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# Impact of extreme cyclone events on coastal agriculture in Bangladesh

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## Abstract

Extreme cyclone events are now occurring more frequently in Bangladesh. Bangladesh experiences severe 52 cyclones from 1960 to 2010 where, the approximate percentage of storm surge impact is 40%, the largest in the world. A severe cyclone in 1970 and 1991 caused loss of 300,000 and 200,000 lives. It is reported that 210000, 36000, and 3500 tonnes of *boro rice*, *aus rice*, and other food crops (e.g. potatoes and vegetables) were totally destroyed by 1991 cyclone. The storm surge killed huge livestock and caused loss of 100% of freshwater fish. Recently, the super cyclonic storm SIDR (2007) and AILA (2009) affected 10,000 and 300,000 people, respectively. Apart from these, cyclones NARGIS (2008) and MOHASEN (2013) are also mentionable. The crop production in the coastal regions of Bangladesh is most vulnerable by cyclones while, sea level rise by 2050 will inundate 17.7% of southern coastal areas. Tropical cyclones could become more frequent with more strength under recent climate change conditions. In this research, a new dimension of extreme weather assessment is done combining GCM and GIS technology and using tropospheric instability indices. The thermodynamic environment, vertical instability characteristics of severe cyclones are indispensable to cope with climate change conditions, and for planning, disaster management, and to reduce the risk of food insufficiency.

**Key words**: Extreme event, cyclone, GCM, instability, coastal agriculture


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## Introduction

It is now recognized that climate variability and extreme events affect society more than changes in the mean climate (IPCC, 2001), and suggests a visible human influence on global climate (AR4, 2007). It is broadly recognized that Bangladesh is more vulnerable to these changes. Indeed, it has internationally been argued that Bangladesh, as a country, may suffer the most severe impacts of climate change (Akter and Ishikawa, 2014). Bangladesh is highly vulnerable because it is a low-lying country located in the deltaic plain of the Ganges, the Brahmaputra and the Meghna and densely populated. The impact of higher temperature and more extreme weather events such as floods, cyclone, severe drought and sea level rise are already being felt in south Asia and will continue to intensify (Huq *et al.*, 1999; Ali, 1999). In this connection proper planning and analyses of extreme weather events are essential for this area. Southern regions of Bangladesh have already faced some super cyclones in recent past where, the northern areas are facing drought in every year. The southern region mainly known as a coastal region of Bangladesh experiences cyclone almost every year and suffers some havoc destruction which are not manageable during the incidence. As found from the statistics that, changes in temperature played a great role to cause such disastrous cyclones in the southern coastal region of Bangladesh. Studies showed that one of the main reasons behind cyclone occurrence is the extreme temperature. As a result, there is an increasing research interest in different parts of the world on extreme temperatures and their variations. Further global warming ranging between 1.4ºC and 5.8ºC is expected by the end of the 21st century (IPCC, 2007), which could also lead to an increase in temperature extremes. The average annual temperature of Bangladesh is expected to increase by 1.4 ± 0.6ºC by 2050 (IPCC, 2007; MoEF, 2008). The BUP-CEARS-CRU (1994) study reported 0.5ºC to 2.0ºC rise in temperature by the year 2030. It was also reported that that, for 2010 the temperature would rise by 0.3ºC and for 2070, the rise would be 1.5ºC (ADB, 1994).

To investigate the most effective climatic variable behind extreme weather events like cyclone, Principal Component Analysis (PCA) and clustering have been used all over the world. This approach of PCA was quite successful in predicting flooding due to a major tsunami in Chile (Hebenstreit *et al.*, 1985). Farukh and Yamada (2014) applied PCA to find out the synoptic climatology related to extreme snowfall events in Japan. So, PCA provides us the guidelines about how to determine the number of components to retain, interpret the rotated solution, create factor scores, and summarize the results (Fernandez, 1995). Cluster analysis applied to meteorological variables is a suitable approach for redefining the climate divisions, and its use is becoming increasingly more common in atmospheric research (Kalkstein *et al.*, 1987; Fovell and Fovell, 1993). In climate classification, the variability of long-term temperature data is the most readily available variables (Fovell and Fovell, 1993). Unal *et al.* (2003) intended to define spatially homogeneous climate regions of Turkey by using a mathematical methodology called cluster analysis. Mizuta *et al.* (2014) made a cluster analysis on tropical SST changes at the end of the 21st century projected by CMIP5 models under the RCP8.5 scenario. Clustering has mainly used in this study so that groups with common climatic conditions of cyclone events can be identified easily.

