entire city when this study is just for an urban forest with 720 hectares.

In addition, the toll highway with an average of 50,000 vehicles per day will contribute significantly to the increase in pollution. The i-Tree model provides relevant information about urban trees and their impact on the urban environment that could serve both scientists and managers. It is now up to scientists to provide good information to allow decision-makers not to take measures that have a negative impact on the health of the population by taking into account only the pecuniary aspect. By preserving the forests, the health of the population can be preserved but also significant benefits with carbon credits and projects within the framework of the clean development mechanism (CDM). Due to time constraints, the work is only carried out on 720 ha, while the agglomeration of Dakar covers 550 km^2, so 1.3% of the area is studied. Hence, it would be interesting to extend the study throughout the Dakar region. The comparisons in the discussion might be more relevant if the areas were approximately equal and the data collection method (complete inventory or stratified inventory) similar.

Although the model was initially developed for US cities, i-Tree can be used worldwide but requires data collection, input, and formatting before use (Yang et al., 2005). i-Tree Eco is now set to work in the U.S., Canada, Australia, and the U.K. To apply i-Tree in other areas such as Senegal, users need to provide additional information regarding study location, new species (if encountered), and local weather and hourly air pollution data. For required and desired data to use the model in non-American cities, along with model limitations, see the i-Tree Eco website (https://www.itreetools.org/eco/international.php).

Ecosystem services encompass a diverse range and there is oxygen production and avoided runoff which remains important for the Mbao forest.

Estimated at 25% of the population in 1987 (Boutinot, 2019), the Senegal urban population was estimated in 1998 at 41% and now amounts to 47.7% of the total population (i.e. 6,105,448 inhabitants out of 12,855,153) in 2011(ANSD, 2011), hence the control of air pollution, carbon sequestration and forest dynamics remain crucial to have a safe population over the forthcoming decades.

4. CONCLUSION AND RECOMMENDATIONS

In this study, the aim was to assess the value of services ecosystems of the classified forest of Mbao (carbon sequestration and air pollution removal) but also to follow their evolution over the last thirty years (1988-2018).

To carry out this study, the dynamics of the forest during the study period were determined using an unstratified forest inventory, the Normalized Difference Vegetation thanks to the Google Earth Engine platform. The R software allowed, knowing the biomass and the NDVI, to create a linear regression model for the monitoring of the dynamics. Biomass was determined using allometric equation models.

The assessment of the value of ecosystem services is carried out by running the i-Tree Eco model, which is an improvement of the Urban Forest Effect (UFORE) model used for the first time in Senegal and probably in West Africa at the current state of our research. To validate the results of the model, the results are compared with the results coming from allometric equations.

This methodology enables us to know that the biomass of the forest is composed mainly of *Anacardium occidentale* L. (67.2 %), *Eucalyptus camaldulensis* Dehnh. (16.0 %), and *Casuarina equisetifolia* L. (5.7 %) underwent a net regression during the period from 1.5 Kg/ha in 1988 to 0.8 Kg/ha in 2018, i.e., a reduction of 46.66%.

The i-Tree model showed that in 2021 the classified forest of Mbao taking into account its woody biomass excluding shrubs and grasses grossly sequestrated 1,506.43 metric tons of carbon per year with an associated value of CFAF 15,547.8 thousand (more than CFA 15 million). The carbon stored during this same period is 7,892.17 metric tons of carbon corresponding to CFAF 813.91 million. Regarding air pollution control, the model estimates that 44,834.78 kg/year of pollutant has been removed from the air corresponding to CFAF 188,173.91 thousand. These pollutants are mainly composed of (ozone (O_3), carbon monoxide (CO), nitrogen dioxide (NO_2), particulate matter less than 2.5 microns ($PM_{2.5}$), and sulfur dioxide (SO_2).

In the 21st century, Artificial Intelligence (AI) has become an essential tool for forest monitoring and assessment. It allows us to test the 3 hypotheses:

The First hypothesis is verified because we notice a net regression during this period from 1.5

Kg/ha in 1988 to 0.8 Kg/ha in 2018.

The second hypothesis was accepted, an amount of 44,834.78 kg/year of pollutant has been removed from the atmosphere.

And for the third hypothesis, we assume that it is partially verified. The lack of data due to time constraints was the main issue.

