RESEARCH ARTICLE

ASSESSMENT OF CARBON STOCK AND FUTURE POTENTIAL OF CARBON SEQUESTRATION OF SOOR SAROVAR BIRD SANCTUARY,KEETHM-UP

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Received-04.05.2020, Revised-25.05.2020

Abstract: Soor Sarovar Bird Sanctuary is a small human-made forest with a lake on the outskirts of Agra, India. The study estimates terrestrial and aquatic carbon. The total carbon stocks estimated at 1.31 million tons bears a social cost of carbon value of ₹21 million. The aquatic carbon stock density was found to be significantly higher than the terrestrial stocks. The study outcomes are usable for maximising ecosystem services in the broader context of sustainability. The research method estimating carbon stocks is relevant to national policies and applicable to similar forests. An optimistic scenario suggests that the sanctuary area by 2030 can sequester per unit area carbon which is 12times the target of achieving our ambitious target. An established theoretical and empirical correlation of increased carbon stocks with biodiversity and other ecosystem services are suggestive of such small urban peripheral sanctuaries playing a critical role in mitigating the climate change.

Keywords: Soor Sarovar Bird Sanctuary, Aquatic carbon, Terrestrial carbon, Carbon stocks,Anthropogenic

INTRODUCTION

Forests are both source and sink of greenhouse gases. The impact of Agriculture, Forestry and Other Land Use (AFOLU) sector to anthropogenic emission is just close to a quarter of the anthropogenic total (Smith et al. 2014). Annual greenhouse gas change from land use and land-use change activities during the first decade of this century accounted for approximately 4.3-5.5 GtCo2 eq/yr, amounting to 9-11 per cent of total anthropocentric gas emissions globally (Smith *et al.* 2014).

Indian forests stock 7 Gigatons of carbon out of 650 Gigatons estimated globally(ISFR 2017). Contrary to the declining global trend of forests(FAO 2018), various Indian proactive conservation policies and legislation seem to have stalled and reversed the deforestation(MOEF&CC 2015). The claim, however, has been contested based on the resolving potential of remote sensing data(Puyravaud et al. 2010)(Davidar et al. 2010)(Ravindranath et al. 2014). Loss of forests through diversion, encroachment, and degradation was a specific problem highlighted in The Forest Commission Report (MOEF 2006). The issue of forest degradation thus needs to be addressed.

None the less, the National Forest Policy also acknowledges and calls for special attention against forest degradation. (MOEF & Forests 1998). Forest Survey of India (FSI) since 2011 has published reports on carbon stock as a separate chapter. The India State of Forest Report (ISFR) now includes state and district wise information on carbon stock and change(ISFR 2017). Sustainability requires that these mesoscale efforts mainly through the satellite imagery are supplemented and correlated with local site-specific microscale environmental parameters. Such quantification becomes critical in the context of our ambitious Nationally Determined Contribution (NDC) goal of creating additional carbon sink of 2.5 to 3.0 billion tons of CO2 equivalent through additional forest and tree cover by 2030 (MOEF&CC 2015).

Forest pathways contribute to ten of the seventeen sustainable development goals (FAO 2018). Country’s commitment to Sustainable Development Goals (SDGs) focuses on enhancing the forest ecosystem services through new technological advancements. It has been recognized that the tangible benefits like firewood, timber, and non-timber forest Products only form an abysmally low proportion of all Ecosystem services(MOEF&CC 2018).

The present study at Soor Sarovar Bird Sanctuary is set in the context of evaluating the total ecosystem services for sustainable development.

Study Area

Soor Sarovar Bird Sanctuary (SSBS), Keetham, Agra is an important protected area in the state of Uttar Pradesh. Unique for scenic beauty, religio-cultural heritage and abundant fauna and flora, it has been named after Soordas - the great blind poet of Hindi literature, whose place of birth is said to be within the boundary of this sanctuary. SSBS lies between latitude N27º 14' 4″ and N27º 31' 51″ and longitude E77º 49' 38″ and E77º 52' 40″. The total area of Soor Sarovar bird sanctuary is 7.99 km2. It consists of a core of 3.96 km2, 0.478km2 for tourism and a buffer zone of 3.55 km2(Uttar Pradesh Forest Department 2010). Figure 1 shows the key plan of the study area.

