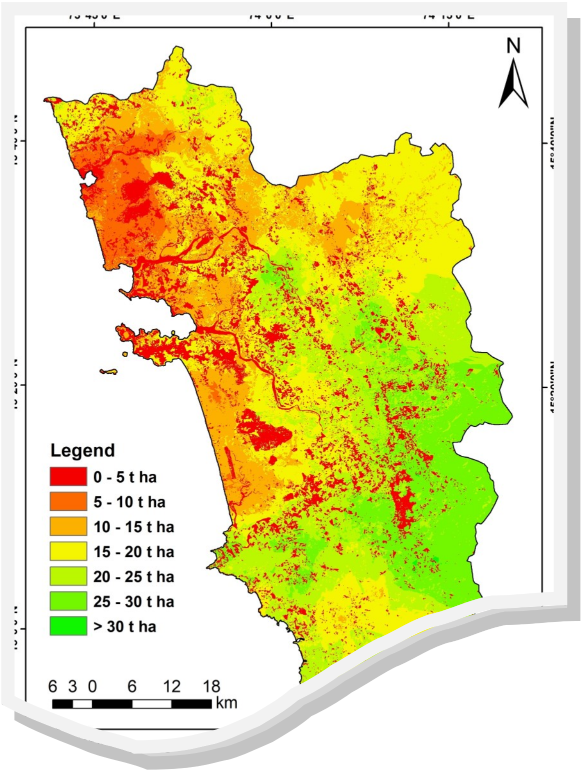

ASSESSMENT OF CARBON STOCK AND CARBON SEQUESTRATION SCENARIO THROUGH LAND USE CHANGE IN THE STATE OF GOA

ABSTRACT

The project deals with the changes in land use and land cover, as well as carbon stock. The empirical soil and forest inventory database is used to estimate above-ground and below-ground biomass using the allometric equation. To estimate soil organic carbon stock the Loss on Ignition, and the Revised Walkley-Black fast titration (W-B) methods were used. The carbon stock scenario and regional sequestration potential were estimated using a land use land cover (LULC) change based on Cellular Automata (CA) and Markov Chain Model (MCM). To extract information on LULC multispectral satellite data for years 1990 to 2020 were used. Overall Kappa coefficient shows better (92%) accuracy of classification. The analysis of the probability of change through the CA-MCM model predicts the loss of forest land (~ 22 %) to the barren and exposed surface by the year 2030. Agriculture land will be lost to built-up (~12%) and barren land (~55%) by 2030. The model also predicts the possibility of an increase in wetlands by 17 % by 2030, as most of the areas of the coastal region are not cultivating the traditional Khazans. Biometric measurements of the forest yielded a biomass of 4.79 million tons. Forest carbon stocks, as determined by soil analysis and biometric data are equal to 14.18 million tons. The total carbon stock of Goa was calculated using chemical and geographical analyses to be 16.50 million tons and 17.06 million tons, with 96.70% accuracy in estimation. The rapid change in ULUC has resulted in a quick change in the regional potential to sequester and store C as SOC stock in the state of Goa. Overall analysis reveals that afforestation and agroforestry should be undertaken to bring positive change to the natural setup of the environment in the state of Goa

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SUMMARY

1. Background

The modern world's industrial revolution and increasing urbanization are increasing the concentration of greenhouse gases (GHGs). CO2 is a significant contributor to global warming (Hangarge L M et al. 2012). The increase in atmospheric CO2 coupled with temperature rise is the primary cause of global climate change. As forest areas are rapidly converted to agriculture, livestock, and other man-made vegetation and degraded areas, the Land Use and Land Cover (LULC) change sector is the second most important source of CO2 emissions. Under the Kyoto Protocol, 37 industrialized countries agreed to reduce their emissions by an average of 5% compared to 1990 levels over the five years 2008-2012. The total global potential for afforestation and reforestation activities from 1995 to 2050 is estimated to be between 1.1 and 1.6 Pg C (1 Pg = Petagram, 1015g) per year, with the tropics accounting for 70%. Forests play an important role in the global carbon cycle and are globally valued for the services they provide to society. International greenhouse gas negotiations necessitate an understanding of the current and potential future roles of forest C emissions and sequestration in both managed and unmanaged forests. Tropical forests are said to play a significant role in the global carbon cycle, storing up to 46% of the world's terrestrial carbon pool. Several studies have found that carbon sequestration by trees can result in relatively low-cost net emission reductions. The fact that carbon is stored for long periods in living biomass and soil has been well-documented since 1992.

