FORECASTING FUTURE OF GREATER FLAMINGO (*Phoenicopterus roseus*) IN MAHARASHTRA, INDIA UNDER THE INFLUENCE OF CLIMATE CHANGE

THESIS SUBMITTED

TO

Symbiosis Institute of Geoinformatics

FOR PARTIAL FULFILLMENT OF THE M. Tech. DEGREE

By

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CERTIFICATE

Certified that this thesis titled "**Forecasting future of Greater Flamingo (Phoenicopterus *roseus*) in Maharashtra, India under the influence of climate change**" is a bonafede work done by Miss Shivani Bhatia, at Symbiosis Institute of Geoinformatics, under our supervision.

Supervisor, Internal	Supervisor, External
Name	Name
Organization	Organization

DECLARATION

I, Shivani Bhatia, hereby declare that the project work entitled "**Forecasting future of Greater Flamingo (Phoenicopterus *roseus*) in Maharashtra, India under the influence of climate change**" is the genuine and unique work carried out by us under supervision of Dr. Navendu Chaudhary, Professor, M Tech. Geoinformatics (Symbiosis Institute of Geoinformatics), Pune, Maharashtra (411006). For the partial fulfilment and the prerequisite for granting of the Spatial Modelling Paper, of Master of Technology in Geoinformatics, Symbiosis Institute of Geoinformatics), Pune, Maharashtra. (411006).

Pune, India

Shivani Bhatia

CONTENTS

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Signature: Shivani Bhatia

LIST OF FIGURES AND TABLES

ABBREVIATION

ARIMA- Auto-regressive Integrated Moving Average

BNHS- Bombay Natural History Society

CSV- Comma Separated Values

CMIP 5- Coupled Model Intercomparison Project - Phase 5

FBProphet-Facebook Prophet

GBIF- Global Biodiversity Information Facility

MSI-Moisture Stress Index

NDWI-Normalized Difference Water Index

SABI- Surface Algal Bloom Index

SARIMA- Seasonal Auto-regressive Integrated Moving Average

SDM-Species Distribution Modelling

Sq. Km- Square Kilometres

USGS- United States Geological Survey

PREFACE

According to an eye-opening survey conducted by the Bombay Natural History Society (BNHS), there was a slight decrease in the number of Greater Flamingos (IUCN (least concern)) in Maharashtra between May 2018 and May 2019. As a result, I conducted this study titled "Forecasting future of Greater Flamingo (Phoenicopterus roseus) in Maharashtra, India under the influence of climate change" to analyse the situation and provide management-based solutions. For this study, I used Generalized Linear Modelling (GLM) to compare current and future species distributions in relation to two major climate factors, Tmin and rainfall. For both factors, I used CMIP5 50-year climate projections.

In order to strengthen our findings, I conducted a short-term time series analysis of the aforementioned climatic factors for the study area.

Furthermore, while Greater Flamingos were seen in a variety of locations throughout the study area, Bhigwan Bird Sanctuary was the location where this species was seen the most, even more than its counterpart Lesser Flamingos. As a result, spectral indices for the region were computed in order to assess the ecological health of its primary habitat.

CHAPTER 1: GENERAL INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

The two most serious dangers to biodiversity in the twenty-first century are environmental change and living space misfortune (Jetz et al., 2007). Environmental change substandards the district's reasonable ecological circumstances for specific species, bringing about a change in their geographic reach (SAINO and AMBROSINI, 2008). It can change the morphology, physiology, phenology, life history, overflow, and dissemination of an extensive variety of living things, from plants to spineless creatures and vertebrates (Hughes, 2000; Parmesan, 2006; Root et al., 2003). In principle, life forms can adjust to environmental change in two ways. They can either adjust their reaches, and that implies species can move. On the other hand, they might answer changing ecological circumstances by creating phenotypic versatility, which alludes to the capacity to adjust conduct, morphology, or physiology (Bradshaw and Holzapfel, 2006).

Birds are vital for environments. Nonetheless, bird eradications are presently happening at a rate that far surpasses their speciation rate (Wijewardhana et al., 2020). Environmental change has brought about birds moving and moving their reaches and colonizing new areas (Böhning-Gaese and Lemoine, 2004; Thomas and Lennon, 1999).Since 1970, the quantity of transient birds has diminished decisively all over the planet. Environmental change is a critical driver of transient bird overflow decline (Jacome et al., 2019). In the midst of evolving environment, the development patterns of relocating birds are seldom in a state of harmony with and during times of bountiful food assets (da Silveira et al., 2021)Migratory birds presently likewise seem to have expanded their colder time of year and summer landings in reasonable perching destinations prompting event of their populace decline (SAINO and AMBROSINI, 2008).

Many migratory birds visit and dwell in India's Kutch and different parts every year. The Phoenicopterus family visits India near August-September and residing until winter, returning in Spring April. (R. L. Meena, 2008). There are two kinds of flamingos found in India: greater and lesser flamingos. When the downpours have halted in the Rann of Kutch, in October, flamingos start their yearly relocation from their favorable places in Gujrat to their taking care of grounds in Maharashtra. More lesser flamingos (Phoenicopterus roseus) relocate to freshwater and estuarine living spaces in Maharashtra, Andhra Pradesh, Telangana, Rajasthan, and other Indian states (Rishika Pardikar, 2020). They eat benthic creatures, which live on the lower part of seas, lakes, and waterways, like molluscs, scavangers, and blue green growth .The

IUCN has designated Greater flamingos as a species of least concern ***(IUCN)***. However, like many other birds and animals across the country, their habitats and natural resources are under threat.

The Bombay Natural History Society (BNHS) has been counting flamingos near Mumbai's wetlands since 2018. They observed a gradual increase in the number of lesser flamingos between May 2018 and May 2019 – but a slight decrease in the number of great flamingos during the same time period(Rishika Pardikar, 2020).

In the present era of rapid global climate change, development of early warning systems of ecological regime shifts should be a major focus in the ecology. Identifying and monitoring shifts in spatial regimes is nowadays a new approach that can enhance understanding of ecological responses to global change **.** Species distribution models (SDMs) combine empirical data on a species' occurrences or abundance with data on environmental factors. Such models are widely used in terrestrial, marine, and freshwater applications to predict distributions of species across landscapes and to gain new insights into ecological and evolutionary development. With a variety of SDM methods available to choose from, it can be difficult to know which to use **.** The modelling method we use is primarily determined by the type of data we want to analyse and the question we want to ask. Methods for species distribution modelling are classified into three types: 'profile', 'regression,' and 'machine learning.'

For our study, we utilized GLM (Generalized Linear Model), a regression-based method, as a mechanistic niche model to detect distribution of Phoenicopterus *roseus* across India and its state Maharashtra under CMIP 5 future scenario for next 50 years.

Predictive analysis has become a popular research area nowadays. Besides, modelling and predicting the spatial distributions of Greater Flamingos over a long period using GLM, accurate analysis of climatic factors effected by their past values can also help us with fate of distribution of birds in near future. In this circumstance, I also used the predictive capabilities using the Fbprophet forecasting model. This study proposes a predictive model that uses the Fbprophet framework and probability to forecast climate factors in recent times.

Apart from this, the current study also deals with calculating spectral indices NDVI, NDWI, SABI and MSI which are also eco-saline indicators to check overall ecological health of our sub study area i.e area in and around Bhigwan Bird Sanctuary, the major feeding grounds of Greater Flamingos in Maharashtra.

1.2 Review of Literature

Biodiversity Conservation in a layman's language is to protect species from extinction. It could be accomplished by maintaining or restoring the habitats, enhancing ecosystem services and protecting biological diversity. A habitat is a specific location where species live and reproduce with specific characteristics, behaviour, interactions, and population patterns**.** Lately, climate change has been considered as serious threat to birds. However, improved identification of major climate variables can aid in the development of effective policies, which is one of the most pressing needs for biodiversity conservation. The holistic ecosystem is interlinked biodiversity and climatic conditions. A biodiverse ecosystem provides crucial ecosystem services that form the foundation of social, economic, and ecological wellbeing.Adequate conservation of biodiversity requires detailed knowledge of a species' natural history and biology and information on the availability of suitable habitat.

1.2.1 The Greater Flamingos

Greater flamingos (Phoenicopterus roseus) are partly migratory and common in brackish waters as they inhabit and breed in this area (Simmons, 2000; CÉZILLY et al., 2008). On the other hand, the lesser flamingo (Phoenicopterus minor) is sociable (Dack, 2008) bird that breeds in colonies and is distributed throughout salt pans. Greater flamingos are easily distinguished from small flamingos, whereas smaller flamingos are smaller with red eyes and black beaks. Lesser flamingos are about 80-90 cm tall, while Greater flamingos are about 110-150 cm tall (Sea World, 2019). These birds typically feed in water at depths of 5-50 cm.

S. Balachandran et al. (2012), found that in east coast of India, due to the degradation of wetlands habitats, populations of various waterbird species are dwindling in their traditional overwintering sites. The decline in Greater Flamingo numbers was well pronounced since the 1990s. For the last three years, during summer the number is less than 50. The peak numbers are seen only for a short duration of two months (January - February).

McCulloch et al. (2003), in his study titled "Satellite tracking of flamingos in southern Africa: the importance of small wetlands for management and conservation", highlights the need for the conservation of the network of small wetlands around southern Africa, to protect the feeding ground of Greater Flamingo species in decline.

1.2.2 Species Distribution Modelling

Habitat suitability refers to a favourable habitat that is important for a species' survival, and it is crucial in ecological research through habitat suitability modelling, which can invaluably aid in conservation and protection plans (***Papeş and Gaubert 2007***). Ecological niche fashions make use of associations among environmental variables and recognized species' incidence localities to define abiotic situations inside which populations may be maintained.

Guisan & Zimmermann (2000) stated that the model formulation process addresses two major goals. That is, (1) the choice of a suited algorithm for predicting a particular type of response variable and estimating the model coefficient, and (2) to find an optimal statistical approach with regard to the modelling context. Today ecologists rely on a diverse range of analytical approaches due to the increasing availability of software to implement these methods and a greater computational ability of hardware to run them (Hegel et al. 2010).

The methods pursue different approaches and can roughly be divided into three categories (***Elith et al. 2006; Franklin 2010***).

Regression models, like the generalized linear models (GLM) use relationships between presence or absence and environmental variables. Absences can be simulated using pseudo-absences. They have widely been used in species distribution modelling since the 1980s and the early 1990s (***Franklin 2010)*** and are still common in this field.

Envelope models, like BIOCLIM or DOMAIN only use presence information and characterize sites that are located within the environmental hyper-space occupied by the species and predict their distribution based on similarity of occurrences ***(Shabani et al.,2015).***

Machine learning or statistical learning methods produce rules based on observations and environmental conditions to predict species distribution. MaxEnt compares probability densities from background and presence locations to derive the probability of occurrence.

Shabani et al. (2016) ,the model's realism and robustness relies upon the predictors' selection and relevance, method, scale, interaction of geographic and environmental factors, extent of model calibration, and levels of projection (i.e., inter- or extrapolation).

1.2.2.1 Generalized Linear Model

The logistic regression is the most commonly used for generalised linear model (GLM), and is widely used in SDM, as it deals with multiple predictors, non-linear response functions and binary response variables ***(Franklin 2010).*** In logistic regression, the dependent variables are subjected to a logit transformation (***Hastie et al. 2009***). Thus, the response variable can only take values between 0 and 1. The response variable for the modelling approach is binary (presence/absence) and the response function binomial, thus the logistic regression has been chosen. Generalized Linear Models are parameter-based models. The regression models relate a response variable (species occurrence) to a single (simple) or a combination (multiple) of environmental predictor variables (explanatory variables) ***(Guisan & Zimmermann 2000; Dormann 2012***). Link-functions describe the way in which response variable and the explanatory variables are connected ***(Dormann & Kühn 2009).*** The GLM can be expresses as:

$$g(yi) = \beta 0 + \beta 1 X1i + \beta 2 X2i + \cdots + \varepsilon$$

where yi is the predicted value at data point i, $X1i$ etc., the values of the explanatory variables at data point i, β the vector to estimate for every model parameter. The link-function $g(\ )$ describes how the mean of y depends on the linear predictor ***(Franklin 2010).*** For binomial distributed data the logit-link is the standard-setting and is defined as followed

$$g(y) = ln\,(y\ 1 - y\ )$$

For minimum/maximum parameter values this equation is approximately 0 or 1. The ideal set of parameters is determined by the Maximum Likelihood ***(Dormann & Kühn, 2009).***

Brotons et al. (2004), found that Generalised Linear Models performed significantly better than Ecological Niche factor Analysis when estimating habitat suitability in an overabundance scenario in which species occupied all optimal habitats and occupied secondary habitats at lower probabilities.

Zuckerberg et al. (2018), with Tmin and precipitation as two predictor variables for their GLM model, found that grassland birds are declining faster than any other bird guild across North

America. Temperate grasslands have been disproportionally affected by climate change. Large grassland patches, the most common metric of grassland conservation, appear to moderate the effects of weather on grassland-bird demography.

1.2.3 Time-Series Analysis

Time series data are those that change over time, and time series forecasting is the prediction of future values. In time series, we have data in regular intervals. Sometimes, data is dependent on its own past values apart from external factors(Sharma et al., 2021). This is where time series comes into role. Time series helps understand trends. It is used in two ways, learn about the underlying forces and structure that produced the observed data. Secondly, to fit a model before moving on to forecasting, monitoring, or even feedback and feedforward control.

There are various ways of performing time series analysis i.e., ARIMA (Auto-Regressive Integrated Moving Average), SARIMA (Seasonal Auto- Regressive Integrated Moving Average), SARIMAX (X- External Factors), deep learning models like LSTM (Long Short-Term Memory) and the ultimate messiah of time series modelling FbProphet from Facebook

(Pandian, 2021). Seasonality and trends are two key concepts associated with time series forecasting. Seasonality is simply the repetition of events over time. The term trend describes the increasing or decreasing trends in data over time (Pandian, 2021).

To check seasonality and better understand our time series, we often decompose our time series i.e., break-down of time-series data into trend, seasonality, and irregular components. Two types of decomposition models are additive and multiplicative.

Y=T+S+I--------*additive (T=Trend, S=Seasonality, I=Irregular Component)*

Y=T*S*I-------*multiplicative (T=Trend, S=Seasonality, I=Irregular Component)*

If seasonality is constant, we use additive model or else multiplicative. There are two major types of time series data-types: stationary and non-stationary. A stationary data set is one that lacks the trend, seasonality, cyclicity, and irregularity components of a time series. During the analysis, the MEAN value of them should be completely constant in the data. The VARIANCE should be consistent in relation to the time frame. COVARIANCE assesses the relationship between two variables. Non-stationary data is the polar opposite of stationary data (Pandian, 2021).

