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RESEARCH ARTICLE

Investigation of cluster-based cyclone track pattern within the Bay of Bengal

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ABSTRACT

Bangladesh is a highly disaster prone flat land country in south Asia. 80% of the disaster comes from cyclonic disaster around this area. To investigate the damage risk due to the cyclonic event around the Bay of Bengal associated with the cyclone track (CT) is an important issue. The present study has extensive analysis on generating a most favorable track along the Bay of Bengal from the MRI-AGCM cyclone track data. We have investigated present (1978-2003) and future (2075-2099) track data from the MRI-AGCM data set to ensure the synthetic track for the present and future climate conditions of Bangladesh. A k-mean clustering technique has been applied to investigate the synthetic track for the present and future climate condition. This work may insight the changes in cyclone track patterns in both the present and future climate conditions with the global warming scenario. This study has found that the Sundarbans and its adjacent areas are the risky coastline area of the landfall zone and for the global warming scenario it will be shifted to the Odisha area in India.

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Introduction

Bangladesh is a riverine delta-shaped country in south Asia. Since the country is the world's number one densely populated country, the number of deaths by natural disasters is higher than other countries in the world. According to the Intergovernmental Panel on Climate Change (IPCC, 2014) the sea level rising trend is 1.5 mm/y for Bangladesh. In future, Bangladesh will be one of the worst ruined countries due to its disaster prone and low elevation geography. Moreover, the tropical storm is a poisonous snake for this country. Therefore, to investigate its path is highly desirable which can reduce the damages and the death toll for human beings. This region faces an increasing number of tropical cyclones associated with the surge and torrential rain causes coastal flooding that can increase the death toll. Most of the notable cyclones around the coast of Bangladesh are 1970, 1985, April 1991, 1997, SIDR 2007, Nargis 2008, AILA 2009 and MORA 2017 (Mizanur Rahman et al., 2011). In the Bay of Bengal, cyclones always move in the north-westerly direction to hit the coast of Bangladesh and India. For this region, the destruction due to the storm surge flooding is a serious concern along the coastal regions of India, Bangladesh and Myanmar. Numerical modeling of storm surges associated with tropical cyclones in the Indian seas has been confined to the Bay of Bengal (Ramsay et al., 2012; Saha, 2015; Gayathri et al., 2016; Al Mohit et al., 2018a, 2018b; Sahoo & Bhaskaran, 2018; Paul & Ali, 2019; Li et al., 2020; Mishra & Vanganuru, 2020; Murty et al., 2020; Rehman et al., 2021; Al Mohit & Towhiduzzaman, 2022; Uma & Sannasiraj, 2022). These studies were adequate for storm surge simulation, but inadequate for track forecasting in this region. Due to the funneling shape of the coastal region of Bangladesh, increasing the probability of storm path makes this region more devastating and that's why it's important to find out the probabilistic storm track. According to (Szczyrba, 2022), there are 26 average number of cyclones occurred globally and 17 of the Pacific Ocean (PO), 10 of the Atlantic Ocean (AO), 9 of the South Indian Ocean (SIO), 5 of the North Indian Ocean (NIO) and 3-5 of the Bay of Bengal (BoB) region per year. The probability of landfall depends upon the storm track and its need to better understand in order to identify the aspect of its life cycle. The worth mentioning work of cyclone track analysis (Chen et al., 2013; Ying et al., 2014; Zhu et al., 2016; Gao et al., 2018; Giffard-Roisin et al., 2020; Wang et al., 2022) was carried out at some different basin around the world. All of the studies were concentrated for the individual basin with their aspects. Their constructed cluster range was 3 to 6 which was not optimal for the accurate prediction. Several methods have been developed to forecast the cyclone track position around the NIO for disaster management. Some useful track prediction techniques were developed by (Gao et al., 2018) and it was found that the track prediction error has not reduced in this area. The dynamical track forecasting model has some difficulties to forecast accurately such as advective, adiabatic and frictional effects. Giffard-Roisin et al. (2020) forecasted the track for 24 hours and 72 hours using deep learning, but the studies could not escape large forecasting errors.

Currently, the clustering method is a useful tool to fit the geographical shapes of the projected tracks. The present study concerned the k-mean clustering method to investigate the more probabilistic track along the Bay of Bengal with present and future climate conditions. K-mean clustering developed on the regression mixture model that tends to find clusters of comparable spatial extent, while clusters arrange expectations and maximization through different shapes. The past study of cluster technique on track detection has been carried out from the regression mixture model (Kowaleski & Evans, 2016). Current research eliminates the limitations of previous research and the second approach of the regression mixture model has been implemented in the present study. We have found the probable future track shifted to the Odisha area in India.