On the other hand, a General Circulation Model (GCM) is a type of climate model of the general circulation of a planetary atmosphere based on the Navier–Stokes equations on a rotating sphere. GCMs are the main tools available for developing projections of an extreme weather event (Houghton *et al.*, 2001). A little work is done on climate change scenarios for Bangladesh using regional climate model (Islam *et al.*, 2009). Despite continuous model development, Atmospheric General Circulation models (AGCMs) still have systematic preferences in simulating the East Asian summer monsoon (Kang *et al.*, 2002). Therefore, nowadays, the use of GCMs for climatic variables is indispensable to assess extreme weather event like cyclone and also their effects on coastal agriculture. Keeping these things in mind the present study was therefore, undertaken with the objectives to find out the synoptic climatology of extreme temperature induced cyclone events in Bangladesh, and to find out their impact on coastal agriculture broadly.

## Materials and Methods

***Data acquisition*****:** Fifty two (52) severe cyclone events in the southern coastal regions of Bangladesh were under investigation. Here, the severe 52 cyclone events denote the deadliest 52 cyclone occurring days from 1960 to 2010. The data of climatic variables and long term crop production data for 3 cropping seasons were collected from BMD and BADC at 16 measuring points (Figure 1) from 1960 to 2014.

***General circulation model (GCM)*****:** The daily mean SLP dataset for the severe 52 cyclone occurring days were obtained from Japanese 25-year reanalysis project (JRA-25) by the JMA (Onogi *et al.*, 2007), encompassing the region 10°N–35°N by 75°E–110°E (shown in Figure 1) with a 1.125° spatial resolution.

***Composite mapping for GCM*****:** The composite mapping for GCM were from the National Centers for Environmental Prediction (NCEP)–National Center for

Atmosphere Research (NCAR) reanalysis project (Kalnay *et al*., 1996), which ensures a good resolution of atmospheric data with a grid of 2.5° resolution.

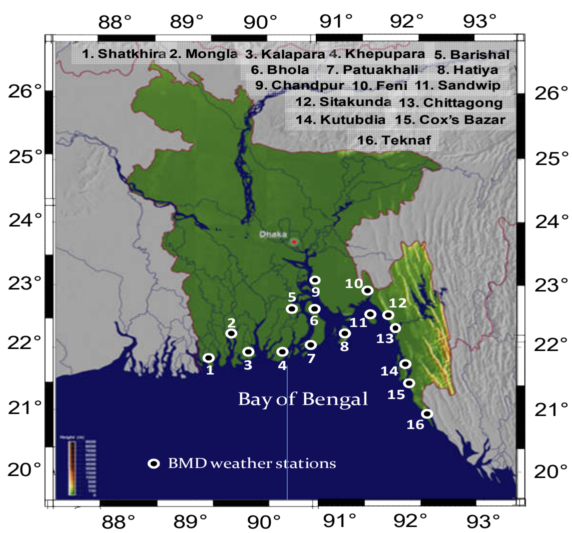


**Figure 1**. Study areas

***Principal component analysis (PCA) and clustering***: The PCA based on S mode data matrix were carried out (Yarnal, 1993), where the most efficient representation of variance in the data set was provided by correlation matrix (Barry and Carleton, 2001). The non-hierarchical K-means method was used to cluster the observations (Hair *et al*., 1998). The synoptic maps of the atmospheric circulation groups were constructed for atmospheric variables firmly contributed to climate changes.