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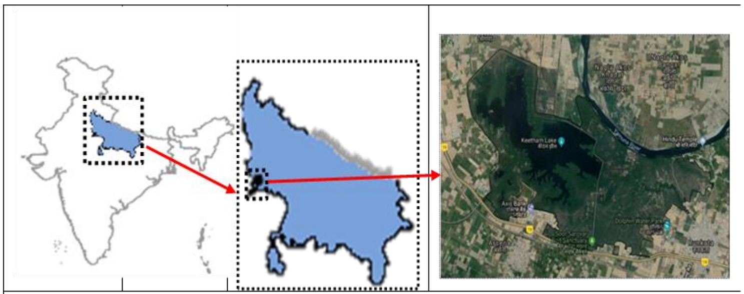


Fig. 1: Key Pan of Soor Sarovar Bird Sanctuary

The Sanctuary meets the criteria laid out by the International Bird Association (IBA). Ministry of Environment, Forest and Climate Change, Government of India has also identified Soor Sarovar Bird Sanctuary's Keetham lake as important Wetland visited by migratory birds (MOEF 2007). The Sanctuary supports three vulnerable bird species, namely, Sarus Crane (*Antigone Antigone*), Lesser Adjutant *(Leptoptilosjavanicus)* and Greater Spotted Eagle *(Aquilaclanga)* listed in the IUCN Red List Category. The artificial lake with more than 90 % reservoir storage capacity has been categorised as near favourable specifically for the habitat of birds. The Sanctuary has also been categorised as a high threat area on account of Biological Resource use and Residential and commercial development (IBA 2019).

Anthropogenic pressures:The study area is set in Agra district for which Census 2011 records a human density population at 1084 inhabitants per square Km. This places Agra at rank 41st amongst 640 Indian districts(The Registrar General & Census Commissioner 2011). High-density habitations surround the Sanctuary except on the east side through which the river Yamuna flows.

Being upstream of a significant population settlement of Agra hydrologically and on the way to National Capital Region, Delhi makes region around Soor Sarovar Bird Sanctuary area an ecological hot spot. Rapid planned and unplanned development at the regional level is causing unprecedented anthropogenic pressures all around.

METHODOLOGY

The study area was acquainted by wandering around using measuring tools including manual compass, GPS, clinometer, a tape of various sizes, survey Chain and flags. Google My Maps mobile application was used as the main tool of site contextualization. Google Earth Pro application was used to crosscheck and get details about the location's altitude and coordinates.

The methodology of measuring carbon and related parameters were developed based on subject knowledgebase for measuring carbon considering the local condition. The level of precision required was kept as provided for in the Forest Survey of India's publication The Manual of Instructions for Field Inventory 2002 (FSI 2002) and ensured that the mean value of carbon stock estimation falls within ± 10% of carbon stock at the 95% confidence interval.

The study area was delimited adopting the boundary specified for SSB Sanctuary by the Forest Department. A categorised study area cover map based on canopy density and forest type was prepared by integrating information available from Google Mymaps, archival records, available forest management plans and ground survey, taking 25 m x 25 m as a unit of observation. The data was plotted using 3D Map tool of the MS Excel spreadsheet application. Five terrestrial classes could be mapped: (i) very dense forest (in more protected central areas near water body with broad leave plantation having tree canopy density of > 70%) ii) moderately dense (Other thorny forest areas, with tree canopy density between 40%-70%) iii) open forest (Tree Canopy density between 10%-40% iv) scrub and v) barren (Areas with no or very little vegetation). Carbon stock in a given stratum was computed from its carbon density (t/ha) and area (ha). The aquatic areas within have been classified by water depth as Deep (>2.5m), mid-deep (1.5m-2.5m), Shallow (<1.5m) and bank (the silty areas around the waters with seasonal grass or nascent vegetation).