In this study, we have applied the updated regression mixture model approach to the MRI-AGCM present data (1978-2003) and future (2075-2099) data set and find the synthetic track along this region. This article is organized through different sections. Section 2 represents the data pattern and policy. Section 3 provides the information about material and methods. Section 4 shows the discussion about the outcomes and conclusion.

Material and Methods

Data and Location

Japan Meteorological Agency (JMA) and the Meteorological Research Institute (MRI) jointly develop a new operational numerical weather prediction model known as MRI-AGCM (Murakami et al., 2012). A semi Lagrangian three-dimensional advection scheme was used for accelerating the time integration (Kitoh & Endo, 2021) with 20 km horizontal grid spacing and 60 level altitude 0.1 hPa vertical grid spacing. The time-slice method was used for the higher resolution (20 km) AGCM experiment. The time-slice method has two layers, the global warming projection system that consists of an

Atmospheric-Ocean General Circulation Model (AOGCM) and the higher part of the vertical level AOGCM generated by AGCM. The present day climate condition simulates 25 years' data from 1978 to 2003 associated with observed sea surface temperature (SST) (Varghese et al., 2020). The future climate data simulation was conducted from 2075 to 2099 years' data. All these works were based on the boundary SST data and the data were prepared with three different stages. At the first step, the Couple Model Intercomparison Project 3 (CMIP3) multi-modeled data set was used to project the Multi-Model Ensemble MME of SST. The second stage represents the linear trend in MME of SST that projected the MIP3 data set. At the third step, a difference between 20th century experiment of the Intergovernmental Panel on Climate Change (IPCC) fourth assessment report (IPCC, 2007a, 2007b) and future simulation under the special report on Emission Scenarios (SRES) A1B emission Scenario (Nakicenovic et al., 2014) in MME of SST. After receiving the simulated data from AGCM, we have separated the necessary data for our study domain. Our study domain is bounded by 50N-270N latitude to 700E-1000E longitude and this area was classified with four different areas according to the classification of cyclone lifestyle. The Figure 1 shows the study domain area for the current research which includes the Bay of Bengal and Indian region.

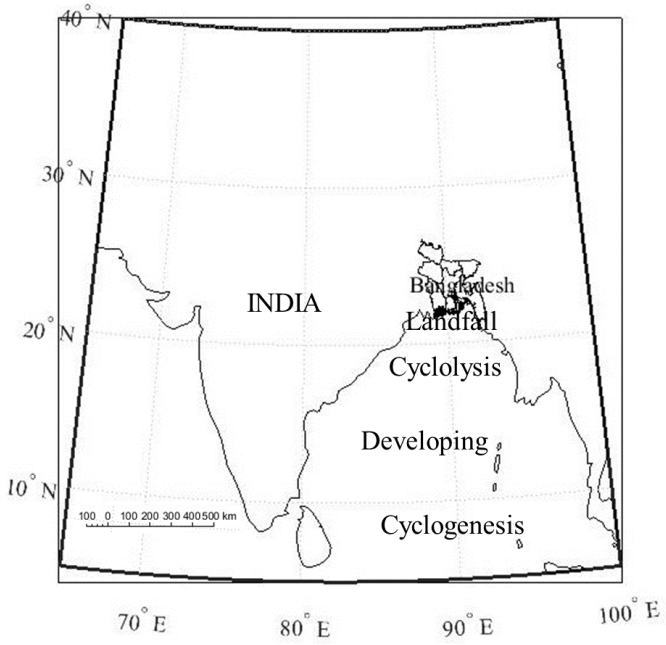

Figure 1. Study domain regions with different classified areas

We have isolated the individual cyclone track from the present (1978-2003) and future (2075-2099) data set which was used for the analysis. Current climate conditions mean storm data from 1978 to 2003. On the other hand, storm data from 2075 to 2099 are identified as future storms. Basically, climate change is assumed to be due to global warming by expecting a 2-degree.

Methodology

To find the homogenous group of objects for a data set is important. So, the clustering method is useful for finding the homogenous group of data. The present research concerns the useful clustering method known as k-mean cluster. The improved k-mean clustering method describes as

$$J = \sum_{i=1}^{C}\sum_{k=1}^{K}(\mu_{ik})^m \|X_k - C_i\|^2 \quad (1)$$

Where, $\mu_{ik} = \left[\sum_{j=1}^{C}\left(\frac{\|X_k - C_i\|^2}{\|X_k - C_j\|^2}\right)^{\frac{2}{m-1}}\right]^{-1}$ and $C_i = \frac{\sum_{k=1}^{K}(\mu_{ik})^m X_k}{\sum_{k=1}^{K}(\mu_{ik})^m}$

Here, μ_{ik} is the membership coefficient, C_i is the ith cluster center.

