Application of Remote Sensing Technology for Bio-Resource monitoring

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Abstract:

Environmental Biotechnology is the application of technology in identification of Biological Resources, found naturally or artificially in the environment surrounding us and monitoring the Resources. Remote Sensing Technology and use of Satellite Imageries, help us in mapping and monitoring the Biological Resources, in macroscopic scale, on real time basis.

Remote Sensing is the science of obtaining information about an object through analysis of data acquired by a device that is not in contact with the object. The sensors in the satellite acquire data on emitted and reflected Electromagnetic energy from various earth surfaces, also known as Earth features, and these data are analyzed to provide information about the various natural earth resources like oceans, Rivers, Wetland, Desert, Forest, Agriculture Soil and natural/ man-made disasters like Forest fire, Flood, Deforestation etc.

In the past, the authors had studied and analyzed the impact of Global Warming on the deltaic mangrove Forests of Sundarban Tiger Reserve in West Bengal, using the modern Technology of Remote Sensing and GIS. Based on satellite data between 2001 and 2014, the research Paper had predicted the trend of decrease of Dense Mangrove Forest over the future years, in Sundarban Tiger Reserve. In the present dissertation paper, I have tried to examine the efficacy of the projection on rate of degradation of mangrove forest in the past and compare the future trends based on the 2017 satellite data.

Introduction:

A. **Remote Sensing Technology**

We define satellite remote sensing as the use of satellite-borne sensors to observe, measure, and record the electromagnetic radiation reflected or emitted by the Earth and its environment for subsequent analysis and extraction of information.

Active and passive Remote Sensing:

A *passive* Remote Sensing system records the energy naturally radiated or reflected from an object. An *active* Remote Sensing system supplies its own source of energy, which is directed at the object in order to measure the returned energy. Flash photography is active Remote Sensing in contrast to available light photography, which is passive. Another common form of active Remote Sensing is radar, which provides its own source of Electromagnetic energy in the microwave region.

Sun is the source of all energies on earth.

The electromagnetic radiations emitted by the sun varies from very High Frequency waves (YT-rays, X-rays and UV radiation) through Visible Bands (Blue Band – 400nm to 500 nm, Green Band- 500 nm to 600 nm and Red Band-600 nm to 700 nm), Near Infra Red (NIR) band -700 to 1300 nm, Thermal Infra Red (3000 nm to 14000 nm) and Radio wave/ Microwaves (1mm to 1 m).

Eye acts as sensor for Visible Band- the sensation of visibility.
Skin acts as Sensor for IR Band – the sensation of heat.
The Sensors for X-ray are X-Ray plates and that of Microwaves/ Radio waves are the Mobile phones/ radio/ TV.
LISS or Linear Imaging Self-scanning Sensor cameras are electronic sensors which measure intensity of E.M. radiation reflected or emitted from objects on earth surface.

Interaction of Energy Bands with Earth features/ Objects:
A number of interactions are possible when Electromagnetic energy encounters matter, whether solid, liquid or gas. The interactions that take place at the surface of a substance are called *surface phenomena*. Penetration of Electromagnetic radiation beneath the surface of a substance results in interactions called *volume phenomena*.

The surface and volume interactions with matter can produce a number of changes in the incident Electromagnetic radiation; primarily changes of magnitude, direction, wavelength, polarization and phase. The science of Remote Sensing detects and records these changes. The resulting images and data are interpreted to identify remotely the characteristics of the matter that produced the changes in the recorded Electromagnetic radiation. The following interactions may occur:

· Radiation may be *transmitted*, that is, passed through the substance. The velocity of Electromagnetic radiation changes as it is transmitted from air, or a vacuum, into other substances.

· Radiation may be *absorbed* by a substance and give up its energy largely to heating the substance.

· Radiation may be *emitted* by a substance as a function of its structure and temperature. All matter at temperatures above absolute zero, 0°K, emits energy.

· Radiation may be *scattered*, that is, deflected in all directions and lost ultimately to absorption or further scattering (as light is scattered in the atmosphere).

· Radiation may be *reflected*. If it is returned unchanged from the surface of a substance with the angle equal and opposite to the angle of incidence, it is termed *specular* reflectance (as in a mirror).

If radiation is reflected equally in all directions, it is termed *diffuse*. Real materials lie somewhere in between.

The interactions with any particular form of matter are selective with regard to the Electromagnetic radiation and are specific for that form of matter, depending primarily upon its surface properties and its atomic and molecular structure.

Thus every object on earth has its own signature characteristics, which means every object interacts uniquely with the incident Radiation and the intensity of the Reflected Radiation is unique to that particular object.

The Spectral Reflectance or Reflectance characteristics of earth surface features is measured by the percentage of incident energy that is reflected.

Atmospheric Windows:
All the E.M. radiations or energy bands that a satellite receives from earth, travels over 600 km to 900 km through the atmosphere. Atmosphere can have serious effect on the intensity and spectral composition of the reflected radiation reaching the Sensors on the Satellite. These effects are primarily caused due to scattering and absorption of the energy bands. Short wavelengths like Blue Band have more tendency to scatter than long wavelengths like Red band or IR Band. **That is why, satellite scanners are designed not to sense or read Blue bands and the LISS scanners operate in 4 bands, namely Green, Red, IR and Thermal IR bands.**

Moreover, atmospheric absorption results in effective loss of energy of specific Bands. The efficient absorbers of solar radiation are water vapour, Carbon dioxide and Ozone. A few specific wavelengths of energy get absorbed while travelling from earth through the atmosphere to the satellite scanners. **There are other specific energy Bands which are least absorbed by the atmosphere and hence the atmosphere is more Trans missive for these particular wave bands which are known as Atmospheric Windows.**

Sensors:
In order for a sensor to collect and record energy reflected or emitted from a target or surface, it must reside on a stable **platform** removed from the target or surface being observed. Platforms for remote sensors are situated on a satellite outside of the Earth's atmosphere.

Satellites are objects which revolve around another object - in this case, the Earth. For example, the moon is a natural satellite, whereas manmade satellites include those platforms launched for remote sensing, communication, and telemetry (location and navigation) purposes. Because of their orbits, satellites permit repetitive coverage of the Earth's surface on a continuing basis. Cost is often a significant factor in choosing among the various platform options.

History of Satellite Technology
Main types of satellites:
Since the early 1960s, numerous satellite sensors have been launched into orbit to observe and monitor the Earth and its environment. Most early satellite sensors acquired data for meteorological purposes. The advent of earth resources satellite sensors (those with a primary objective of mapping and monitoring land cover) occurred when the first Landsat satellite was launched in July 1972. Currently, more than a dozen orbiting satellites of various types provide data crucial to improving our knowledge of the Earth's atmosphere, oceans, ice and snow, and land.
The path followed by a satellite is referred to as its **orbit**. Satellite orbits are matched to the capability and objective of the sensor(s) they carry. Orbit selection can vary in terms of altitude (their height above the Earth's surface) and their orientation and rotation relative to the Earth. Satellites at very high altitudes, which view the same portion of the Earth's surface at all times have geostationary orbits. **These geostationary satellites,** at altitudes of approximately 36,000 kilometers, revolve at speeds which match the rotation of the Earth so they seem stationary, relative to the Earth's surface. This allows the satellites to observe and collect information continuously over specific areas. Weather and communications satellites commonly have these types of orbits. Due to their high altitude, some geostationary weather satellites can monitor weather and cloud patterns covering an entire hemisphere of the Earth.

Many remote sensing platforms are designed to follow an orbit (basically north-south) which, in conjunction with the Earth's rotation (west-east), allows them to cover most of the Earth's surface over a certain period of time. **These are near-polar orbits**, so named for the inclination of the orbit relative to a line running between the North and South poles. Many of these satellite orbits are also **sun-synchronous** such that they cover each area of the world at a constant local time of day called **local sun time**. At any given latitude, the position of the sun in the sky as the satellite passes overhead will be the same within the same season. This ensures consistent illumination conditions when acquiring images in a specific season over successive years, or over a particular area over a series of days. **This is an important factor for monitoring changes between images or for mosaicing adjacent images together, as they do not have to be corrected for different illumination conditions**.
Most of the remote sensing satellite platforms today are in near-polar orbits, which means that the satellite travels northwards on one side of the Earth and then toward the southern pole on the second half of its orbit. These are called ascending and descending passes, respectively. If the orbit is also sun-synchronous, the ascending pass is most likely on the shadowed side of the Earth while the descending pass is on the sunlit side. Sensors recording reflected solar energy only image the surface on a descending pass, when solar illumination is available. Active sensors which provide their own illumination or passive sensors that record emitted (e.g. thermal) radiation can also image the surface on ascending passes.
As a satellite revolves around the Earth, the sensor "sees" a certain portion of the Earth's surface. The area imaged on the surface, is referred to as the swath. Imaging swaths for space borne sensors generally vary between tens and hundreds of kilometers wide. As the satellite orbits the Earth from pole to pole, its east-west position wouldn't change if the Earth didn't rotate. However, as seen from the Earth, it seems that the satellite is shifting westward because the Earth is rotating (from west to east) beneath it. This apparent movement allows the satellite swath to cover a new area with each consecutive pass. **The satellite's orbit and the rotation of the Earth work together to allow complete coverage of the Earth's surface, after it has completed one complete cycle of orbits.**
Satellite Imageries:

The complex interaction of light with matter involves reflection. As each material has its own unique interaction with light, we can find the unique reflectance spectra of each material. The reflectance spectra of a material is also dependent upon the mixture ratio of the material with other, and the material’s grain size.

Vector and Raster data

The two primary types of spatial data are **vector and raster data** in GIS. But what is the difference between raster and vector data?

Vector data model: [data models] A representation of the world using points, lines, and polygons. Vector models are useful for storing data that has discrete boundaries, such as country borders, land parcels, and streets. **Vector data** consists of individual points, which (for 2D data) are stored as pairs of (x, y) co-ordinates. The points may be joined in a particular order to create lines, or joined into closed rings to create polygons, but all vector data fundamentally consists of lists of co-ordinates that define vertices.

POINTS are XY coordinates

Vector points are simply XY coordinates. Generally, they are a latitude and longitude with a **spatial reference frame**.

When features are too small to be represented as polygons, points are used. For example, you can't see city boundary lines at a global scale. In this case, maps often use points to display cities.

Raster data model: [data models] A representation of the world as a surface divided into a regular grid of cells. Raster models are useful for storing data that varies continuously, as in an aerial photograph, a satellite image, a surface of chemical concentrations, or an elevation surface. **Raster data** is made up of pixels (or cells), and each pixel has an associated value. Simplifying slightly, a digital photograph is an example of a raster dataset where each pixel value corresponds to a particular colour. In GIS, the pixel values may represent elevation above sea level, or chemical concentrations, or rainfall etc. The key point is that all of this data is represented as a grid of (usually square) cells.

B. Mangrove Forest of Indian Sundarban

The total area of Indian Sundarban region is about 9630 sq. km., out of which the Reserve Forest occupies nearly 4260 sq. km. At present, out of 102 islands of the Sundarban region, 54 are inhabited with a population of more than 4 million (2011 census), spread over 1093 mouzas. The region is spread over two administrative districts, namely South 24-Parganas (13 blocks) and North 24-Parganas (6 blocks) [1].

A close network of rivers, channels and creeks intersects the whole area, which has resulted in formation of innumerable islands. The main rivers of the Reserve are Kalindi, Raimangal, Harinbhanga, Jhilla, Kapura, Gomdi, Bidya, Matla, Gosaba and Gona.

Sundarban delta is very dynamic. The origin of Sundarbans is very recent and it is the only alluvial plain of lower Bengal raised by the deposition of sediments formed due to water erosions [10]. Mangrove and mangrove associates, which are salt-loving plants constitute the dominant vegetation type of the area.

There has been premature reclamation of land in the region from 1883 onwards, with more than 3500 km. of earthen embankments protecting the settlements in the region. Most of the reclaimed are as, guarded by the embankments, and are lying at lower depth than the riverbeds. The aquifer of potable water lies at a depth of about 350M from the ground level and in many islands no sweet water (non-saline) is found making life of inhabitants difficult.

Sundarban Tiger Reserve (STR) had been carved out of Indian Sundarbans mangrove, in the year 1973, with the objective of conserving the threatened species of Bengal tiger *(Panthera tigris)* along with its associated ecosystem comprised of mangrove flora and fauna. It is located in the Southern-most part of the state West Bengal in the districts North and South 24-Parganas. It lies between latitude $21^{0}31'$ & $22^{0}31'$ North and Longitude $88^{0}10'$ & $89^{0}51'$ East.

STR bounded by fringe villages along the northern boundary, Bay of Bengal on the South, territorial division South 24-Pargana on the West and Bangladesh on the east separated by Raimangal and Kalindi rivers [1, 14].

Total area of the Reserve is 2585 s q. km. out of which 362.40 sq. km. area belongs to Sajnekhali Wildlife Sanctuary, 1330.10 sq. km. area under Sundarban National Park and area of the Reserve d Forest is 892.43 sq. km.

Global importances of Sundarban Tiger Reserve are highlighted below [14]:

a. It is one of the first nine tiger reserves in India, declared under Project Tiger scheme in the year 1973.

b. National Park area of the reserve is a Natural "World Heritage Site" of UNESCO, declared in the year 1 987.

c. It is a part of Sundarban Global Biosphere Reserve, declared by UNESCO in the year 2001.

d. It constitutes over 60% of the total mangrove forest area in the entire county and has 90% of the total Indian mangrove species.

e. It is the only tiger reserve containing mangrove landscape of the country.

f. Besides tiger, STR is a home of a large number of endangered and globally threatened species like Fishing Cat (Felis viverrina), Estuarine Crocodile (Crocodylus porosus), Gangetic Dolphin (Platanista gangetica), Irrawady Dolphin (Oracella brevirostris), King Cobra (Ophiophagus hannah) and Water Monitor Lizard (Varanus salvator).

g. It harbours significant population of River Terrapin (Batagar baska) and provides the nesting ground of Olive Ridley Turtle (Lepidochelys olivacea), Green Sea Turtle (Chelonia mydas) and Hawksbill Turtle (Eretmochelys imbricata).

h. It is also very rich in aquatic/ estuarine avi-fauna.

The mangrove forests act as a natural shelterbelt and protect the hinterland from natural calamities. The total plant species are grouped into 59 families, 101 genera and 140 species. These comprise of true mangroves or major elements, minor elements of mangroves or/and mangrove associates, back mangrove trees and shrubs, non- halophytic non-mangrove associates in the area, halophytic herbs, shrubs & weeds and epiphytic & parasitic plants [14].

The animals that once existed in Sundarbans and have become extinct over a period of time include Javan Rhinoceros, wild buffalo, swamp deer, barking deer etc. Apart from tiger, the secondary predators found are fishing cat, jungle cat, leopard cat etc. Other major species found are spotted deer, wild boar, gangetic dolphin, irrawady dolphin, estuarine crocodile, water monitor lizard, olive ridley turtle, hawksbill turtle, king cobra, python, monocellate cobra, banded krait, russels viper etc.

Wildlife of the mangrove forests helps in maintaining ecological balance as the plants and animals are directly interdependent on each other. The tiger on the land and crocodiles in the water are the two top consumer groups of animal in this eco-system. Their presence is very much necessary to keep in control the ecological flow by the sustained growth of other species. The birds, mammals, reptiles, fishes and microorganisms associated with the mangroves represent characteristics of this estuarine Sundarbans [14].

Background of study:

Major Conspicuous Changes that have been noted in the Habitat since inception of the Tiger Reserve are as follows [14]**:**

1. Exponential increase in the fringe population leading to increased pressure on the natural sources.

2. Many of the upstream rivers have silted up which is becoming a problem in navigation of watercrafts.

3. Purbasha Island which was the southernmost island has disappeared in the sea.

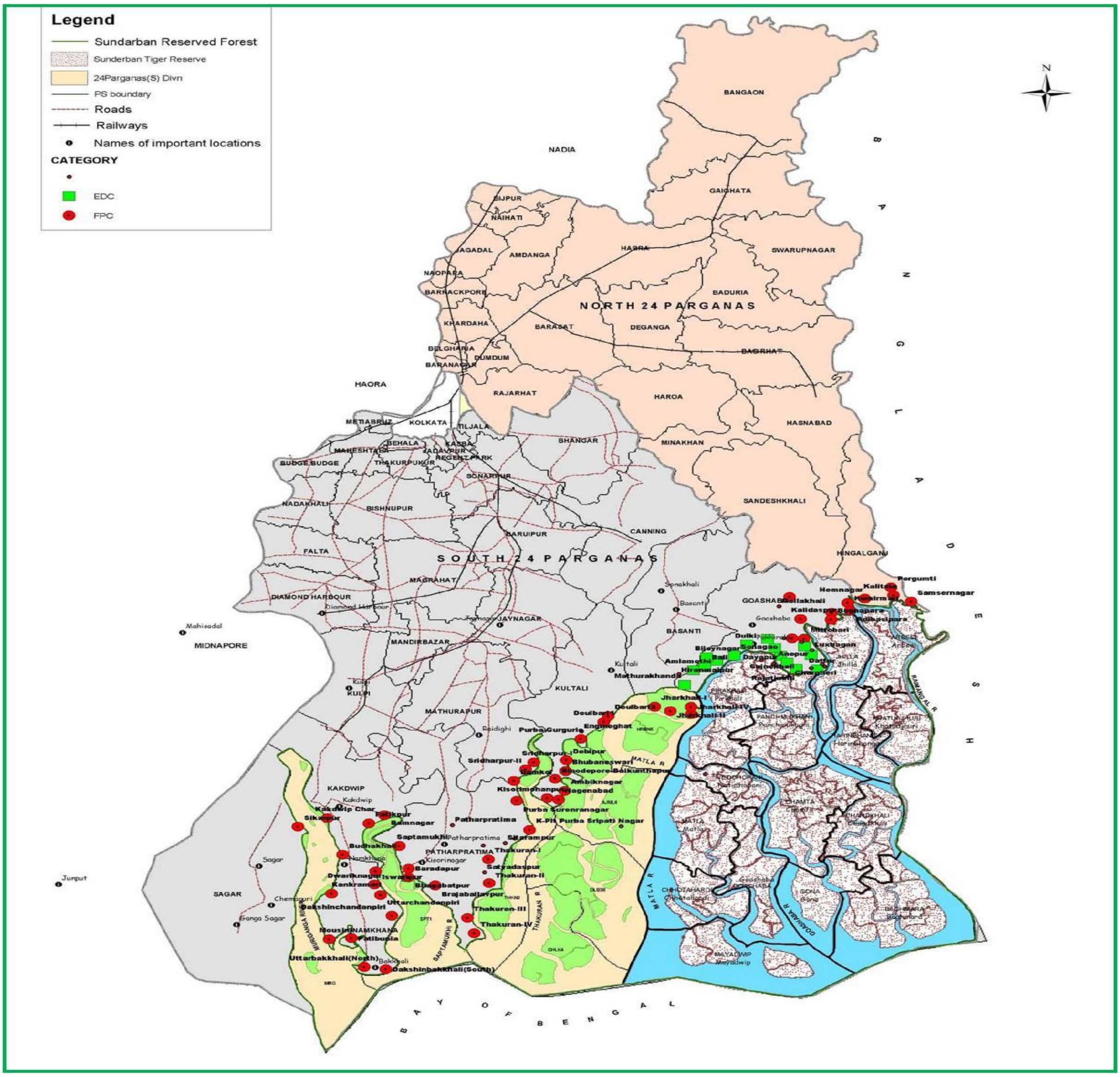
4. A continuous cycle of erosion and deposition has led to decrease in the area of certain blocks and compartments and increase in the area of others. The accretion is more on the southern side and the erosion more on the northern side.

According to a recent report, published by NASA in August 2015, Global sea level has risen about 3 millimeters (0.1 inch) a year since 1993. Seas around the world have risen an average of nearly 3 inches (8 centimeters) since 1992. In 2013, the United Nations Intergovernmental Panel on Climate Change issued an assessment based on a consensus of international researchers that stated global sea levels would likely rise from 1 to 3 feet (0.3 to 0.9 meter) by the end of the century. However, new research available since the 2013 IPCC report suggest that the actual rise, if the present trend continues, may be still higher than the highest predicted range [18].

Sea level rise due to climate change is threatening the biodiversity, flora and fauna of the Sundarban. While tigers are a highly adaptable species, the Sundarbans ecosystem has become an isolated one, facing the potential habitat loss due to sea level rise. A study on the predicted impact of sea level rise on Bangladesh Sundarbans and the associated impact on the tiger population, has focused on the loss of estuarine land and inundation of mangroves due to the projected sea level rise [7].