2. Origin of the Research Problem:

India has a diverse biodiversity, with 1, 26188 plant and animal species. It is regarded as one of the 12 mega biodiversity hotspots for the origins and diversity of various plant species. India has a direct impact on carbon sequestration, with over 116 million tonnes of CO2 sequestered each year, helping to reduce atmospheric carbon. Living vegetation, seawater, and soils all play important roles in CO2 absorption from the atmosphere.

Goa is the country's smallest state, with a total land area of 3702 Km2. The state has a total population of 1.46 million people (Census 2011). The state's average temperature ranges from 16.2°C to 36.7°C. There are rich biological diversity of the Western Ghats on the east and the coastal Ecosystem along the west. Goa has four types of vegetation regimes: estuary vegetation of mangroves along swampy river banks, strand and creek vegetation along the coastal area, and plateau vegetation along undulating terrain and hills. It is made up of lateritic semi-evergreen and evergreen forests. The lush vegetation on the slope and foothill zones is supported by a dispersed region of Cree and talus. Plateaus' lateritic surfaces are coated by very thin veneer debris. The tourism business benefits from scenic sandy beaches along the coastline.

Forest cover is rapidly dwindling as a result of growing urbanization and development. Rapid urbanization has put a strain on land, water, vegetation, and other natural resources. As a result, forest cover has decreased, land quality has deteriorated, and water has become contaminated. Rapid industrialization, tourism, urbanization, mining, and deforestation all contribute to CO_2 emissions.

Soil is the largest reservoir of carbon in terrestrial ecosystems and soil organic carbon (SOC) plays an important role in the global carbon cycle and soil ecosystems. Thus, small changes in the carbon contents of soils can alter the concentration of carbon dioxide in the atmosphere, leading to global warming. SOC is a key indicator of sustainable development goal for estimating degraded land areas in the context of achieving land degradation neutrality and targets by 2030. Therefore, a timely understanding of the spatial distribution of soil organic carbon content is important for the terrestrial carbon cycle, future climate change monitoring and ecosystem restoration. In view of this the present work aims to estimation of SOC sock and sequestration potentials in the state of Goa, using land-use and land-cover change model to provide insights into potential future prediction.

3. Objectives

The current research topic, "Assessment of Carbon Stock and Carbon Sequestration Scenario Through Land Use Change in the State of Goa," seeks to

A. examine the dynamics of land use and land cover to assess carbon sequestration potentialities in the study region.

B. To investigate the spatial and temporal fluctuations in above- and below-ground biomass in the study region.

C. To track the regional and temporal distribution of carbon stock and sequestration in the study area.

D. To recommend a reasonable change in potential reforestation, afforestation, and agroforestry sites in the study region.

4. Methodology

The methodologies for carbon inventory are determined by the scale of the project. Small-scale projects can monitor carbon stock changes with field measurements, whereas large-scale initiatives require the use of remote sensing and modeling approaches. Smaller-scale projects are more likely to be homogeneous in terms of soil, terrain, and species dominance (Sanz et al. 2005). Because this is a large-scale undertaking, remote sensing, GIS, and modeling approaches have been used. Field measurements were chosen as the primary methods in the research field.

4.1 Sampling

A stratified random sample design was used for the current investigation. Strata for carbon inventory may be most logically described by projected total carbon pool weight. Because above-ground biomass is so important, stratification criteria that represent biomass are often the most appropriate. Satellite images, aerial photography, and maps of vegetation, soils, or terrain are useful tools for determining strata and may be preferred depending on availability (MacDicken, 1997a; Brown, 1997; Ravindranath and Ostwald, 2008). Researchers have gathered 280 soil samples from Goa's agriculture (160), forest (50), wetlands (45), and mangroves (25) areas. Soil samples were collected from a depth of 0-10cm and dried at room temperature for 8-10 days. Each sampling site's GPS location was recorded using a Garmin Etrex-vista at +10 ft (3m) accuracy. This level of precision is suitable for most land area assessments (Greenhouse, 2002).