The k-mean algorithm represents the process of the fundamental working procedure. Choosing a data randomly from the data set to consider as a centroid and then compute the distance from each observation and centroid. When the allocation of an object to another cluster decreases within- the cluster variation and the data is assigned to that cluster. After that, their center is changed based on the next feasibility. The previous process is repeated until there is no change in cluster membership. The next section describes the process to utilize the method to find the cluster of the track data. This process may be helpful and useful because the time requirements facilities are linear, less affected by outliers and the homogeneity, heterogeneity makes optimizing the final solution. Furthermore, we may apply to very large data sets since this process has no computation demand (Xu et al., 2020).

Determining the optimal cluster is important because the morphology of the k-mean cluster depends on the choice of cluster number. According to Kaufman, Silhouettes are an important factor for measuring the gumminess and validate the cluster data speardness. Basically, the considerable silhouette coefficient values are from -1 to +1 range and the value determines the cluster number. In this study, silhouette value analysis shows that the five numbers of clusters are important for the cluster analysis.

We have applied this process for all the designated areas like genesis, cyclolysis and landfall. The same cluster number is used in all the areas like genesis, cyclolysis, landfall to reduce the complexity of cluster technique. The fewest number of data shows the negative silhouette values that represent the inhomogeneity with that cluster data. We have several times

run the procedure of clustering to minimize the negative silhouette values. Finally, reduce track points which are outlier. In this study, the mean silhouette values are represented as cluster3<cluster<4<cluster5 and we consider the mean silhouette values is 0.5445 to get the best solutions.

Numerical procedure

The aim of this study is to find the k-mean cluster based synthetic track detection from the available track data. So, for this reason we have collected the data from the Atmospheric Global Circulation Model (AGCM) 1978 to 2003 (Present) and 2075 to 2099 (Future) global track data. The track data is six hourly interval data with the information on wind speed and barometric pressure. The track data was then separated from the original data set to be useful for the target region. After that, we find the individual tracks for different years. The twenty-five years track data 1979 to 2003 was then separated in each year to better analyze their activities. Using the same approaches, we have applied the future track data for investigating the future cyclone activity and the synthetic track with future climate conditions. Based on this same theory, the number of storm events in the current climate condition is upwards, but the rate of cyclone genesis in the future will be higher due to the future climate condition and the number of storm events is slightly lower. From the eye point of the storms in each cluster, it appears that the genesis is shifting to higher latitudes. However, various studies have shown that the Power Dissipation Index (PDI) and Accumulated Cyclone Energy (ACE) of the future storm will be a little higher (Knutson et al., 2010). And that's why we want to find a synthetic track that will explain the direction of a storm for a lot of importance for Bangladesh. For this reason, find a more probabilistic cluster zone from the k-mean cluster. After that, find the probability density from each data point of the probabilistic cluster zone by using the equation (2).

$$P(x) = f(x|\mu,\sigma) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \text{q} \quad (2)$$

where μ and σ represent the mean and variance of the data point.

Finally, find the maximum probabilistic point from the cluster zone and the similar process applies for the individual cyclone area like developing area cyclolysis area and landfall area. Based on those probabilistic points we make a new synthetic track which is a cluster base probabilistic synthetic track. Both present and future climate conditions we have found the synthetic track for the Bangladesh region.

Results

We have some output and some valuable information after analyzing the cyclone track data. From the data of MRI-AGCM3.2, we found the Event, genesis occurrence and their trend of a cyclone that struck the Bay of Bengal Coast. At first, we separated the global data to a regional data (study area). After that we have separated the cyclone track data from each climatic condition data. For the present scenario and the future scenario of three cases C0, C1, C2, we have separated the cyclone track data. After that, we have analyzed the data for various criteria. Before that we have checked the track information with observed track information. We have checked the seasonal behavior of observed data and the simulated data.