Hazra et al, in their research paper on impact of sea level rise on Indian Sundarbans, published in 2002, had concluded that the sea level rise has a dominant influence on coastal erosion. Results from the study area of Sagar Island, which is located in the extreme western part of Indian Sundarbans, have established the linkage between the erosion-accretion rate with the rise and fall of relative mean sea level. The authors had further concluded that the mangrove forest cover was predicted to diminish further along with the degradation of existing species combination [2, 4, 6].

In another study [13], it has been observed that the southern islands of STR facing the Bay of Bengal e.g. Baghmara, Chandkhali, Gona, Mayadwip have shown considerable loss of land “between 1986 to 2009” due to tidal erosion whereas the islands in central and northern STR i.e. Harinbhanga, Netidopani, Chamta has shown little erosion or accretion. This has been attributed to the high tidal currents duly impacted by sea level rise. The loss of discharge of fresh water due to blocade of river Bidyadhari in central Sundarban, which forms the eastern boundary of Sundarban Tiger Reserve allows the tidal currents from Bay of Bengal to strike the western Sundarban Tiger Reserve islands unchallenged by the upstream fresh water flow.



Map showing Indian Sundarbans in the district of South 24 Parganas, W. Bengal

A study on Bangladesh Sundarbans had shown that the coastline had lost around 170 sq. km of land area during the 37 years of study period from 1973 to 2010 [8].

However, other than the published papers on impact of sea level rise on the human population in coastal/ estuarine zones and erosion/ accretions of the islands in the estuary [10,11], no detailed study or data was available to measure the changes that have occurred in the mangrove forests of Sundarban Tiger Reserve over the last few decades.

The present study is to test the efficacy of the Research Paper published by Dr. Atanu Kumar Raha in 2016 to

(i) Map, monitor and predict the comparative changes in densities of mangrove forests in the Southern, Central and Northern parts of Sundarban Tiger Reserve,

(ii) A comparative study of mangrove vegetational changes in Western and Eastern sectors of STR as well as,

(iii) Study the progressive changes in the mangrove vegetation of the Sundarban Tiger Reserve as a whole.

Materials and Methods:

For a difficult and highly inaccessible terrain like Sundarbans estuary, satellite imagery from the Indian Remote Sensing satellites are found to be the most cost-effective mode of real-time mapping of the Sundarbans estuary as well as mangrove vegetation over a very large area[12,16]. In a related study in the recent past, Digital satellite data covering the entire Indian Sundarbans were procured from NRSC, Hyderabad up to the year 2014. For the period Dec 2001, imageries were obtained from IRS 1D satellites and the data pertaining to the period Dec 2005, Dec 2009, Dec 2010 and Dec 2014 were AWiFS data from IRS P6 satellites. For my present study, AWiFS, Resourcesat II satellite digital data for Sundarban region, for the period Dec 17-Jan 18 was procured from NRSC Hyderabad.

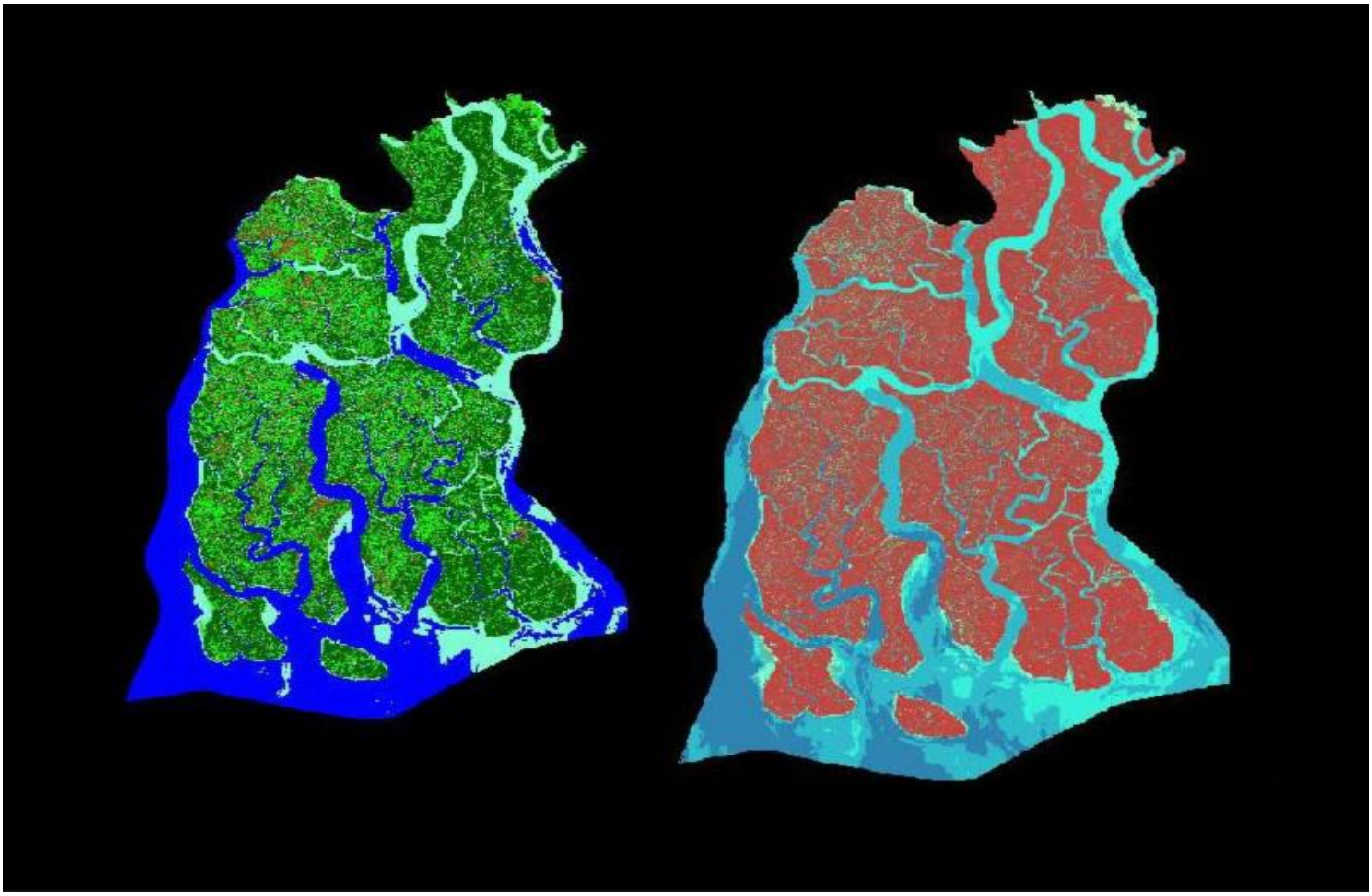
ERDAS Imagine Image processing software, version 2014 was used for Image geometric correction, with reference to earlier registered Images of Sundarbans, and subset of Sundarban Tiger Reserve, within the South 24 Parganas district were generated for each year. The small portion of mangrove forest of STR, around 8 sq. km, belonging to North 24 Parganas part of STR, were left out due to non-availability of data for the said part in all the reference years.

For Each set of image of STR, further subsets were generated as North East, North West, Central East, Central west, South East and South West. The objective was to compare the relative changes of mangrove density and erosion/ accretion/ submergence status in the six different spatial regions of STR due to the impact of sea level rise on Sundarbans mangroves.

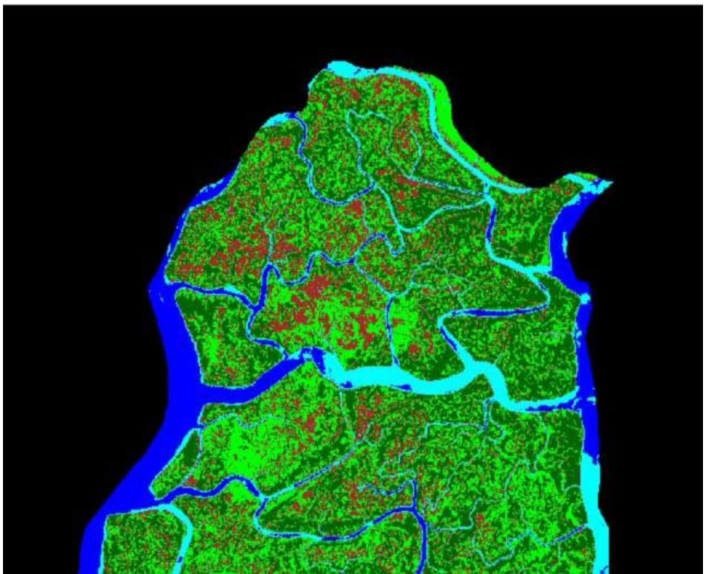
Sub-sets/ Zone	STR N-E Region	STR N-W Region	STR C-E Region	STR C-W Region	STR SOUTH Region
Forest Blocks	Jhila, Arbesia, khatuajhuri, Harinbhanga	Pirkhali, Panchamukhani	Chamta, Chandkkhali, Gona, Baghmara	Matla, Netidhopani, Chotohardi, Goashaba	Mayadwip

STR Zones	North	Central	South
Forest Blocks	Jhila, Arbesia, khatuajhuri, Harinbhanga, Pirkhali, Panchamukhani	Chamta, Chandkkhali, Gona, Baghmara, Matla, Netidhopani, Chotohardi, Goashaba	Mayadwip

STR ZONE	Eastern sector	Western sector
Forest Blocks	Jhila, Arbesia, khatuajhuri, Harinbhanga, Chamta, Chandkkhali, Gona, Baghmara	Pirkhali, Panchamukhani, Netidhopani, Chotohardi, Goashaba, Matla

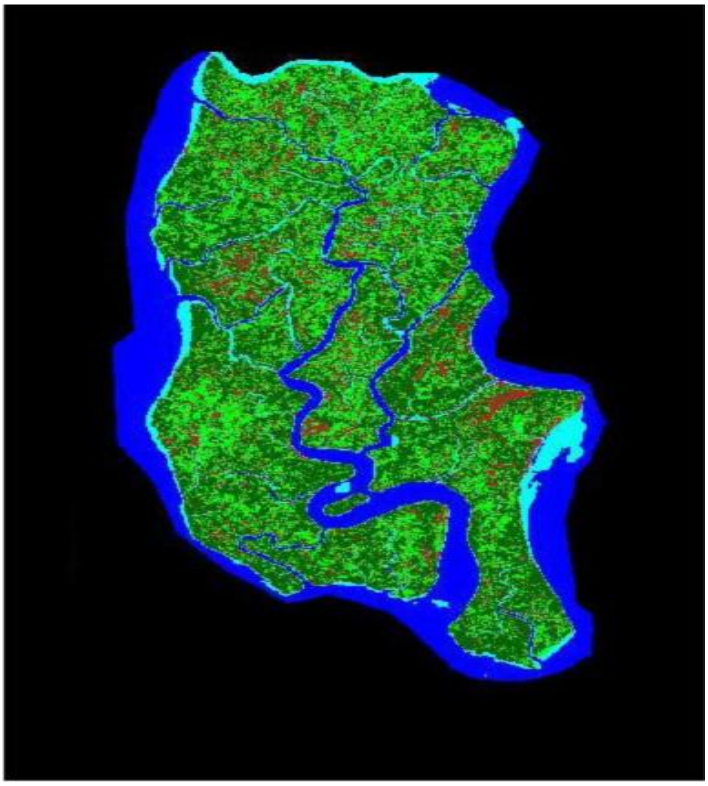


Map-1: Classified and Unclassified image of STR for 2017

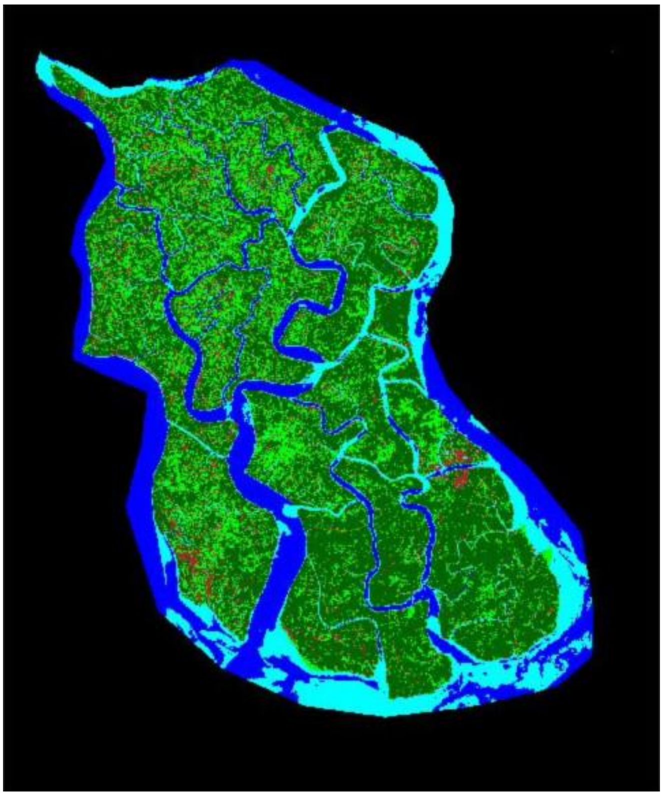


Map-2: Classified Image of STR North West Region

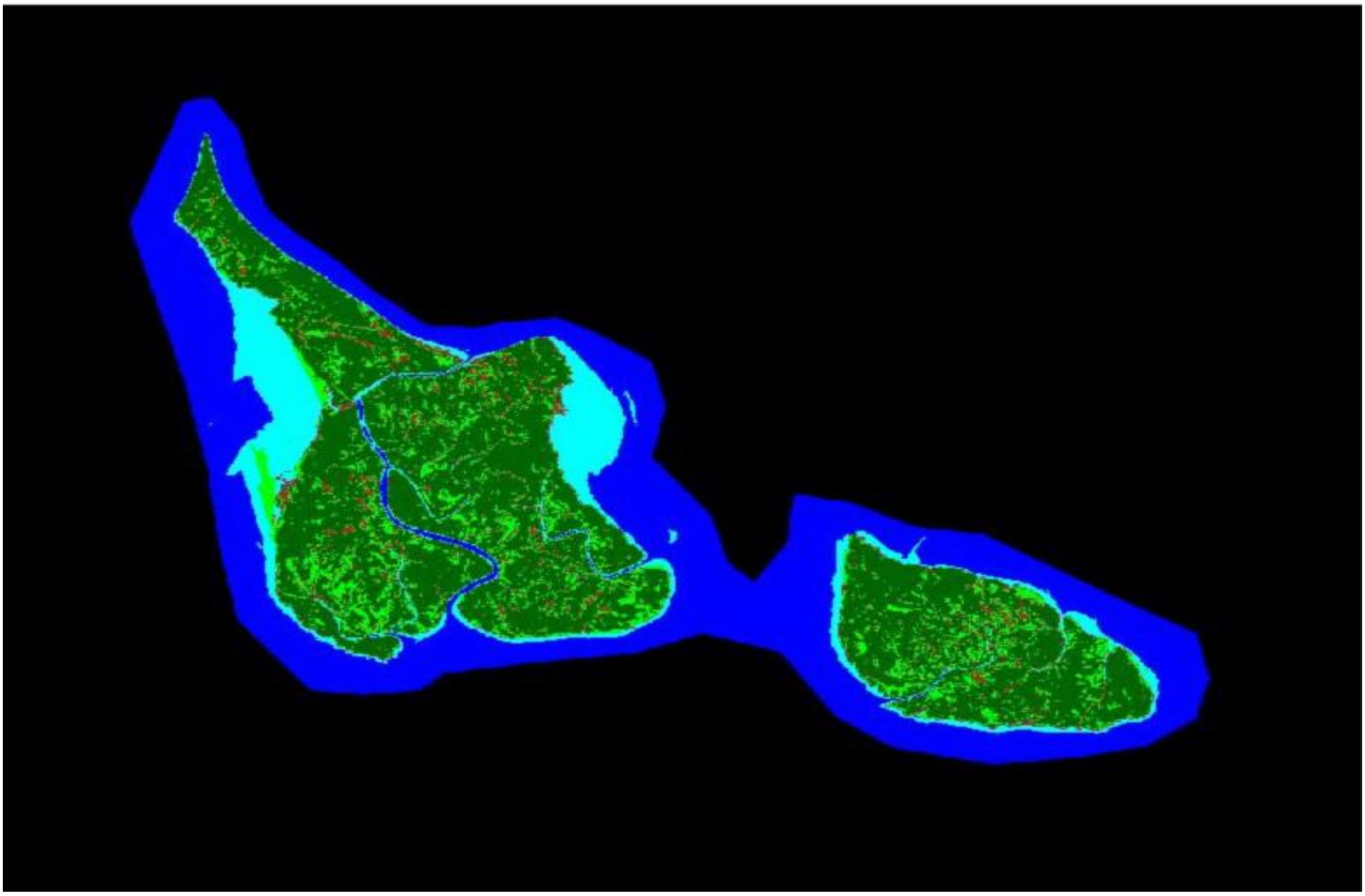
Map-3: Classified Image of STR North East Region



Map-4: Classified Image of STR Central West Region



Map-5: Classified Image of STR Central East Region



Map-6: Classified Image of STR South Region

Each of the standard FCC subset was then classified using “Unsupervised classification technology” available in ERDAS software, into Dense mangrove, open mangrove, Mudflat and water. The protocol followed were Standard deviation 2, no of classes 20 and no of iterations were 20. On the basis of field knowledge and Ground Truth Verification, final density wise classification was carried out. Mangrove vegetations with canopy density more than 40% was classified as Dense mangrove and those with density less than 40% was classified as open mangroves. Mudflats included the saline blanks, inter-tidal zones as well as shallow Tidal creeks/ channels within the forest areas, devoid of vegetation.

Graphs were plotted for the dense mangrove, open mangrove, mud flats and total land area vis--a-vis year of monitoring, for different regions of STR as well as for the entire STR area. Regression equations and correlation coefficients were calculated for each plotted graph.

Graphs were generated for different regions of STR to find out the degree of correlation of density classes of mangrove vegetation with progressive time.

Results and discussions

The classified data have been analysed for the period of 17 years, from 2001 to 2017 for monitoring of land area [Fig-1], and from 2001 to 2017 for monitoring the changes in mangrove vegetation density.

The data for the period 2010 is for the post Aila period. The cyclone Aila had struck Sundarbans and adjoining areas in middle of May 2009 and had caused massive devastations in the island-villages adjoining the Sundarbans Reserved mangrove forest. There had been large scale damages to the embankments, surrounding the villages, resulting into inundation of hundreds of sq. kilometres of habitation areas in Sundarbans. However, there had not been any scientific and quantitative assessment of impact of this Aila storm on the mangrove vegetations and the Reserved Forests of Sundarbans.

In the present study, we are studying about the gradual decrease in the dense mangrove within this 17 years. After left out the data period of 2010 (post-Aila) of the analysis, the regression equations were much more consistent and predictive and the changes had a strong correlation.

In the past study[20], Trend of reduction of dense mangrove with time had revealed that the percentage change of dense mangrove in the Northern and Central Sector were around 22% [Table-11,12], whereas the change was around 14% [Table-8] in case of Southern sector. It had indicated that the increase in salinity in the northern and central parts of the Tiger Reserve are much more as compared to the changes in salinity level in the Southern sector.

Comparative study of changes in mangrove densities between Eastern sector and western sectors of Tiger Reserve had shown that the changes from dense to open mangroves is less for Eastern sector [Table-9] (around 16%) as compared to western sector [Table-10] (around 28%). The possible reasons given in the past paper was relatively higher increase of salinity in the western sector of STR, i.e. central portion of Indian Sundarban estuary [9]. This appeared to be due to availability of more sweet water in the eastern part of Sundarbans and reduction of fresh water flow in western part of STR due to sedimentation of tidal rivers and reclamation of low lying areas in upper reaches of western part for habitations and aquaculture. When the data for the dense mangrove vegetation for the entire Tiger Reserve were extrapolated [Fig-3,23], it was found that the total quantum of dense mangrove forest would have reduced to half of the year 2001 value by the year 2029, and the entire STR would have been taken over by open mangroves by 2056.

When similar graphs were plotted with the additional data of year 2017, the Regression Equation and Correlation Coefficient almost matches with that based on data up to year 2014.