Terrestrial Carbon:The Intergovernmental Panel on Climate Change(IPCC 2003) specifies five carbon pools viz., above ground biomass, below-ground biomass, litter, woody debris and soil organic matter except that aboveground woody debris component was assumed to be insignificant because of regular removals by the people around the study for fuelwood.

Sampling design:Eighty-four samples distributed across the study proportionate to the strata areas were selected, all trees with more than 10 mm diameter at breast height and with a least 2 meters' height were marked. The sample geolocation, tree species and their Diameter at Breast Height (DBH) and heights were recorded as per the procedure of measuring detailed in the Measuring Carbon Stock Manual of the World Agroforestry Center (Hairiah et al. 2010).

The samples were rectangular /circles of a size of approximately .01 ha area. Above ground tree biomass was calculated using available volume equations (Picard, Saint-André & Henry 2012)(FAO 2018), a biomass expansion factor of 3.4 as per the Good Practice Guidance for Land Use, Land Use Change and Forestry (IPCC 2003) and wood density databank of FAO's (FAO 2018) was taken.

The below-ground biomass was calculated based on the root: shoot factor (RSR) of 0.27 as per IPCC Good Practice Guidelines (IPCC 2003).

Soil Organic Carbon: Forty-two monoliths (30 cm x 30 cm x 30 cm) representing all five strata were excavated, soil from three depths (0-10, 10-20 and 20-30 cm) were stored separately. The samples were mixed to form three composite samples for each forest stratum which were analysed in the laboratory. The soil was air-dried and passed through 250-micron sieve after removing gravels. Soil organic carbon was estimated by Walkley-Black wet digestion method (IS : 2720 (Part XXII) 1972-(Reaffirmed 2010)). The soil bulk dry density was estimated using excavation method which involved digging out a small hole for taking out soil sample and measuring the volume of the hole by pouring water from a calibrated measurement jar into a hermetically sealed and tested polythene bag filling the hole. The soil taken out was oven dried (at 105°C) and weighed as per soil lab modules. (https://labmodules.soilweb.ca/soil-compaction-bulk-density/). Carbon density was calculated using men carbon percentage for each stratum and their bulk values (Hairiah et al. 2010).

Aquatic carbon Estimation

Carbon Pools: Aquatic carbon was estimated by totaling i) Alluvium carbon deposits ii) Lake waters in the form for both dissolved and particulate carbon and iii) Carbon contained in Fish and water birds.

Soil/ Alluvium carbon Estimation: Levels for all segments of and around the lake were worked out using google earth pro imagery. Data analysis of the segments depths was conducted and plotted on the 3D map to demarcate lake stratum. While sample on the lake bank and shallow waters could be obtained using a 4 meter PVC pipe which was vertically driven and created a space for lowering and working the SPT hammer for sample collections; two such pipes were hermetically sealed to obtain samples from deep and mid-deep water stratum.

For alluvium sampling in waters, the boat, with the help of google my map mobile geolocation, was taken to the sample coordinates and fixed to be lake bottom with the help of three ballies. The hermetically sealed pipe was then used to create a vertical working space for lowering and working of the SPT hammer for obtaining the alluvium sample. The rope for pounding the hammer for sample collection was marked at 0.5 m, 1.0 m, 1.5 meter and 2.0 m using red cotton ribbons. Water from collected alluvium from the hammer was drained and about 200 gm of alluvium was collected in the pre-marked sample bags.

Alluvium soil samples from six locations in each of the four aquatic strata were collected using a Standard Penetration Test (SPT) hammer sampler (IS : 9640 1980). The loose alluvium consisting mostly of silt and fine sand and did not allow undisturbed sampling.

Three soil samples representing five alluvium depths of each stratum were prepared. Sixty samples representing the four strata at five depths were lab tested. The carbon for the 2.5 m sediment column was calculated by multiplying the mean carbon proportion reported for each stratum for the representative depth segment. Bulk dry density of sample as calculated in the laboratory was used in calculations.