4.2 Secondary data of Soil OC

A total of 7834 soil OC data for cycles ranging the testing cycles 2017-18 (2047), 2018-19 (2074), and 2019-20 (3474). This data was taken from the website https://soilhealth.dac.gov.in/PublicReports/GridFormNSVW.

4.3 Analytical methods

For this project, the plant biomass Above Ground Biomass (AGB) and Below Ground Biomass (BGB) were estimated using Allometric equations derived for the Western Ghats (Murali et al. 2005).

Carbon conversion coefficients range from 0.45 to 0.55 depending on species, age, formation, and community structure of vegetation types (Kauppi et al. 1992; Goodale et al. 2002; Xia et al. 2005, and Ramachandran et al. 2007). Because such coefficients are not available for the study area, the current study uses a carbon conversion coefficient of 0.5.

4.4 Lab testing

Using a mortar and pestle, dried materials were smashed into fine pieces. Using an electrical sieve shaker, the fine bits were passed through 40mm sieves. Each soil sample's bulk density was calculated using a conventional approach. The sieved samples were examined in the soil laboratory for Soil Organic Carbon (SOC) and Soil Organic Matter (SOM) estimation using two distinct methods: (a) Loss on Ignition (LOI) (Storer 1984) and (b) Revised Walkley-Black fast titration (W-B) (Trivedi and Goel, 1986). Both approaches were utilized to estimate SOC and SOM for comparison purposes. When compared to the LOI approach, the W-B method was demonstrated to be more efficient in terms of accuracy and time consumption (Ismael et al. 2017). To obtain the corrected SOC, the % of SOC value obtained via the W-B technique was multiplied by a standard correction factor of 1.32 (De Vos et al. 2007). The SOC stock was calculated by multiplying the SOC values (g/kg) by the bulk density (g/cm3) and depth (cm), and it was expressed in metric tons per acre (Joao Carlos et al. 2001).

Tree species biomass was assessed from four different forest sites, including Cotigao Wildlife Sanctuary (CWS), Netravali Wildlife Sanctuary (NWS), Bhagwan Mahaveer Wildlife Sanctuary (BMWS), and Mhadei Wildlife Sanctuary (MWS). The current forest sites were further classified as Semi-Evergreen (SE), Moist Deciduous (MF), and Open Forest (in some cases Plantations) (OF/PT). In Goa, 35 prominent tree species were identified from four forest locations.

4.5 Use of Remote sensing and GIS

Remote sensing and geographic information systems (GIS) are commonly utilized to estimate the geographical distribution of SOCs at the micro level. The three map change model employs Cellular Automat (CA) and Marco Chain Model (MCM). Cloud-free Landsat-5, Landsat-7, and Landsat-8 data taken on 17^{th} July for the years 1990, 2000, 2010, and 2020 were used in this study. The Maximum Likelihood Classification Algorithm (MLC), a robust supervised classification method, was used to classify the Images.

The Kappa Coefficient was also used to calculate classification accuracy after removing the effect of random error. Based on the CA-MCM model, the likelihood of change is anticipated for 2030. IDW and Kriging methods are used to interpolate the collected soil sample points. Finally, the SOC distribution of the study area has been mapped.

5. Study Region

Goa is India's smallest state by area and the fourth smallest by population. It is located in West coast of India known as the Konkan. The state lies between the latitudes 14°53′54″ N to 15°40′00″ N, and longitudes 73°39′33″ E to 74°20′13″ E. Goa has more than forty estuarine, eight marine, and about ninety riverine islands. The low land area is mainly coastal lines. Plateau land height ranges from 30 meters to 100 meters. Some of the parts of plateau land are called the headland of Goa. The soils in the state have been predominantly categorized into lateritic, alluvial, sandy coastal, saline, and marshy soils. Land on the plateau region is not fertile; few crops are taken in this region. Sahyadri Mountains are to the east of South Goa, this part is covered with dense forest.

The state has a warm and humid climate for most of the year. The temperature generally ranges from a mean minimum of 200C to a mean maximum of 350C. Monsoon enters normally in the first week of June. The State receives good rainfall on an average of 2500 mm annually, mostly during June to September period.

The climate, topography, geology, and vegetation have played a prominent role in the development of the soils of Goa.