Chaturvedi et al. (2022) in their study titled "A comparative assessment of SARIMA, LSTM RNN and Fb Prophet models to forecast total and peak monthly energy demand for India" found Fb Prophet models to be best model for short term forecast with least amount of RMSE (Root Mean Square Error) (Chaturvedi et al., 2022).

1.2.4 Spectral Indices

The NDVI is a dimensionless record that depicts the distinction among visible and close infrared reflectance of vegetation cover and can be utilized to assess the density of green on an area of land (Weier and Herring, 2000). NDVI is a widely used method for estimating not only vegetation cover and greenness, but also forest and non-forest vegetation productivity dynamics in response to climate change (Chu et al., 2019).

"NDVI = (NIR – Red) / (NIR + Red)"

NDVI values range from +1.0 to -1.0. Barren rocks, sand, or snow usually show very low NDVI values at 0.1 or less.

The NDWI is water content examination through the mix of satellite band symbolisms. The band mix of NIR and green shows the reflectance of saline water bodies. As a rule, the NDWI can improve water data successfully. It is delicate to developed land and frequently brings about over-assessed water bodies, yet AOI is a water body just; it doesn't stray from the outcomes. McFeeters (1996) proposed NDWI using satellite pictures' green and close infrared (NIR) gatherings, as water bodies have high absorbability and low radiation in the perceptible to infrared recurrence range. NDWI has been the most comprehensively recognized and by and large used records in light of its straightforwardness, complete aggression to any water system, and accommodation with any satellite datasets (Watson et al. 2018, for instance, for water body recognizable proof (zelkan 2020), surface water arranging at 91% accuracy (Li et al. 2013), surface water components (Sathianarayanan 2018), and isolating between water body and settlement locales (Singh et al. 2015).

"NDWI= (Green-NIR) / (Green+ NIR)"

The reflectance of water in NDWI is maximised by using green band wavelengths and minimised by absorbing the maximum wavelength. Water features are enhanced by positive values, while vegetation and soil are suppressed by zero or negative values. The NDWI values are in the following ranges: 0.0 - 0.2 (water surface flooding), -0.3 - 0.0 (moderate drought), and -1 - 0.3 (extreme drought) (Drought).

SABI is an algorithm developed for detecting water floating biomass that has a similar response in NIR to that of land vegetation, with some specific inclusions of water-sensitive spectral bands, blue being characteristic of clear water and green being the one for water column blooms.

"SABI = (NIR-Red)/ (Blue+ Green)"

Here, we utilized B5, B4, B3, B2 for NIR, Red, Blue, and Green respectively.

In NDWI, water reflectance is maximised by using green band wavelengths and minimised by absorbing the maximum wavelength. Positive values enhance water features, while zero or negative values suppress vegetation and soil. NDWI values range from 0.0 to 0.2 (water surface flooding), -0.3 to 0.0 (moderate drought), and -1 to 0.3 (extreme drought) (Drought).

"MSI= SWIR/NIR"

Sharma et al. (2019), in the study titled "Geospatial Integration of Eco-Saline Indicators with Maxent Model for Flamingo's Habitat Suitability Conservations" discussed the reducing population density of Greater Flamingos in the Sambhar Lake, owing to changing climatic conditions and deteriorating food resources in the region. The study used habitat suitability modelling coupled with eco-saline indicators such as NDWI,MSI ,SABI to model distribution of species in the future.

CHAPTER 2: RESEARCH OBJECTIVES

- To model species distribution of Greater Flamingos using GLM for the year 2070 in Maharashtra.
- Time-series analysis of predictor variables (Tmin, Precipitation) to comprehend trends for short-term climate forecast of the study area and ecologically relevant areas to species in the current scenario.
- Calculating Spectral Indices to assess the ecological health of the sub-study area, Bhigwan Bird Sanctuary (only known major hotspot of Greater Flamingos in Maharashtra).

CHAPTER 3: STUDY AREA

Maharashtra is a state in India's western and central peninsular area that encompasses much of the Deccan Plateau. Maharashtra is India's second-most populous state, as well as the world's second-most populous country subdivision. The state is divided into six divisions and 36 districts, with the Godavari and Krishna rivers serving as the state's primary waterways. The state land area, with 307,713 square kilometres and accounting for 9.36% of the country's total geographical area. The state's latitude ranges from 15°35' N to 22°02' N, while its longitude ranges from 72°36' E to 80°54' E.

State has a tropical monsoon climate, which includes hot, rainy, and chilly seasons, as well as dry summers. The month of March heralds the start of summer, with temperatures continuously rising until June. The winter season generaly lasts from December through February, with the coldest months being December and January.

Lonar natural lake, Nathsagar reservoir, Yeldari reservoir, Nandur Madhmeshwar Tank, Navegaon notified wetland, and Ujani reservoir are among the six wetlands. A 5-kilometer buffer zone around the wetlands' boundaries. Forests dominate the vegetation in the eastern region, as well as the Sahyadri Ranges, Satpura Ranges, and Chandrapur region.

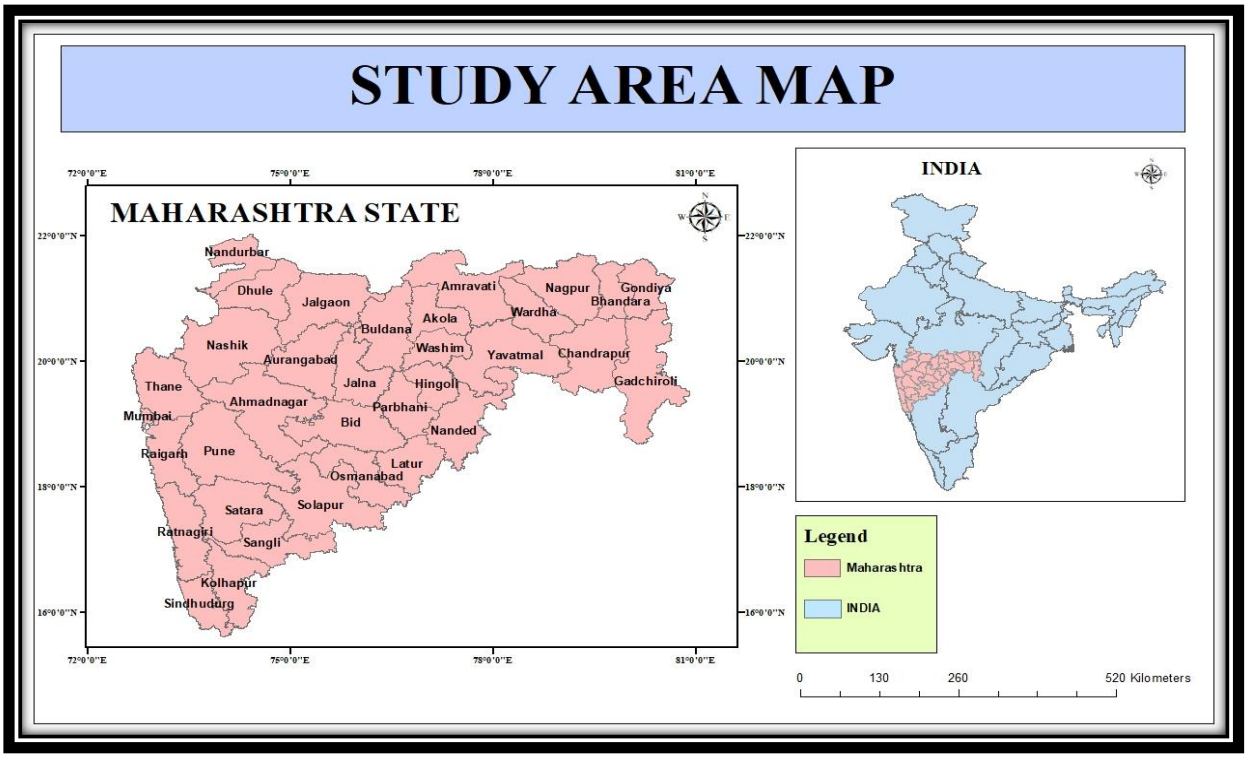

Fig 1: Study Area- Maharashtra, India

The Greater Flamingo is the flamingo family's most widespread and largest species. Africa, the Indian subcontinent, the Middle East, and southern Europe are all home to this species. Maharashtra hosts the highest flamingo population in the country. Flamingos can be seen in Sewri Creek, Thane Creek, Bhigwan Bird Sanctuary and in Talwe wetlands near Navi Mumbai among other places. With Greater Flamingos specifically, majorly residing in Bhigwan Bird Sanctuary.

3.1 Bhigwan Bird Sanctuary (Sub-Study Area)

Karmala and Indapur is a municipal council in Solapur and Pune district of Maharashtra, respectively. Kumbhargaon-Bhigwan Bird sanctuary falls on the shared border of these two municipal council.The study area is visited by flamingos every year between October to March. It is a breeding ground and source of salt water for Greater Flamingos.

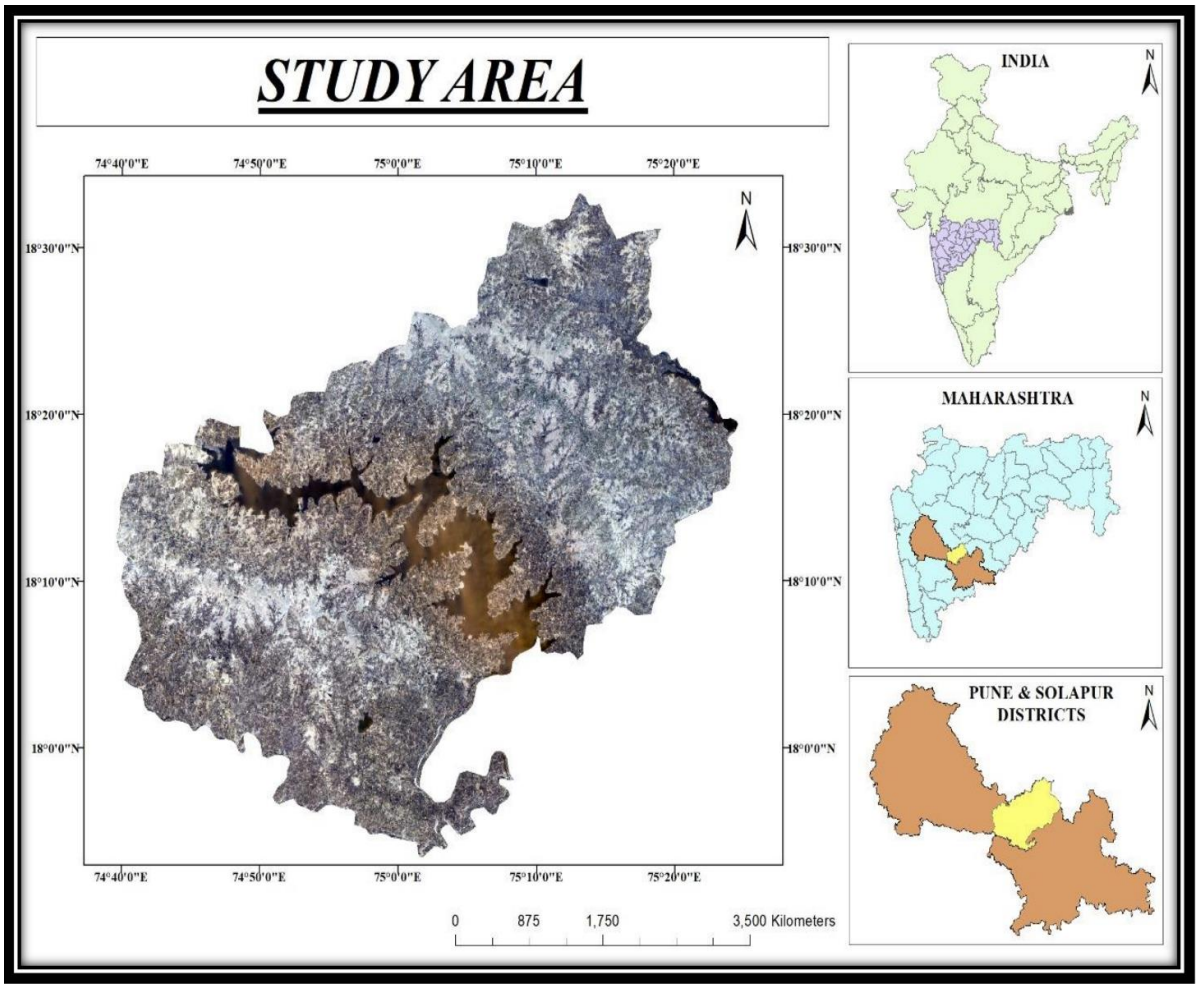

Fig 2: Sub- Study Area – Bhigwan Bird Sanctuary, Maharashtra, India

CHAPTER -4: MATERIAL AND METHODS

Objective 1: *To model species distribution of Greater Flamingos using GLM for the year 2070 in Maharashtra.*

4.1.1Climate Data

The near current data of precipitation and minimum temperature from WorldClim and future climate data from the CMIP5 scenario by IPCC for next 50 years or year 2070 was directly sourced from Weecology lab of the University of Florida in GRD format.

4.1.2 Species Data

Total 489 species occurrence records were retrieved from GBIF in CSV format. The presence records in GBIF were majorly sourced from iNaturalist and Ebird. We prepared absence records also, concluding final occurrence data to 581 records.

4.1.3 Software Applications Used:

R Studio, Arc GIS Pro

4.1.4 Methodology:

We first went pre-processing i.e. preparing data for our model.