Carbon Estimation of lake waters: As per the USGS publication Methods for Assessing Carbon Stocks, Carbon Sequestration, and Greenhouse-Gas Fluxes of Aquatic Ecosystems the lake water carbon is contained as Dissolved Inorganic carbon(DIC), Dissolved Organic carbon (DOC), and Particulate Inorganic carbon (POC) (Zhu, et al. 2010).

The estimation for dissolved carbon Dioxide in the lake was based on the Soor Sarovar's mean water pH and alkalinity values collected and analyzed between September 2014 to July 2015 at The Academy of Environmental Biology, India. (Gopal, Verma & Tripathi 2015).

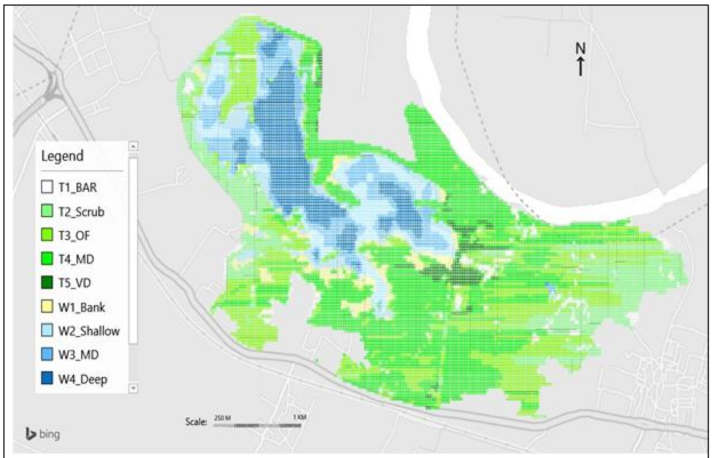
Carbon dioxide values were calculated for the given pH and Alkalinity following method elucidated in the Southern Regional Aquaculture Center Publication 468 carbon Dioxide in Fish Ponds(John Hargreaves and Martin Brunson 1996). Charts for various water alkalinities showing the variation of free Carbon Dioxide with pond water pH have been provided. Step 1 involved drawing a straight line up for the measured pH to the curved line representing the total alkalinity value of the pond. Another straight line extended (Step 2) to the left-hand axis indicated the free Carbon Dioxide.

Calculations for dissolved and particulate organic matter in the lake water was determined based on the reported values in similar physiochemical parameters and climate of pond waters at Central Inland Fisheries Research Institute, Karnal by (Singhal, Swarn Deep & Davies 1986).

The fish and water birds are also an essential part of the aquatic system and their biomass estimation has been based on the archives data of the Uttar Pradesh Forest department and through local information gathering. Water bird and fish biomass has been converted to carbon by multiplying the carbon fraction @ 18% as per the details noted from(Emsley 1988). Due weights for residence at SSBS has been accounted for migratory birds.

RESULTS AND DISCUSSION

Fig. 2:Visualises the study area coverage categories.



Legend:T1_BAR: Terrestrial Barren Areas; T2_Scrub:Terrestrial Scrub Areas; T3_OF: Terrestrial Open Forrest Areas;T4_MD: Terrestrial Moderate Density Forest Areas; T5_VD: Terrestrial Very Dense Forest Areas ; W1_Bank: Lake Bank Areas; W2_Shallow: lake shallow Areas of depth less than 1.5 m; W3_MD: Lake areas with water depth between 1.5 m - 2.5 m ; W4_Deep: Lake areas with water depth of more than 2.5 m.

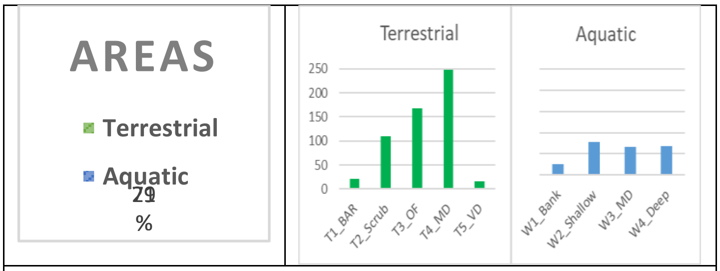
Figure-2: Study Area Land Cover

Strata Areas:Table 1 provides areas for each strata in ha.