The main rivers are the Mandovi, the Zuari, the Terekhol, the Chapora River, and the Sal. The total navigable length of Goa's rivers is 253 km. Rivers are used for transportation and play an important role in the transport of mineral ores. Goa's major cities include Vasco, Margao, Mormugao, Panaji, and Mapusa.

6. Findings

Land use land cover (LULC) change

- A region's Land Use and Land Cover (LULC) pattern is the result of natural and socioeconomic elements, as well as man's use of them over time and place. LULC change has emerged as a critical component of modern natural resource management and environmental monitoring systems.
- Forest areas cover 2012.61 Km^2 (54.37%), agriculture or agro-ecosystems 1094.17

(29.57%), settlements 481.1 (13%), water bodies 60.13 (1.62%), wetlands 27.19 (0.73%), and mangroves 26.8 (0.72%).

- The Kappa statistic validates the strong classification quality, with an overall accuracy of 0.82 (82.86%), indicating a good classification for LULC and CA MCM models ranging from 85 to 95%. The Kappa statistic supports the high quality of the LULC categorization. Overall accuracy is 0.82 (82.86%), indicating a correct classification. Overall accuracy in 1990 is 91%, whereas overall accuracy in 2000 is 96.5 percent, with forest and agricultural showing the highest degree of agreement, followed by other classifications with 85% accuracy. Data classification for the years 2010 and 2020 shows 85% overall agreement. The estimation of forest (1990 & 2010) and agricultural (1990 & 2020) varies due to seasonal change.
- Settlements saw the greatest gain in the area, while agricultural areas saw the greatest decline. The current scenario shows that agro-ecosystems are 92.02% accurate, wetlands are 90.63% accurate, mangroves are 88.89% accurate, and forest areas are 75.51% accurate. Goa's total forest cover has grown by 20.59 Km^2, including wildlife sanctuaries, a national park, a bird sanctuary, a mangrove forest, and hilly regions, which is a welcome addition to the contribution of the Western Ghats. The forest area increased by 16.4 Km^2 between 2007 and 2017.

Estimation of Aboe Ground and Bellow ground Biomass

- From four forest areas in Goa, 35 dominant tree species were identified. In Semi-Evergreen forests, 11 species belong to 8 families; in Moist Deciduous forests, 16 species belong to 11 families; and in Open forest/Plantation regions, 8 species belong to 7 families.
- Anacardium occidentale L, Leea Indica (Burm.f.) Merr, Tectona grandis L.f, Terminalia bellerica (Gaertn.) Roxb, Terminalia paniculata Roth, and Xylia xylocarpa (Roxb.) Taub was the most common tree species in all forest areas.

The average height and DBH of the tree species present in Goa's forest locations are 14.50 + 6.63 m2 and 0.84 + 0.46 m2, respectively. The mean aboveground tree biomass (Mg) in SE, MD, and OF/PT forests is 14.66 + 8.08, 3.01 + 2.34, and 0.83 + 0.89, respectively. CWS, NWS, BMWS, and MWS have AGB (Mg C/ha) contents of 621.5, 1681.8, 1680.4, and 2059.22, respectively. Below-Ground Biomass (BGB) is an important carbon pool for many vegetation types, accounting for about 20% of total biomass.

- The average below-ground biomass of the tree species found in Goa's forest locations is 1.23 + 1.50 Mg. The average BGB of the tree species found in SE, MD, and OF/PT is 2.93 + 1.62 Mg, 0.60 + 0.47 Mg, and 0.17 + 0.18 Mg, respectively. Goa's forest sites have a
  total biomass of 4.79 million tons.
- The projected biomass from the tree species is 0.14 + 0.10 million tons. The biomass calculated for all forest cover categories, namely SE, MD, and OF/PT, is 0.25 + 0.07 million tons, 0.11 + 0.07 million tons, and 0.04 + 0.02 million tons, respectively.
- The foregoing results demonstrate that comparable site 3 has a high biomass content, whereas site 1 has the lowest. In terms of tree species, Schleichera Oleosa (Lour.) Oken has the highest biomass content, while Leea Indica (Burm.f.) Merr has the lowest.
- In terms of forest cover, tropical semi-evergreen forests have a high biomass value, whereas open forest regions contain a low biomass value. The carbon content of the forest sites is 2.4 million tons, calculated by the conversion factor of 0.5.