Given the importance of maintaining this forest in the Dakar metropolitan area for the health of the populations and the increase in their income, we recommend:

- Performing another regression model taken account the rainfall in this area because it exists a strong correlation between NDVI and rainfall;
- Comparative cost-benefit studies between ecosystem services and infrastructure before any new establishment.
- Carry out awareness-raising campaigns among decision-makers using ecosystem values that are much easier to figure out.
- Continue the work throughout the Dakar region (550 Km^2) to take better account of all green spaces and other parks (Hann Park, Technopole, etc.)
- Train technicians on the use of the i-Tree Eco model, which assesses the ecosystem values of trees belonging to individuals to quantify the effort made to preserve their plantations or shade trees.
- Popularize the i-Tree method in West Africa for better evaluation and monitoring of urban forestry.
- Use long-lived trees to reduce long-term pollutant emissions from planting and removal.
- Maximize the use of low VOC-emitting trees to reduce ozone and carbon monoxide formation.
- Increase the toll of rangers to enhance the surveillance and avoid illegal logging that threatens Mbao Classified Forest.

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APPENDIX

Annex 1: Mbao classified forest inventory sheet

Fiche d'inventaire de la Forêt classée de Mbao (Mbao Classified Forest inventory sheet)

N° Layon----------N° placette---------coord X---------------------coord Y--------------------------
Nom du pointeur---Date-----------------------------

N°Ordre	Nom Espèces	Code Espèces	DHP (cm)	HF (cm)	HT(m)	Diamètre Houppier
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						