Table 1. Stratificationareas at soorsarovar bird sanctuary

Soor Sarovar Bird Sanctuary Area 799 ha								
Terrestrial 563 ha				**Aquatic 236 ha**				
Barren	**Scrub**	**Open**	**Mod Dense**	**Very Dense**	**Bank**	**Shallow**	**Modeep**	**Deep**
21	105	169	247	17	26	77	66	67

The figure 3 compares the estimated areas of land categories at Soor Sarovar Bird Sanctuary.



Legend:T1_BAR: Terrestrial Barren areas;T2_Scrub areas;T3_OF: Terrestrial Open forest areas; T4_MD Terrestrial moderately dense forest areas; T5_VD:Terrestrial Very Dense forest areas
W1_Bank: Aquatic lake bank areas; W2_Shallow: Aquatic shallow depth water areas; W3_MD: Aquatic lake mid-depth water areas;W4_Deep: Aquatic lake deep depth water areas

Fig. 3: Soorsarovar bird sanctuary area pattern

While the Moderately Dense forest with an area of 247 ha was estimated to form the maximum of the terrestrial forest, shallow waters (77 ha) were the largest size of the aquatic areas. The Very Dense forest (17 ha) and Bank (26 ha) areas respectively formed the least of the terrestrial and aquatic areas.

Carbon Densities: The respective carbon densities represented as t/ha were estimated as shown in the figure 4.

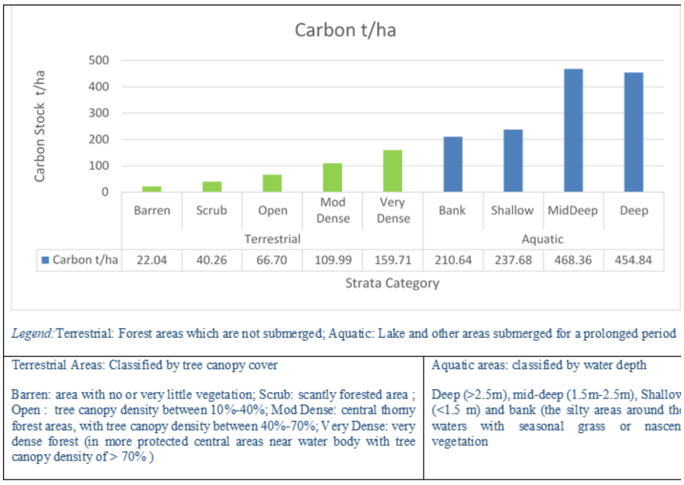


Fig. 4: Carbon stock densities in various terrestrial and aquatic categories

The MidDeep and Deep Aquatic strata with more than 450 t/ha carbon stock were estimated way ahead of the very dense terrestrial carbon density. The highest carbon density in the terrestrial forest was calculated as 110 t/ha. The areas categorised as Barren and Bank had the least density for terrestrial and aquatic categories. It is worth noting that the carbon density even in the least of an aquatic category was 1.3x more than the maximum terrestrial carbon density of the very dense forest.

The average aquatic carbon density was estimated more than three times the average terrestrial density. Figure 5 shows the carbon stocks at SSBS.