Estimation of Soil Organic Carbon Stock

- The mean SOC content (%) in agro-ecosystems, wetlands, and mangrove and forest regions is 3.19%+1.93; 4.06%+1.18; 4.73%+2.24; and 6.24%+3.28, respectively, with B.D (g cm-3) of 1.40, 1.15, 1.09, and 1.46. Agro ecosystems, wetlands, and mangrove and forest habitats had average SOCS (t ha-1) of 44.84, 46.72, 51.62, and 86.42, respectively.
- When comparing soil samples collected from forest areas, soil samples collected from mangroves, wetlands, and agro ecosystems had higher mean SOC concentrations. The entire carbon stock of Goa was calculated using chemical and geographical analyses to be 16.50 million tons and 17.06 million tons, respectively. When comparing both methodologies, chemical and geographical analysis, utilized for estimating Goa's carbon store, around 96.70% accuracy was discovered in terms of total carbon.
- The SOC is classified into seven groups ranging from 0 to 5 t/hectare and covers the majority of the built-up area, rocky outcrops, desolate and exposed areas, and surfaces with very shallow soil surfaces. Pockets of such circumstances can be found throughout the state, covering 30% of the geographical area and contributing 31944 Mt of OC to the region's carbon pool.

- The wide foothills and valley regions of eastern Pednem, Bardez, Bicholim, Ponda, Sattari and the eastern section of Cancona tehsil comprise the area. These areas are mostly used for intensive agriculture, forestry, and plantation agriculture, with SOC ranging from 15 to 20 Mt per hectare. This region contributes 45369 Hectares (12% of geographical space) and 907387 Mt (9% of OC) to the state's carbon stock. The transition from vegetation and forest-dominant regions is growing commercial importance in the state, and the region is extremely essential.
- The region includes the steep area of Quepem and the western portion of Cancona, the southwestern part of Sangues at the Quepem and Cancona boundary, and the important area of Dharbandona, Bicholim, and Ponda tehsil along the Khandepar and its tributaries. This region contributes 111023 hectares (29%) of the state's land and 27775584 tons (28.23%) of the state's SOC stock.
- This region has a very large SOC stock of 30 tons per hectare, and it includes a portion of Sanguem tehsil, the Netravali Wildlife Sanctuary, and some minor pockets of inter-mountain valleys in Quepem and Ponda tehsils. This section spans 201496 hectares (55%) of the State's geographical area and contributes around 6044871Mt (62%) of SOC.
- Kriging used in interpolation of SOC gives a SOC range of 5 t/h to 30 t/h. More than 54% of the area has SOC in the 25-30 t/h range, accounting for 61% of the state's SOC stock. This pattern is followed by SOC rage 20-25 by 30% area, which represents 28% of SOC stock.
- The median SOC for the key land use and land cover groups shows that forest has the highest median SOC (1.27%), followed by bare land (land that is not regularly cultivated or present fallow land). Barren, uncultivated, and fallow areas in this group have a high concentration of SOC due to minimal tillage techniques or disturbance to the natural setting. Wetlands, agriculture, and water bodies appear to be viable OC reservoirs, with OC levels ranging from 0.88% to 1.00%. The observation also demonstrates that there are seasonal variations in SOC, as the OC in each succeeding cycle changes.

Prediction of LULC change

- Changes in Land Use and Land Coverage According to the CA-MCM model results, the geographical coverage of barren land and built-up areas is expected to rise dramatically by 2030. According to the analysis, there would be unfavorable changes in the geo-

Regional potential of SOC in the state of Goa

- Vast portions of the coastal belt, including Pednem, Bardes, Tiswadi, Salcete tehsil, Bicholim, and Ponda tahsils, contain OC stocks ranging between 5 and 10 tons per hectare of OC. The region in this range contains around 3043 and 2880 hectares of land and contributes approximately 30426 Mt and 43205 Mt of OC to the state carbon Stock.
- The CA-MCM model's probability of change study predicts a loss of forest area (22%) to the barren and exposed surface by 2030. By 2030, agricultural land would be lost to development (12%) and barren land (55%). The model also projects a 17% increase in wetlands by 2030, because most coastal areas do not cultivate traditional Khazans.
- Decadal change in LULC demonstrates that there have been constant negative changes in forest coverage since the year 2000. Similarly, agricultural land has changed by -12 to -27 percent. Barren land is expected to increase in size (+12) by 2030.
- By 2030, built-up land is expected to show a 63% increase. When compared to the base year (1990), it is expected to reach 280 times the area under built-up surfaces, as the chance of converting barren and naked open surfaces to built-up land is estimated to be around 50%.
- The study is based on the statistics produced from the CA-MCM model results. The model predicts that the geographical coverage of barren and naked surfaces will rise by 60% by 2030. This is in addition to the SOC stock and potential values that have been assessed by interpolation and fieldwork.