***Atmospheric Instability***: Upper atmosphere air temperature, depression and trough, mobile troughs, dew point depression, k index, lifted index, convective available potential energy, convective inhibition, and showalter index were calculated to predict the formation of tropical cyclone. The Skew-T Log-P diagrams were used for the severe cyclonic days. The calculations were done using following equations:

$$\Delta Te_{850-500} = Te_{850} - Te_{500} \quad \text{......(i)}$$

$$\Delta Te_{700-500} = Te_{700} - Te_{500} \quad \text{......(ii)}$$

$$DD_{850} = Te_{850} - Td_{850} \quad \text{......(iii)}$$

$$DD_{700} = Te_{700} - Td_{700} \quad \text{......(iv)}$$

$$KINX = \Delta Te_{850-500} + Td_{850} - DD_{700} \quad \text{......(v)}$$

$$LIFT = Te_{500} - Tp_{500} \quad \text{......(vi)}$$

$$SHOW = Te_{500} - Tp_{850} \quad \text{......(vii)}$$

$$CAPE = \int_{Zf}^{Zn} g\left\{\frac{Tp-Te}{Te}\right\}dz \quad \text{......(viii)}$$

$$CINS = \int_{\approx bottom}^{\approx top} g\left\{\frac{Tp-Te}{Te}\right\}dz \quad \text{......(xi)}$$

| | | |
|---|---|---|
| $\Delta Te_{850-500}$ & $\Delta Te_{700-500}$ | *Temp. diff. between 850 to 500hPa & 700 to 500hPa* | °C |
| $Te_{850}$ & $Te_{500}$ & $Te_{700}$ | *Environmental temp. at 850, 500, & 700hPa* | °C |
| $DD_{850}$ & $DD_{700}$ | *Dew point depression at 850 & 700hPa* | °C |
| $Td_{850}$ & $Td_{700}$ | *Dew point temperature at 850 & 700hPa* | °C |
| $Tp_{500}$ & $Tp_{850}$ | *Temp. of air parcel lifted adiabatically to 500 & 850hPa* | °C |
| $\approx_{bottom}$ | *Bottom altitude of a CIN layer* | *m* |
| $\approx_{top}$ | *Top altitude of a CIN layer* | *m* |
| $Z_f$ | *Height of the level of free convection (LFC)* | *m* |
| $Z_n$ | *Height of the equilibrium level (EL)* | *m* |
| $g$ | *Acceleration due to gravity* | $ms^{-2}$ |

***Assessment of coastal rice grain production, consumption, and sufficiency***: Three types of rice grain (*Aus, Aman* and *Boro*) production were estimated by metric ton unit. Total *aus* production considered Local and high yielding variety (HYV) while, total *aman* and *boro* production considered broadcast + local transplant+HYV and local+HYV+ hybrid, respectively.

Ct = P*Y*Co/1000000 (MT)

where,

Ct = Total consumption, P =Total people

Y=1 year = 365 days

Co = consumption person-1 day-1 = 416 gm

Conversion of 1MT=1000000 gm

Estimation of total people,

P=Po (1+r/100) n

where,

P = No. of people to be estimated

Po = No. of people of previous year

r = growth rate

n = year

Food sufficiency was measured on the basis of the difference between total production of rice grain and total consumption.

Sufficiency = Total production (MT) - Total consumption (MT).

## Results and Discussion

***Cyclone history***: The intense low pressure areas where the pressure increases from centre towards the outer part is generally called cyclone (Abbott, 2004). Recent studies indicate that cyclones originating from the Bay of Bengal and Arabian Sea have been noted to decrease since 1970 but the intensity has increased (Lal, 2001). It is to be noted that major cyclone disasters are still continuing in Bangladesh and India (Ali, 1999). Examples are the recent Bangladesh cyclones of 1985, 1988, 1991, 1994, 1995, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2007 and 2009 (Figure 2). Cyclones normally originate from deep depression which is a consequence of high amount of temperature in the coastal region which is quite common in Bangladesh. They generally occur in early summer of the month from April-May or late rainy season from November-December (Choudhury, 1992; Wisner et al., 2004; Ali 1999; Paul 2009; Farukh and Baten, 2015).