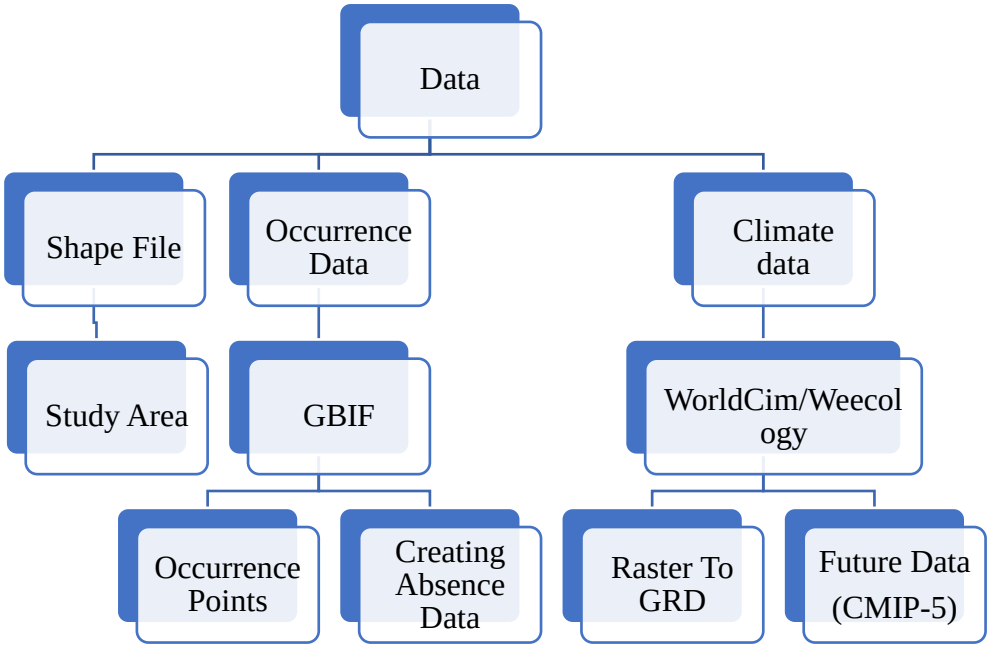

Fig 3: Pre- Processing of Data for GLM Model

After that we used R studio in following sequence,

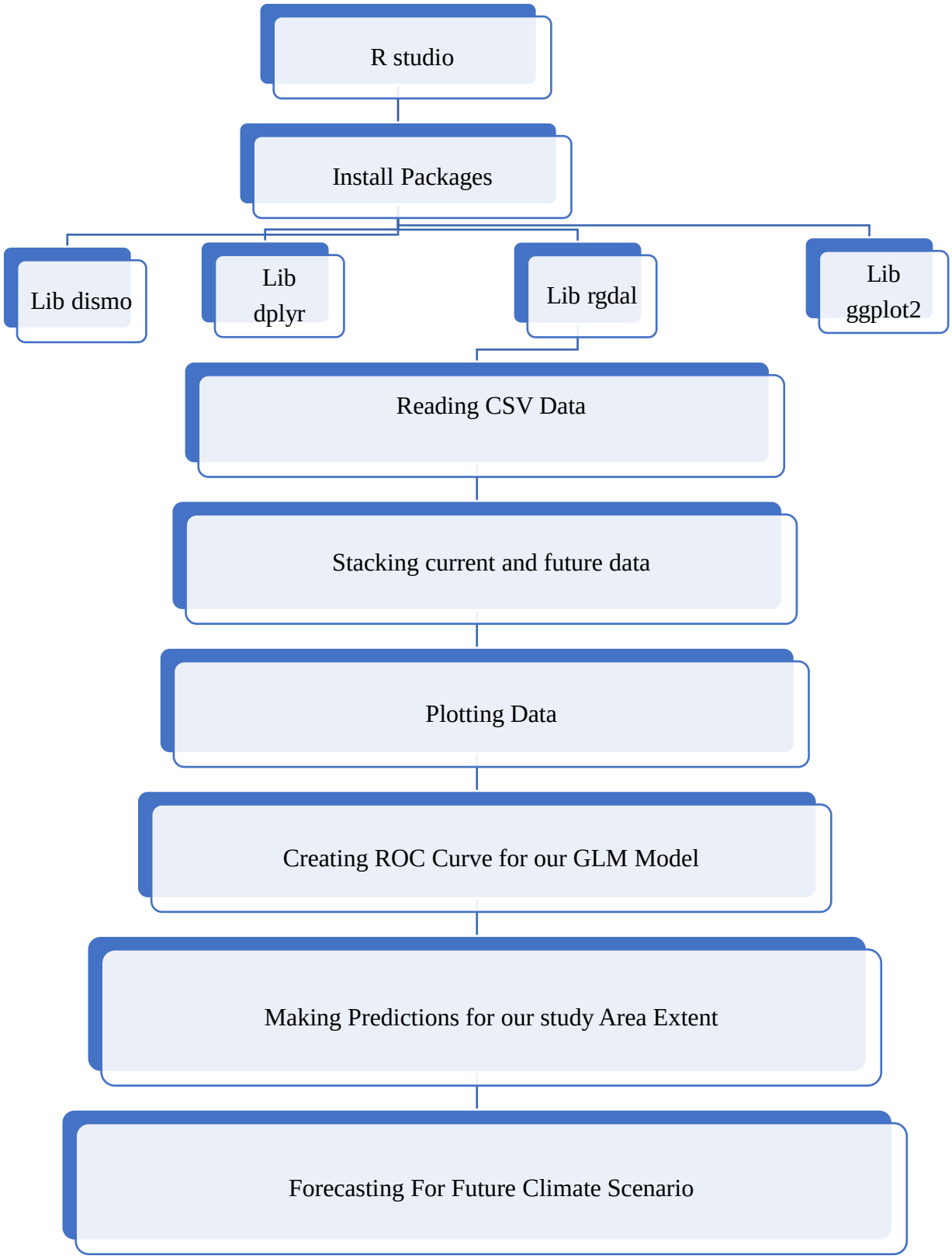

Fig 4: Approach to GLM Model in R studio

Objective 2: *Time-series analysis of predictor variables (Tmin, Precipitation) to comprehend trends in short-term climate forecast in the study area and ecologically relevant areas to species in the current scenario.*

4.2.1 Precipitation and Tmin Data

NASA POWER Data Access Viewer daily data 01/01/2000 to 31/12/2021.

4.2.2 Software Used

Python, Jupyter Notebook, MS Excel

4.2.3 Methodology

- *Major Libraries used:* Pandas, Numpy
- *Time-Series Analysis Method:* FbProphet

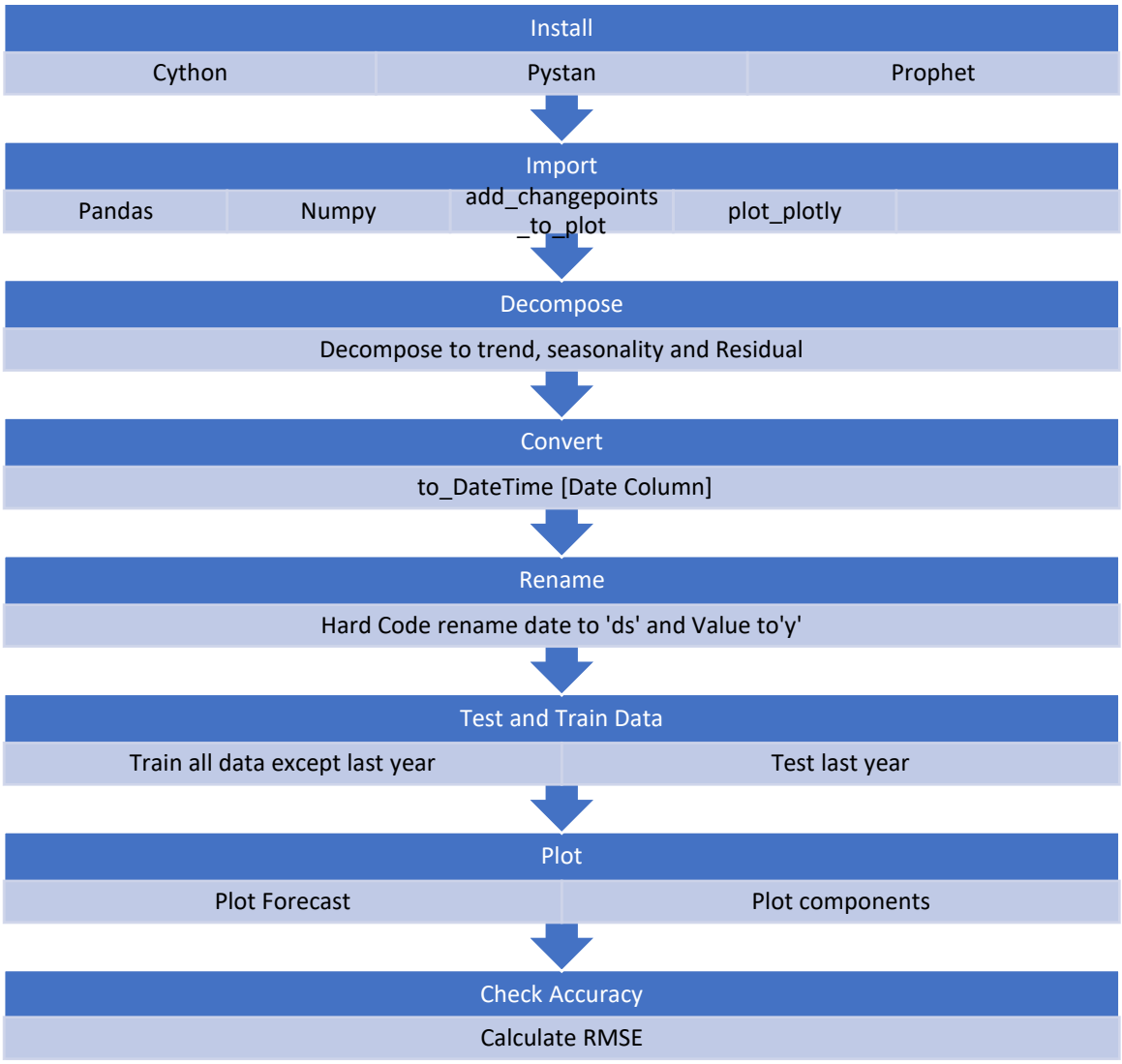

Fig 5: Approach to Time Series Analysis

Objective 3: *Calculating Spectral Indices to assess the ecological health of the sub-study area, Bhigwan Bird Sanctuary (only known major hotspot of Greater Flamingos in Maharashtra).*

4.3.1 Software used:

Google Earth Engine, R Studio, Google Earth Engine

4.3.2 Methodology:

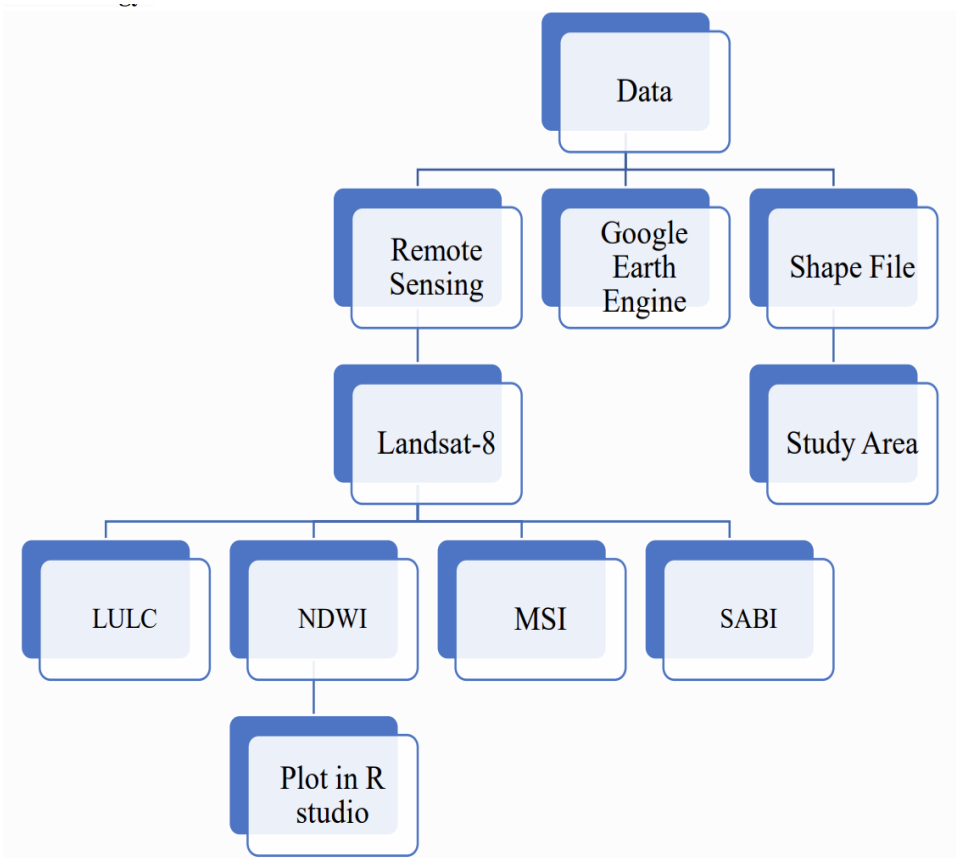

Fig 6: Approach to Calculating Spectral Indices

Results

Objective 1: *To model species distribution of Greater Flamingos using GLM for the year 2070 in Maharashtra.*

We generated a scatter plot for our species occurrence by plotting our species data over the current environment layer. We first extracted environmental conditions for species location, bind them and then using ggplot2, plotted a scatter plot. The scatter Plot described that in general species like lower precipitation and comparatively higher temperatures regions.