Prediction of SOC gain and loss

This is based on the SOC stock and potential values that have been assessed by interpolation and fieldwork.

- If bare surfaces (barren, wasteland) are covered with vegetation, the state will obtain an extra 6.3 million tons of SOC stock. According to a sub-divisional study, Sattari tehsil will contribute an additional 3.31 million tons of stock (52%).
- Sanguem and Dharbandoda tehsils will contribute an extra 10% of SOC stock, while Mormugao, Bicholim, and Pednem will contribute approximately 8% of new SOC stock by 2030. Cantona, Ponda, Tiswadi, Bardez, Salcete, and Quepem tehsils may provide the remaining 30%. These are the state's coastal and developing tehsils.

- From 2010 to 2020, agricultural land is shrinking at a much greater rate (30%). According to the CA-MCM probability study, agricultural land will change by -25% by 2030. This will add 6.67 million tonnes to the state's negative SOC stock by 2030. Currently, the agricultural region's negative change in coverage shows a negative change of 16.6 million tons of SOC during the last decade.
- Tehsil-level variance reveals that Sattari, Sanguem, Dharbandoda, and Ponda would be the biggest losses in terms of SOC stock by 2030. These factors account for 52% of the loss of the state's forest-dominated ecological setting. Urban tehsils such as Tiswadi, Bardez, Salcete, and Mormugoa contribute to a 20 percent reduction in SOC anticipated by the LULC, CA, and MCM models.

8. Conclusion:

• The current study focuses on Land Use Land Cover (LULC) change, biomass estimation, and potential SOC stock in the State of Goa.

• The Kappa statistic shows that the overall accuracy is 0.92(92%). Biometric measurements of the forest yielded a biomass of 4.79 million tons. Forest carbon stocks, as determined by soil analysis and biometric data, total 14.18 million tons.

• The total carbon stock of Goa was calculated using chemical and geographical analyses to be 16.50 million tons and 17.06 million tons, respectively. When comparing both methodologies, namely chemical and geographical analysis, utilized for estimating Goa's carbon stock, around 96.70% accuracy in estimating Goa's total carbon stock was discovered.

• CA and MCM forecasted the probability of change in the area classified as agriculture, forest, wetland, barren land, and built-up land. This will result in a quick change in the regional potential to sequester and store C as SOC stock in the state of Goa.

•Overall analysis reveals that afforestation and agroforestry should be undertaken to bring about good improvements in the state. Agriculture, mangroves, and forests are experiencing negative spatial alterations, while barren, bare, and non-productive surfaces are developing at an alarming rate, suggesting the need to conduct such steps to bring positive change to the natural setup of the environment in the state of Goa.

9. Significance of the Study

In recent years, carbon sequestration in the form of forestry projects has evolved into a viable alternative to tackle global warming and climate change. Carbon sequestration also constitutes valuable environmental services provided by forests, other important services being watershed protection, biodiversity conservation, eco-tourism, etc. Recent efforts to put a monetary value on such services have also led to an increase in awareness of the need to protect forest resources.

There is an urgent need to look at emerging markets for environmental services such as carbon sequestration. Such a study will bridge the present gap that exists on the subject and help in regulating the evolving markets. It will also make specific recommendations on how they could be made pro-poor to meet the scale requirements of the Clean Development Mechanism (Aukland, 2002).

The present research work is based on empirical analysis using remote sensing, GIS, and GPS technology. This study would be of importance in Spatio-temporal perspectives for researchers and scientists for academic degrees in geography and environmental science. The generated database could be applied in disseminating knowledge to related individuals or groups for governance, management, and conservation for sustainable development. Results and model can be utilized for other States of India to assess the carbon stock and carbon sequestration potentials of their terrestrial forest, grassland, and mangrove forests.