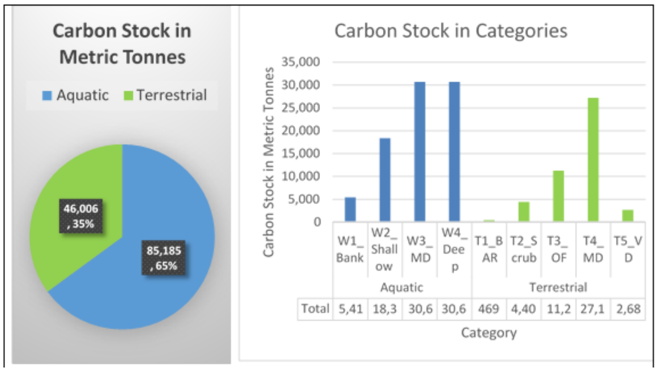
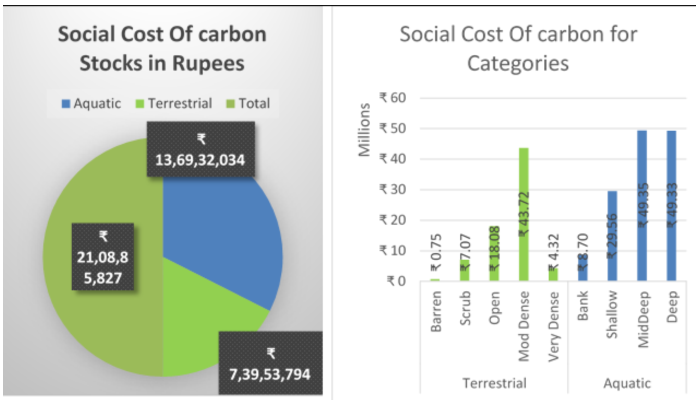


Fig. 5: Charts showing carbon stocks at Soor Sarovar Bird Sanctuary

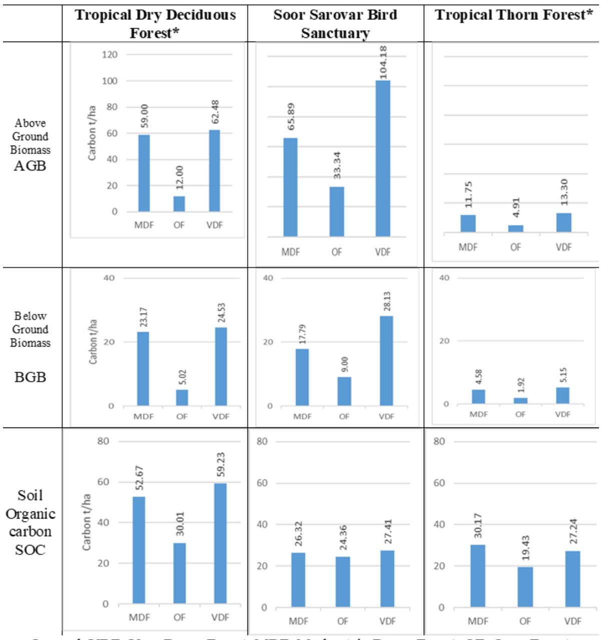
The carbon and their values were calculated as per the social cost of carbon dioxide of $86 per tCO_2 as the social cost of carbon for India [27] in each of the strata is depicted in the figure 6.



The total Social cost of Soor Sarovar Bird Sanctuary was estimated as ₹ 21.1 million (₹210885827)

Fig. 6: Social cost of carbon of Soor Sarovar Bird Sanctuary

Comparing results with other similar Forest type in ISFR 2017: According to Champion and Seth classification, the SSBS falls under Northern Tropical Dry Deciduous Forests (subgroups 5 B: 5/E1 and 5/E2) and Northern Tropical Thorn Forest (sub-group 6B) [28]. The figure 7 compares the carbon densities at SSBS in comparison with the carbon Density estimated in the ISFR Report 2017 in comparative forest type.



Legend: VDF: Very Dense Forest; MDF: Moderately Dense Forest; OF: Open Forest
*Reference (ISFR 2017)

Fig. 7: Carbon stock (tonnesC / hectare) as per ISFR 2017in the comparative forest types and as estimated for SSBS

The average above ground biomass carbon densities at Soor Sarovar Bird Sanctuary for the Very Dense Forest were estimated markedly higher as compared with national figures for Tropical Dry Deciduous Forests. The statistics for Moderately Dense Forests were slightly higher. Nevertheless, the above ground carbon Statistics for this protected bird sanctuary are much higher than the national average for Tropical Thorn Forest.

The statistics for Soil Organic carbon were estimated to be lower than both the Tropical Dry deciduous and Tropical Dry Evergreen Forests. It may be due to Bird Sanctuary's recent origin and indicate a high potential for carbon sequestration.

The Above Ground Biomass carbon density for SSBS's Scrub forest category of 13.72 t/ha is comparable to the national statistics of Tropical Thorn Forests Very Dense Forest category which is 13.30 t/ha.