Annex 2: Benefits Summary of trees by Species

Benefits Summary of Trees by Species

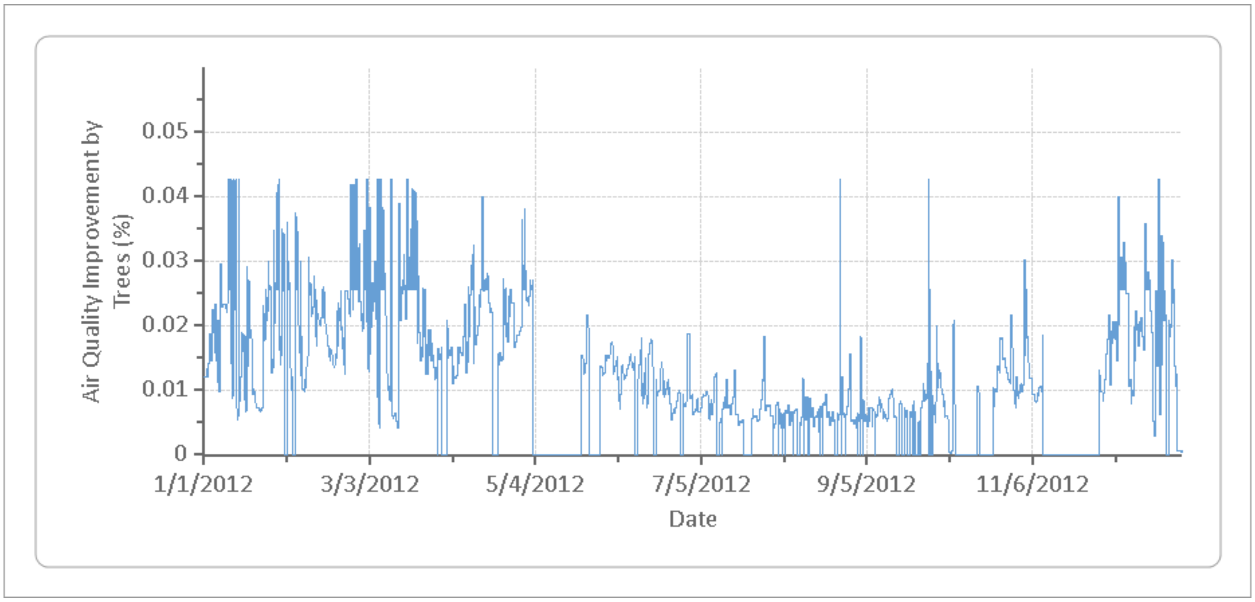
Location: Pikine, Mbao, Dakar, Senegal

Project: Mbao_Forest_Senegal, Series: Ecosyst_services1, Year: 2021

Generated: 5/17/2021

Species	Trees	Carbon Storage		Gross Carbon Sequestration		Avoided Runoff		Pollution Removal		Structural Value
	Number	(metric ton)	(CFAF)	(metric ton/yr)	(CFAF/yr)	(m^3/yr)	(CFAF/yr)	(metric ton/yr)	(CFAF/yr)	(CFAF)
Black thorn acacia	4	0.11	10,933.10	0.02	1,950.80	0.13	173.32	0.00	1,144.18	0.00
Gum arabic tree	4	0.10	10,745.80	0.01	622.48	0.57	733.74	0.00	4,843.95	0.00
acacia spp	2	0.06	6,007.01	0.00	208.92	0.03	41.15	0.00	271.63	0.00
Baobab	2	3.39	349,742.62	0.20	21,061.13	0.20	253.08	0.00	1,670.76	0.00
Cashew	281	9.12	940,803.46	2.53	261,321.66	51.20	66,303.13	0.10	437,714.38	0.00
Neem Tree	5	1.06	109,508.77	0.01	767.52	1.88	2,439.72	0.00	16,106.31	0.00
Balanites spp	3	0.20	20,757.13	0.05	5,009.28	0.03	40.86	0.00	269.75	0.00
Australian pine	24	2.52	260,283.70	0.68	69,950.55	1.55	2,001.27	0.00	13,211.84	0.00
Red gum eucalyptus	67	1.63	167,725.35	0.35	36,464.48	4.48	5,799.92	0.01	38,289.44	0.00
faidherbia spp	11	2.78	286,794.47	0.29	29,464.50	0.67	873.38	0.00	5,765.83	0.00
fig spp	1	0.02	2,239.92	0.01	1,075.03	0.02	21.95	0.00	144.92	0.00
Senegal mahogany	4	0.53	54,240.59	0.11	10,987.07	1.65	2,134.02	0.00	14,088.22	0.00
Red spike-thorn	2	0.04	3,741.94	0.01	1,521.12	0.01	12.38	0.00	81.75	0.00
White paperbark	3	0.07	7,229.11	0.01	1,448.18	0.45	579.76	0.00	3,827.39	0.00
Mesquite	4	0.89	92,004.50	0.02	2,501.94	0.35	456.62	0.00	3,014.49	0.00
India tamarind	1	0.16	16,655.47	0.02	2,220.57	0.02	27.42	0.00	181.05	0.00
Total	**418**	**22.69**	**2,339,412.94**	**4.33**	**446,575.22**	**63.24**	**81,891.75**	**0.13**	**540,625.88**	**0.00**

Annex 3:Air quality improvement by trees (%)



Annex 4: Carbon Storage of Trees by Species

Species	**Carbon Storage (metric ton)**	**Carbon Storage (%)**	**CO_2 Equivalent**
Black thorn acacia	0.1	0.5%	0.4
Gum arabic tree	0.1	0.5%	0.4
acacia spp	0.1	0.3%	0.2
Baobab	3.4	15.0%	12.4
Cashew	9.1	40.2%	33.5
Neem Tree	1.1	4.7%	3.9
Balanites spp	0.2	0.9%	0.7
Australian pine	2.5	11.1%	9.3
Red gum	1.6	7.2%	6.0
faidherbia spp	2.8	12.3%	10.2
fig spp	0.0	0.1%	0.1
Senegal	0.5	2.3%	1.9
Red spike-thorn	0.0	0.2%	0.1
White paperbark	0.1	0.3%	0.3
Mesquite	0.9	3.9%	3.3
India tamarind	0.2	0.7%	0.6
Total	**22.7**	**100%**	**83.2**

Due to the limits of available models, i-Tree Eco will limit carbon storage to a maximum of 7,500 kg (16,534.7 lbs) and not estimate additional storage for any tree beyond a diameter of 254 cm (100 in). Whichever limit results in lower carbon storage is used.