Table-1: Comparison of Regression Equation and Correlation Coefficient of the year 2014 to 2017

Study Area	Data period up to 2014	Data period up to 2017	Data period up to 2014	Data period up to 2017
	Regression Equation	Regression Equation	Correlation coefficient	Correlation coefficient
Total STR	y = -23.54x + 4844	y = -24.06x + 4948	0.97	0.98
North East of STR	y = -3.22x + 6754	y = -3.02x + 6344	0.91	0.94
North West of STR	y = -6.47x + 1317	y = -6.33x + 1289	0.97	0.98
Central East of STR	y = -6.94x + 1433	y = -7.30x + 1505	0.95	0.97
Central West of STR	y = -5.99x + 1226	y = -6.26x + 1280	0.99	0.99
South STR	y = -0.93x + 1935	y = -1.16x + 2395	0.96	0.96

Table-2: Prediction based Data for Area of Dense Mangroves on 2014 and 2017

Prediction based on Data up to	Area of Dense Mangrove to become half by the year	Area of Dense Mangrove to become nil by the year
2014	2029	2058
2017	2029	2056

Table-3: Change in Total Mangrove Area of STR between 2001 and 2017

Zone	Year of Images	Dense Mangrove	Open Mangrove	Total Mangrove vegetation
STR	2001	1335	105	1440
	2005	1257	254	1511
	2009	1090	347	1437
	2014	1049	424	1473
	2017	942	418	1360

Table-4: Mangroves of North Easter Zone of STR between 2001 and 2017 (DM- Dense Mangrove; OM- Open Mangrove)

STR North East	DM	OM	TOTAL
2001	308	18	326
2005	292	39	331
2009	267	52	319
2014	269	55	324
2017	257	78	335

Table-5: Mangroves Area of North West Zone of STR between 2001 and 2017 (DM- Dense Mangrove; OM- Open Mangrove)

STR North West	DM	OM	TOTAL
2001	232	20	252
2005	205	60	265
2009	163	95	258
2014	152	112	264
2017	128	99	227

Table-6: Mangroves Area of Central Easter Zone of STR between 2001 and 2017 (DM- Dense Mangrove; OM- Open Mangrove)

STR Central East	DM	OM	TOTAL
2001	441	31	472
2005	425	71	496
2009	369	99	468
2014	359	124	483
2017	323	120	443

Table-7: Mangroves Area of Central West Zone of STR between 2001 and 2017 (DM- Dense Mangrove; OM- Open Mangrove)

STR Central West	DM	0M	TOTAL
2001	275	30	305
2005	257	73	330
2009	220	73	293
2014	201	90	291
2017	174	107	281

Table-8: Mangroves of STR South Zone between 2001 and 2017 (DM- Dense Mangrove; OM- Open Mangrove)

STR South	DM	OM	TOTAL
2001	79	6	85
2005	78	11	89
2009	71	11	82
2014	68	12	80
2017	60	14	74

Table-9: Mangroves of STR East Zone between 2001 and 2017 (DM- Dense Mangrove; OM-Open Mangrove)

STR EAST	DM	OM	TOTAL
2001	749	49	798
2005	717	110	827
2009	636	151	787
2014	628	179	807
2017	575	198	773

Table-10: Mangroves of STR West Zone between 2001 and 2017 (DM- Dense Mangrove; OM-Open Mangrove)

STR WEST	DM	OM	TOTAL
2001	586	56	642
2005	540	144	684
2009	454	199	653
2014	421	245	666
2017	302	206	508

Table-11: Mangroves of STR North Zone between 2001 and 2017 (DM- Dense Mangrove; OM-Open Mangrove)

STR NORTH	DM	OM	TOTAL
2001	540	38	578
2005	497	99	596
2009	430	147	577
2014	421	167	588
2017	385	177	562

Table-12: Mangroves of STR Central Zone between 2001 and 2017 (DM- Dense Mangrove; OM-Open Mangrove)

STR CENTRAL	DM	OM	TOTAL
2001	716	61	777
2005	682	144	826
2009	589	189	778
2014	560	245	805
2017	497	227	724

Graphs of Fig 1 to 41 below have been plotted with areal extent (along Y-axis) against Year of observation (along X-axis) comparing the 2014 data with 2017 data –

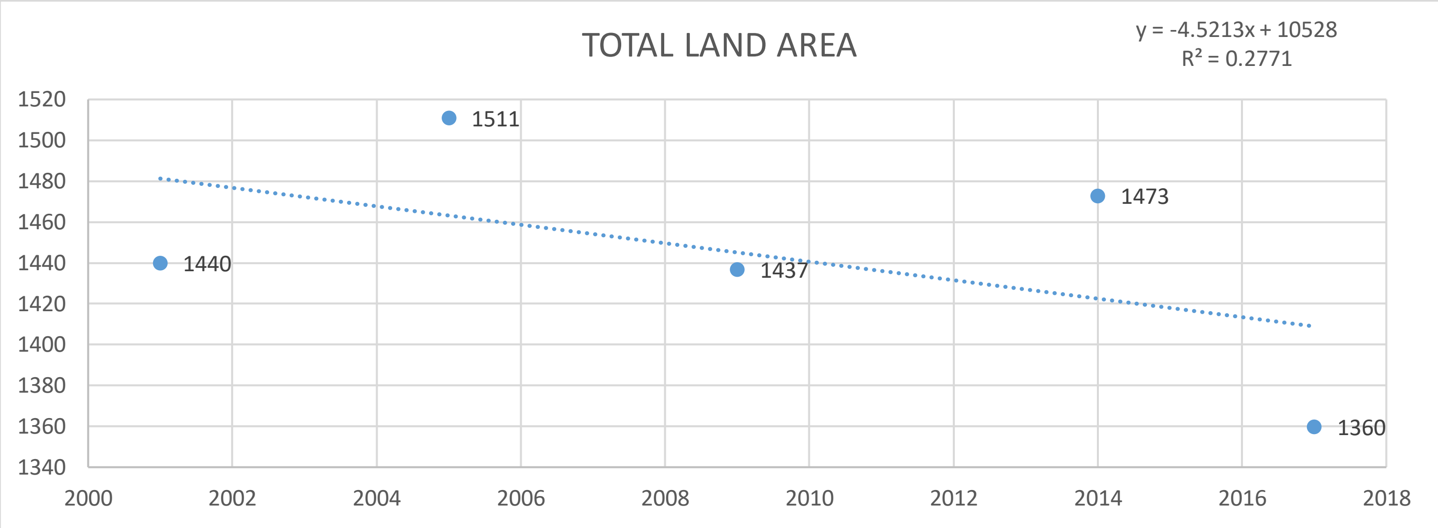


Fig-1: Trend line showing total Land Area of STR (Y-axis) against year of observation (X-axis) over the period 2001 – 2017

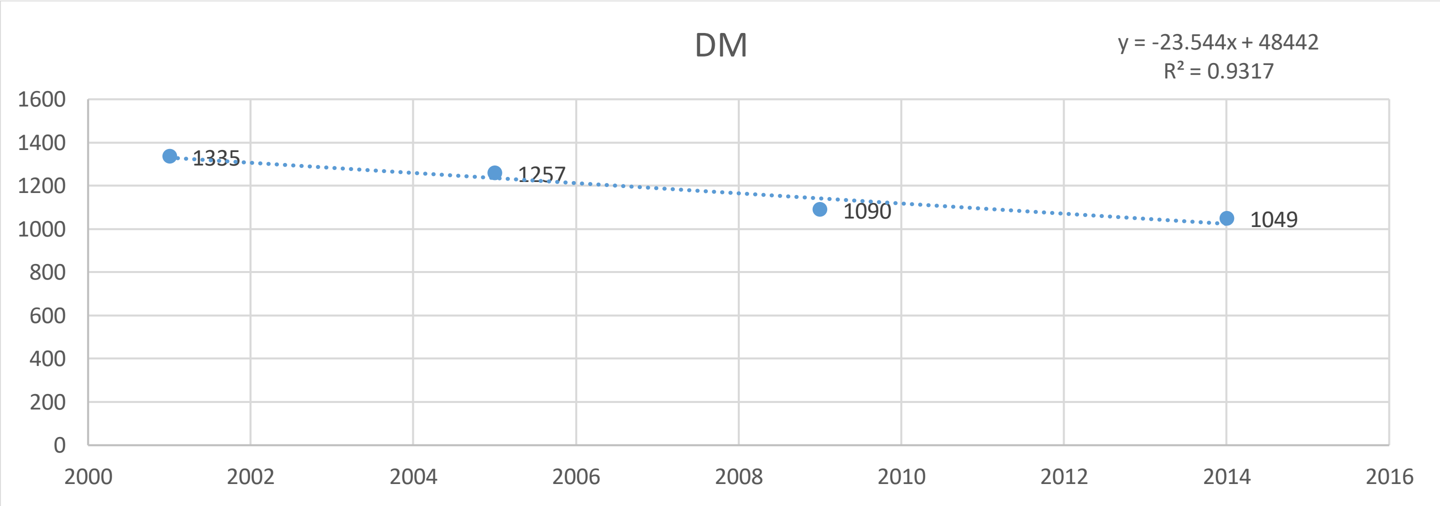


Fig-2: Correlation of Dense Mangrove data with progressive year - STR Region
Trend line showing Total Dense Mangrove area of STR (Y-axis) against year of observation (X-axis) over the period 2001- 2014

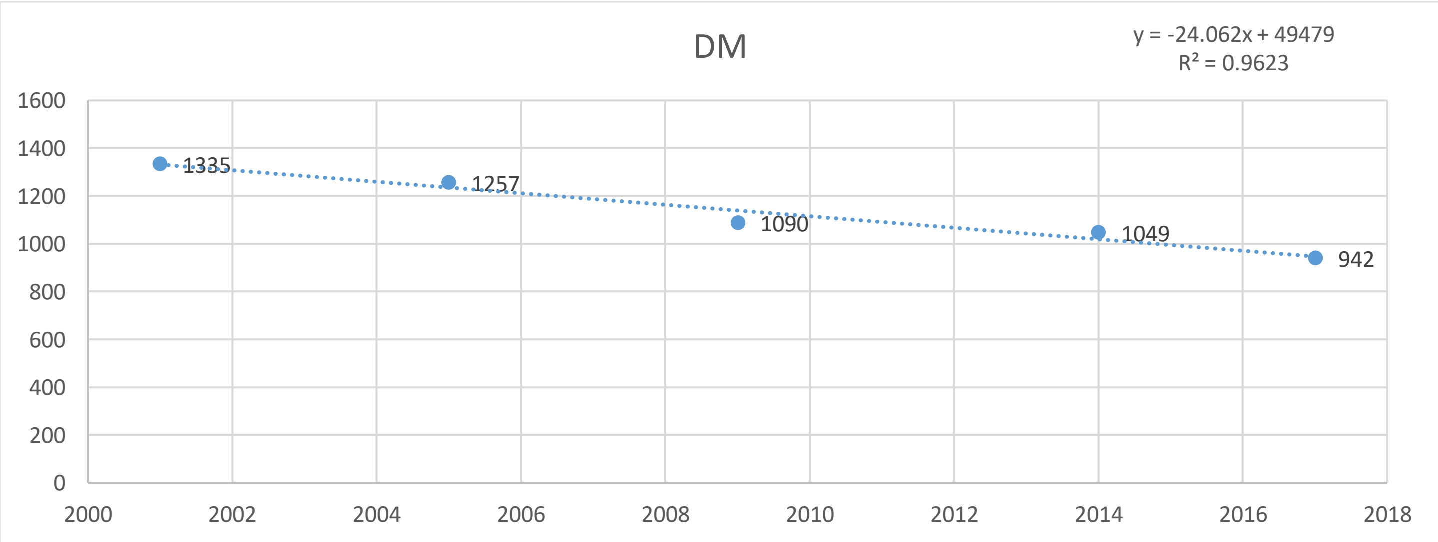


Fig-3: Correlation of Dense Mangrove data with progressive year - STR Region
Trend line showing Total Dense Mangrove area of STR (Y-axis) against year of observation (X-axis) over the period 2001 – 2017

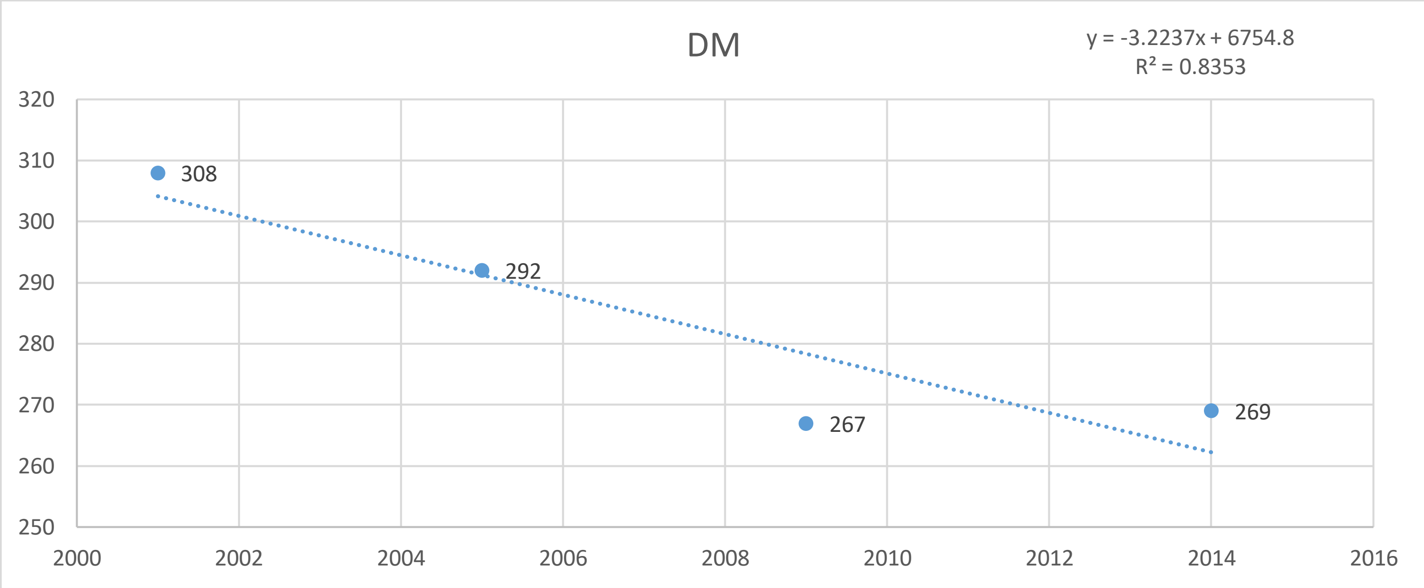


Fig-4: Trend line showing gradual decrease in the area of dense mangrove area (Y-axis) in North East Region of STR over year of observation (X-axis) up to the year 2014

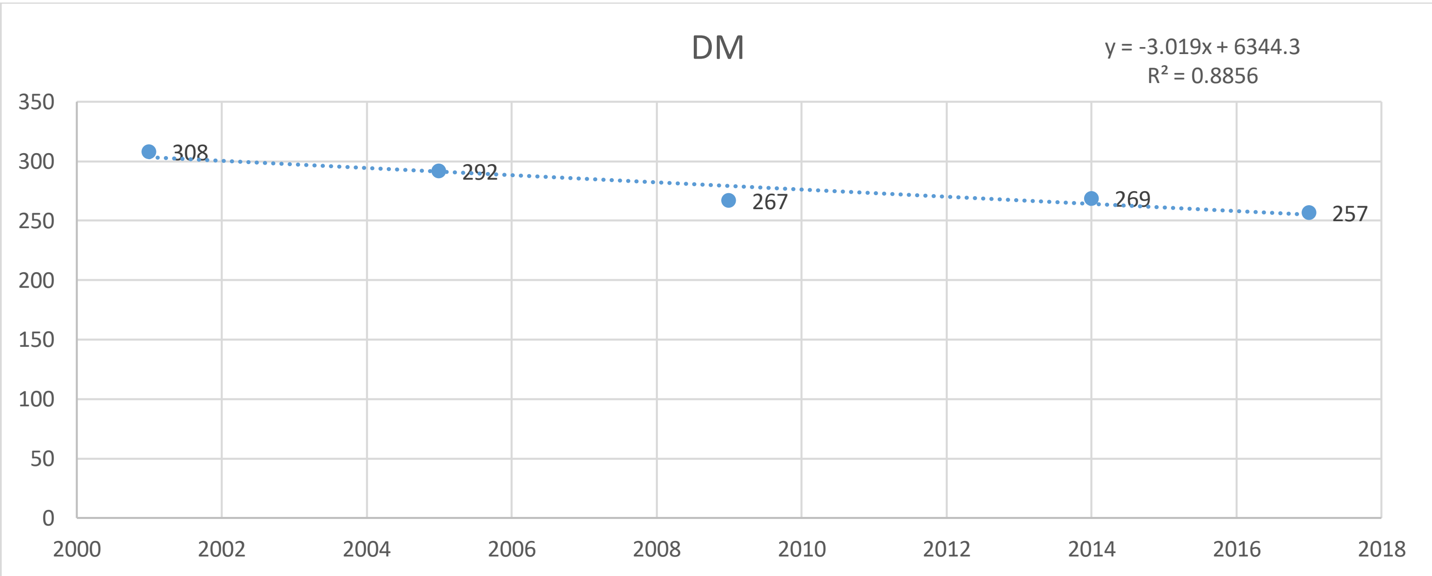


Fig-5: Trend line showing gradual decrease in the area of dense mangrove area (Y-axis) in North East Region of STR over year of observation (X-axis) up to the year 2017

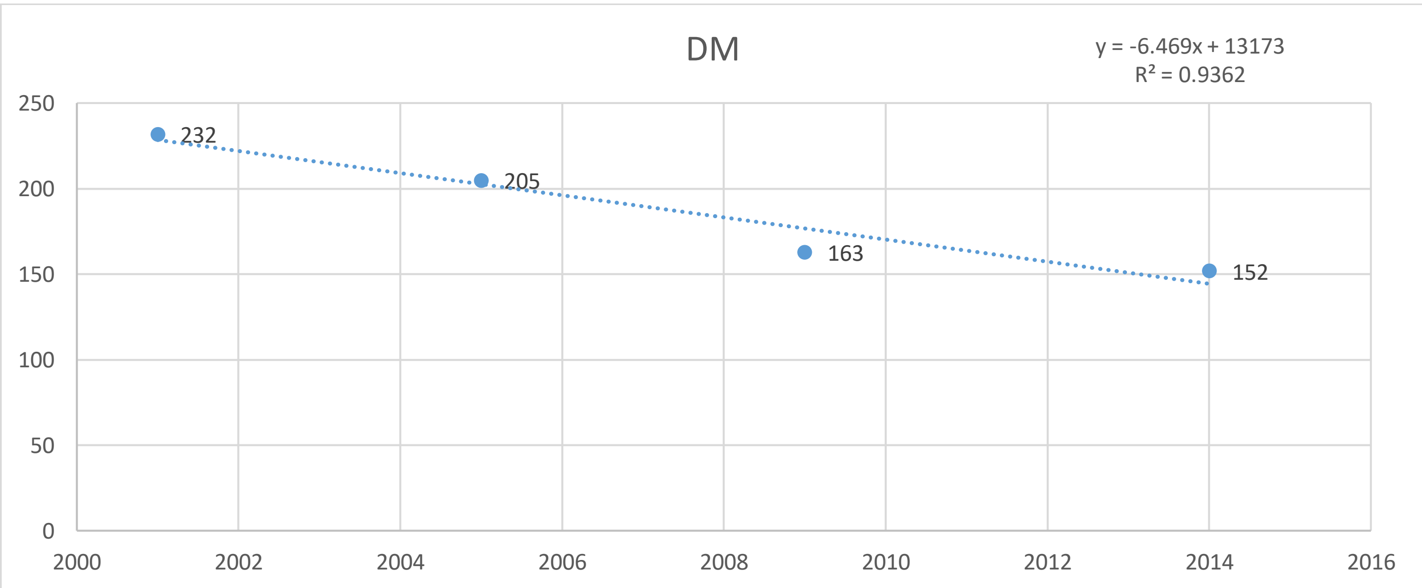


Fig-6: Trend line showing gradual decrease in the area of dense mangrove area (Y-axis) in North West Region of STR over year of observation (X-axis) up to the year 2014