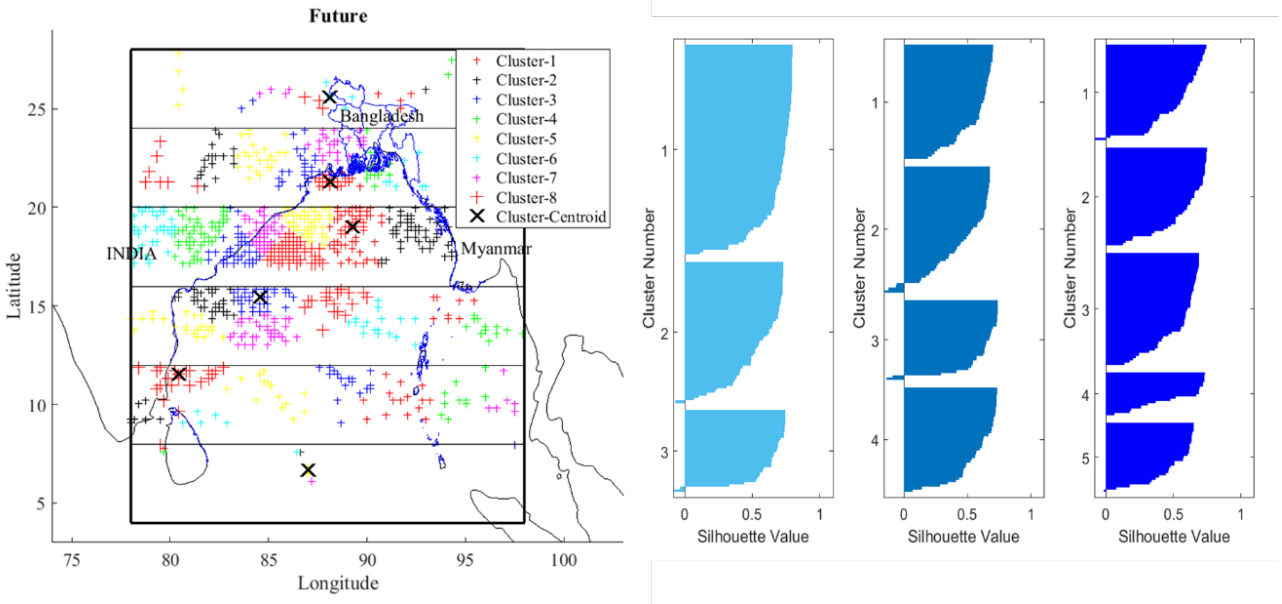

Figure 2. k-mean clustering and silhouette value

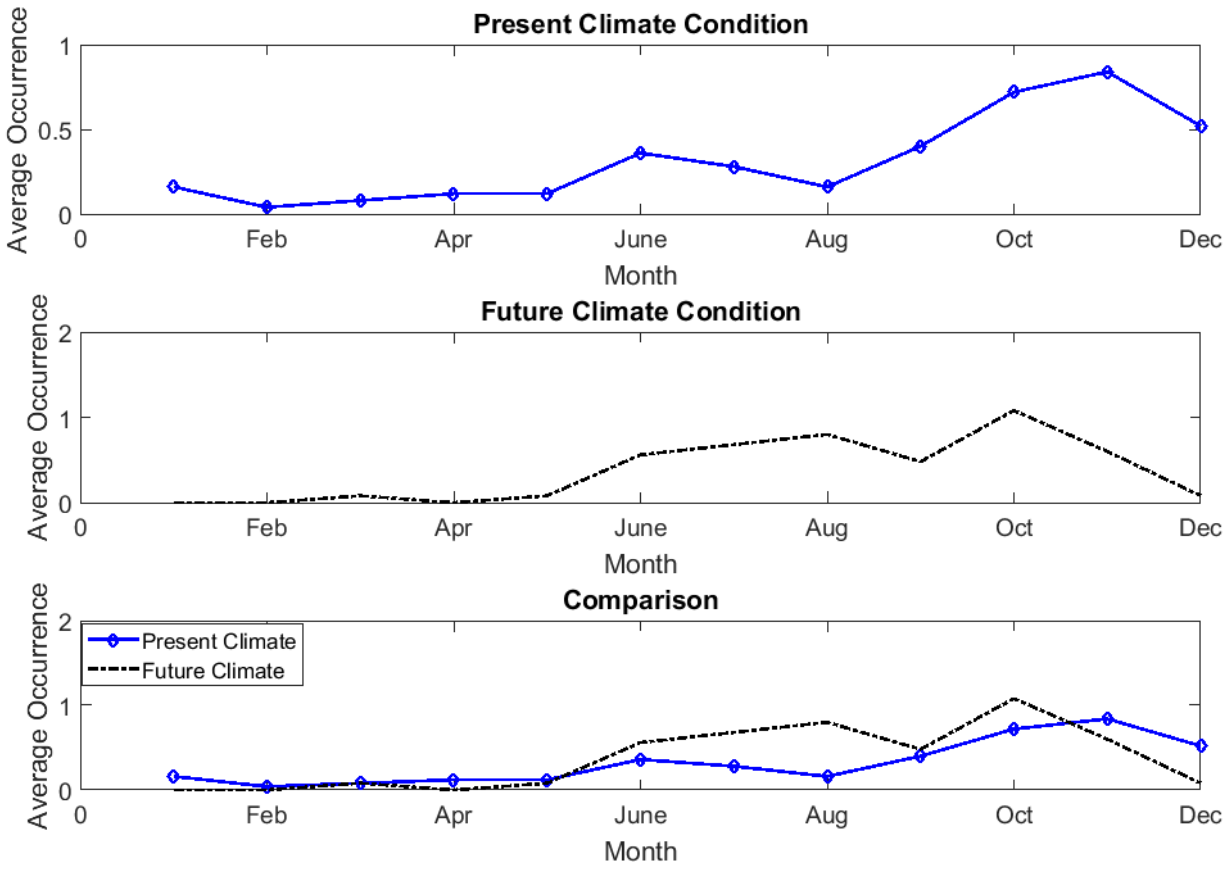

Figure 3. Cyclone occurrences along the Bay of Bengal are associated with different climate conditions and their comparison