Annex 5: Benefits Summary of Trees by Stratum and Species

Stratum	Species	**Trees Number**	Carbon Storage		Gross carbon sequestration		Avoided Runoff		Pollution Removal	
			(metric ton)	**(CFAF)**	(metric	(CFAF/yr)	(m³/yr)	(CFAF/yr)	(metric	(CFAF/yr)
Urban	Black	4	0.1	10,933.1	0.02	1,950.8	0.1	173.32	0.00	1,144.18
	Gum	4	0.1	10,745.8	0.01	622.4	0.5	733.74	0.00	4,843.95
	acacia	2	0.0	6,007.0	0.00	208.9	0.0	41.15	0.00	271.6
	Baobab	2	3.3	349,742.6	0.20	21,061.13	0.2	253.08	0.00	1,670.76
	Cashew	28	9.1	940,803.4	2.53	261,321.66	51.2	66,303.13	0.10	437,714.38
	Neem	5	1.0	109,508.7	0.01	767.5	1.8	2,439.72	0.00	16,106.31
	Balanites	3	0.2	20,757.1	0.05	5,009.2	0.0	40.86	0.00	269.7
	Australia	24	2.5	260,283.7	0.68	69,950.55	1.5	2,001.27	0.00	13,211.84
	Red gum	67	1.6	167,725.3	0.35	36,464.48	4.4	5,799.92	0.01	38,289.44
	faidherbia	11	2.7	286,794.4	0.29	29,464.50	0.6	873.38	0.00	5,765.83
	fig spp	1	0.0	2,239.9	0.01	1,075.0	0.0	21.95	0.00	144.9
	Senegal	4	0.5	54,240.5	0.11	10,987.07	1.6	2,134.02	0.00	14,088.22
	Red	2	0.0	3,741.9	0.01	1,521.1	0.0	12.38	0.00	81.7
	White	3	0.0	7,229.1	0.01	1,448.1	0.4	579.76	0.00	3,827.39
	Mesquite	4	0.8	92,004.5	0.02	2,501.9	0.3	456.62	0.00	3,014.49
	India tamarind	1	0.16	16,655.47	0.02	2,220.57	0.02	27.42	0.00	181.05
	Total	**418**	**22.69**	**2,339,412.94**	**4.33**	**446,575.22**	**63.24**	**81,891.75**	**0.13**	**540,625.88**

Carbon storage and gross carbon sequestration value are calculated based on the price of CFAF103,123.07 per metric ton.

Due to the limits of available models, i-Tree Eco will limit carbon storage to a maximum of 7,500 kg (16,534.7 lbs) and not estimate additional storage for any tree beyond a diameter of 254 cm (100 in). Whichever limit results in lower carbon storage is used.

Avoided runoff value is calculated by the price CFAF1,294.865/m³. The user-designated weather station reported 31.6 centimeters of total annual precipitation. Eco will always use the hourly measurements that have the greatest total rainfall or user-submitted rainfall if provided**.**

Pollution removal value is calculated based on the prices of CFAF882,692.90 per metric ton (CO), CFAF6,214,762.28 per metric ton (O3), CFAF6,214,762.28 per metric ton (NO2), CFAF1,521,475.42 per metric ton (SO2), CFAF4,149,311.07 per metric ton (PM2.5). Structural value is not calculated in this project.

A value of zero may indicate that ancillary data (pollution, weather, energy, etc.) is not available for this location or that the reported amounts are too small to be shown

Annex 6: Monthly Pollution Removal by Trees of Mbao Forest

Pollution Removal by Trees and Shrubs - Monthly Removal

Location: Pikine, Mbao, Dakar, Senegal

Project: Mbao_Forest_Senegal, Series: Ecosyst_services1, Year: 2021

Generated: 5/17/2021

		Removal (kilograms)			Value (CFAF)		
Pollutant	**Month**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**
CO	1	0.374	N/A	N/A	329.98	N/A	N/A
	2	0.387	N/A	N/A	341.83	N/A	N/A
	3	0.375	N/A	N/A	331.01	N/A	N/A
	4	0.179	N/A	N/A	158.38	N/A	N/A
	5	0.217	N/A	N/A	191.19	N/A	N/A
	6	1.461	N/A	N/A	1,289.51	N/A	N/A
	7	1.224	N/A	N/A	1,080.14	N/A	N/A
	8	1.504	N/A	N/A	1,327.16	N/A	N/A
	9	1.417	N/A	N/A	1,251.11	N/A	N/A
	10	0.668	N/A	N/A	589.22	N/A	N/A
	11	0.867	N/A	N/A	765.49	N/A	N/A
	12	1.379	N/A	N/A	1,216.94	N/A	N/A
	Annual	**10.051**	**N/A**	**N/A**	**8,871.96**	**N/A**	**N/A**
NO2	1	3.092	5.635	1.574	19,215.39	35,017.29	9,783.04
	2	3.202	5.419	1.487	19,896.70	33,677.49	9,239.76
	3	3.139	5.279	1.455	19,507.34	32,808.49	9,043.15
	4	3.737	5.786	1.543	23,222.78	35,956.53	9,590.77
	5	2.939	4.696	1.231	18,264.49	29,182.49	7,650.41
	6	0.593	0.952	0.250	3,684.27	5,914.34	1,555.69
	7	0.725	1.214	0.316	4,506.47	7,546.81	1,966.35
	8	1.111	1.852	0.489	6,906.27	11,512.46	3,040.75
	9	1.279	2.236	0.587	7,949.16	13,898.65	3,648.71
	10	1.618	2.629	0.729	10,057.63	16,340.73	4,529.84
	11	0.000	0.000	0.000	0.00	0.00	0.00