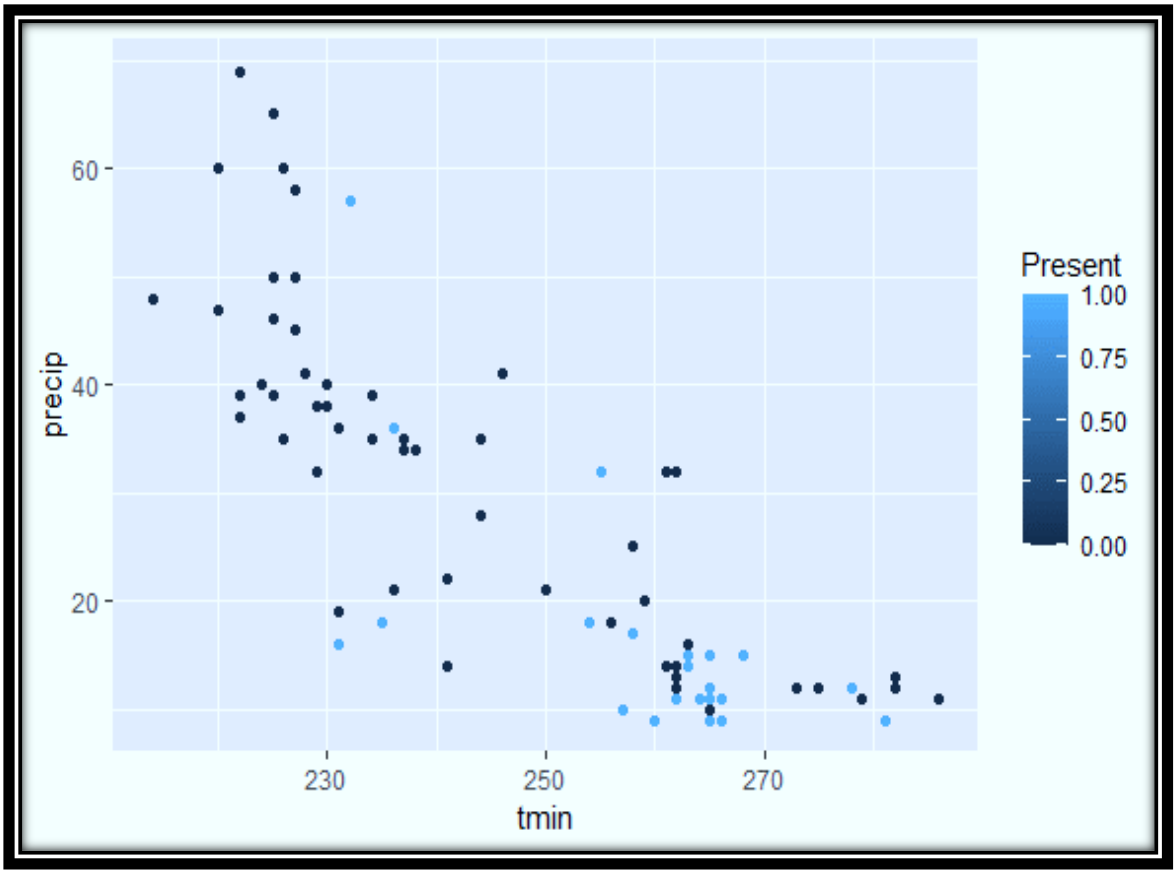

Fig 7: Scatter Plot of Occurrence of the Greater Flamingos based on Environmental Predictors

Next the logistic regression model for Greater Flamingos was run with logit transit:

logistic_regr_model=glm (Present ~ tmin + precip, family = binomial (link = 'logit'),

data= flamingo_data)

To find summary of our logistic regression model, following function was used:

summary(logistic_regr_model)

From the summary, we deduced the p values. The p-value ideally should be equal to or less than 0.05, here it denotes higher significance of precipitation as environment variable for presence of species and comparatively lower value for t min. Also, after calculating chi-square from null and residual deviance i.e ***pchisq=1.791881e-09***, it was established that extremely small chi-square denotes, null hypothesis is rejected and it is plausible that deviation is not same with constants and variables. The negative values of coefficient here denotes that the presence of species is unlikely to happen in the regions with high precipitation.

```
> logistic_regr_model=glm(Present ~ tmin + precip,family = binomial(link = 'logi
t'),
+                         data= flamingo_data)
> summary(logistic_regr_model)

Call:
glm(formula = Present ~ tmin + precip, family = binomial(link = "logit"),
    data = flamingo_data)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-2.6289   0.3587   0.4096   0.6947   1.5143

Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) 15.73457    6.48627   2.426 0.015274 *
tmin        -0.04488    0.02340  -1.918 0.055114 .
precip      -0.10678    0.02772  -3.853 0.000117 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 441.90  on 562  degrees of freedom
Residual deviance: 401.62  on 560  degrees of freedom
  (18 observations deleted due to missingness)
AIC: 407.62

Number of Fisher Scoring iterations: 5
```

Fig 8: Summary of Logistic Regression for Generalized Linear Model

A ROC curve (Fig 7) is a 2-D plot that shows how well a classifier system performs as the discrimination cut-off value varies across the range of the predictor variable.

A progression of focuses inside the ROC space were produced, that can be associated by a bend as we increment the segregating slice off worth to incorporate an ever increasing number of data of interest. The (1, 1) point was produced by a segregating cut-off esteem more noteworthy than the most elevated esteem noticed. The slanting line interfacing (0, 0) and (1, 1)

demonstrates that test expectations are no greater than irregular conjectures. The higher a point in the ROC space is over the corner line, the better the test's prescient worth.

A ROC bend delineates the compromise among responsiveness and particularity. Awareness and particularity are contrarily related; that is, as responsiveness increments, explicitness diminishes, as well as the other way around. The Recipient Working Trademark (ROC) bend chooses the legitimacy of the model and portrays how well the model is. Note that the particularity in ROC is characterized utilizing the anticipated region, as opposed to genuine commission (see Phillips, Anderson et al). This infers that the most extreme feasible AUC esteem is in every case under 1. The X-axis shows a proportion of explicitness that implies how explicit the model is for a specific region. The Y-pivot signifies awareness that implies how delicate the model is to various kind of conditions.

The AUC (otherwise called the c-measurement) can be utilized to evaluate a test's capacity to recognize an animal types' actual dispersion status. By and large, coming up next is the guideline for deciphering AUC esteem is, AUC=0.5 implies no segregation, AUC 0.6≥AUC>0.5 deciphers unfortunate separation, AUC above 0.7≥AUC>0.6 characterizes adequate separation, 0.8≥AUC>0.7 deciphers phenomenal segregation. Nonetheless, AUC>0.9, characterizes incredible separation (Shengping Yang PhD).

For our model, we got an AUC (Fig 8) of 0.685 demonstrating an OK separation for our model with two indicator factors.

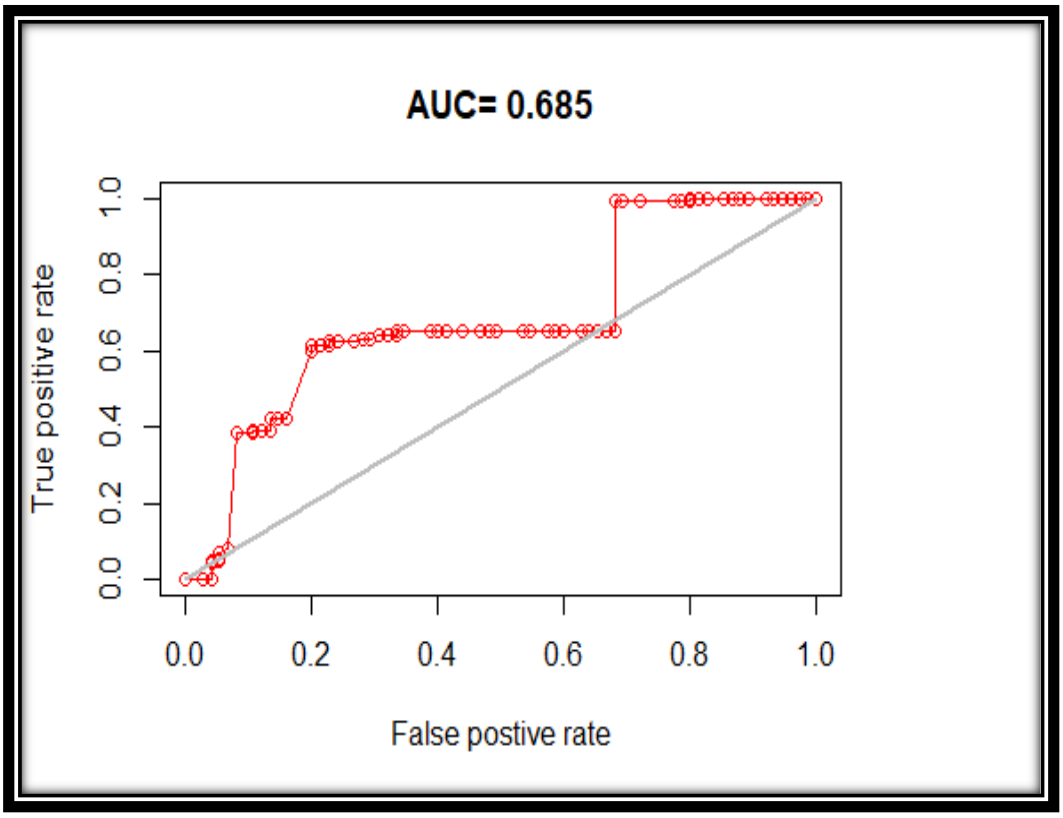

Fig 9: The ROC Curve

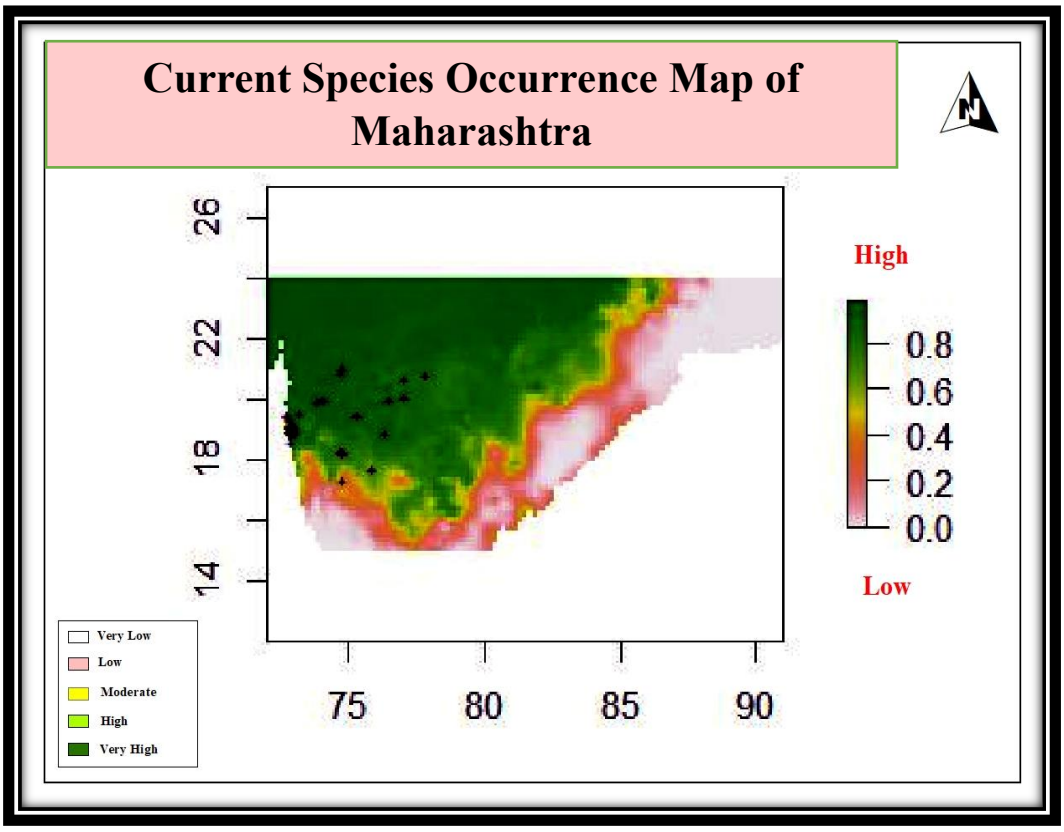

Fig 10: Species occurrence map under present environmental conditions

The current map was created using predict function of Raster Package. It denotes the probability of species presence for the whole study area under present predictor climate variables. The layout was prepared in Arc GIS Pro. The map showed a response plot for the occurrence of species in the current environment. The plot did denote a high species occurrence probability near Mumbai and Thane creek followed by Bhigwan Bird sanctuary near Pune for current time point for our predictor variables.

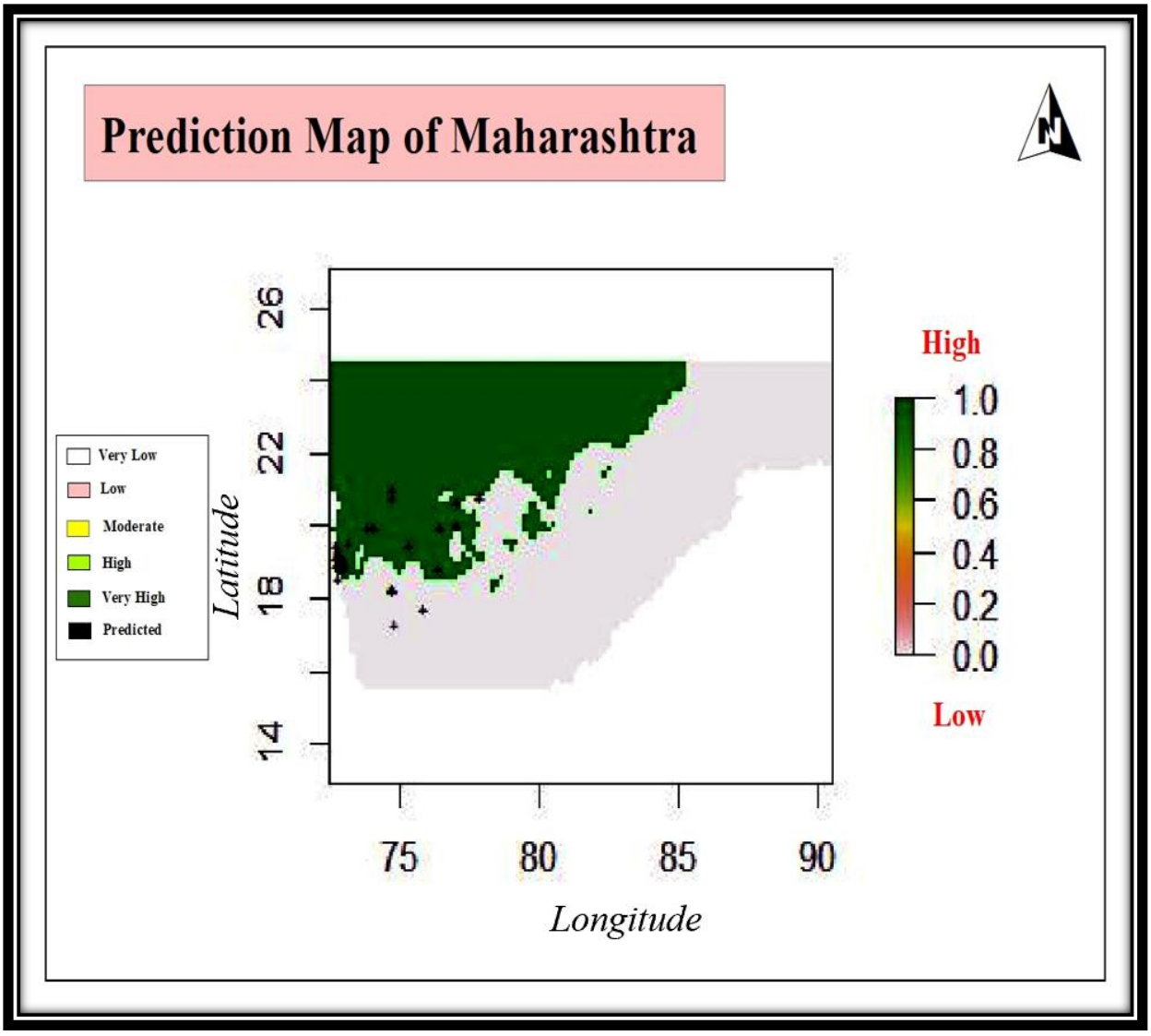

Fig 11: Species occurrence map under future environmental conditions

At last, we did forecast of future environment data we sourced CMIP 5 environmental layer for the year 2070 for our predictor variables. It was found that in Year 2070, species will tend to

shift towards Pune and Satara districts as well as towards Ahmednagar. The current highly suitable regions like Mumbai, for species tend to turn into extremely low suitable areas.