Figure 3 demonstrates the yearly averaged monthly event of the storm where it is reflected that the month of November for the Bangladesh region is a very probable month for the cyclone. On the other hand, February is the lowest probable month for a cyclone event.

The Figure 4 shows the Event, genesis occurrence and their trend in present and future climate conditions. The left column and right column are cyclone activity for the present and future climate condition, and the consecutive downward figure shows the Events, occurrence trend and genesis trend respectively. The result shows the increasing trend of cyclone genesis in the future that is lower than the present climate condition. We also review the storm's monthly activity to make a clearer view, which shows the cyclone seasonality.

Basically, we will create a suitable synthetic track based on current and future climate conditions which will play an important role for the people of the coastal region of Bangladesh. This study also found that, the sea surface temperature SST which plays an important role in increasing the event along the coastal region of Bangladesh. There is some correlation between SST and the frequency and intensity of tropical cyclones in Bangladesh (Ying et al., 2014). The figure 5 represents the SST changes along the Bay of Bengal. This figure can help to understand the cyclone event under the present and future climate conditions.

The left of the figure is based on the current climate of 2003 and the right-side figures are on future climate conditions of the year 2099. To ensure the future SST, the simulations used to obtain data on future storms simulated changes in SST assuming global temperature increases of up to 2 degrees. From the figure we have seen that the SST of current climate conditions is the upward trend that represents the trend of growing uncomfortably than the future SST behavior. According to the concept, we have applied mathematical and statistical methods to find the path of a cyclone for present and future climate scenarios. Table 1 shows the estimated path of a cyclone. Here we have used only the Longitude and latitude information to find the cyclone path.