Pollution Removal by Trees and Shrubs - Monthly Removal

Location: Pikine, Mbao, Dakar, Senegal

Project: Mbao_Forest_Senegal, Series: Ecosyst_services1, Year: 2021

Generated: 5/17/2021

i-Tree Eco

		Removal (kilograms)			Value (CFAF)		
Pollutant	Month	Mean	Max	Min	Mean	Max	Min
	12	2.585	4.471	1.383	16,064.16	27,788.99	8,594.83
	Annual	**24.019**	**40.170**	**11.045**	**149,274.67**	**249,644.27**	**68,643.30**
O3	1	2.473	4.343	0.861	15,366.59	26,993.35	5,352.14
	2	2.942	4.325	0.828	18,286.86	26,878.83	5,148.49
	3	0.752	1.247	0.240	4,676.26	7,751.32	1,489.85
	4	4.507	5.629	1.006	28,011.19	34,984.42	6,251.04
	5	5.492	7.220	1.291	34,129.96	44,873.08	8,023.20
	6	4.181	5.707	1.030	25,984.67	35,470.63	6,404.30
	7	4.275	6.117	1.096	26,566.39	38,016.26	6,809.73
	8	4.110	5.746	1.047	25,540.64	35,709.32	6,505.23
	9	2.768	4.121	0.751	17,203.96	25,612.00	4,664.91
	10	6.664	9.368	1.813	41,413.28	58,222.06	11,268.03
	11	7.352	10.158	2.053	45,691.51	63,129.54	12,759.08
	12	4.226	6.720	1.507	26,264.79	41,762.67	9,364.50
	Annual	**49.742**	**70.703**	**13.523**	**309,136.10**	**439,403.49**	**84,040.50**
PM2.5	1	0.283	0.699	0.033	1,174.93	2,899.63	136.48
	2	0.127	0.377	0.009	526.41	1,563.67	35.44
	3	0.106	0.181	0.019	439.45	751.88	80.06
	4	0.158	0.512	0.020	655.97	2,125.82	83.32
	5	-0.282	-0.831	-0.033	-1,171.61	-3,449.61	-136.62
	6	0.028	0.002	0.004	115.55	7.81	18.35
	7	-0.025	-0.064	-0.002	-103.29	-265.64	-9.21
	8	0.669	1.435	0.083	2,777.25	5,955.05	346.44
	9	0.358	0.796	0.054	1,483.67	3,300.84	224.52