Objective 2: *Time-series analysis of predictor variables (Tmin, Precipitation) to comprehend trends in short-term climate forecast in the study area and ecologically relevant areas to species in the current scenario.*

From the Summary of Logistic Regression for Generalized Linear Model we can clearly deduce that precipitation has slightly more impact on distribution of species than Tmin. Further, the negative values of coefficient in Logistic Regression Model, denotes that the presence of species is unlikely to happen in the regions with high precipitation. So, to analyze the trend of precipitation in the study area for near future we did a time series analysis of twenty years data to forecast the climate conditions for next ten years in the study region Maharashtra and then specific presence areas of Flamingo in present day, Mumbai.

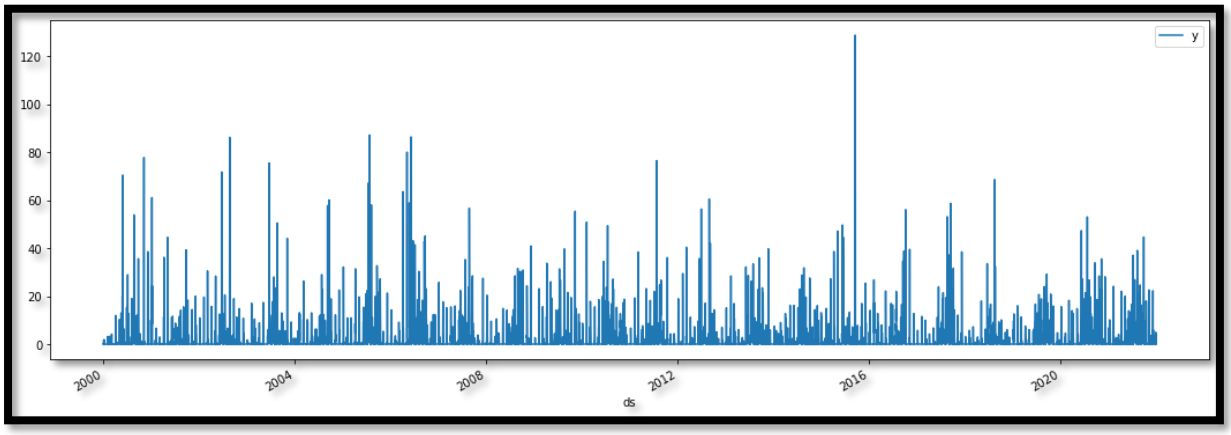

Fig 12: Preciptation Plot of Maharasahtra from year 2000-2021

To check seasonality in data, we decomposed our timeseries and got following results clearly indicating high influence of constant seasonal patterns on the plot.

Using prophet, we trained our model and further did a forecast for 10 years. The plot did show a slight increase in precipitation of 1.5 mm from 6.432 mm in July 2020 to 7.5 mm in July 2030.

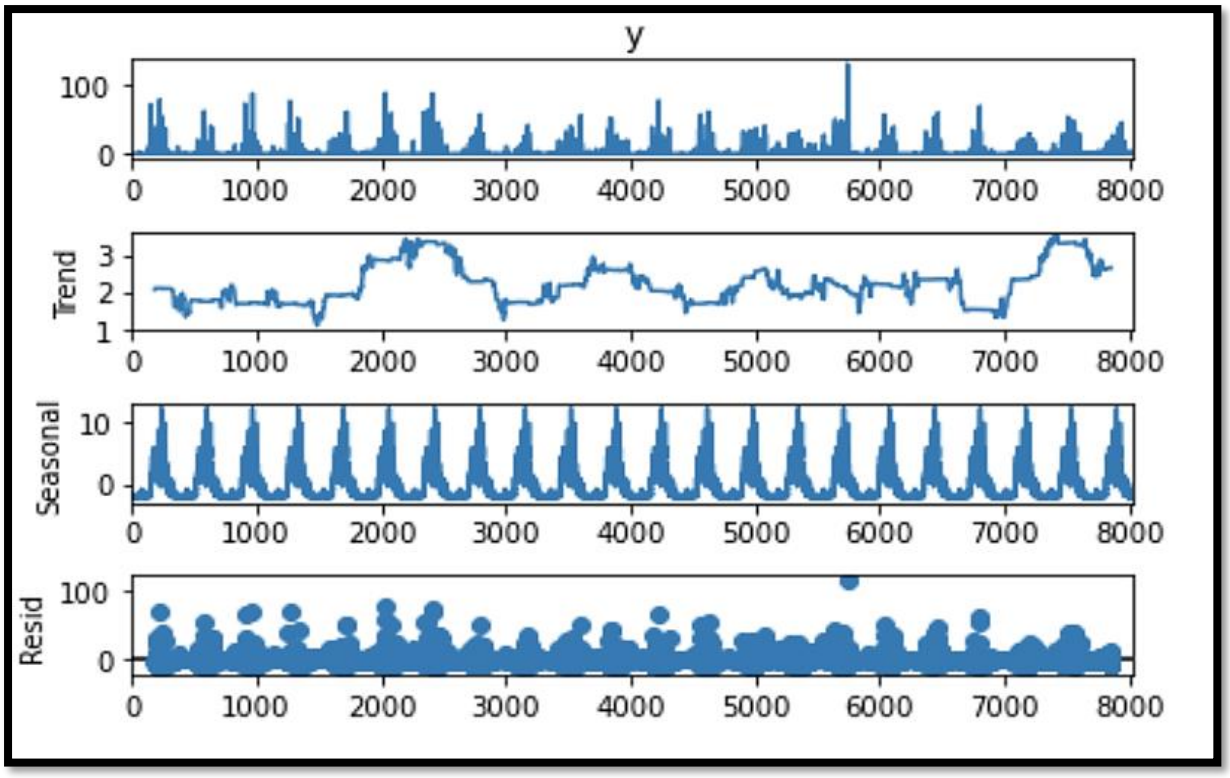

Fig 13: Observed (Precipitation), Trend, Seasonal, Residual plot for daily data of Precipitation in Maharashtra from year 2000-2021

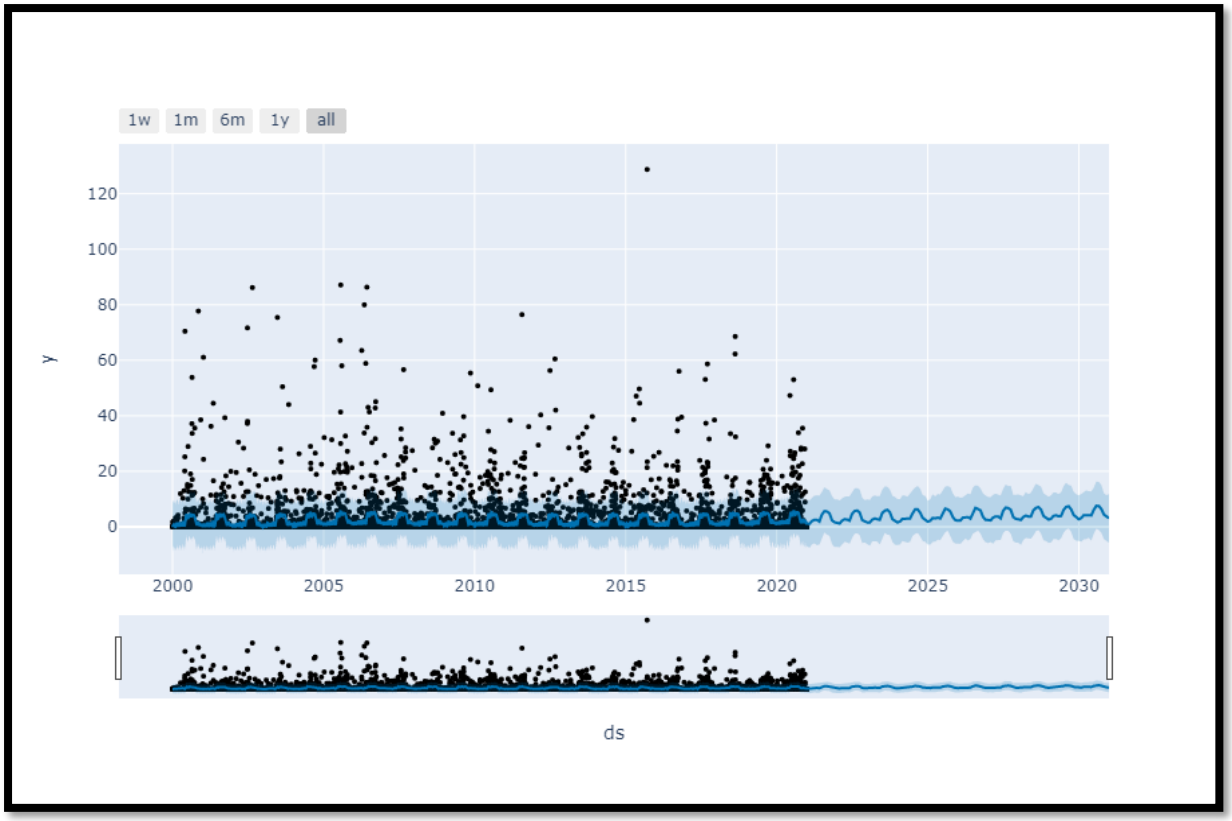

Fig 14: Interactive Forecast Plot of precipitation in Maharashtra for upcoming years

We further computed component of our forecast to understand the trend of precipitation in next 10 years. In our yearly trend, we can clearly find out that precipitation will certainly increase in coming years in state of Maharashtra with highest rainfall in month of august.

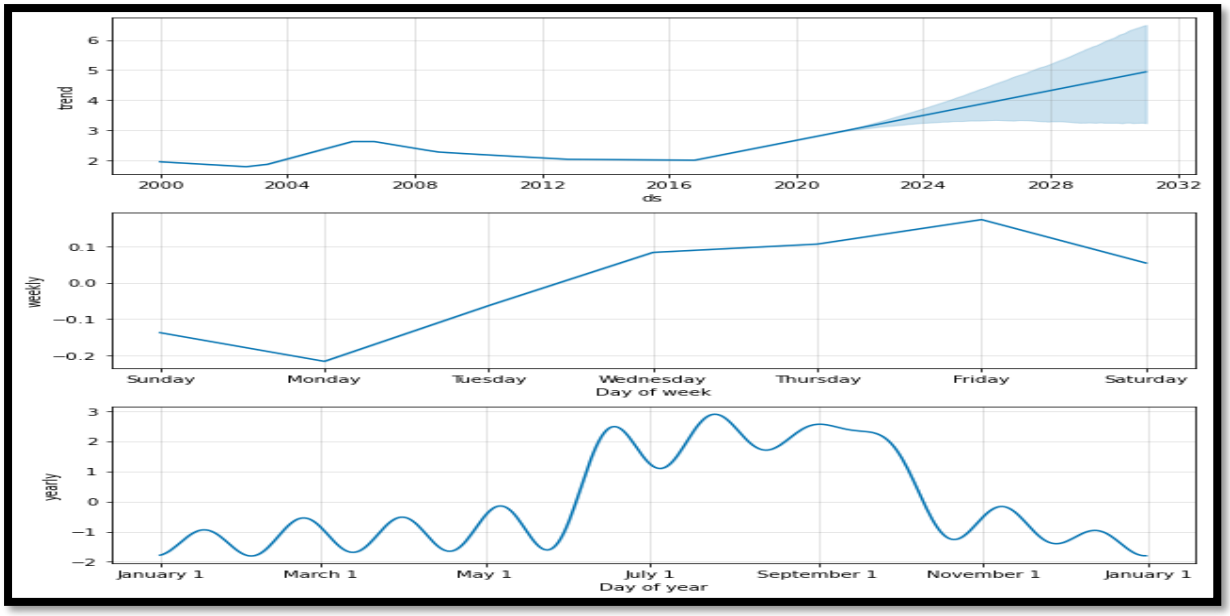

Fig 14: Trends in Forecast Plot of precipitation in Maharshtra for upcoming Ten years

Next, we detected changepoints to find out the exact time steps when the mean or standard deviation of the data changed from one value to another. This is crucial to find out climate change detection. Year 2016, was the latest change development for change in precipitation pattern in the state.

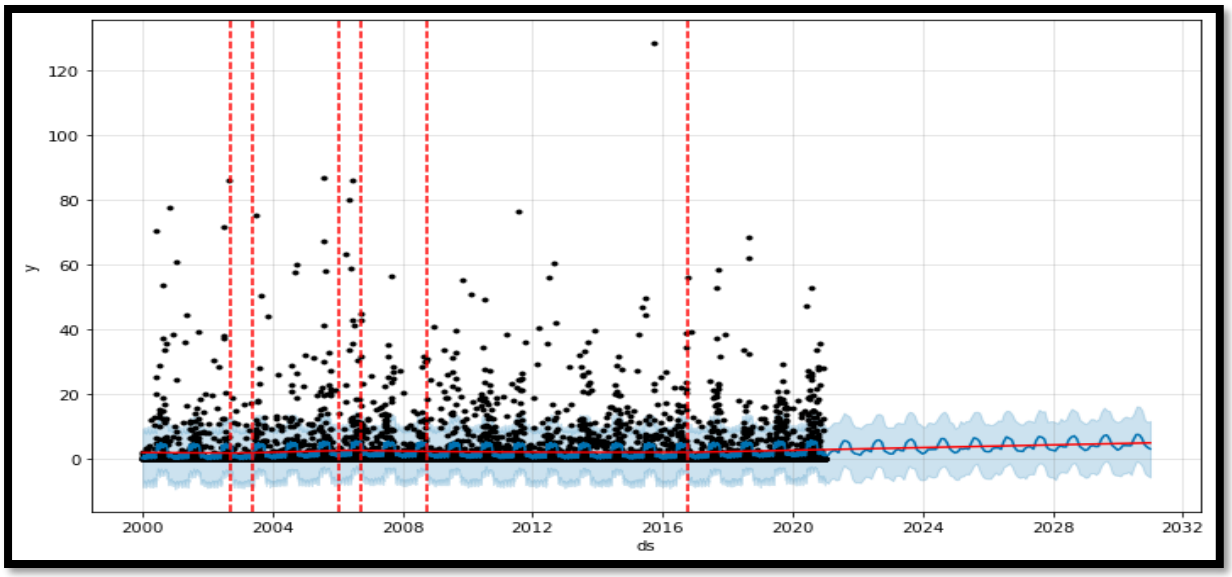

Fig 15: Detecting Change points for Precipitation in Maharashtra

I did repeat a similar process to find Tmin trends in the state and precipitation for Mumbai and Bhigwan, the current hotspot for flamingos in general. Interestingly, I found identical results for rainfall trends in Mumbai just like the state but for Tmin, it was observed that unlike rainfall, Tmin will further decrease in coming ten years i.e., from 13.22 in Jan, 2019 to 9.22 in Jan, 2029.