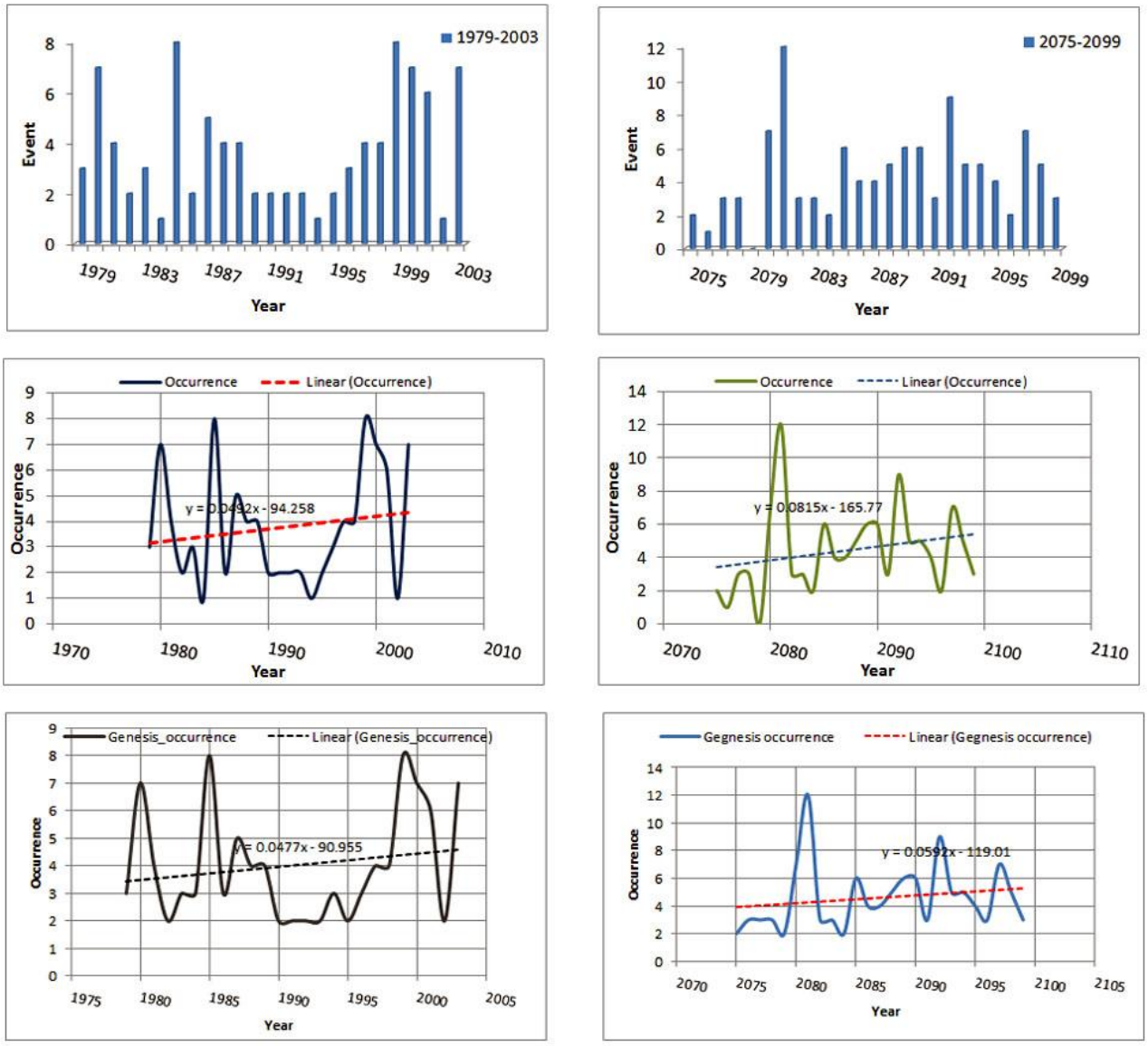

Figure 4. A simple statistical activity analysis of present and future climate conditions along the Bay of Bengal