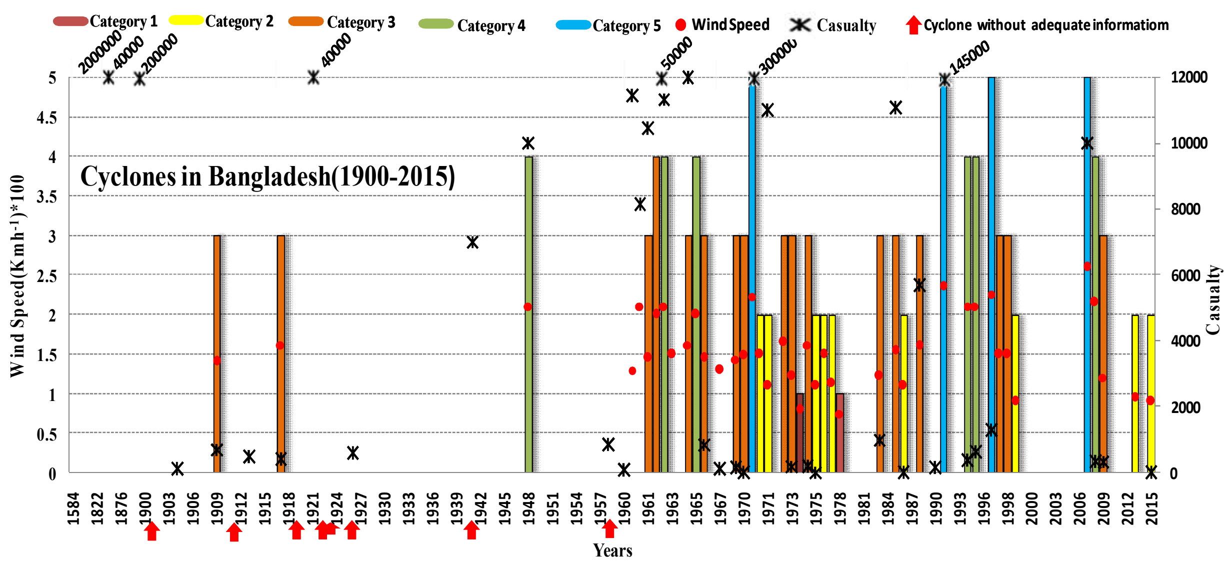


**Figure 2**. Cyclone history of Bangladesh

***Surface Weather Conditions***: To investigate the surface weather conditions, 16 coastal BMD stations were taken under consideration (Figure 1). Due to space limitation only one stations result is shown and described here. Bhola is an important area in the southern part of Bangladesh. It is covered by the rivers and that's why it is known as the largest island in Bangladesh. Maximum, minimum, mean, and mean ± SD of all the parameters are shown in the Figure 3. Figure 3(b) shows the trend of temperature is increasing from July to August and then the trend has fallen down to January. Then it's again rises up from January to May and then drops little bit to June. The $T_{max}$ has shown in the month of May (35.1ºC) and the $T_{min}$ has shown in the month of January (9.69ºC). The $T_{mean}$ in this area throughout the year is ranging from 18-28.5ºC where the highest $T_{mean}$ is about 28.5ºC in the month of May. The $T_{max}$ in this area is ranging from 28-35ºC throughout the year. The $T_{max}$ in this area has strong influence in creating unstable condition. Again

$T_{max}$ also shows powerful indication for the formation of cyclone by creating low atmospheric pressure in the adjacent area. The abrupt 7-10ºC difference of the temperature between the maximum range and the mean value are strong indication of changing temperature in the area in such a day where the condition of the environment may become unstable which in later may turn into cyclone. Relative humidity (RH) of Bhola has given in the Figure 3(c) while July has the $RH_{max}$ (99.97%) with the $RH_{mean}$ of about 91%. This highest mean value in the area indicated hot and humid circumstances in that specific month in Bhola.