The national statistics for aquatic areas are not published in the ISFR. However, the reported average carbon density of 110 g of carbon per kg of soil for tropical aquatic sediments [29] is an order of magnitude higher than the estimated carbon average of 4.79 grams of carbon per kilogram of soil for SSBS.

Limitations and opportunities: The size of grid 25mX25m limits the precision of the demarcation of strata and study area boundary, but the deviations in the measurements occur on the either (plus or minus) side and are thus noncumulative. The innovative deployment of the commonly used Excel spreadsheet application, however, liberates the process from the steep learning curve of deploying an expensive professional GIS software. It also makes the study process very transparent which is an essential requirement of NDC implementation.

The study, synchronous with the national policies integrates new mobile geolocation and simple excel map and visualisation techniques into a practical microscale measurement solution. The methodology evolved is simple enough to be clearly understood and implemented by the field staff for its replication in other areas. Geolocation with mobile and visualisation through spreadsheet technologies are expected to simplify the process further and democratise the difficult research process to bring it within reach of an ordinary forester.

Soil Degradation: Besides a rainfall range of 300 to 600 mm, the human actions and landforms are considered as critical parameters of predictability of land desertification [27]. The results showing a vast range of carbon densities and their dramatic spatial variation at Soor Sarovar Bird Sanctuary corroborate this. The temporal process of a barren area creation due to recent anthropogenic disturbance was also established through historical imagery as shown in the figure 8.

Historical imagery between latitude $27^0$14´32.63´´N to $27^0$14´35.18´´N and longitude $77^0$50´10.7.15´E to $77^0$50´10.75´E showing the progress of barren area evolution.

Fig. 8: Temporal process of barren area creation at Soor Sarovar Bird Sanctuary

Other important ecosystem services, conflict of Interests and Synergy: Ecosystem Services are the various benefits that human beings get from functioning ecosystems [28]. Other essential ecosystem services (not measured) besides measured carbon stock at SSBS are enumerated below.

1.Biodiversity (Bird Habitat)
2.Water Provision
3.Weather & Climate Change Mitigation
4.Ecotourism
5.Meaningful Employment
6.Cultural Heritage
7.Erosion and Sedimentation Control

There is strong theoretical and empirical evidence that these ecosystem services support each other. Globally there is a generally positive relationship between carbon stocks and biodiversity (Hicks et al. 2014).

Conclusion and further research needs: The relationships amongst these services are complex. However, as study visualisation and results at SSBS indicate, lesser anthropogenic disturbance and better forest management are likely to enhance all the services. Forest Management Plan for SSBS, however, points to a conflict in the provision of water to Mathura Refinery which requires deeper water for enhancing the reservoir capacity and the birdlife which thrives on shallower waters. Synergy in the two can be thought by increasing the lake area by extending it to the newly emerged barren areas and appropriate peripheral plantations (which as indicated by historical imagery is a product of anthropogenic pressure of forest degradation and topological disturbances of nearby constructions). It is likely to enhance the biodiversity and carbon stock as also all other ecosystem services. The recommendation, however, would be to go for a test case first as complex relationships in nature sometimes defy common sense (Lewis Michael, 2003).

A scenario assuming conversion of barren areas into shallow waters and upgrading of 30% forest types to the next level up along with an increase of 5% in aquatic carbon densities up to 2030 would result in adding up of 22,500 t (15%) of carbon within the sanctuary area. This is about 12 times the national average required for meeting a target of 3 billion tons of additional carbon dioxide equivalent storage. However, only 5000 t (4%) carbon would be added in a scenario involving the routine approach resulting in the status quo of the barren areas and modest growth of 10% upgradation in the forest stratum. A situation where the random urban growth is not stopped, barren areas are likely to increase further, is the worst possible scenario.

ACKNOWLEDGEMENT

The authors thank the Chief wildlife warden of U.P. Forest for granting permission for research and all Officers and staff of Forest Department at Soor Sarovar Bird Sanctuary for sharing archival data, useful suggestions and insights.

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