Pollution Removal by Trees and Shrubs - Monthly Removal

Location: Pikine, Mbao, Dakar, Senegal

Project: Mbao_Forest_Senegal, Series: Ecosyst_services1, Year: 2021

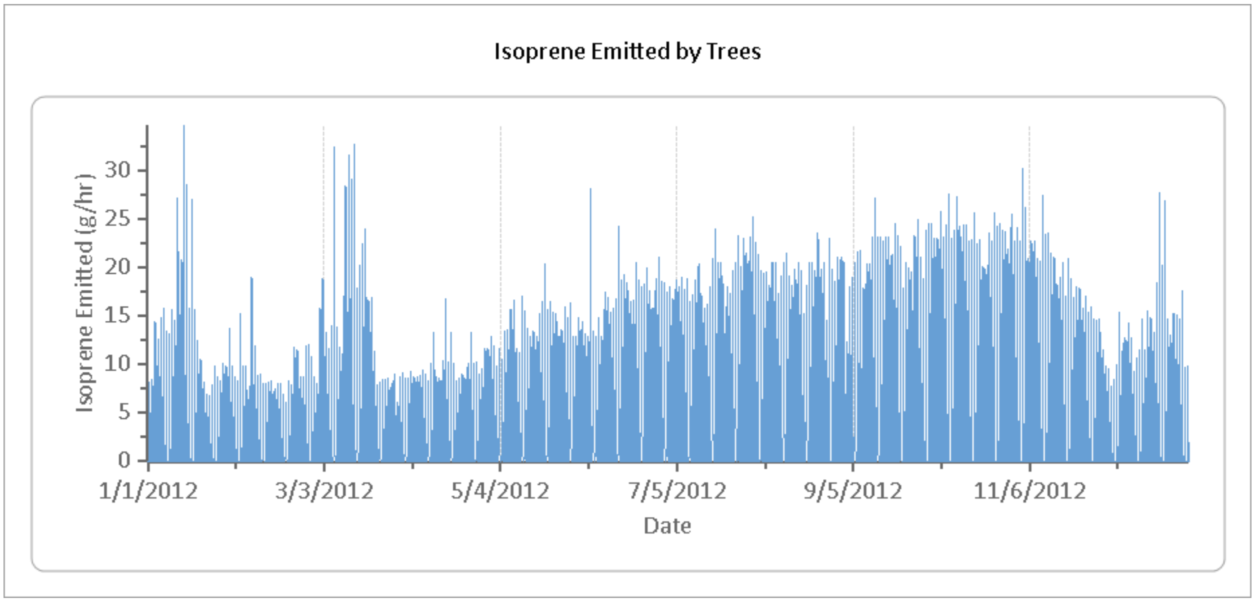
Generated: 5/17/2021

		Removal (kilograms)			Value (CFAF)		
Pollutant	Month	Mean	Max	Min	Mean	Max	Min
	10	0.015	0.034	0.001	60.27	140.68	4.09
	11	0.514	1.410	0.051	2,131.17	5,850.77	211.12
	12	-0.171	-0.582	-0.009	-710.57	-2,412.91	-37.64
	Annual	**1.778**	**3.969**	**0.230**	**7,379.19**	**16,467.99**	**956.35**
SO2	1	2.976	6.423	1.590	4,528.48	9,772.90	2,419.15
	2	5.513	10.018	2.457	8,388.23	15,242.36	3,737.79
	3	5.792	10.322	2.550	8,812.68	15,704.77	3,879.76
	4	5.941	8.772	2.105	9,038.66	13,346.72	3,202.91
	5	1.450	2.180	0.516	2,206.13	3,316.74	785.47
	6	0.963	1.612	0.382	1,465.78	2,452.08	581.59
	7	5.031	8.496	2.003	7,654.37	12,926.36	3,048.16
	8	5.450	9.177	2.173	8,291.54	13,961.86	3,306.24
	9	4.783	8.187	1.912	7,276.77	12,456.35	2,909.40
	10	0.066	0.109	0.027	99.67	165.89	41.18
	11	0.723	1.232	0.317	1,100.32	1,873.75	482.36
	12	4.667	9.222	2.467	7,101.48	14,030.92	3,753.11
	Annual	**43.355**	**75.749**	**18.500**	**65,964.11**	**115,250.68**	**28,147.12**

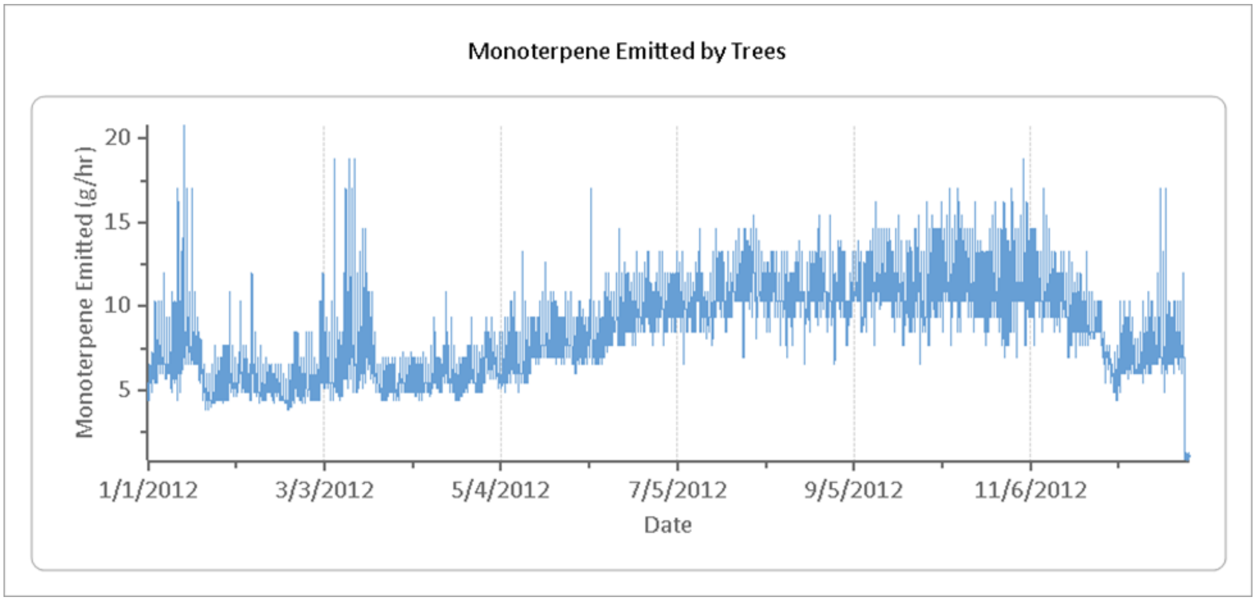
Pollution removal value is calculated based on the prices of CFAF882.69 per kilogram (CO), CFAF6,214.76 per kilogram (O3), CFAF6,214.76 per kilogram (NO2), CFAF1,521.48 per kilogram (SO2), CFAF4,149.31 per kilogram (PM2.5). Min and max values for CO are not calculated.