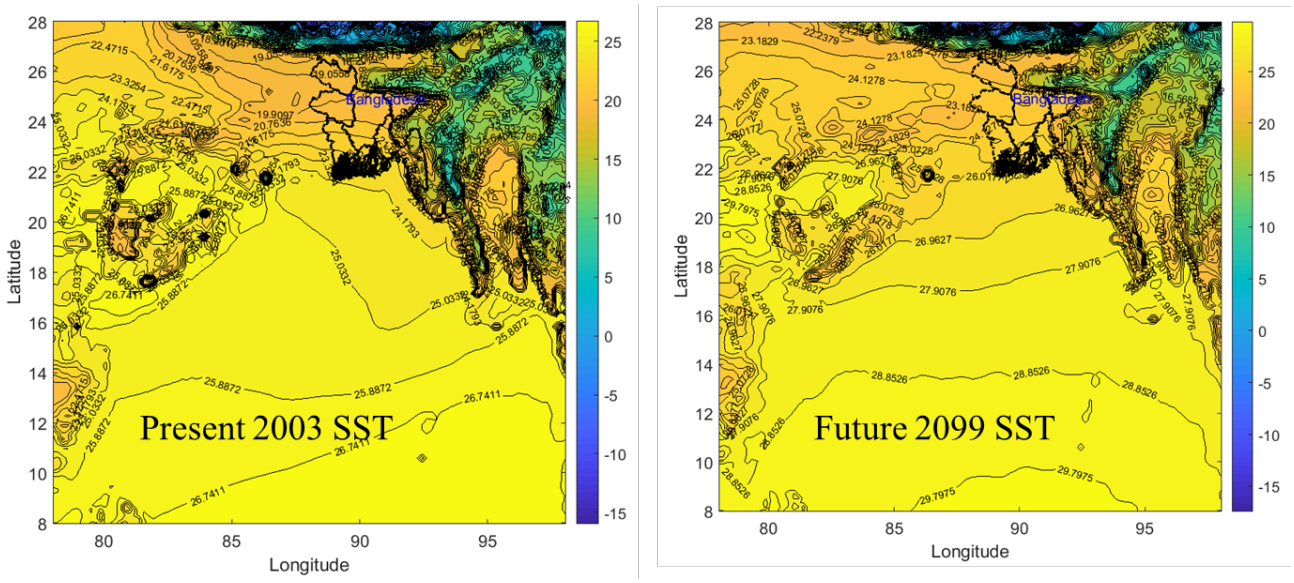

Figure 5. SST condition at present and the future climate scenario

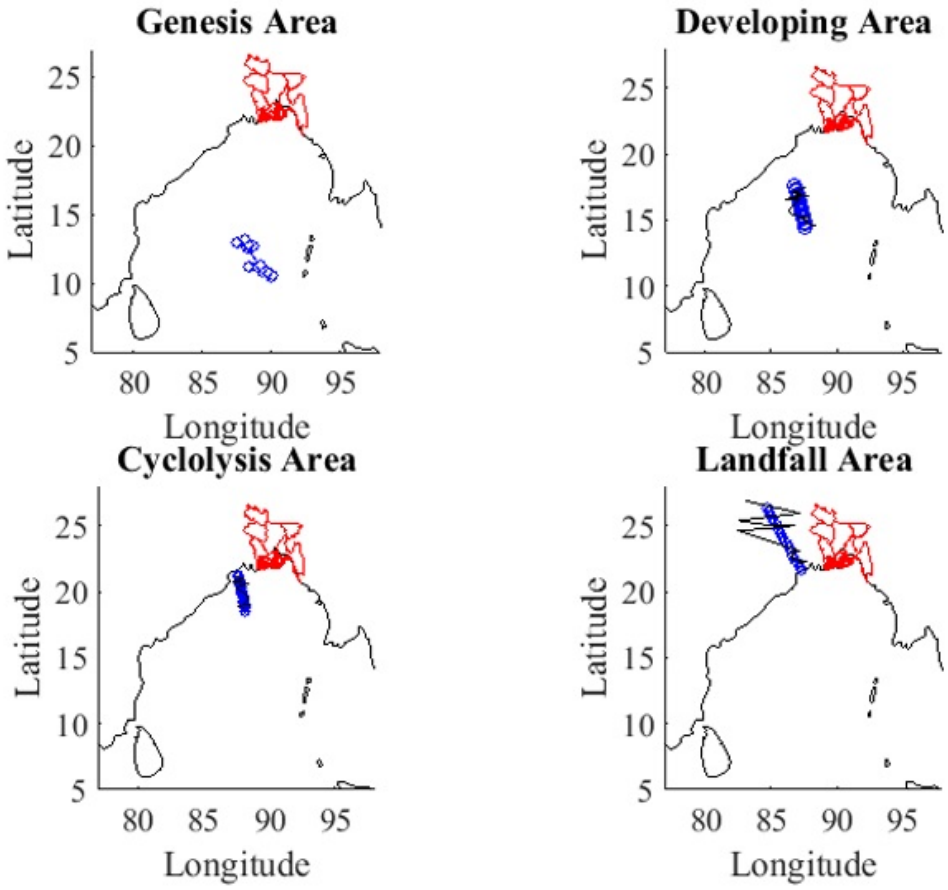

Figure 6. Clustering data of cyclone track data in different stages for present climate condition

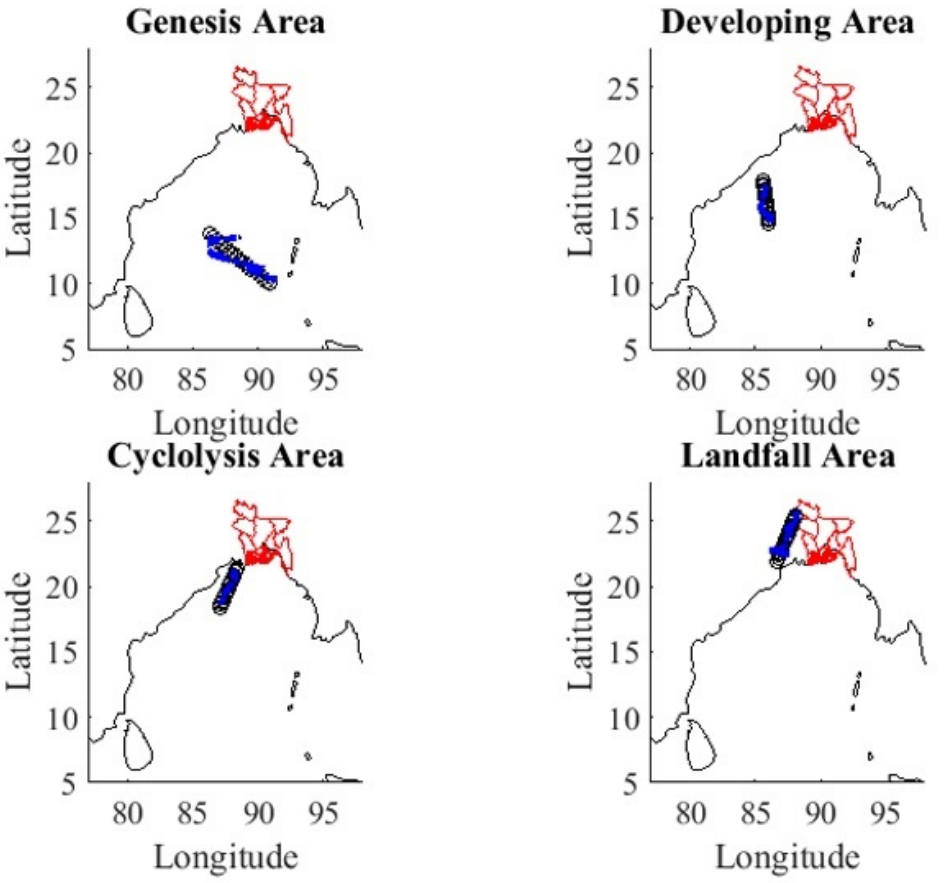

Figure 7. Clustering data of cyclone track data in different stages for future climate condition