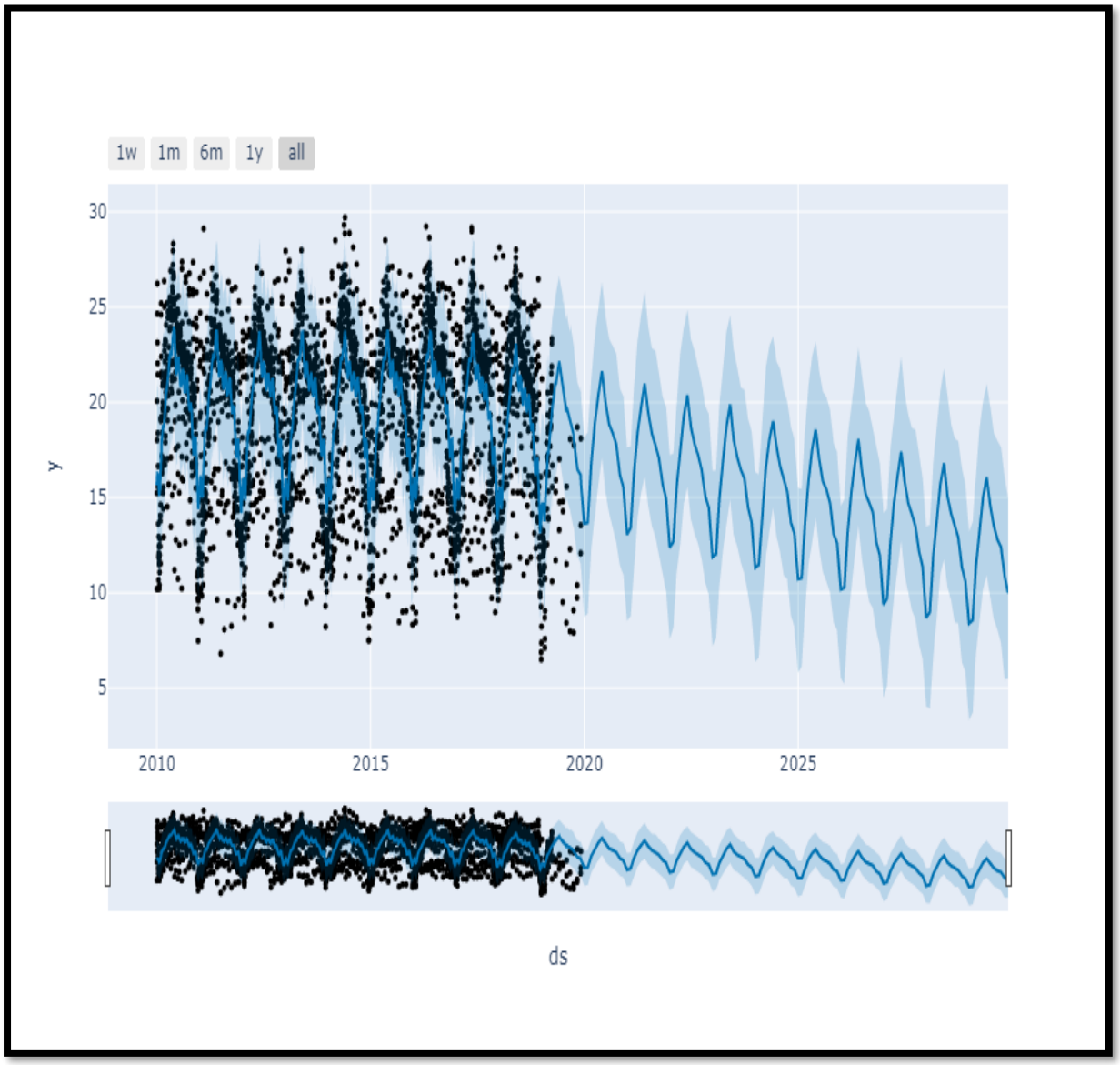

Fig 16: Interactive Forecast Plot of Tmin in Maharashtra for upcoming years

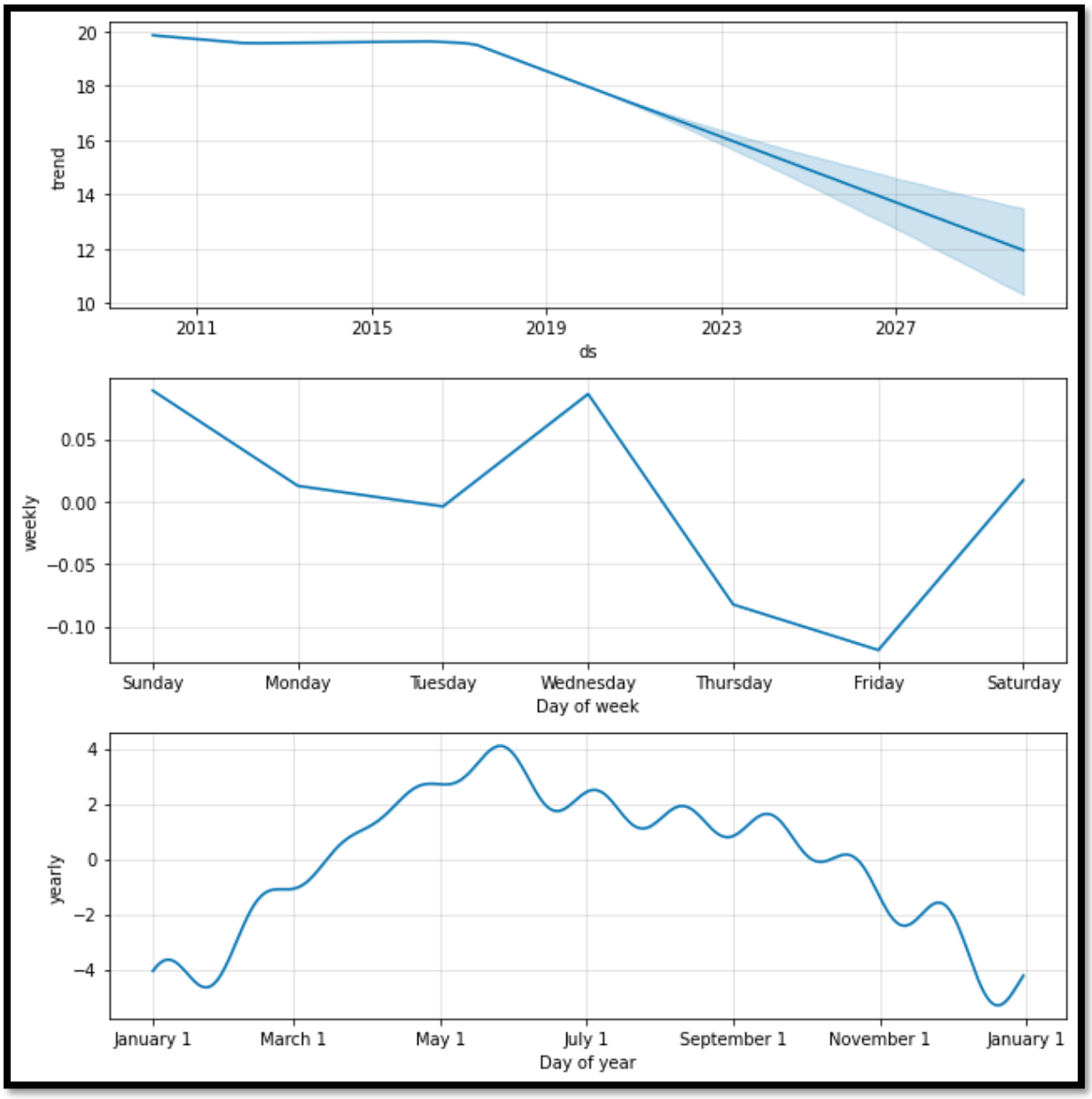

Fig 17: Trends in Forecast Plot of Tmin in Maharashtra for upcoming Ten years

The changepoints were further calculated and it was observed that steep change in Tmin occurred during the end of 2017.

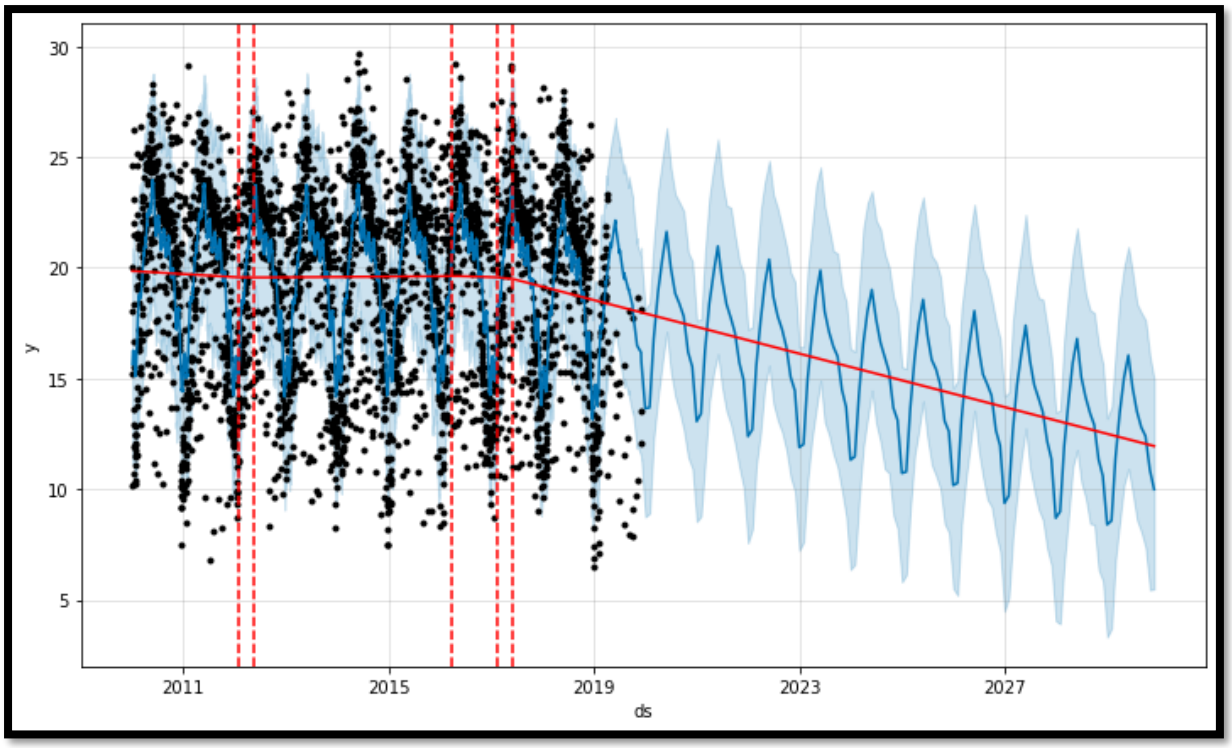

Fig 18: Detecting Change points for Precipitation in Maharashtra

Objective 3: *Calculating Spectral Indices of recent past years to assess the ecological health of the sub-study area, Bhigwan Bird Sanctuary (only known major hotspot of Greater Flamingos in Maharashtra).*

NDVI

To conclude, the thickness of vegetation aground, specialists notice the particular tones - (recurrence) of evident and close infrared light reflected by the plants. Chlorophyll holds clear light decidedly (from 0.4 to 0.7 m), yet the telephone development of the leaves immovably reflects close infrared light (from 0.7 to 1.1 m). The more leaves a plant has, the more these light frequencies are influenced. When in doubt, expecting that a pixel has basically more reflected radiation in close infrared frequencies than in recognizable frequencies, the vegetation in that pixel is presumably going to be thick and may contain some forest. If there is little qualification in the power of reflected recognizable and close infrared frequencies, the vegetation is possible pitiful and could be grassland, tundra, or desert. For our audit, we included the Conventional Difference ability in Google Earth Motor to work out NDVI from Band 5,4 of Landsat - 8. The review region has NDVI esteem ranges between - 0.2 - 0.6. It was seen that as the greater part of the site in our assessment locale has a high NDVI of 0.6,

demonstrating thick vegetation in the district. There was very little contrast between the year 2017 and 2021 in focal piece of the review region. Notwithstanding, there is distinct expansion in vegetation in year 2021 towards north east of study region.