A value of zero may indicate that ancillary data (pollution, weather, energy, etc.) is not available for this location or that the reported amounts are too small to be shown.

Annex 7: Isoprene emitted by Trees



Annex 8: Monoterpene emitted by Trees



Annex 9: Volatile Organic Compounds Emissions of Trees by Species

VOC Emissions of Trees by Species

Location: Pikine, Mbao, Dakar, Senegal

Project: Mbao_Forest_Senegal, Series: Ecosyst_services1, Year: 2021

Generated: 5/17/2021

Species Name	Monoterpene (kg/yr)	Isoprene (kg/yr)	Total VOCs (kg/yr)
acacia spp	0.1	0.0	0.1
Australian pine	0.1	10.7	10.7
Balanites spp	0.0	0.0	0.0
Baobab	0.0	0.0	0.0
Black thorn acacia	0.4	0.0	0.4
Cashew	60.3	0.0	60.3
faidherbia spp	0.0	2.4	2.4
fig spp	0.0	0.0	0.0
Gum arabic tree	1.8	0.0	1.8
India tamarind	0.0	0.0	0.0
Mesquite	0.0	0.0	0.0
Neem Tree	0.1	0.0	0.1
Red gum eucalyptus	12.6	30.8	43.4
Red spike-thorn	0.0	0.0	0.0
Senegal mahogany	0.1	0.0	0.1
White paperbark	0.0	1.7	1.7
Total	**75.5**	**45.6**	**121.0**

Annex 10: Pollution Removal by Trees and Shrubs - Monthly Removal

Pollution Removal by Trees and Shrubs - Monthly Removal

Location: Pikine, Mbao, Dakar, Senegal
Project: Mbao_Forest_Senegal, Series: Ecosyst_services1, Year: 2021
Generated: 5/17/2021

Pollutant Removal

Month	Pollutant	Amount (kilograms)
1	CO	0.374
	NO2	3.092
	O3	2.473
	PM2.5	0.283
	SO2	2.976
2	CO	0.387
	NO2	3.202
	O3	2.942
	PM2.5	0.127
	SO2	5.513
3	CO	0.375
	NO2	3.139
	O3	0.752
	PM2.5	0.106
	SO2	5.792
4	CO	0.179
	NO2	3.737
	O3	4.507
	PM2.5	0.158
	SO2	5.941
5	CO	0.217
	NO2	2.939
	O3	5.492
	PM2.5	-0.282

Pollution Removal by Trees and Shrubs - Monthly Removal

Location: Pikine, Mbao, Dakar, Senegal
Project: Mbao_Forest_Senegal, Series: Ecosyst_services1, Year: 2021
Generated: 5/17/2021

Pollutant Removal

Month	Pollutant	Amount (kilograms)
	SO2	1.450
6	CO	1.461
	NO2	0.593
	O3	4.181
	PM2.5	0.028
	SO2	0.963
7	CO	1.224
	NO2	0.725
	O3	4.275
	PM2.5	-0.025
	SO2	5.031
8	CO	1.504
	NO2	1.111
	O3	4.110
	PM2.5	0.669
	SO2	5.450
9	CO	1.417
	NO2	1.279
	O3	2.768
	PM2.5	0.358
	SO2	4.783
10	CO	0.668
	NO2	1.618
	O3	6.664