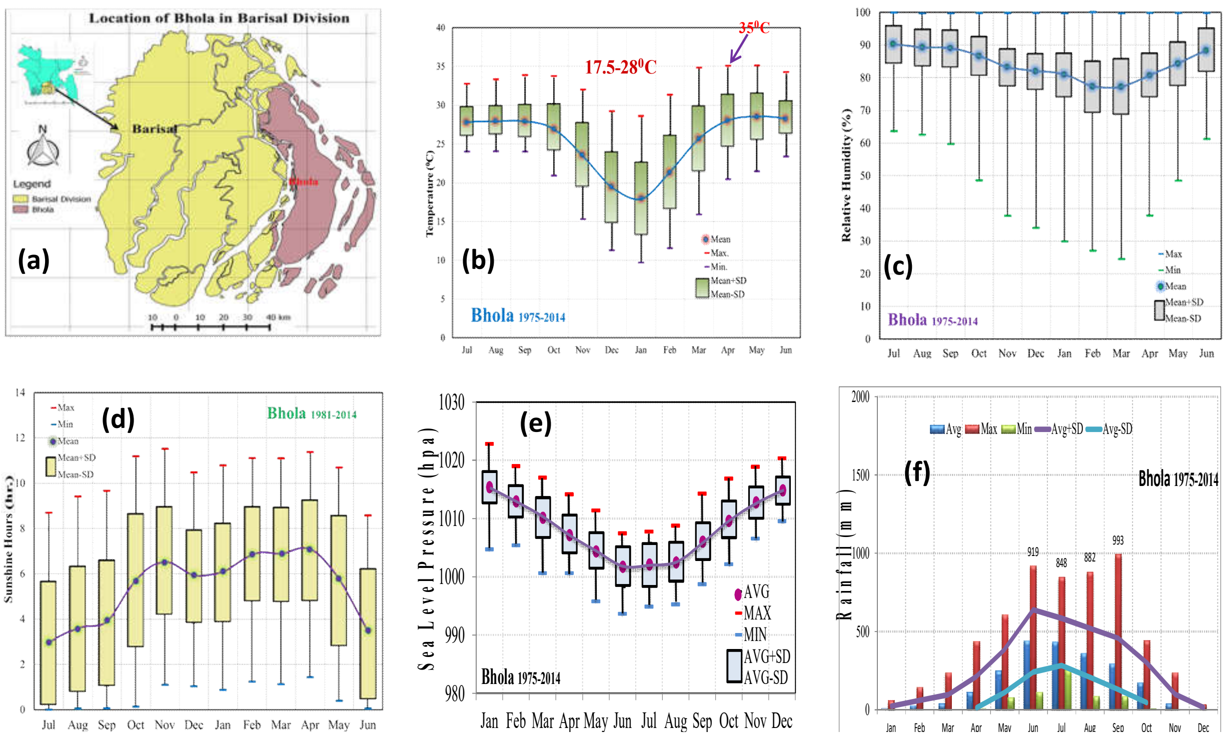


**Figure 3**. (a) Location of Bhola, (b) temperature (ºC), (c) relative humidity (%), (d) sunshine hour (hr.), (e) SLP (hPa), and (f) rainfall (mm)

In both cyclone occurring months, the $RH_{mean}$ is comparatively low and is not in at that level of forming cyclone though the maximum range is high enough in almost every month. The high amount of RH also may cause unstable condition in the specific area which in later may form deep depression and ultimately forms cyclone. The sunshine hour of Bhola is shown in the Figure 3(d) that depicts the SH trend is increasing from its starting point July and continued up to November. Then it falls slightly from November to December but again started to rise. The $SH_{max}$ is 11.37 hr. has found in the month of April and the $SH_{min}$ is 0.05 hr. has found in the month of July. The highest SH also indicates higher amount of temperature in April at Bhola which may induce atmospheric low pressure in the area and may form cyclonic activity.

***Upper atmospheric instability*:** The instability of weather condition begins at the end of April and continues up to June. May was the most unstable month obtained from the Radiosonde data from 2000 to 2014. As a result three devastating cyclones Nargis, Aila and Mahasen were held 3 May 2008, 25 May 2009 and15 May 2013, respectively.

The showalter index (SHOW) is a measure of storm potential and severity (Khan and Farukh, 2015). A negative SHOW indicates that the upper PBL is unstable with respect to the middle troposphere. The more negative the SHOW the more unstable the troposphere and the more buoyant the acceleration will be for rising parcels of air from the upper PBL. The SHOW measures instability from 850 to 500 kPa and from 1472 to 5650 meter height. Figure 4 shows the average value of SHOW was the highest in March (4.06) and the lowest in May (-1.71) along with 850hPa geopotential height and air temperature.