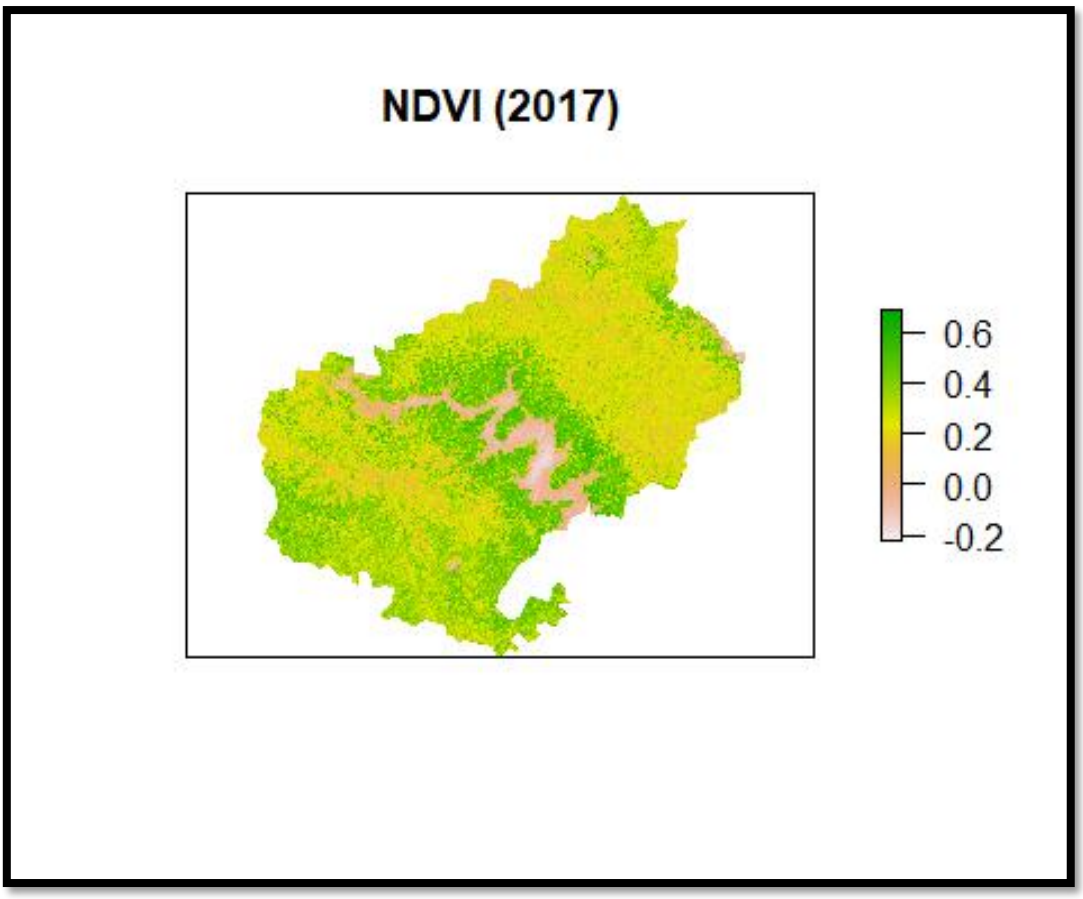

Fig 19: NDVI 2017 of Sub Study Area Bhigwan Flamingo Sanctuary

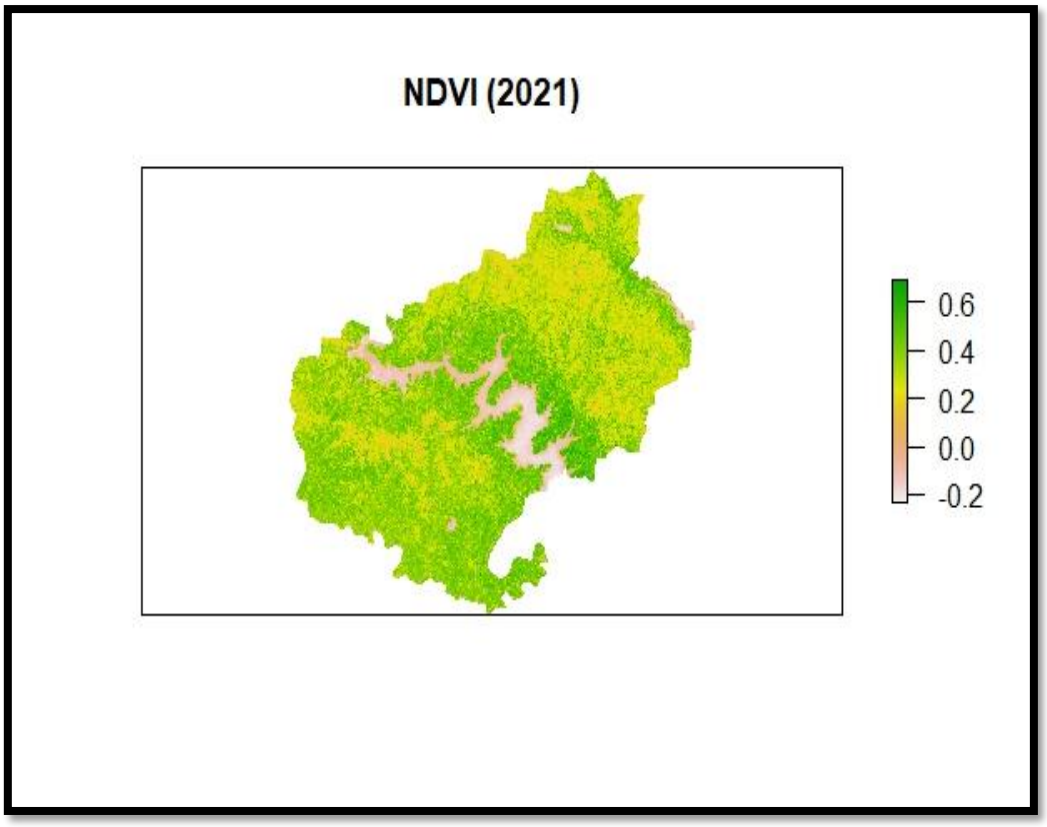

Fig 20: NDVI 2021 of Sub Study Area Bhigwan Flamingo Sanctuary

NDWI

The NDWI is utilized in satellite symbolism to feature vast water highlights, permitting a waterway to contrast the dirt and vegetation. The NDWI is utilized to follow changes in water content in waterways. Since water retains light unequivocally in the noticeable to the infrared electromagnetic range, NDWI features water bodies utilizing green and close infrared groups. It is delicate to developed land and can misjudge water bodies. The NDWI in study area was calculated using band 5 and band 3 of Landsat 8, it ranges between -0.6 to 0.2. The areas with 0.2 NDWI value denotes water body. It was observed that NDWI in northen eastern part of study area increased and we can observe more water patches in the study area.

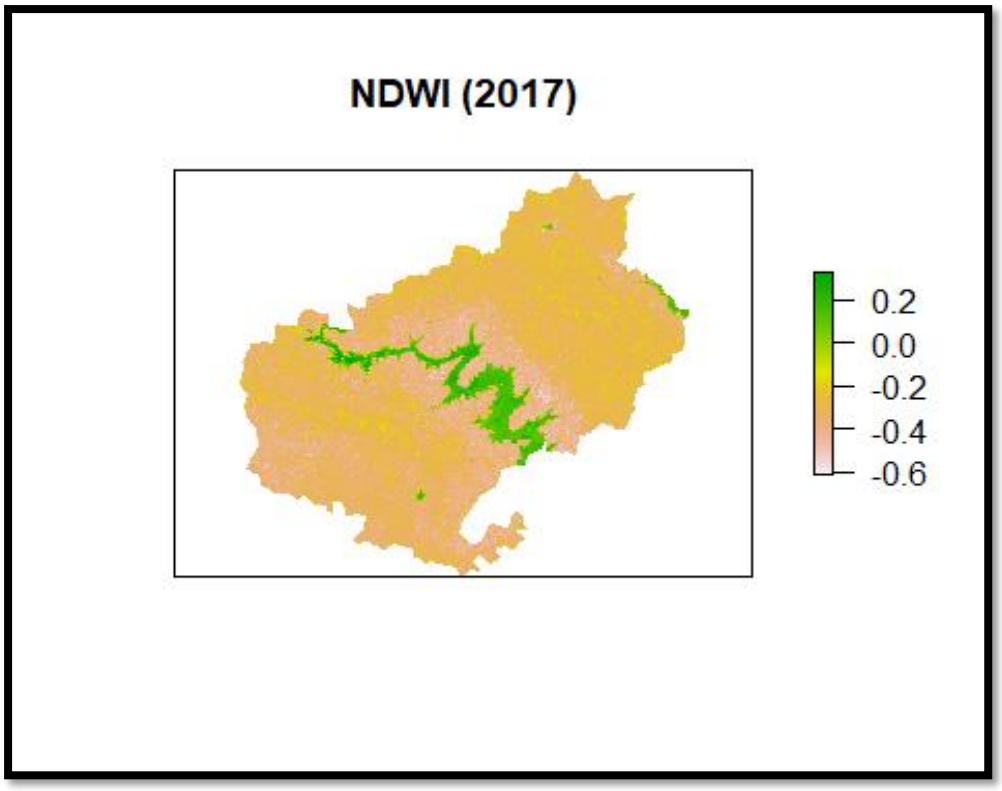

Fig 21: NDWI 2017 of Sub Study Area Bhigwan Flamingo Sanctuary

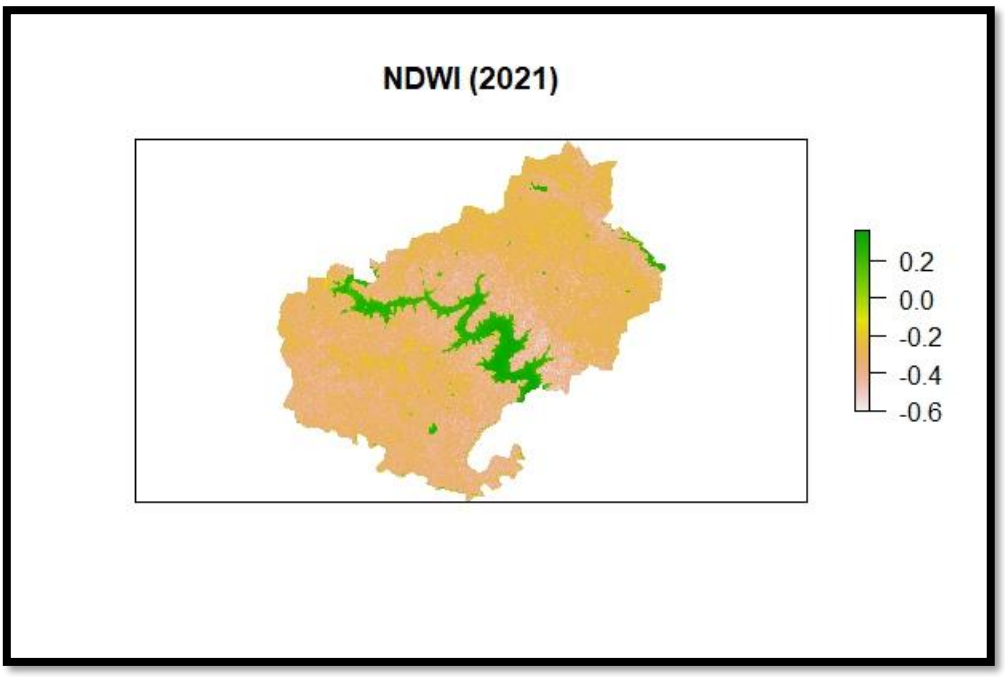

Fig 22:NDWI 2021 of Sub Study Area Bhigwan Flamingo Sanctuary

MSI:

The MSI is a reflectance metric that is sensitive to changes in leaf water content. As the water content of vegetation canopy leaves increases, so does the absorption at wavelengths around 1599 nm. Because it is nearly unaffected by changes in water content, absorption at 819nm is used as a reference. The MSI is used for canopy stress analysis, productivity prediction and modelling, fire hazard analysis, and ecosystem physiology research. In comparison to the other water vegetation indices, the index is inverted; higher values indicate greater water stress and less water content.

We can observe that in 2017 and reflectance of vegetation is high due to large vegetation cover which certainly decreased in coming years. However, MSI is in range 2 to 8 for year 2021 is extremely concerning, denoting high stress and less water content in leaves of study area.