Pollution Removal by Trees and Shrubs - Monthly Removal

Location: Pikine, Mbao, Dakar, Senegal

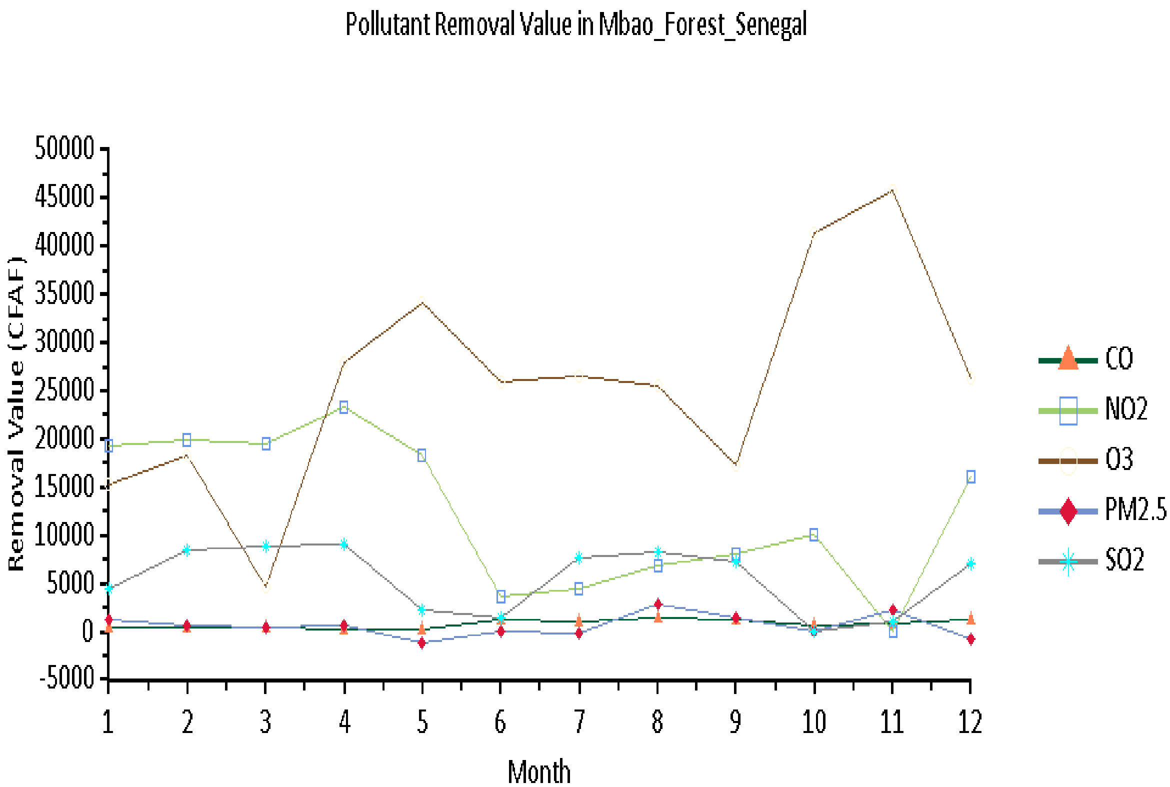
Project: Mbao_Forest_Senegal, Series: Ecosyst_services1, Year: 2021

Generated: 5/17/2021

Pollutant Removal

Month	Pollutant	Amount (kilograms)
	PM2.5	0.015
	SO2	0.066
11	CO	0.867
	NO2	0.000
	O3	7.352
	PM2.5	0.514
	SO2	0.723
12	CO	1.379
	NO2	2.585
	O3	4.226
	PM2.5	-0.171
	SO2	4.667

Annex 11: Pollutant Removal Value in Mbao Classified Forest



Pollution removal value is calculated based on the prices of CFAF882.69 per kilogram (CO), CFAF6,214.76 per kilogram (O3), CFAF6,214.76 per kilogram (NO2), CFAF1,521.48 per kilogram (SO2), CFAF4,149.31 per kilogram (PM2.5).

A value of zero may indicate that ancillary data (pollution, weather, energy, etc.) is not available for this location or that the reported amounts are too small to be shown.

Pollution Removal by Trees and Shrubs - Monthly Removal

Location: Pikine, Mbao, Dakar, Senegal
Project: Mbao_Forest_Senegal, Series: Ecosyst_services1, Year: 2021
Generated: 5/17/2021

Pollutant Removal Value

Month	Pollutant	Value (CFAF)
1	CO	329.985
	NO2	19,215.395
	O3	15,366.590
	PM2.5	1,174.926
	SO2	4,528.479
2	CO	341.833
	NO2	19,896.704
	O3	18,286.860
	PM2.5	526.409
	SO2	8,388.231
3	CO	331.006
	NO2	19,507.339
	O3	4,676.257
	PM2.5	439.448
	SO2	8,812.675
4	CO	158.378
	NO2	23,222.785
	O3	28,011.186
	PM2.5	655.966
	SO2	9,038.658
5	CO	191.187
	NO2	18,264.494
	O3	34,129.963
	PM2.5	-1,171.606