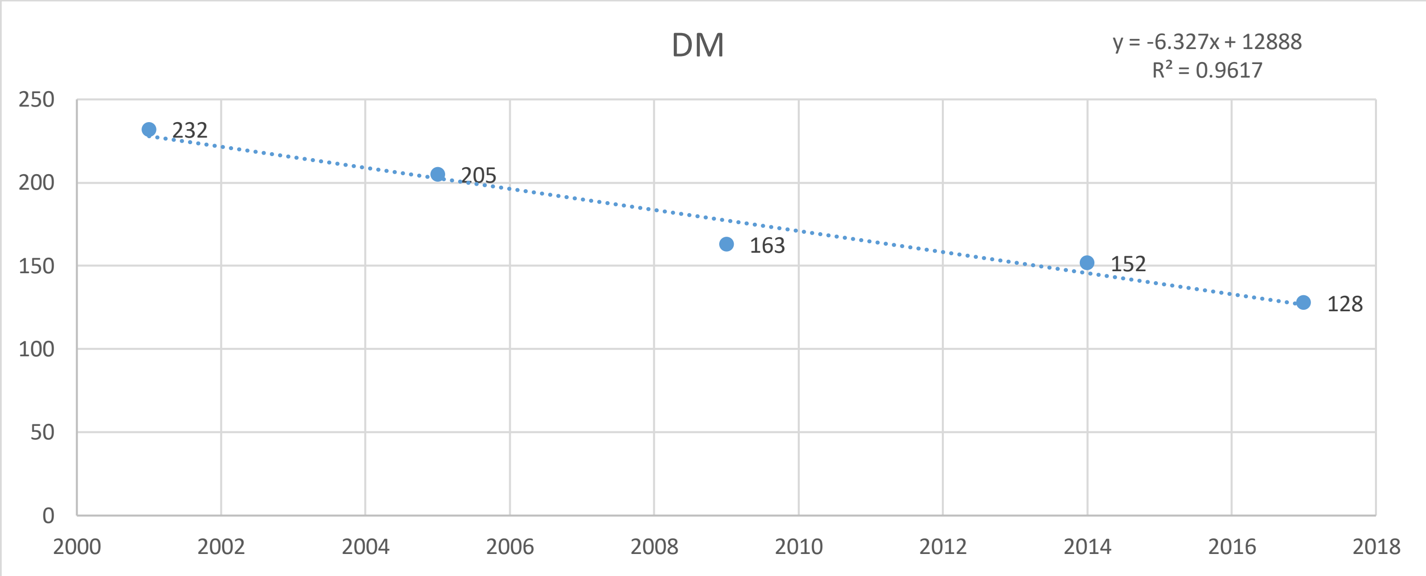


Fig-7: Trend line showing gradual decrease in the area of dense mangrove area (Y-axis) in North West Region of STR over year of observation (X-axis) up to the year 2017

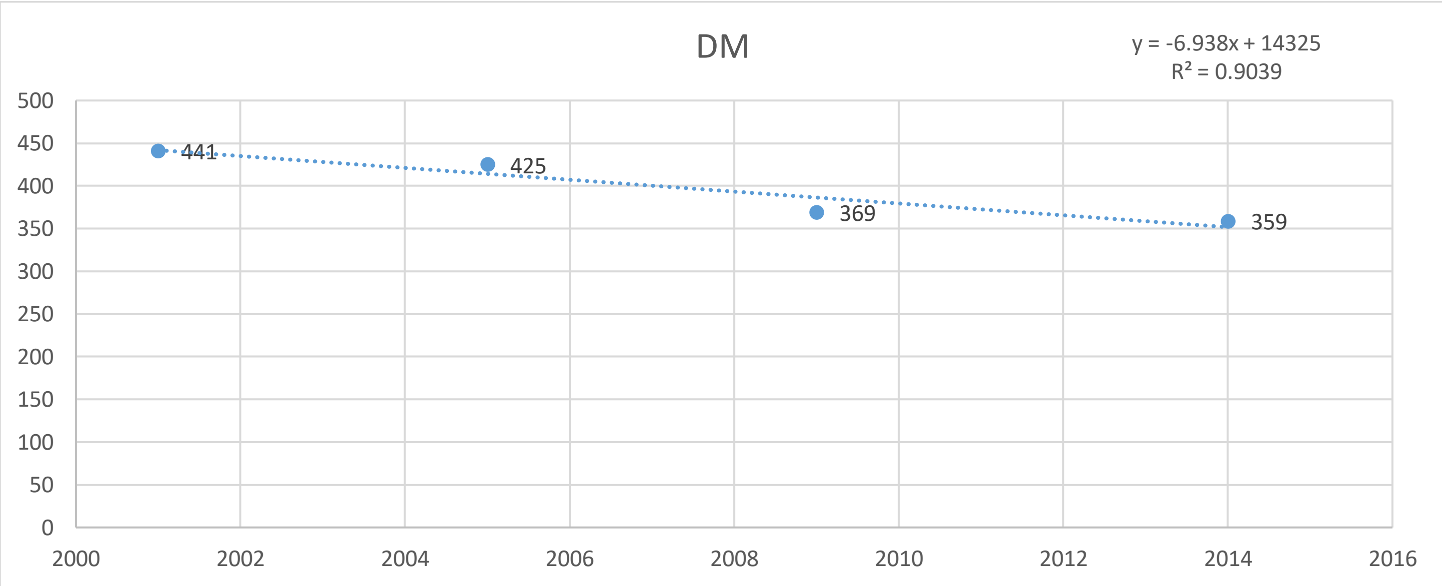


Fig-8: Trend line showing gradual decrease in the area of dense mangrove area (Y-axis) in Central East Region of STR over year of observation (X-axis) up to the year 2014

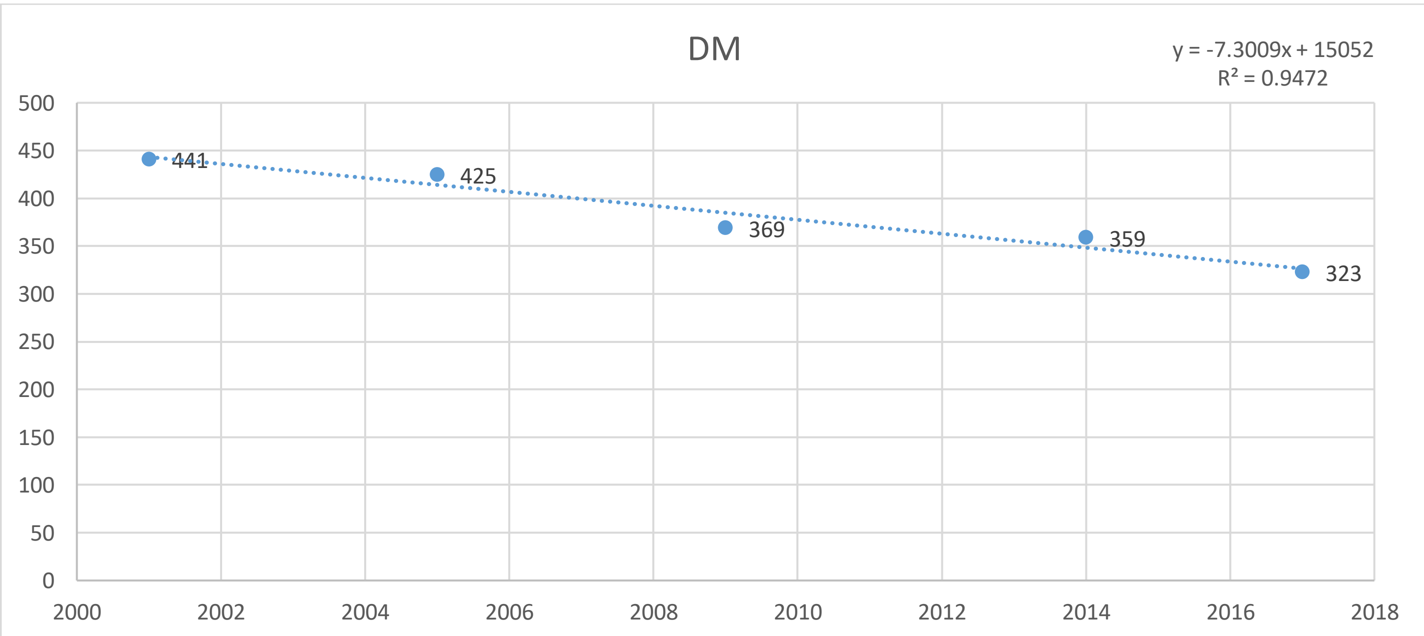


Fig-9: Trend line showing gradual decrease in the area of dense mangrove area (Y-axis) in Central East Region of STR over year of observation (X-axis) up to the year 2017

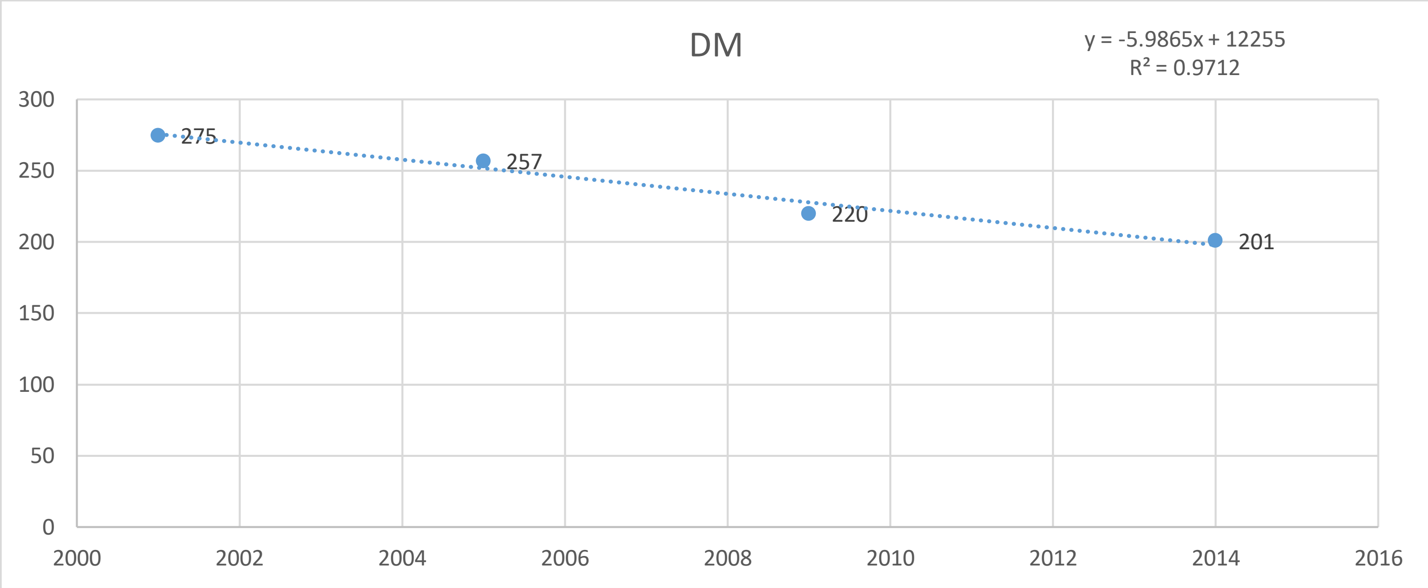


Fig-10: Trend line showing gradual decrease in the area of dense mangrove area (Y-axis) in Central West Region of STR over year of observation (X-axis) up to the year 2014

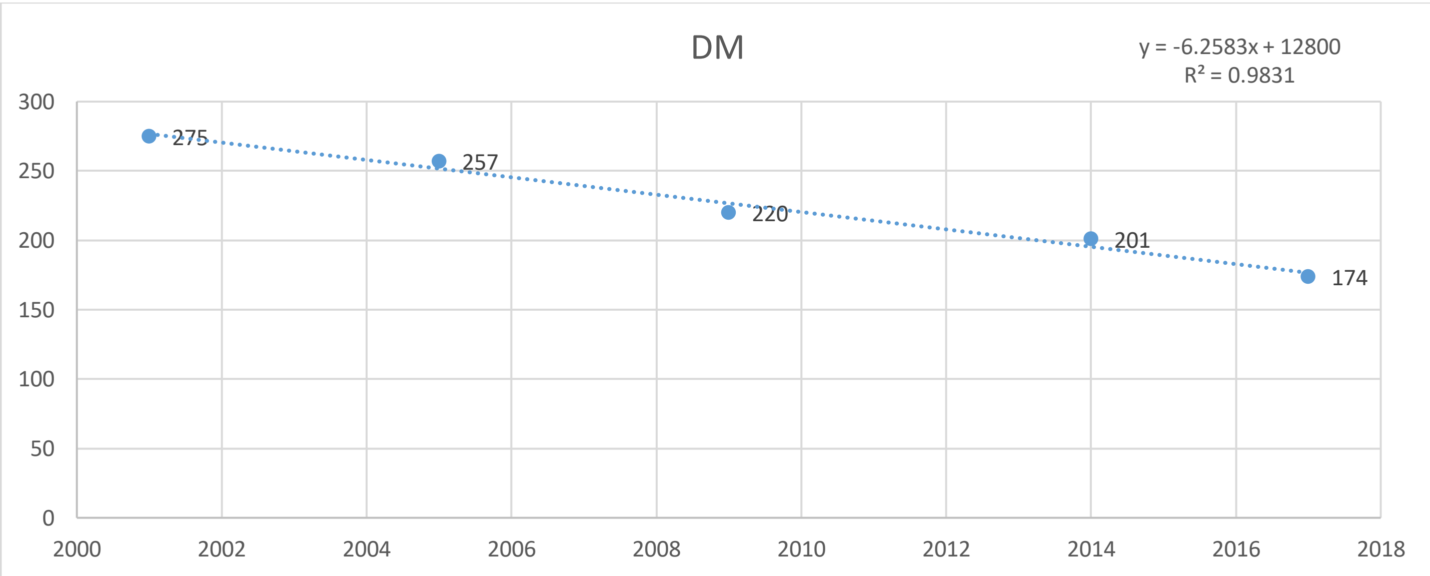


Fig-11: Trend line showing gradual decrease in the area of dense mangrove area (Y-axis) in Central West Region of STR over year of observation (X-axis) up to the year 2017

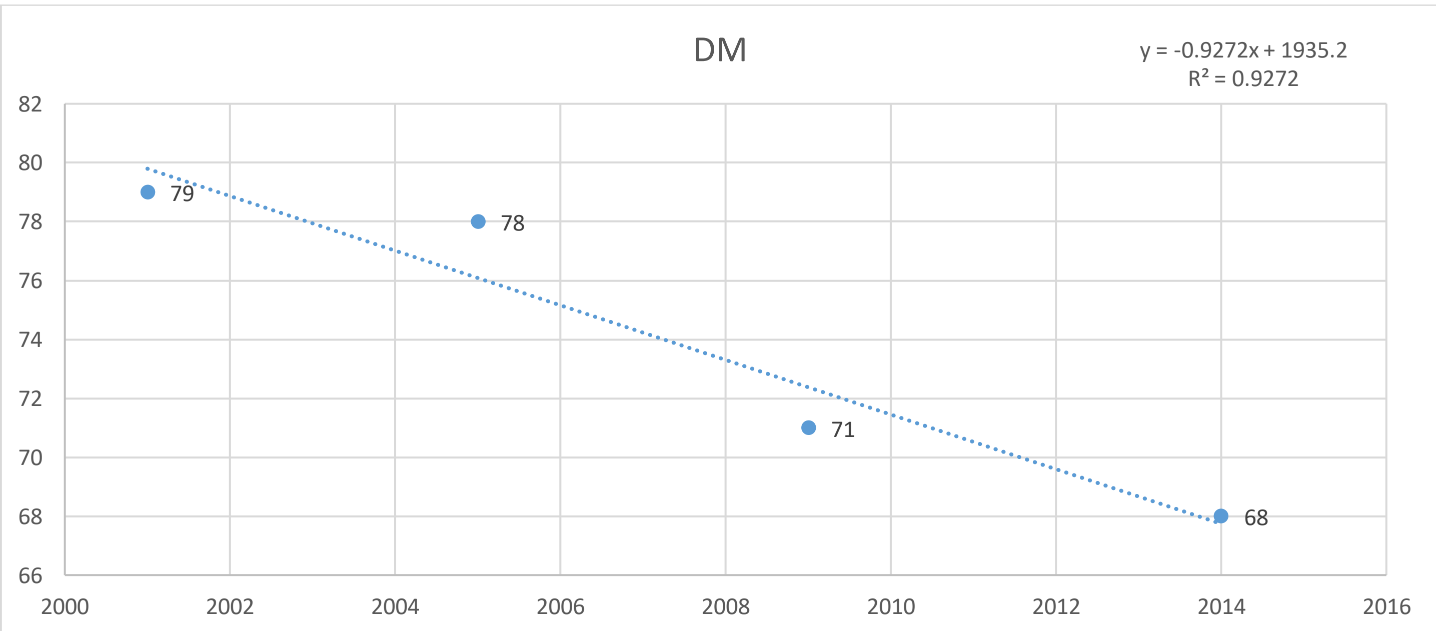


Fig-12: Trend line showing gradual decrease in the area of dense mangrove area (Y-axis) in South Region of STR over year of observation (X-axis) up to the year 2014

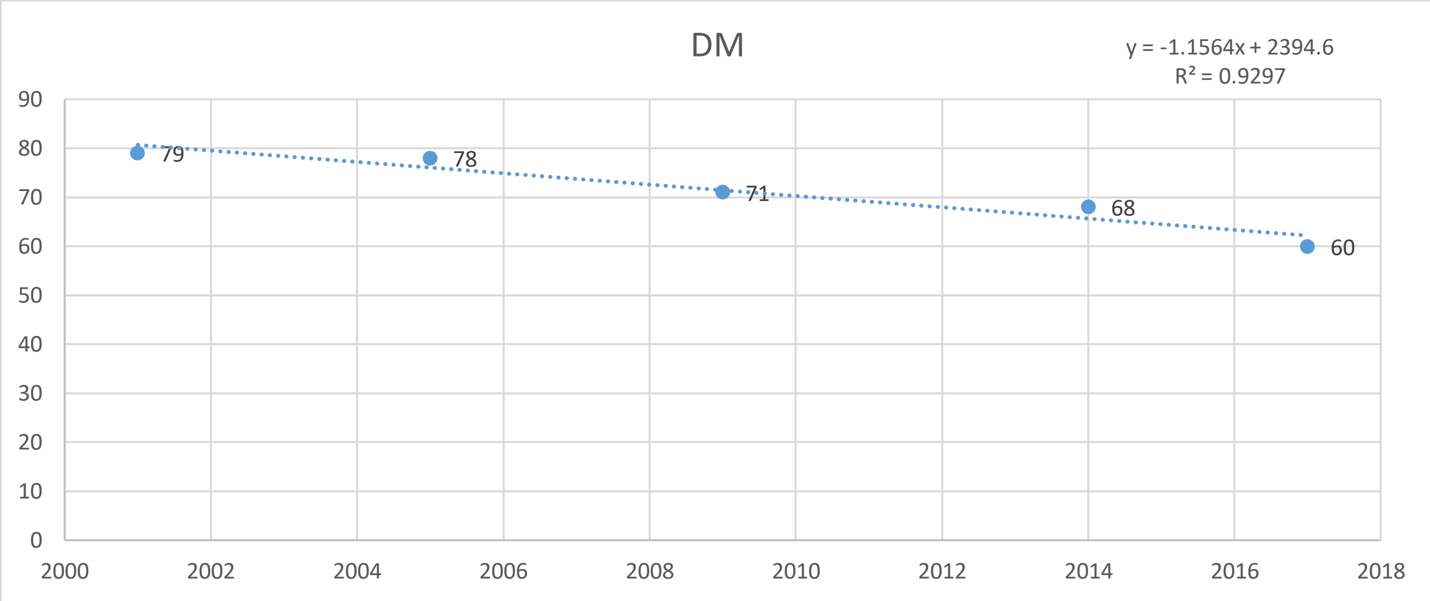


Fig-13: Trend line showing gradual decrease in the area of dense mangrove area (Y-axis) in South Region of STR over year of observation (X-axis) up to the year 2017