Table 1. The estimated path of a cyclone

Life Cycle of Storm	Eye Point	Present Climate	Future Climate	Future Climate C1	Future Climate C2	Future Climate C3
Cyclogenesis	Latitude	7.41	6.65	7.31	7.31	7.41
	Longitude	96.00	87.00	84.56	90.28	89.62
Developing	Latitude	10.97	11.53	11.43	9.8	10.41
	Longitude	90.17	80.44	96.56	80.71	81.56
Mature	Latitude	13.97	15.47	15.37	15.09	15.66
	Longitude	81.56	84.56	85.69	84.75	83.81
Cyclolysis	Latitude	18.84	19.03	18.28	18.09	18.66
	Longitude	81.19	89.25	84.46	84.94	83.81
Landfall	Latitude	21.84	21.28	22.22	22.22	22.03
	Longitude	88.50	88.12	89.81	87.56	86.25

Discussion

In our research we were looking for a significant storm track that we could predict mathematically and statistically. Therefore, we extract and analyze storm track information from climate simulation data and collect storm data at different stages of the storm's life cycle, such as cyclogenesis, development, maturity, cyclolysis, and landfall, using a reliable method k-mean clustering method.

From the collected data we determine the probable location of the probable storm. Since the storm data is random, we see variations in the trajectories. For example, the genesis region of storms is found somewhat closer to the equator at present. But, for future storms, the genesis region of the storm is slightly higher i.e., at a higher latitude Figure 6 shows the direction of change in the path of storms based on the results obtained by the k-means clustering method during the lifetime of current storms.

Similarly, from Figure 7 we can see the likely location of future storms. However, for current and future storms in the Developing and Mature stages, they are much more stable and the separation of their position changes is much less. However, the tendency of the storms to strike is more in the south-west, and in the future, it will move slightly to the south-east and hit the Sundarbans region of Bangladesh. Although these facts are not completely true, the probability of occurrence is very high. It is also worth noting that the possibility of the storms changing direction after hitting the land is also very high and it will move south-east after hitting south-west and hit Bangladesh, which we can see on the right-hand side in Figure 7 titled as Landfall Area. The synthetic storm track obtained in our study provides an approximate direction of current and future storms.

From the above explanation, we may successfully make a probabilistic cluster base synthetic track in the Bay of Bengal region. At the first stage, from the genesis area to developing area cyclone may shift the North-West part of the Bay of Bengal then stabilized and takes some energy from this area and shifted towards the cyclolysis area. At this time the cyclone moves slightly East side and goes into the fort quickly, after that it shifts to the landfall area. For the future climate condition, we have found that the track follows the definition of cyclone properly, but after landfall the behavior surprisingly changes dramatically due to the data pattern. But, from this study, we have found that the trend of cyclone movement from genesis to the development area is North-West side of the Bay of Bengal region.

Therefore, we believe that this research will play an important role in considering the storm track and sustainable development of coastal areas of Bangladesh. Besides, the disaster response and cyclone prevention and adaptation process will play a good role in shaping the development map. Although there are many limitations and weaknesses in the research, we think that the research will be useful for creating new research and improving research. The k-means clustering method of this research is the most accepted method and the results obtained from it are more acceptable. The authors of this study believe that this study will play an important role in considering the future storm trajectories and sustainable development of the coastal region of Bangladesh. Besides, as a part of the Cyclone Preparedness and Disaster Management Program of the Bangladesh Government. Cyclone prevention

and adaptation processes will contribute well to map development.

Conclusion

Storm data derived from climate simulation data indicates that current storm tracks and future storm tracks are somewhat different. Storm data derived from climate simulation data indicates that current storm tracks and future storm tracks are somewhat different. Data obtained from K-means clustering of storm data at different latitudes have different central tendencies and are very stable over the inter-storm lifetime. In addition to the present time Cyclone impact location is different from the future cyclone impact location. Which, moving slightly eastwards from the south-west, tends to hit Bangladesh from the south-west direction.

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Compliance With Ethical Standards

Authors' Contributions

MAAM: Conceptualization, Methodology, Software and Writing- Original draft preparation
MT: Software, Data curation, Writing- Reviewing and Editing
AKJ: Software, Investigation and Validation
MSN: Visualization and Investigation
MRK: Visualization and Validation
All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

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