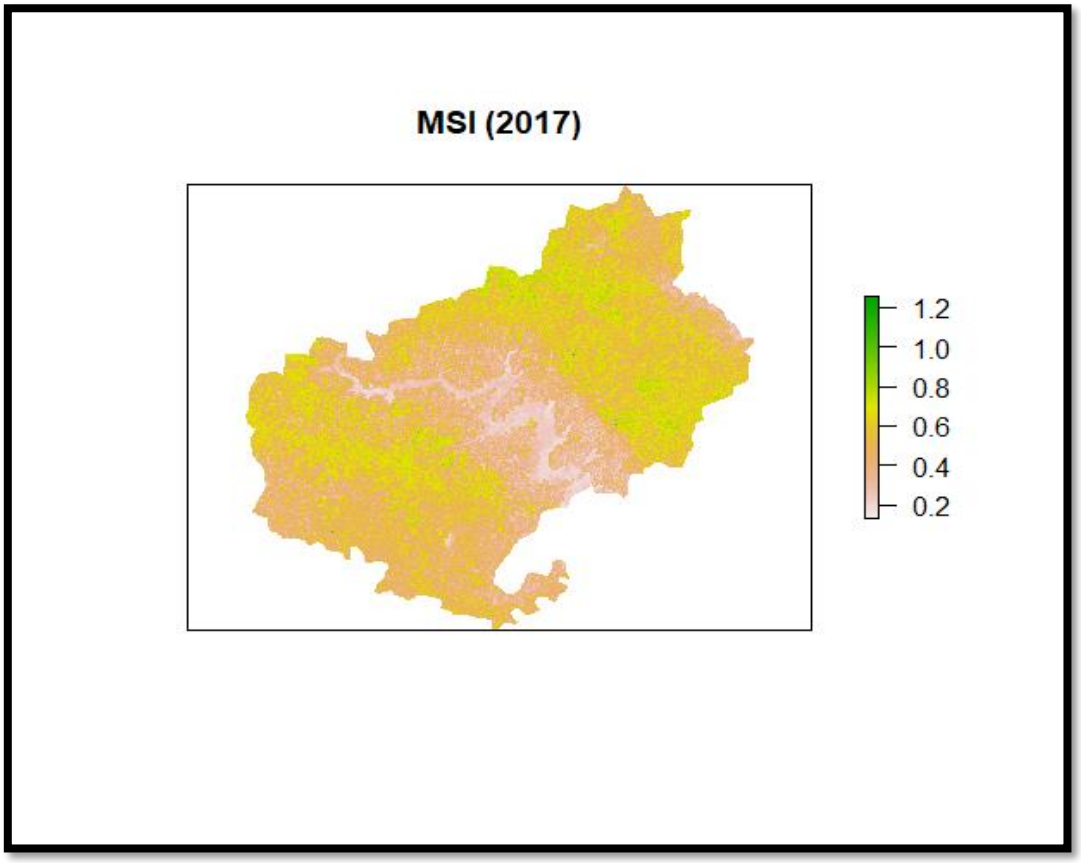

Fig 23: MSI 2017 of Sub Study Area Bhigwan Flamingo Sanctuary

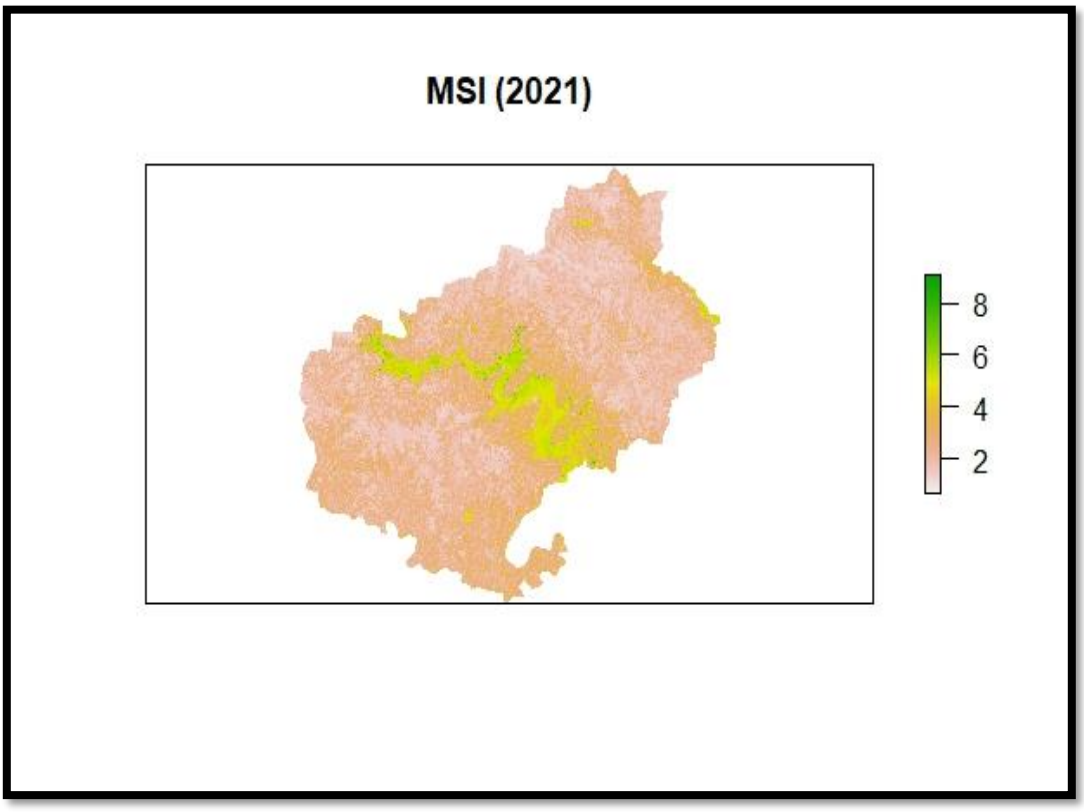

Fig 24: MSI 2021 of Sub Study Area Bhigwan Flamingo Sanctuary

SABI:

Every year, a large number of flamingos congregate in Bhigwan and the surrounding areas. Flamingos visit the study area to meet their dietary requirements; algae is a major component of the flamingo's diet. To determine the suitability of the environment for flamingos, the SABI in the study area had to be calculated. SABI values in the study area ranged from -0.0 to 1.5, with the regions near the south east of the study area at the end of the river mouth having more values nearing 1.5, indicating the presence of water column algal blooms, and the northern region, near Bhigwan Wildlife sanctuary, having values nearing 0.5 or above, indicating the presence of less algal blooms in the region. In 2021, we can see that algal blooms have decreased on the sanctuary's northern side but have slightly increased on the sanctuary's southern side.

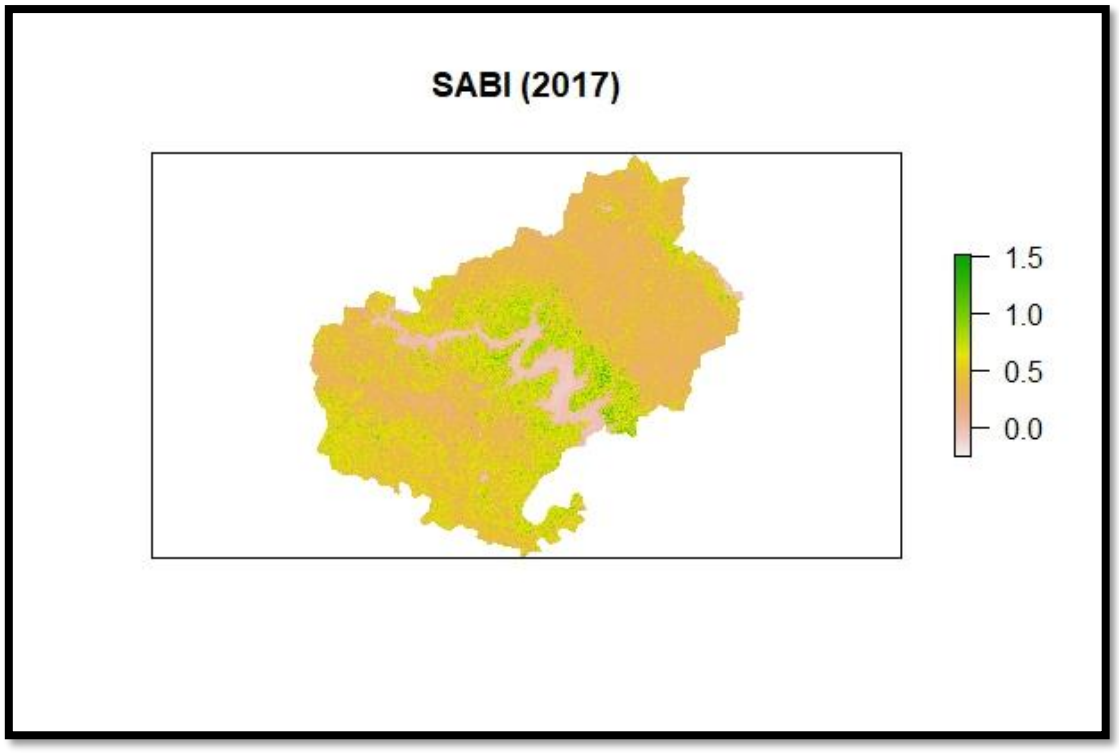

Fig 25: SABI 2017 of Sub Study Area Bhigwan Flamingo Sanctuary

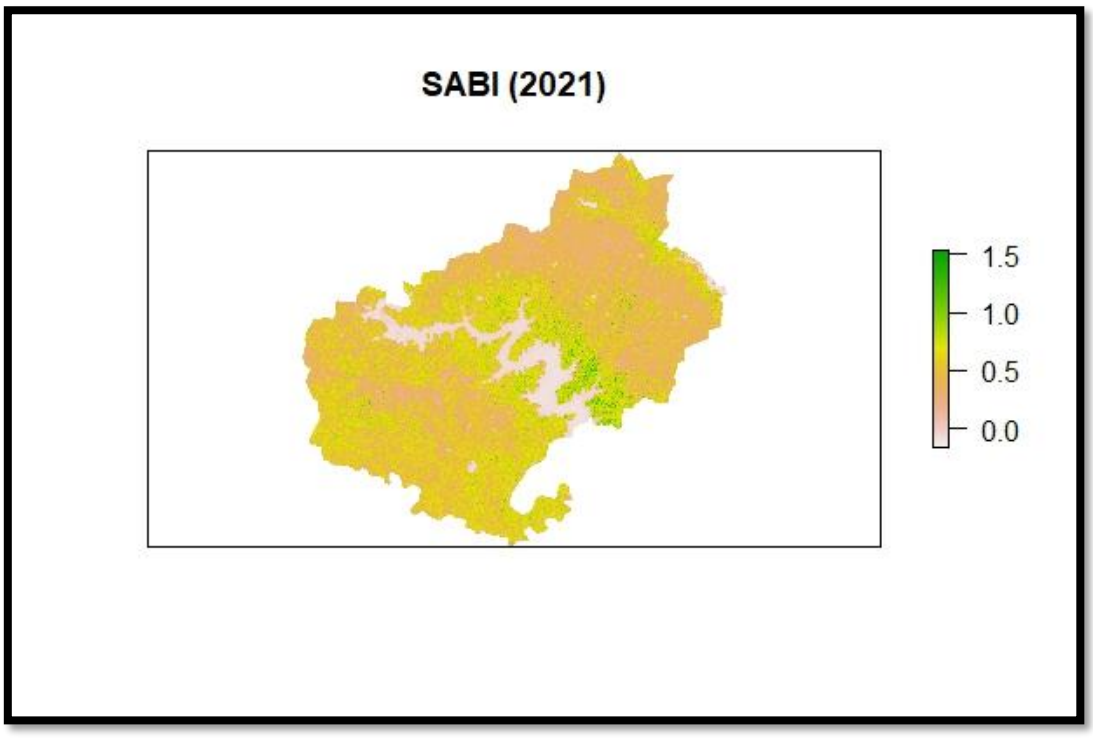

Fig 26: SABI 2021 of Sub Study Area Bhigwan Flamingo Sanctuary

DISCUSSIONS

The number of migratory birds has declined dramatically worldwide since 1970 (Wijewardhana, U. A., Meyer, D., & Jayawardana, M., 2020). The key driver of migratory bird abundance decline is climate change and unsuitable habitat. (Jacome et al., 2019). Climate change deteriorates the region's suitable environmental conditions for certain species, resulting in a shift in their geographic range (Keogan et al., 2018, Saino et al., 2011). Birds are essential to ecosystems. There are two kinds of flamingos found in India: Greater and Lesser Flamingo. The IUCN[1] has designated Greater flamingos as a species of least concern (IUCN) and Lesser Flamingos as Near-Threatened (IUCN). As suggested by scatter plot of current distribution of Greater Flamingos, species *Phoenicopterus roseous* prefer tropical climates. That is the main reason why, once the species has finished breeding in Gujarat, they tend to migrate to Maharashtra, feeding grounds, to avoid harsh winters and to fulfil their dietary needs in shallow waters. From a through literature review, we could deduce that species prefer areas with moderate rainfall, shallow waters, such that species could easily feed on the staple diet, algae. Emerald Pellot discussed climate change and its threat to the world's flamingo population in a 2009 article published in Yahoo's "In the Know" section. She reported, heavy rains in Kenya Wildlife Sanctuary, make it difficult for algae, which flamingos feed on, to survive. Also, a very extreme winters is not what species prefer. Study titled, "Impacts of extreme climatic events on the energetics of long-lived vertebrates: the case of the greater flamingo facing cold spells in the Camargue," deville et al., 2014 discussed how cold spells kill adult flamingos within a population, and thus have profound effects on population dynamics; a similar case for flamingos in the Camargue has also been highlighted by Johnson et al., 1991. In an eye-opening survey of the Bombay Natural History Society (BNHS[2]) it was observed that between May 2018 and May 2019 there was a slight decrease in the number of Greater Flamingos during the same time period.

Species distribution models (SDMs) join experimental information on an animal groups' events or overflow with information on ecological elements. For our review, we used GLM (Summed up Direct Model), to identify appropriation of More noteworthy flamingos across province of Maharashtra under CMIP future environment situations for next 50 years. (Coetzee et al., 2009; Elith and Graham, 2009; Marmion et al., 2009; Morin and Thuiller, 2009; Thuiller

[1] IUCN-International Union for Conservation of Nature
[2] BNHS-Bombay Natural History Society

et al., 2009b; Aertsen et al., 2010; Kampichler et al., 2010) specifies model execution normally fluctuates for various cases (various species with various topographical and natural disseminations. The AUC worth of 0.685 for our model signified adequate model legitimacy. Be that as it may, as examined prior by, (Segurado and Araujo 2004), no single model is best for all cases. More straightforward models work best in certain circumstances, particularly when the review region is little (e.g., on a mountain slant with a dull height slope). With only two boundaries being main issue, I went with Summed up Straight Model for the review region.

The short-term trends for climatic parameters in the study area for the coming year overlap with the forecast story for long-term situations in the study area. For our time series analysis result, we discovered that rainfall will undoubtedly increase in the state of Maharashtra in the next five to ten years. The findings were similar to another study on extreme rainfall and flood risk in India conducted by a team of scientists Meteorology (ITM) in Delhi, which discovered that the frequency of heavy rainfall events is decreasing in major parts of central and north India while increasing in peninsular, east, and north east India.

From the results of objective first, it can be established that the current feeding grounds of Greater flamingos may not be the apt fulfilling source in future. The species will move towards south and central parts to fulfill its dietary needs. However, in order to obtain a comprehensive picture of suitable habitat for flamingos, we went on to assess the ecological health of the most pre-dominant presence area of Greater flamingo *(Phoenicopterus roseous)*. While we recorded many observations for the species throughout the Maharashtra study area, Bhigwan Bird Sanctuary has the most records for Greater flamingo *(Phoenicopterus roseous).* According (Gupta & Pandey, 2021), spectral indicators aid in determining forest health at various scales. From our results for objective three we can clearly see that ecological health of Bhigwan Bird Sanctuary is in deteriorating state. Apart from climatic factors anthropogenic factors has great role to play. A stark decrease in leaf water content in Bhigwan is extremely concerning and need urgent attention from authorities.

CONCLUSION

Evaluating the effect of climate factors on species distribution is of considerable significance to species conservation. The GLM model results made it clear that environmental conditions are extremely important for species occurrence. A negative P value for rainfall in study area indicates towards diminishing occurrence of Greater flamingos with increasing precipitation. The AUC value of 0.685 denotes acceptable model validity. Also, with increasing global warming and more pollution, the climate for the species will not be favorable in the future in the study area.The current feeding grounds of Greater flamingos may not be the apt fulfilling source in future. The species will expand its range in the study area, it will move towards south and central parts to fulfill its dietary needs in future. Based on the results, the future of species seems bleak in the country.

The short-term trend of ten years with increasing precipitation and decreasing Tmin in state of Maharashtra, further depicts unfavorable conditions for presence of Greater flamingos in near future. It clearly indicates unfavourable conditions of Maharshtra being a feeding ground in recent future. In NDWI and NDVI of year 2021, we can observe significant decrease in NDVI and NDWI towards east of study area from year 2017. High reflectance of MSI in study area denotes high extent of vegetation in study area in year 2017. Notwithstanding, values till 1.2 signifies high pressure and less water content in leaves of study area.SABI values went from -0.0 to 1.5, with the districts close to the south east of the review region toward the finish of the stream mouth having more qualities approaching 1.5, showing the presence of water section algal sprouts, and the northern locale, close to the Bhigwan Untamed life safe-haven, having values approaching 0.5 or above, demonstrating the presence of less algal blossoms in the region.Hence, with reducing water assets and algal blossom inside a time of 3 years, we can derive that natural circumstances for taking care of ground of flamingos is in weak state and preservation moves ought to be made at earliest.

Based on the results, the future of species seems bleak in the country. The now least concern species, is migratory, joins links between different climatic landmasses. Hence, apt conservation efforts should be taken for the Greater Flamingo species in Maharashtra.

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