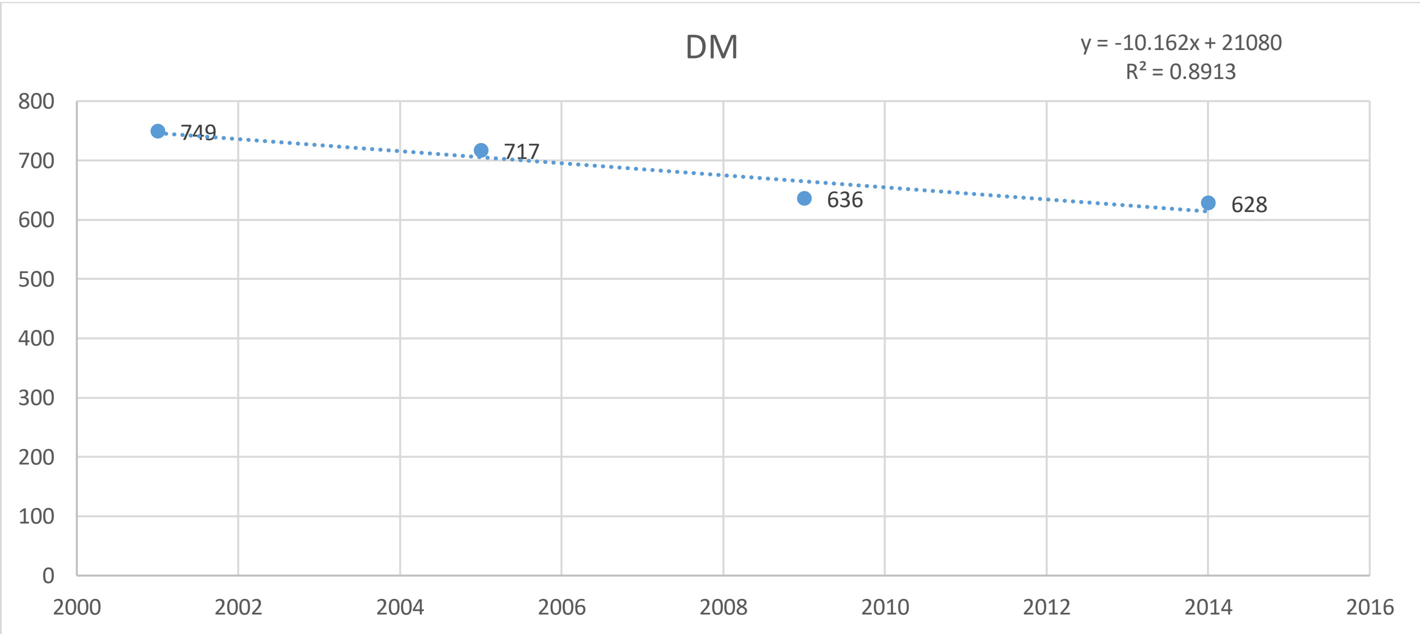


Fig-14: Trend line showing gradual decrease in the area of dense mangrove area (Y-axis) in East Region of STR over year of observation (X-axis) up to the year 2014

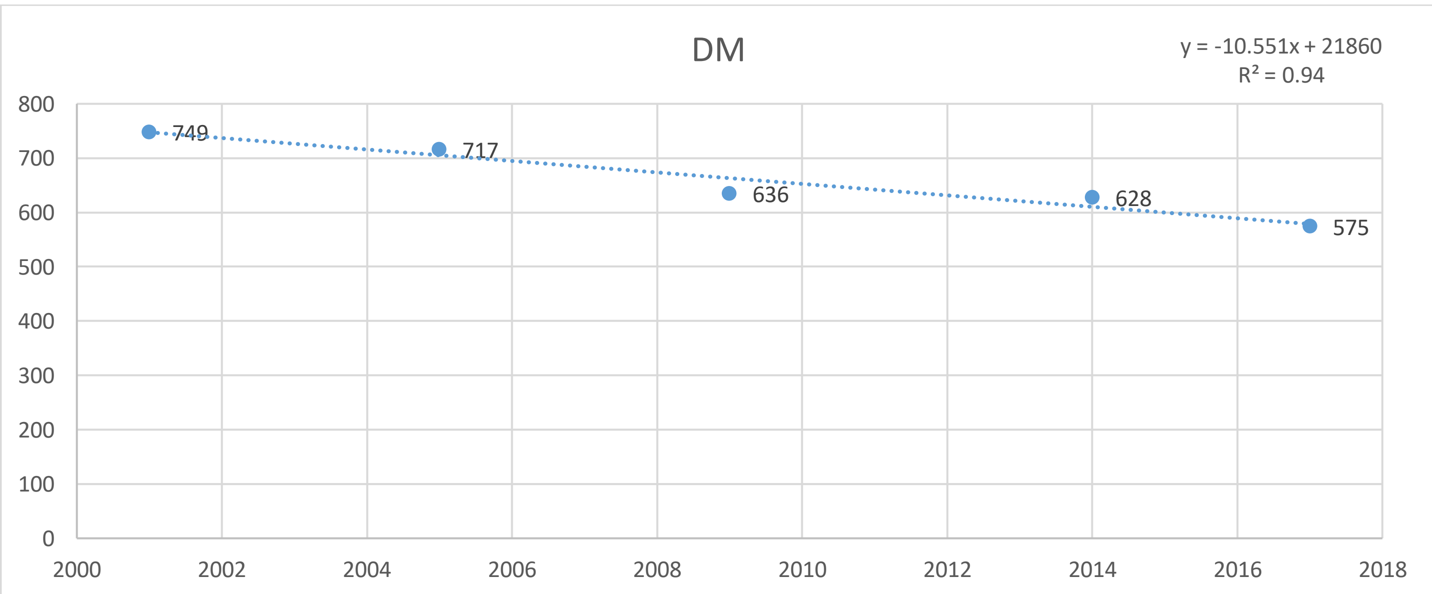


Fig-15: Trend line showing gradual decrease in the area of dense mangrove area (Y-axis) in East Region of STR over year of observation (X-axis) up to the year 2017

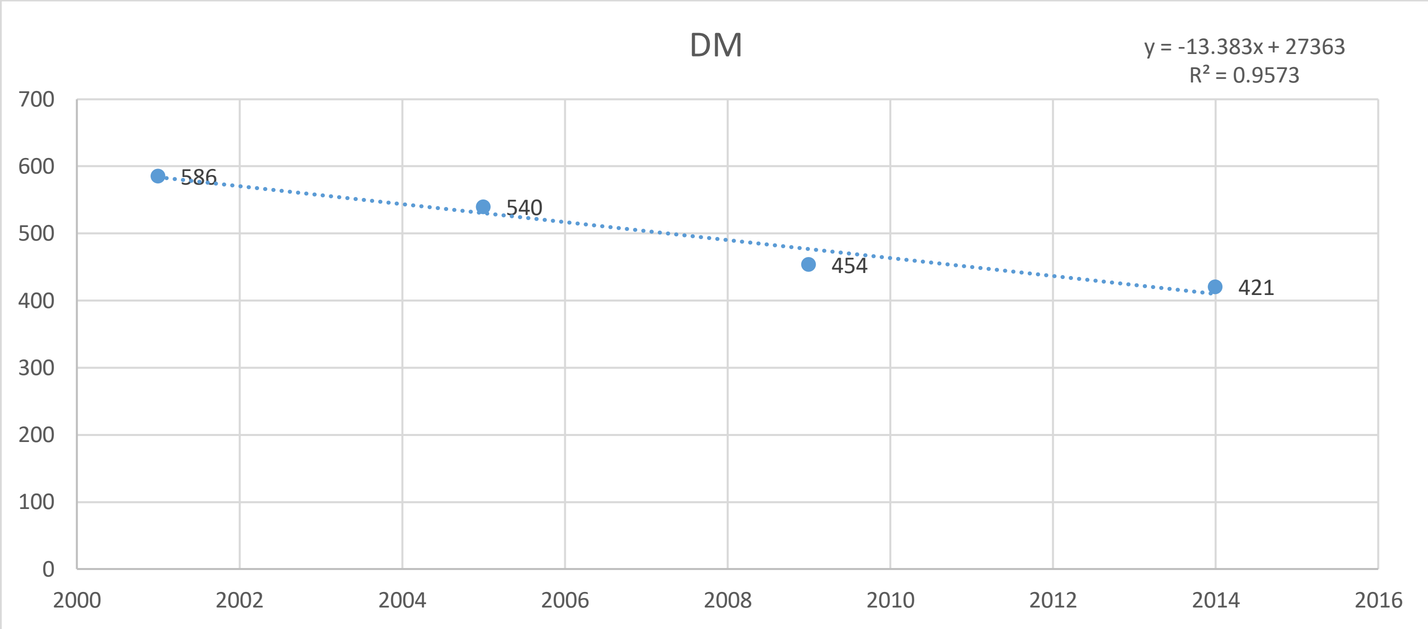


Fig-16: Trend line showing gradual decrease in the area of dense mangrove area (Y-axis) in West Region of STR over year of observation (X-axis) up to the year 2014

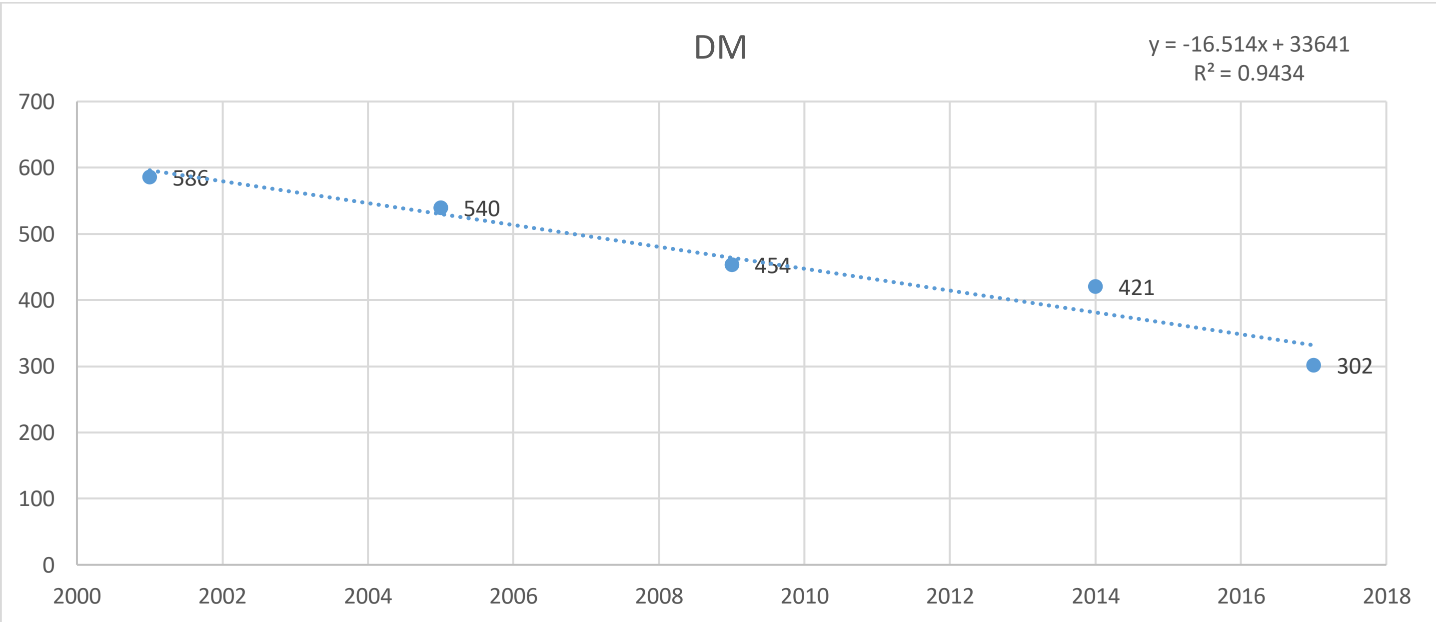


Fig-17: Trend line showing gradual decrease in the area of dense mangrove area (Y-axis) in West Region of STR over year of observation (X-axis) up to the year 2017

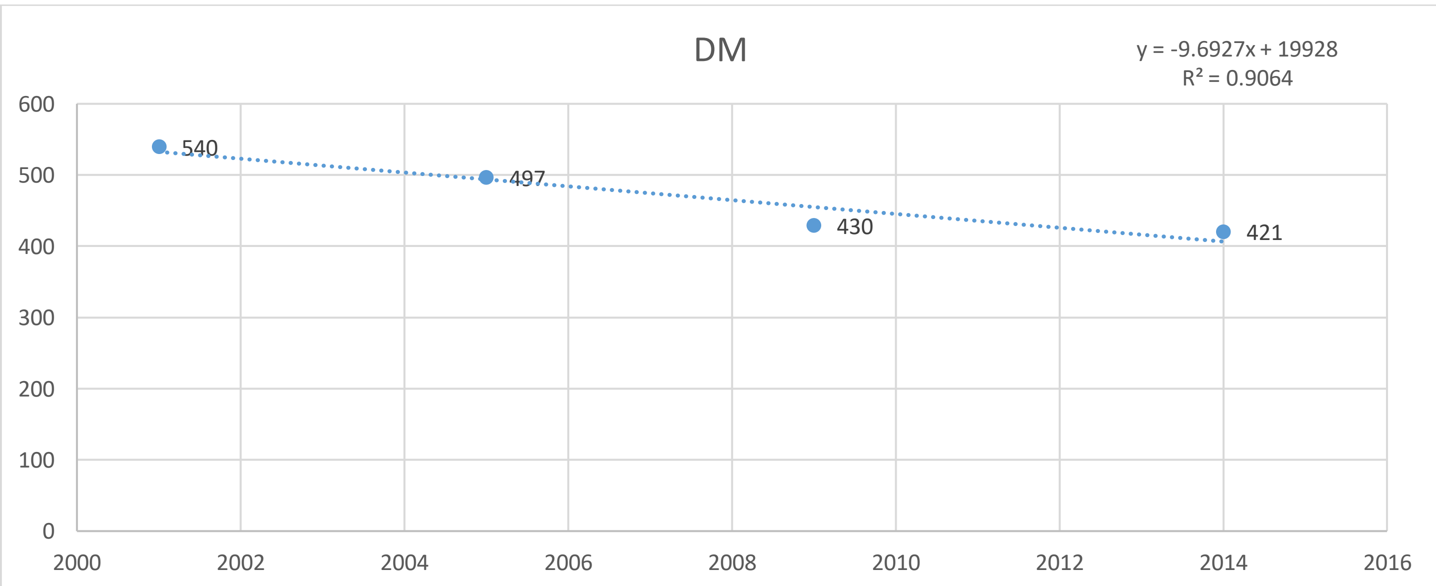


Fig-18: Trend line showing gradual decrease in the area of dense mangrove area (Y-axis) in North Region of STR over year of observation (X-axis) up to the year 2014

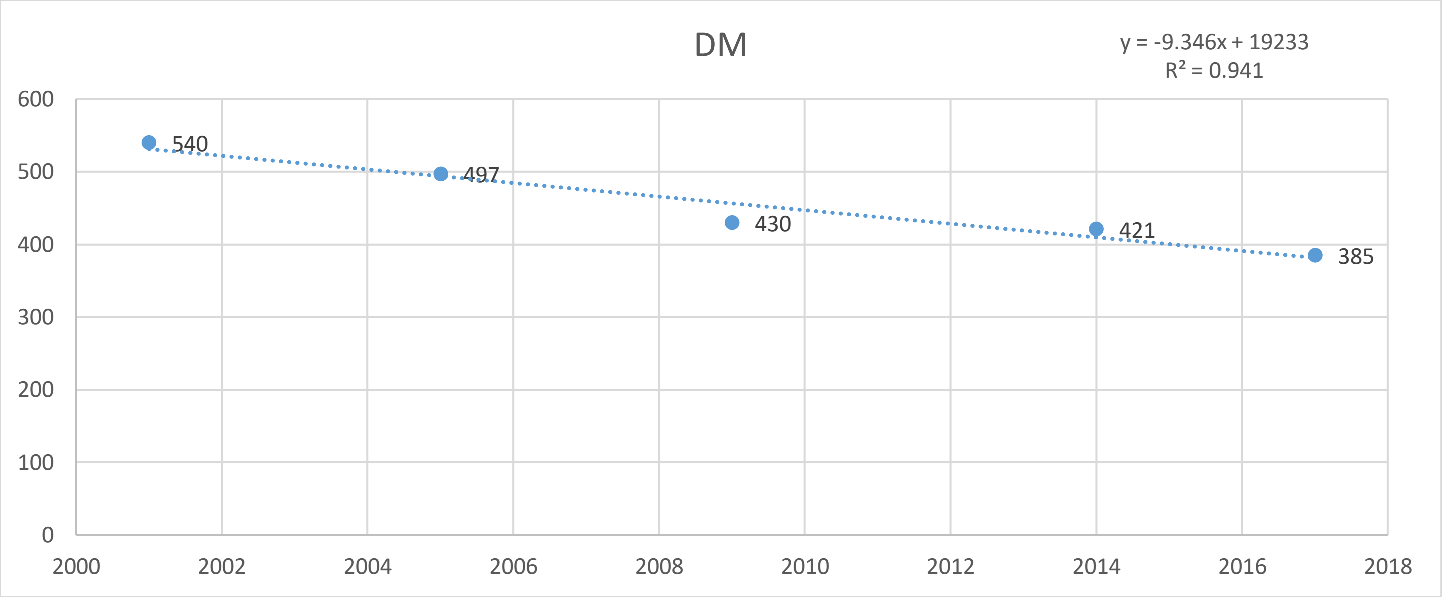


Fig-19: Trend line showing gradual decrease in the area of dense mangrove area (Y-axis) in North Region of STR over year of observation (X-axis) up to the year 2017

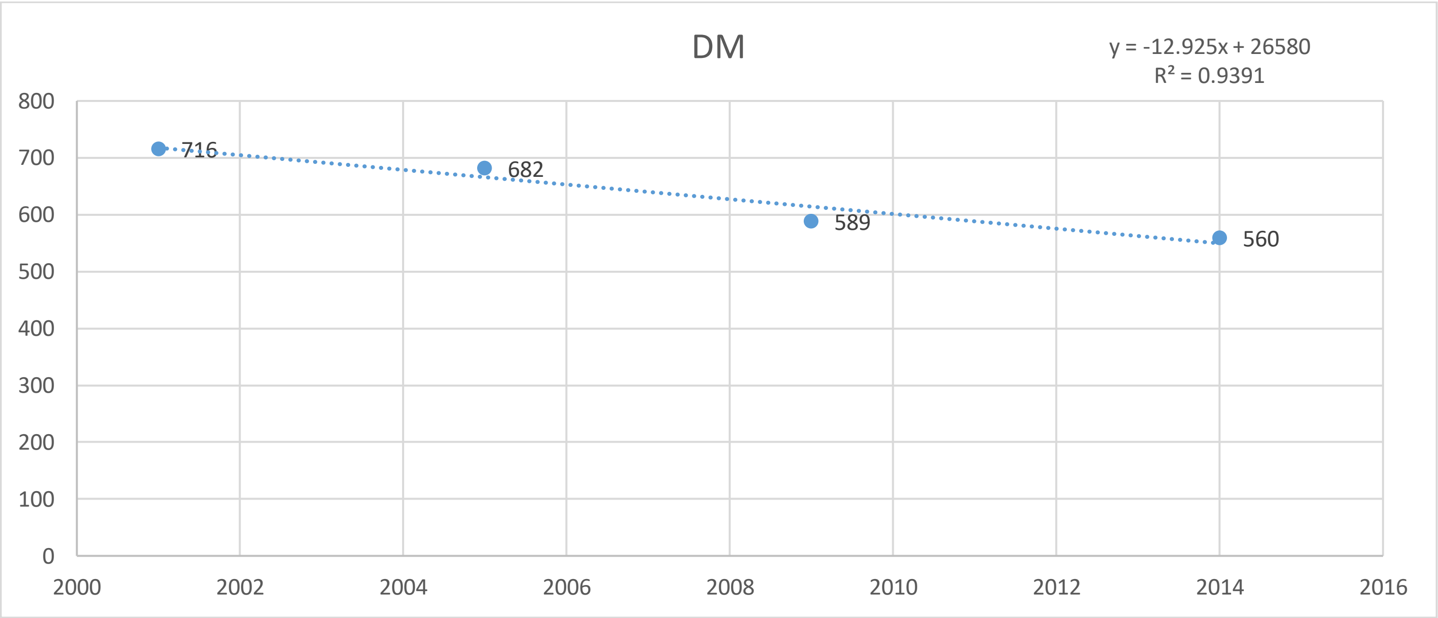


Fig-20: Trend line showing gradual decrease in the area of dense mangrove area (Y-axis) in Central Region of STR over year of observation (X-axis) up to the year 2014

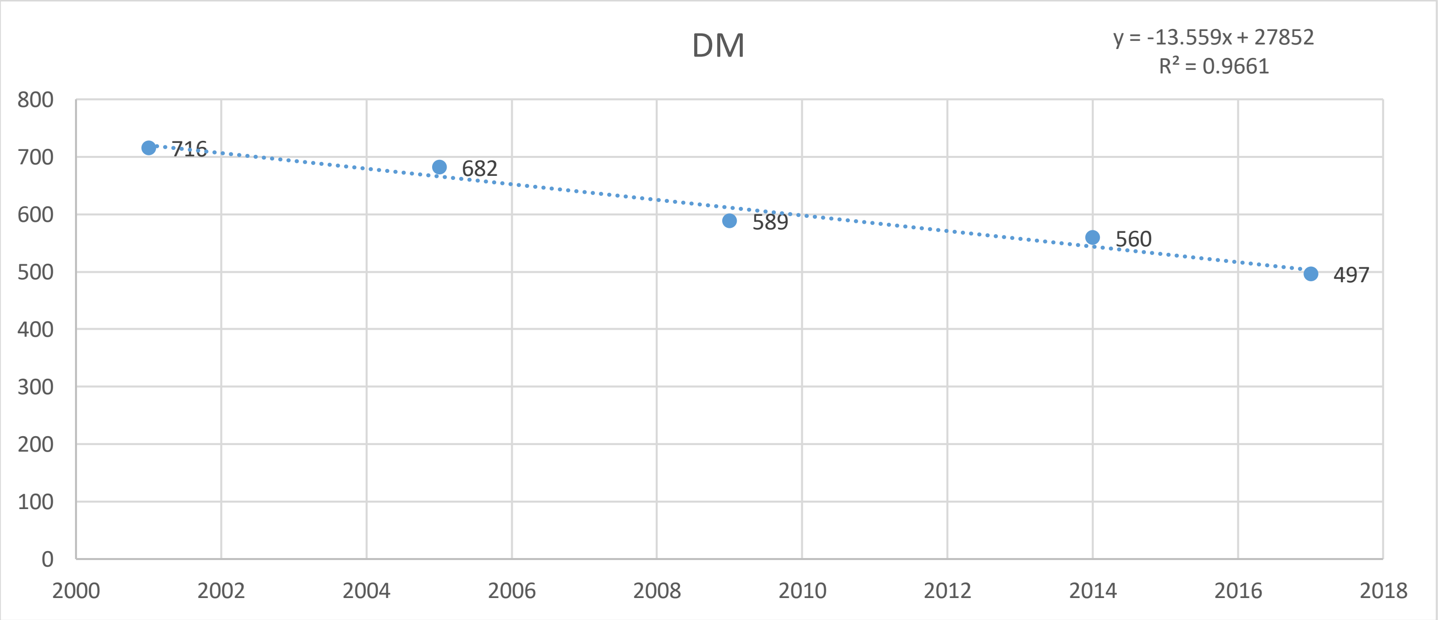


Fig-21: Trend line showing gradual decrease in the area of dense mangrove area (Y-axis) in Central Region of STR over year of observation (X-axis) up to the year 2017

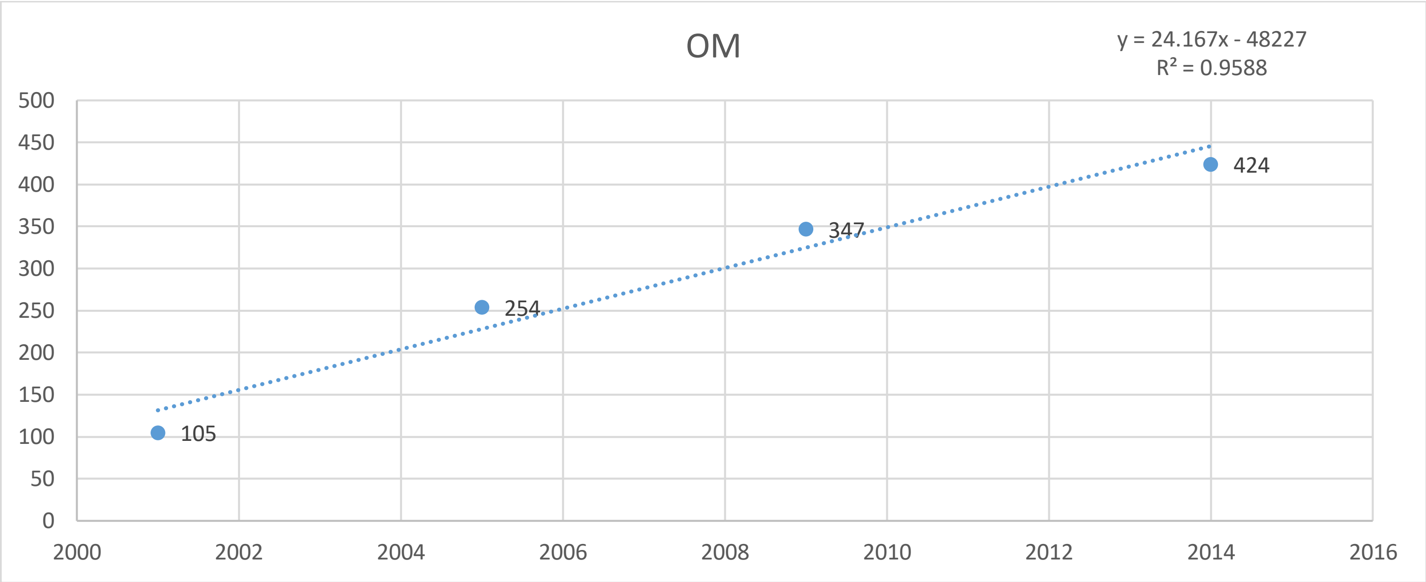


Fig-22: Correlation of Open Mangrove data with progressive year - STR Region
Trend line showing total Open Mangrove area of STR (Y-axis) against year of observation (X-axis) over the period 2001 – 2014

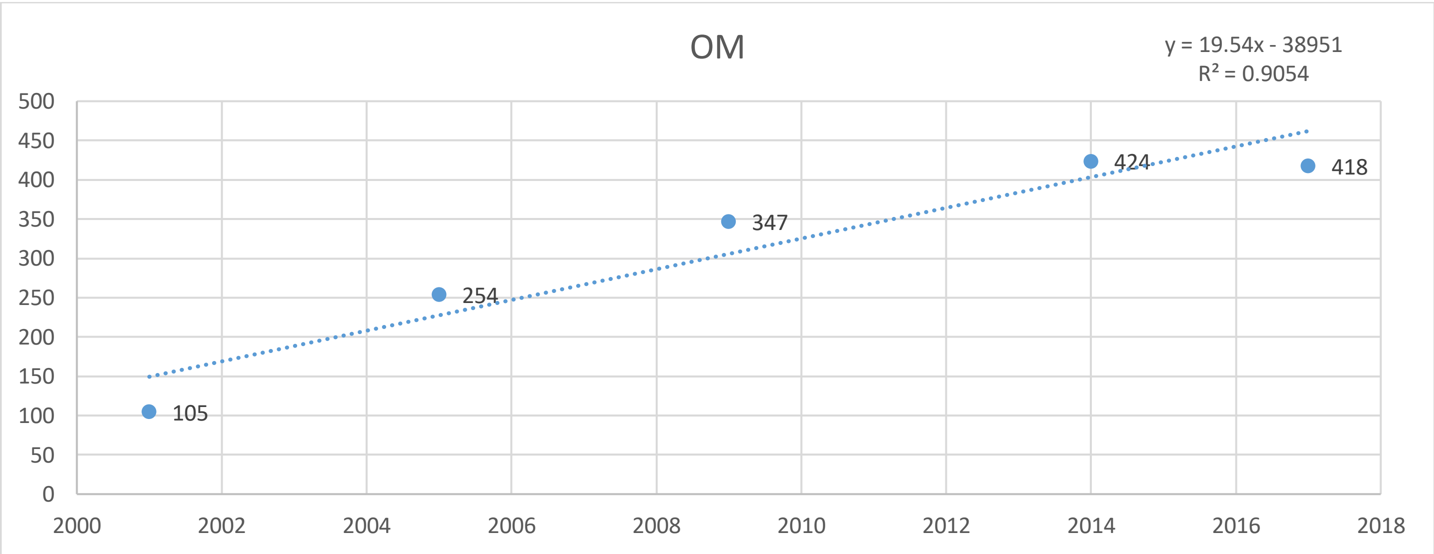


Fig-23: Correlation of Open Mangrove data with progressive year - STR Region
Trend line showing total Open Mangrove area of STR (Y-axis) against year of observation (X-axis) over the period 2001 – 2017

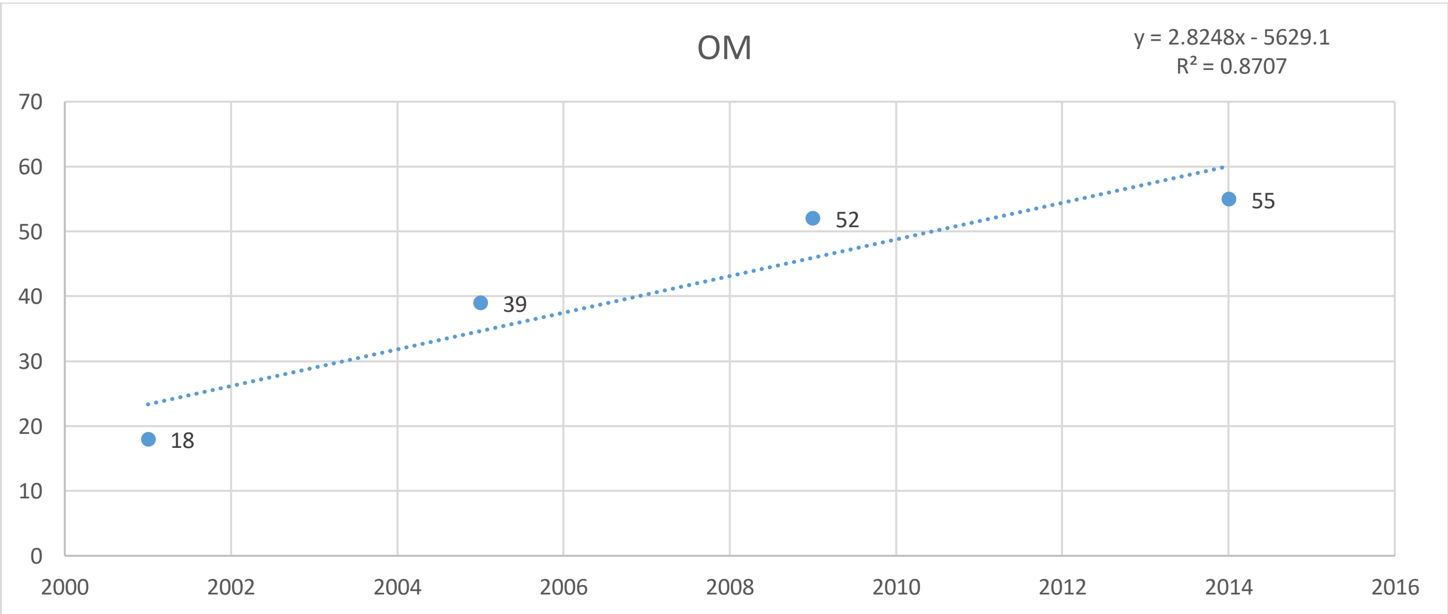


Fig-24: Trend line showing gradual increase in the area of Open mangrove area (Y-axis) in North East Region of STR over year of observation (X-axis) up to the year 2014

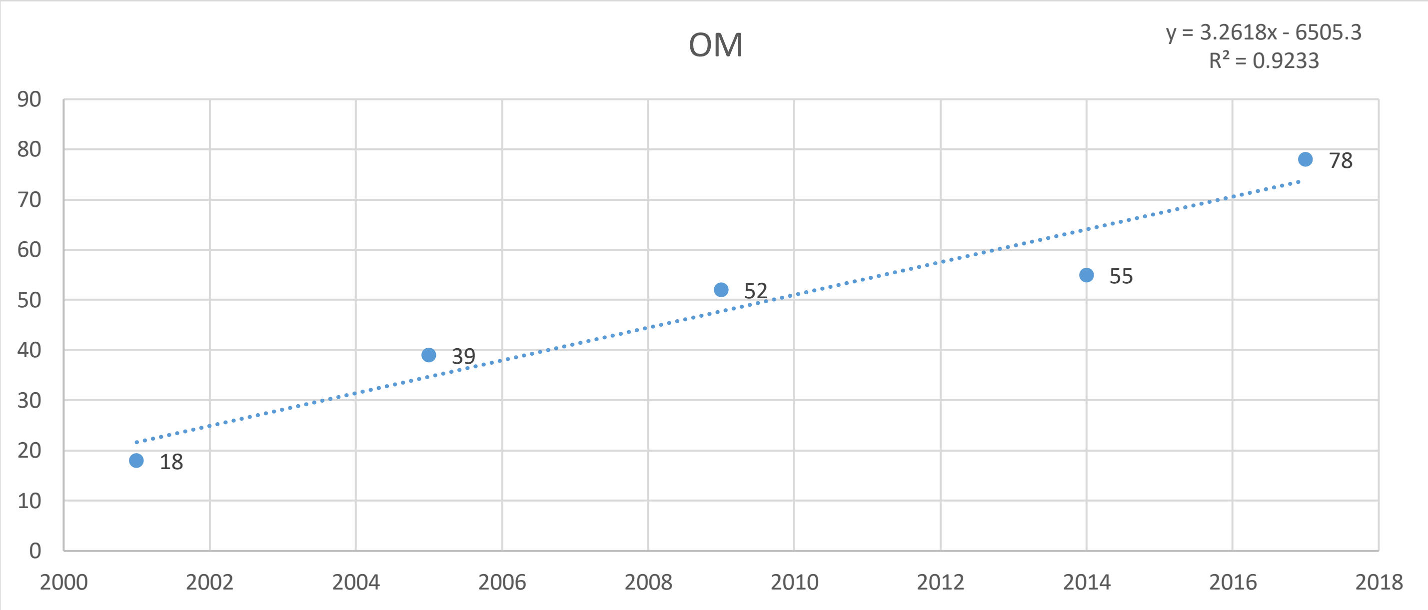


Fig-25: Trend line showing gradual increase in the area of Open mangrove area (Y-axis) in North East Region of STR over year of observation (X-axis) up to the year 2017

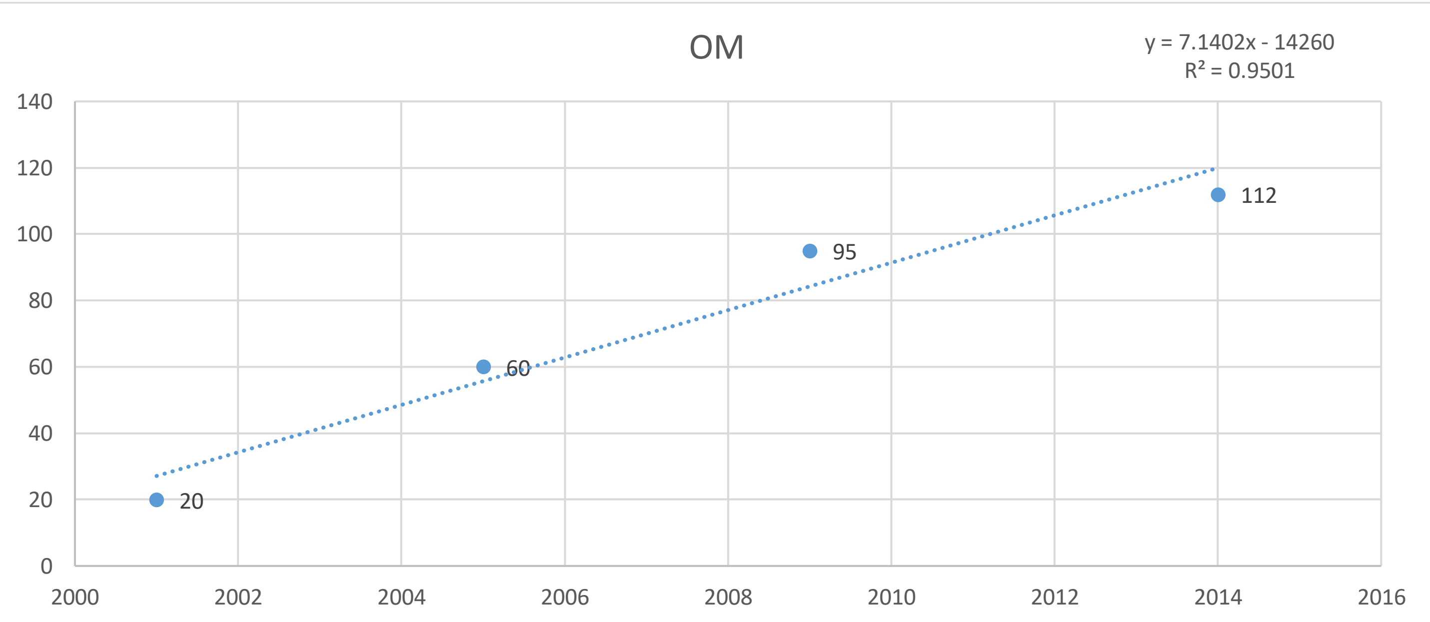


Fig-26: Trend line showing gradual increase in the area of Open mangrove area (Y-axis) in North West Region of STR over year of observation (X-axis) up to the year 2014

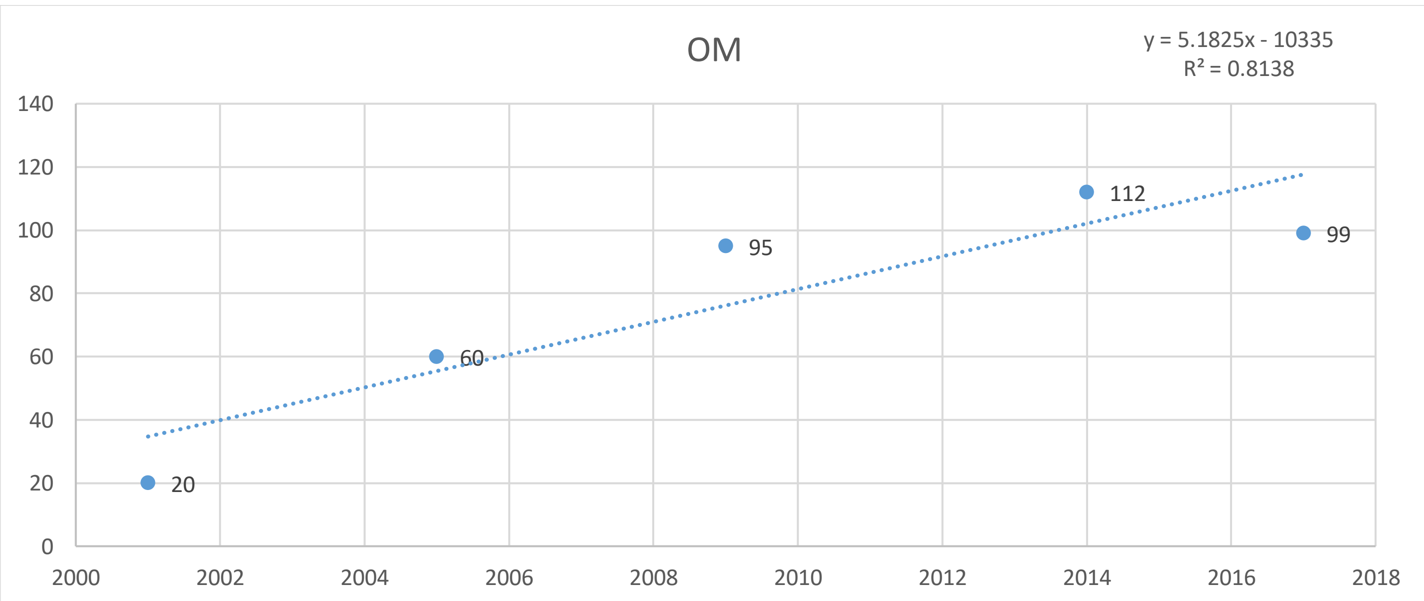


Fig-27: Trend line showing gradual increase in the area of Open mangrove area (Y-axis) in North West Region of STR over year of observation (X-axis) up to the year 2017

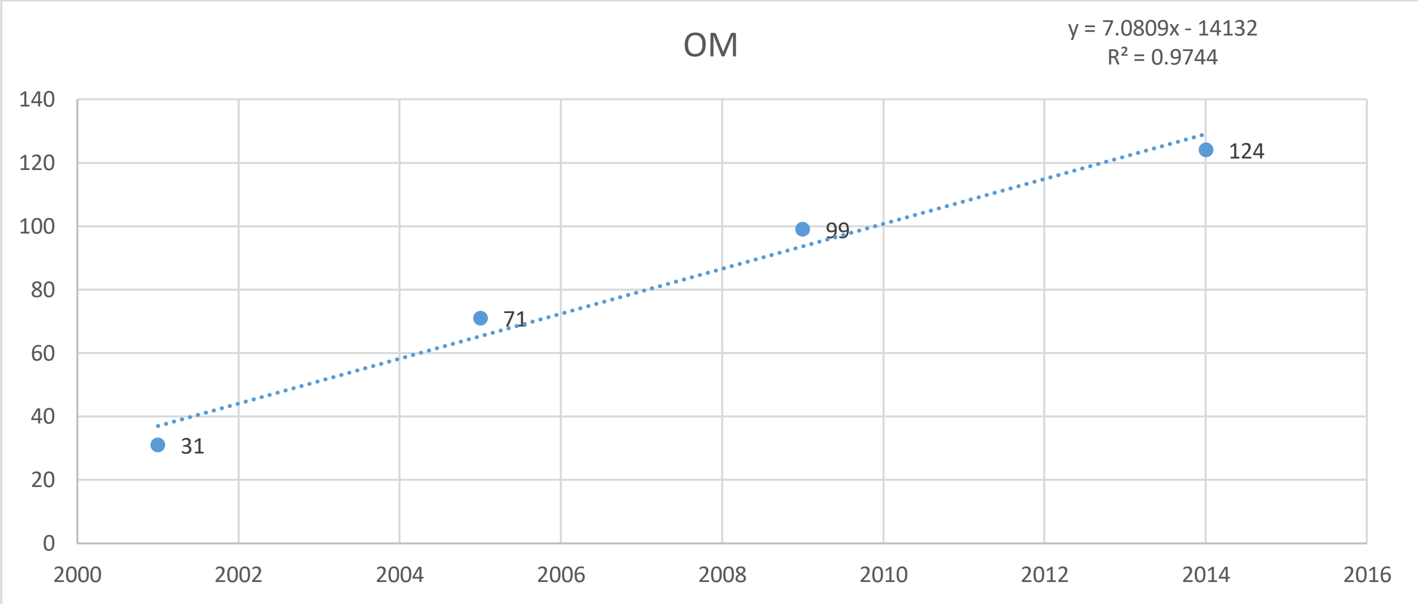


Fig-28: Trend line showing gradual increase in the area of Open mangrove area (Y-axis) in Central East Region of STR over year of observation (X-axis) up to the year 2014

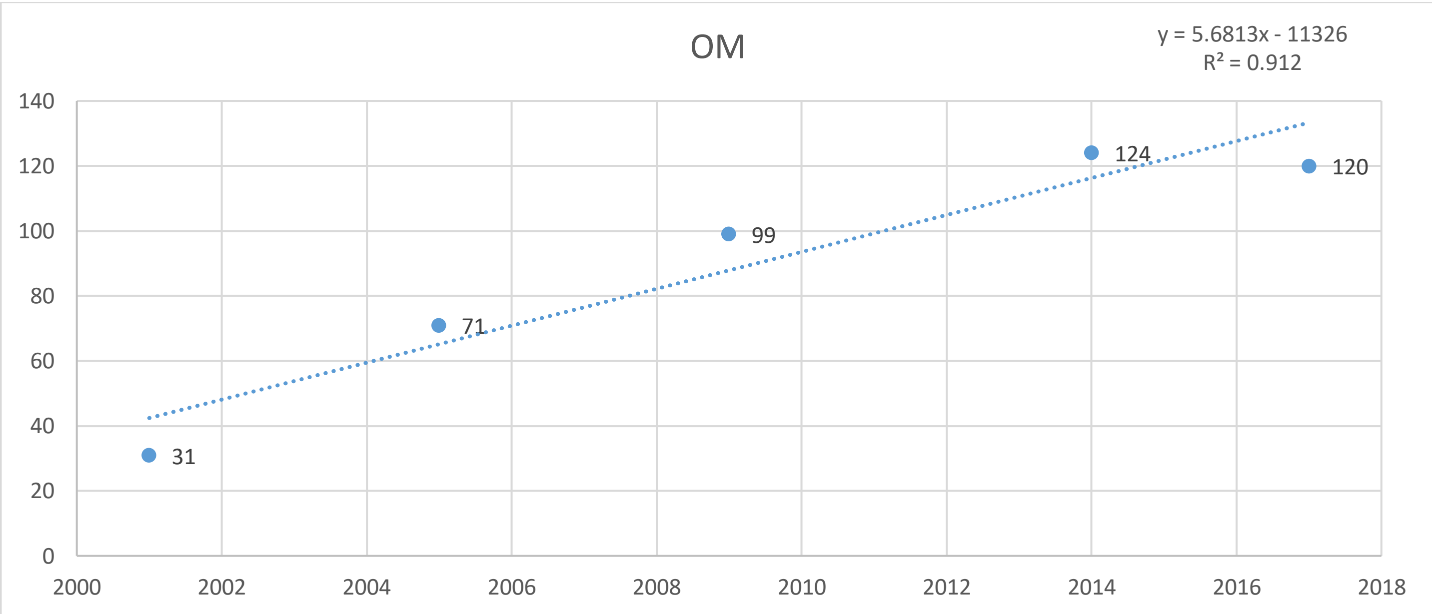


Fig-29: Trend line showing gradual increase in the area of Open mangrove area (Y-axis) in Central East Region of STR over year of observation (X-axis) up to the year 2017

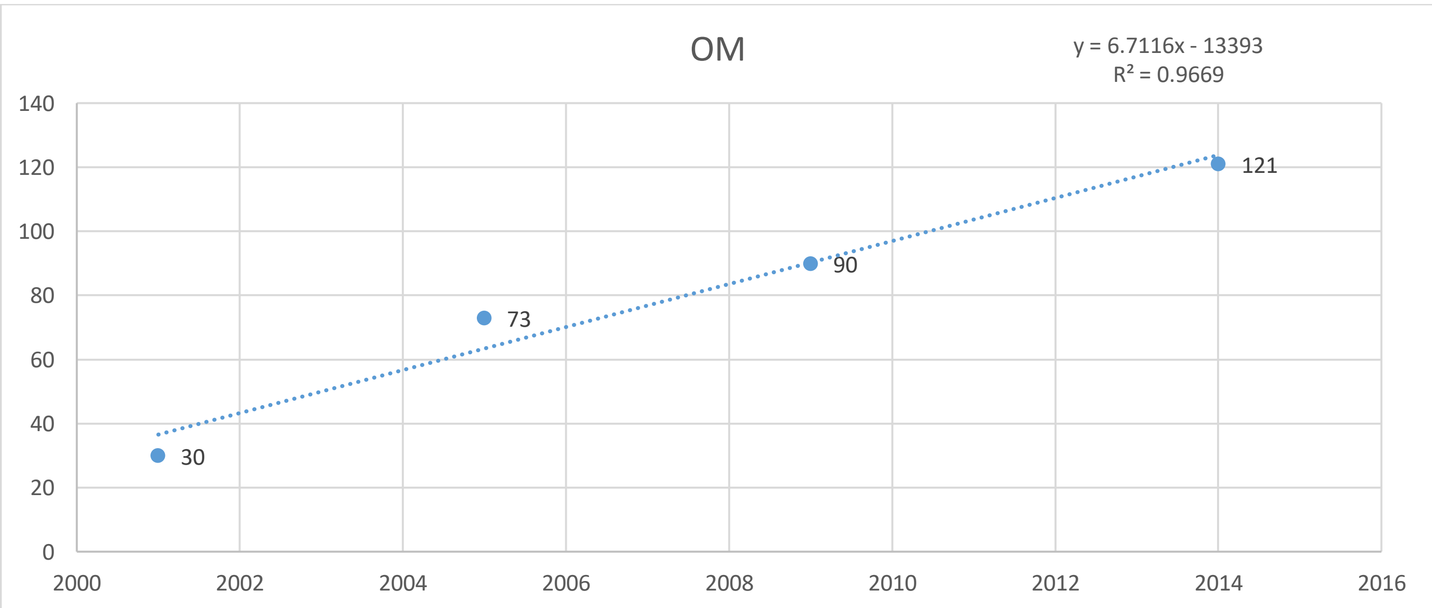


Fig-30: Trend line showing gradual increase in the area of Open mangrove area (Y-axis) in Central West Region of STR over year of observation (X-axis) up to the year 2014

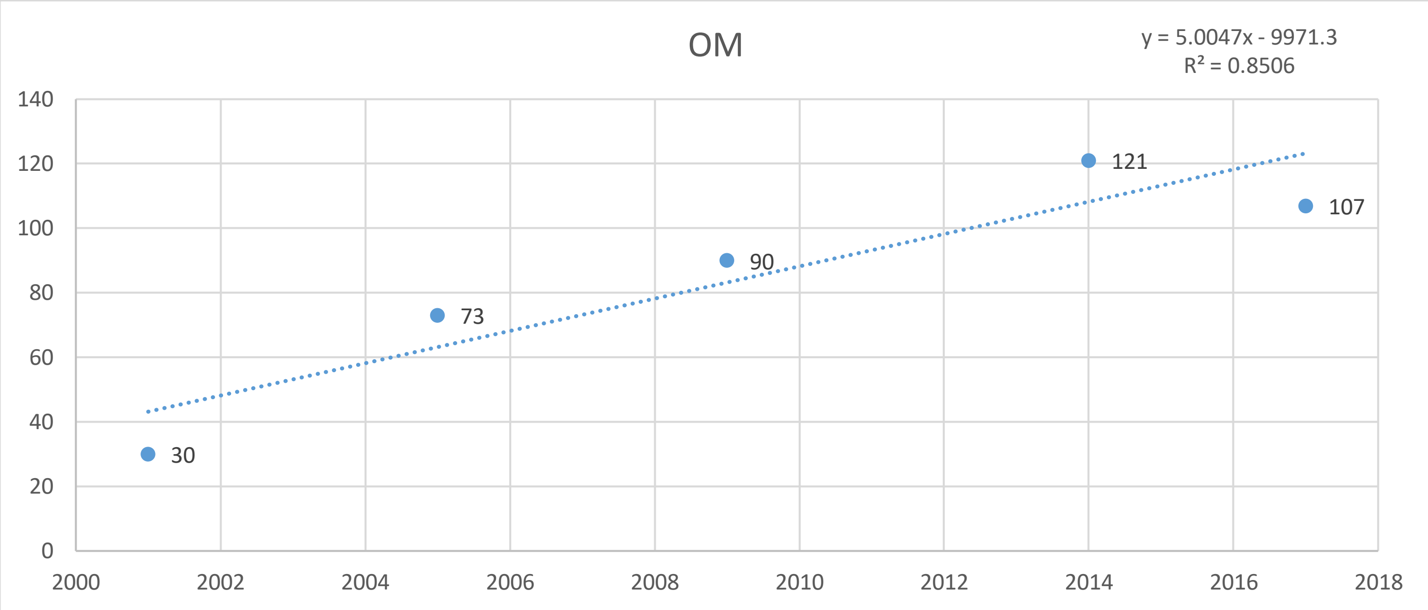


Fig-31: Trend line showing gradual increase in the area of Open mangrove area (Y-axis) in Central West Region of STR over year of observation (X-axis) up to the year 2017

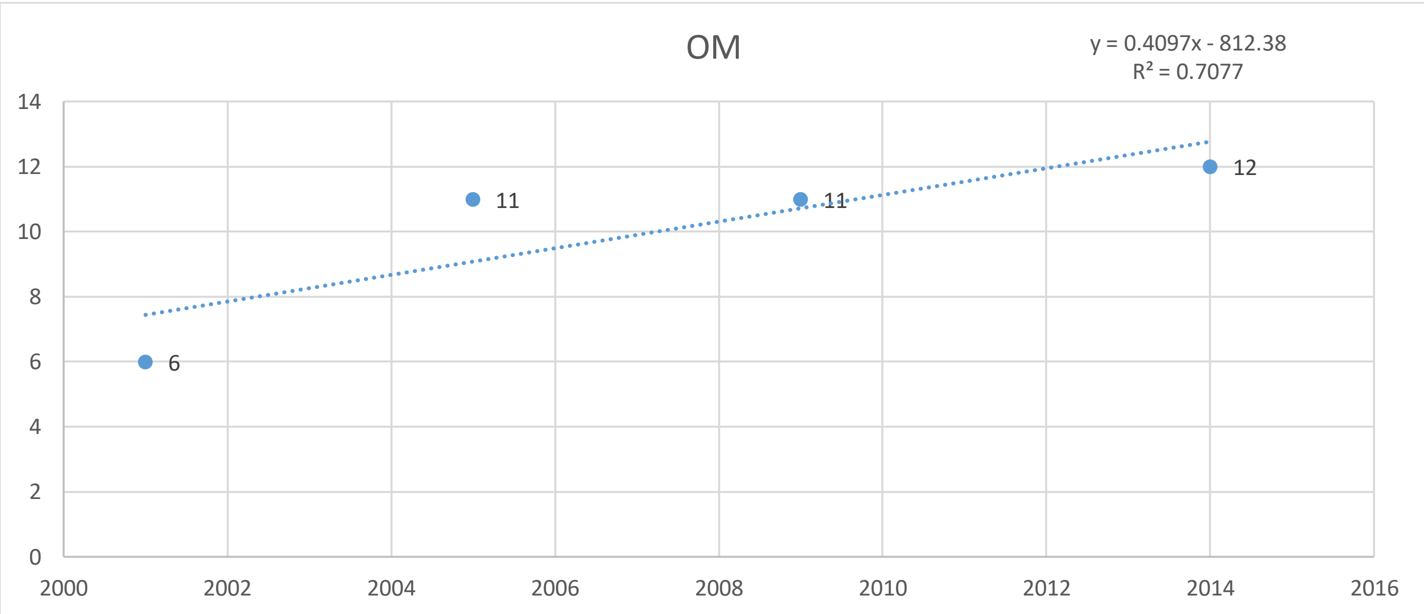


Fig-32: Trend line showing gradual increase in the area of Open mangrove area (Y-axis) in South Region of STR over year of observation (X-axis) up to the year 2014

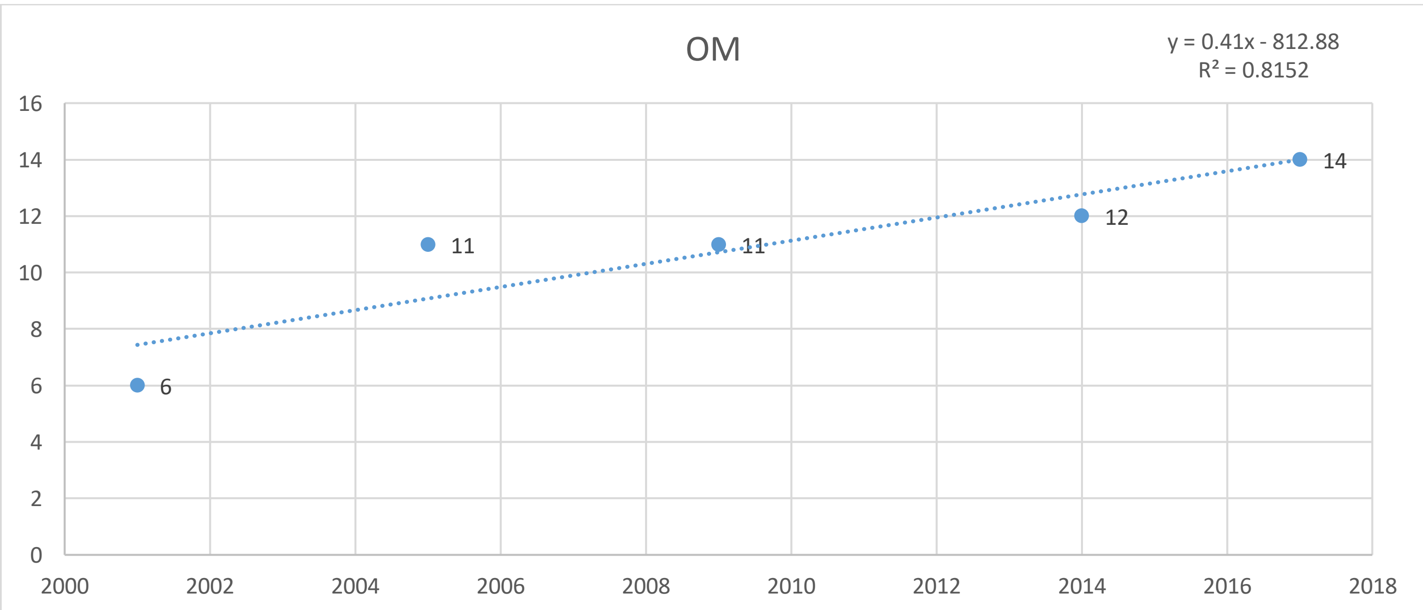


Fig-33: Trend line showing gradual increase in the area of Open mangrove area (Y-axis) in South Region of STR over year of observation (X-axis) up to the year 2017

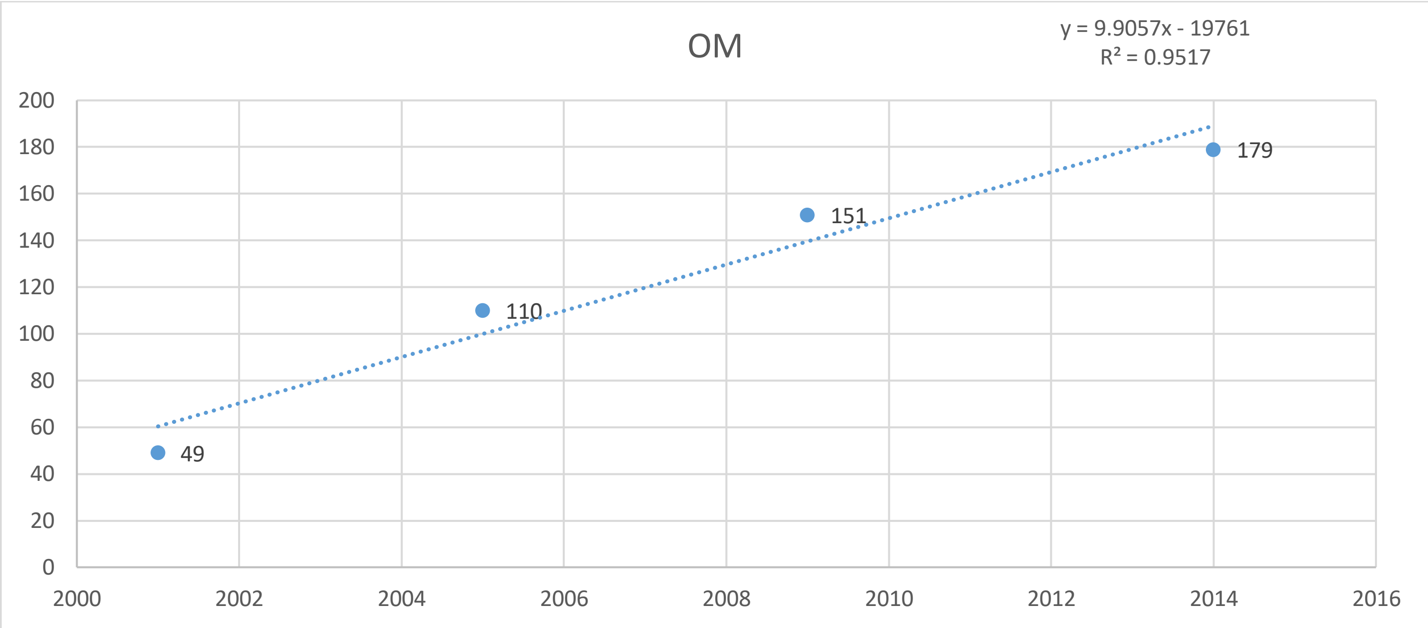


Fig-34: Trend line showing gradual increase in the area of Open mangrove area (Y-axis) in East Region of STR over year of observation (X-axis) up to the year 2014

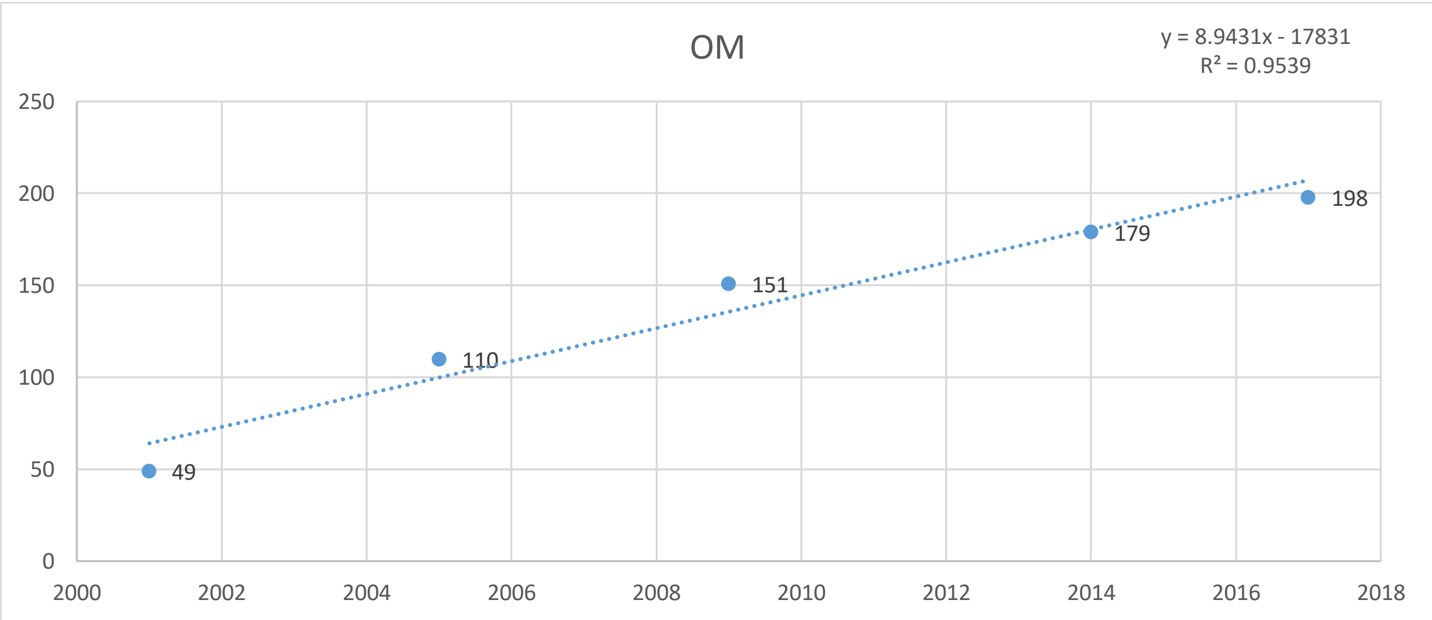


Fig-35: Trend line showing gradual increase in the area of Open mangrove area (Y-axis) in East Region of STR over year of observation (X-axis) up to the year 2017

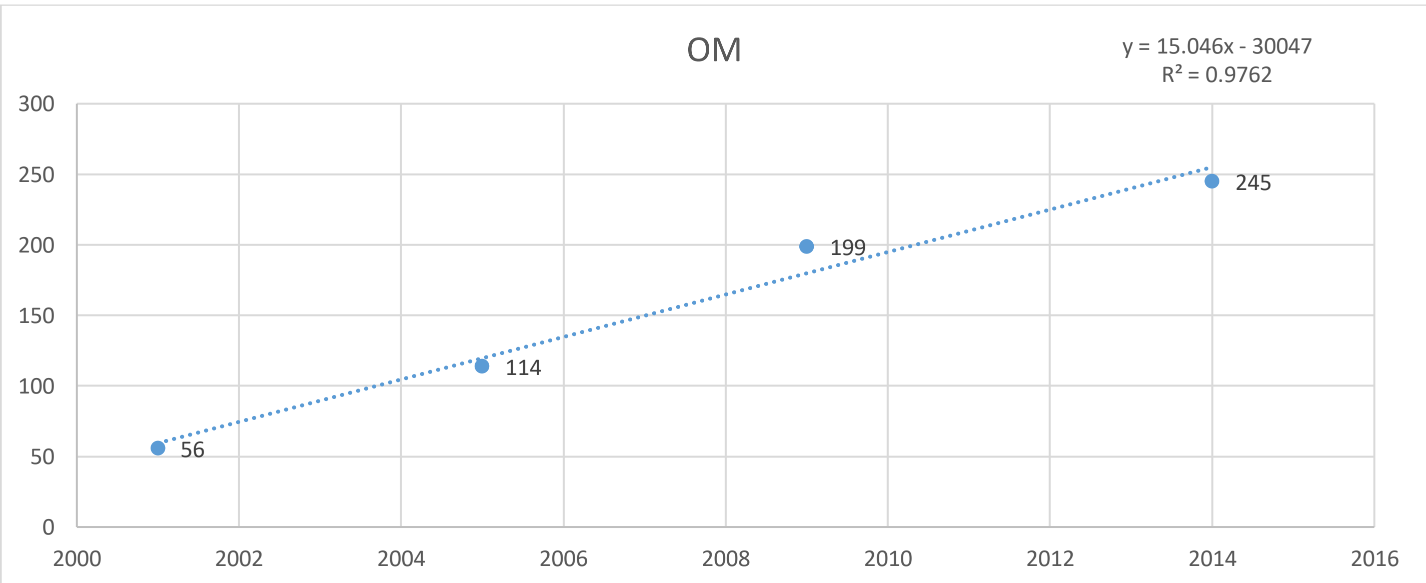


Fig-36: Trend line showing gradual increase in the area of Open mangrove area (Y-axis) in West Region of STR over year of observation (X-axis) up to the year 2014

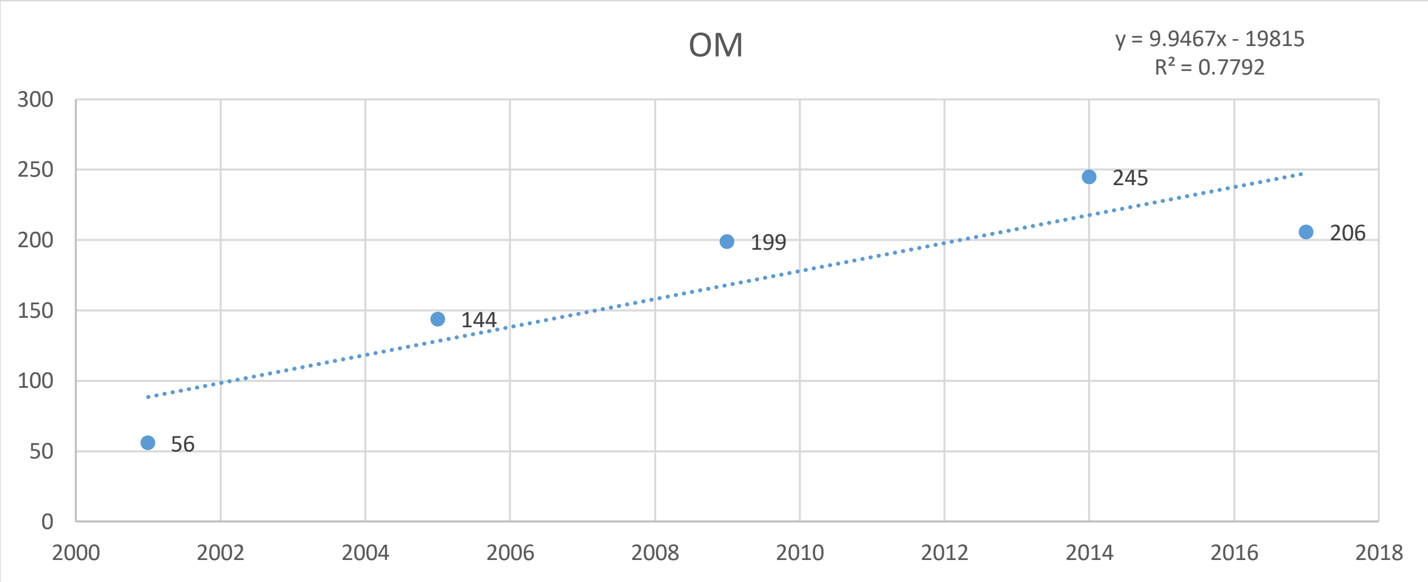


Fig-37: Trend line showing gradual increase in the area of Open mangrove area (Y-axis) in West Region of STR over year of observation (X-axis) up to the year 2017

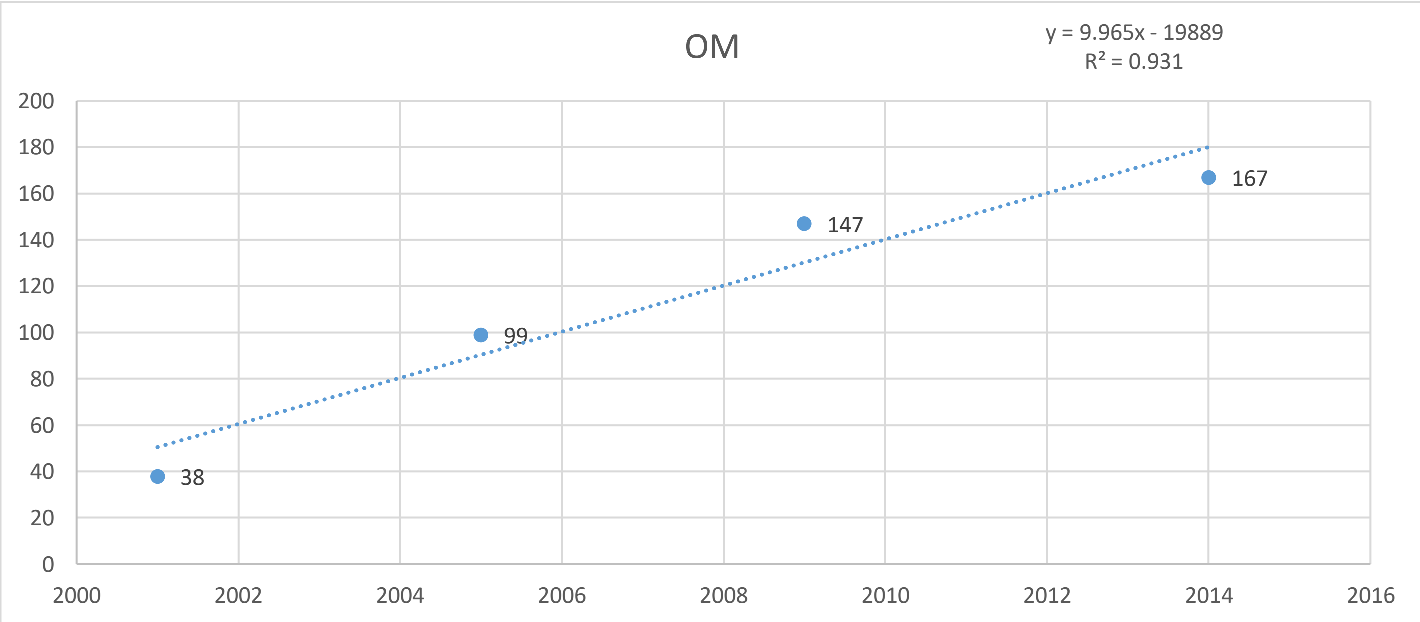


Fig-38: Trend line showing gradual increase in the area of Open mangrove area (Y-axis) in North Region of STR over year of observation (X-axis) up to the year 2014

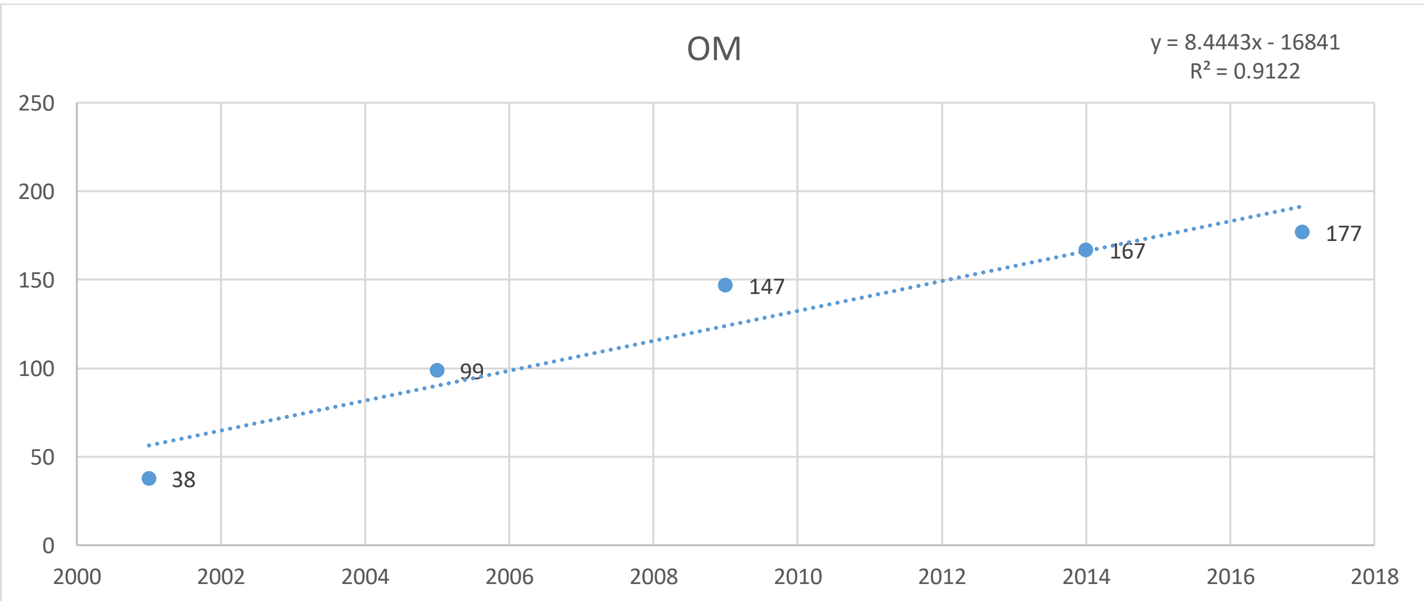


Fig-39: Trend line showing gradual increase in the area of Open mangrove area (Y-axis) in North Region of STR over year of observation (X-axis) up to the year 2017

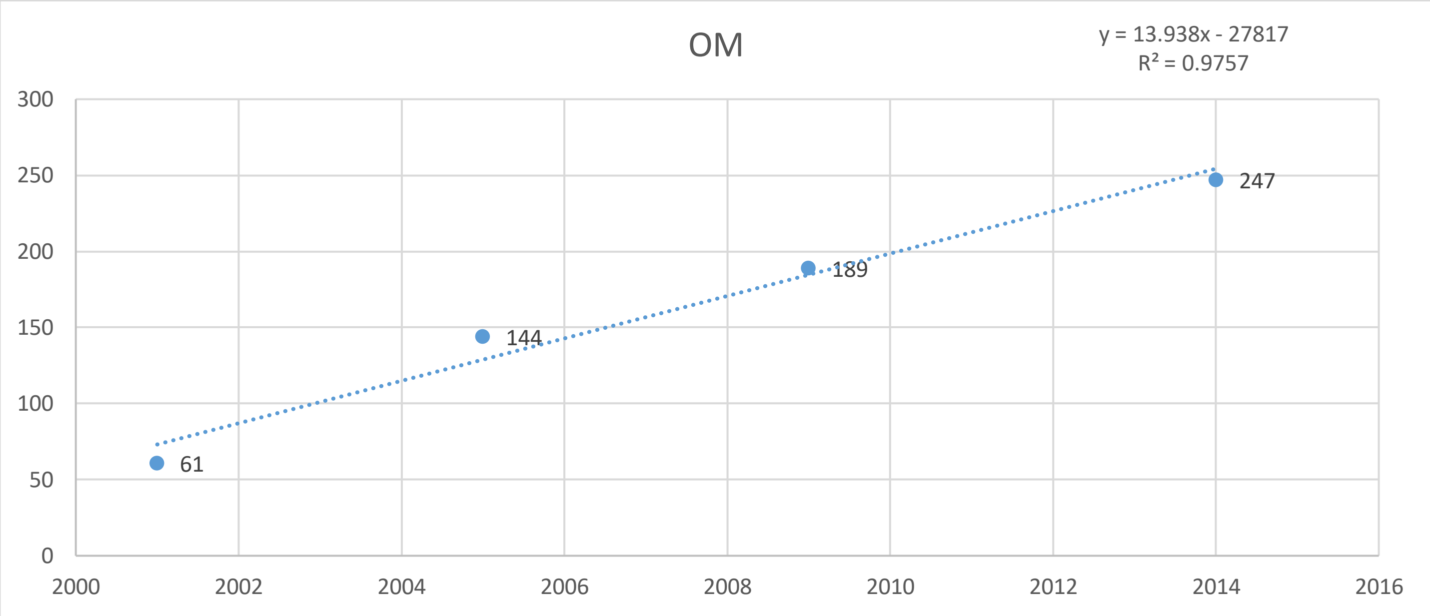


Fig-40: Trend line showing gradual increase in the area of Open mangrove area (Y-axis) in Central Region of STR over year of observation (X-axis) up to the year 2014

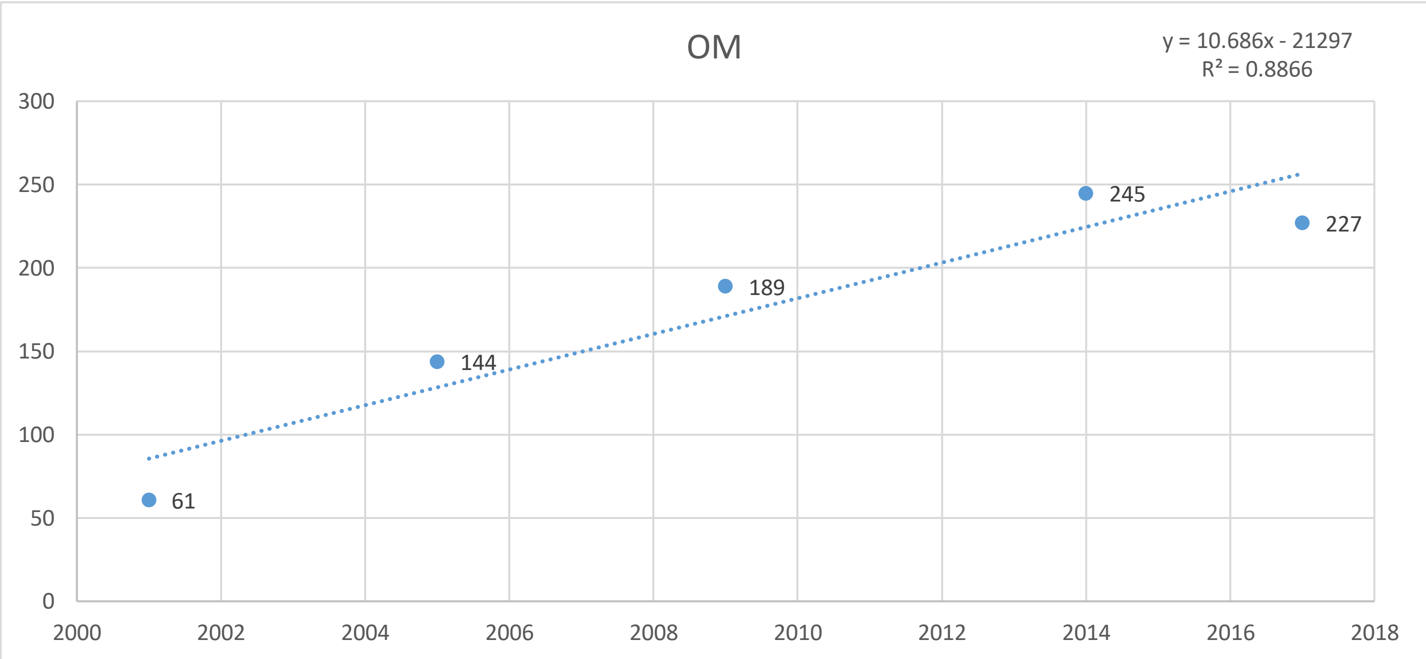


Fig-41: Trend line showing gradual increase in the area of Open mangrove area (Y-axis) in Central Region of STR over year of observation (X-axis) up to the year 2017

Conclusions:

The present study conclusively shows that the rate of net loss of Dense Mangrove area due to the sea level rise, as predicted [20] by the researchers till now, is extremely significant in case of Sundarban Tiger Reserve. The most important outcome of the present study is the fact of faster degradation of mangrove vegetation in the northern/ central zones of the Tiger Reserve, as well as, faster degradation of mangrove density in the western sector of STR, as predicted by the researchers in the past study [20]. The study also predicts that most of the dense mangrove forest will degrade into less dense, open mangrove forest by the turn of 2029 and by the year 2056, only open mangroves will exist in Sundarban Tiger Reserve.

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