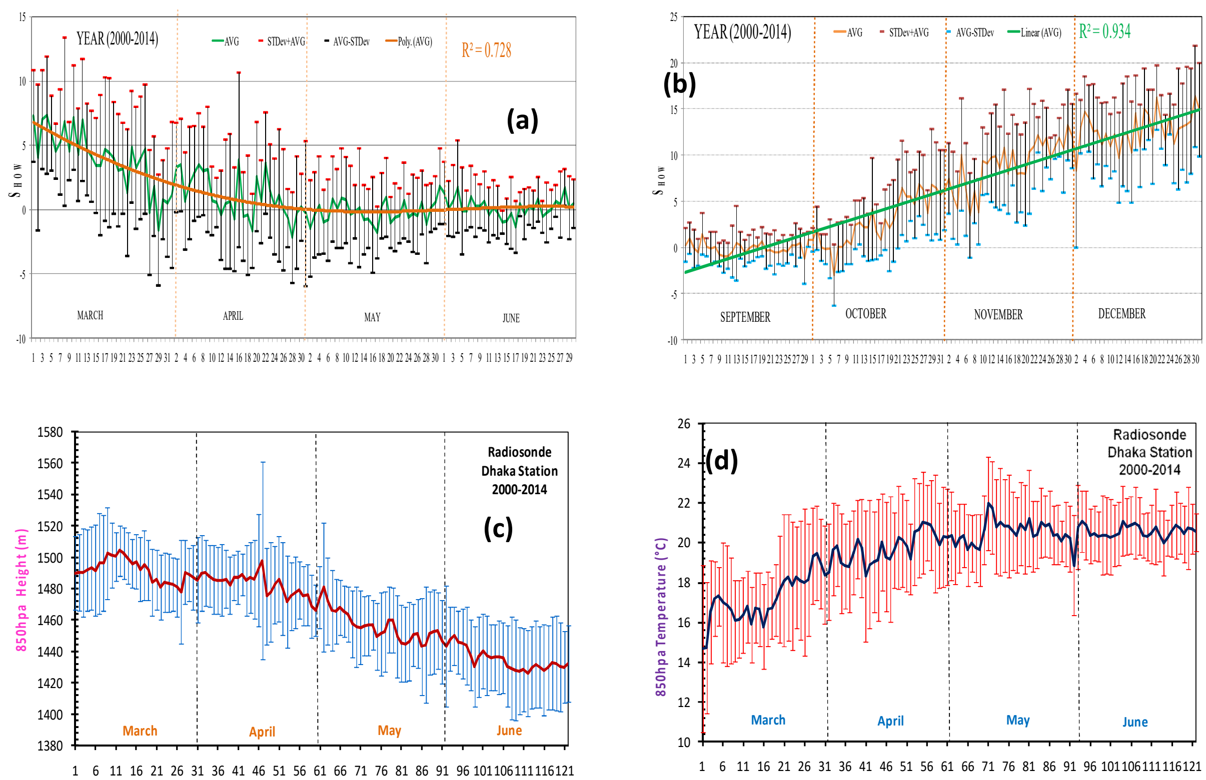


**Figure 4**. Upper atmospheric instability indices (a) Showalter index (Mar.-Jun.), (b) Showalter index (Sep.-Dec.), (c) 850hPa height (m), (d) 850hPa air temperature (ºC).

***Synoptic climatology*:** The composite geographical distribution of synoptic temperature anomalies compared with the climatology from 1975-2014 for the cyclone occurring days are shown in Figure 5. The surface level air temperature in Bangladesh alongside with south-western India was comparatively hotter than some part of Myanmar on the cyclone occurring days.

***Food Sufficiency*:** The crop area for coastal agriculture is reducing and the cultivation of *Aus*, *Boro* and *Aman* are getting restricted. Among coastal districts Satkhira is the most vulnerable due to climatic hazards. Figure 6 shows that rice production in Satkhira was the lowest in 2009-10, because of two devastating cyclones *Sidr* and *Aila*. But in 2010-11 production was higher while in 2011-12 the production tended to decrease again. Production also started to increase from 2011-12 to 2013-14, because of adopting high yielding and saline tolerant rice varieties. The production, however, was greater than the consumption in last few years suggests apparently positive food sufficiency in Satkhira district.

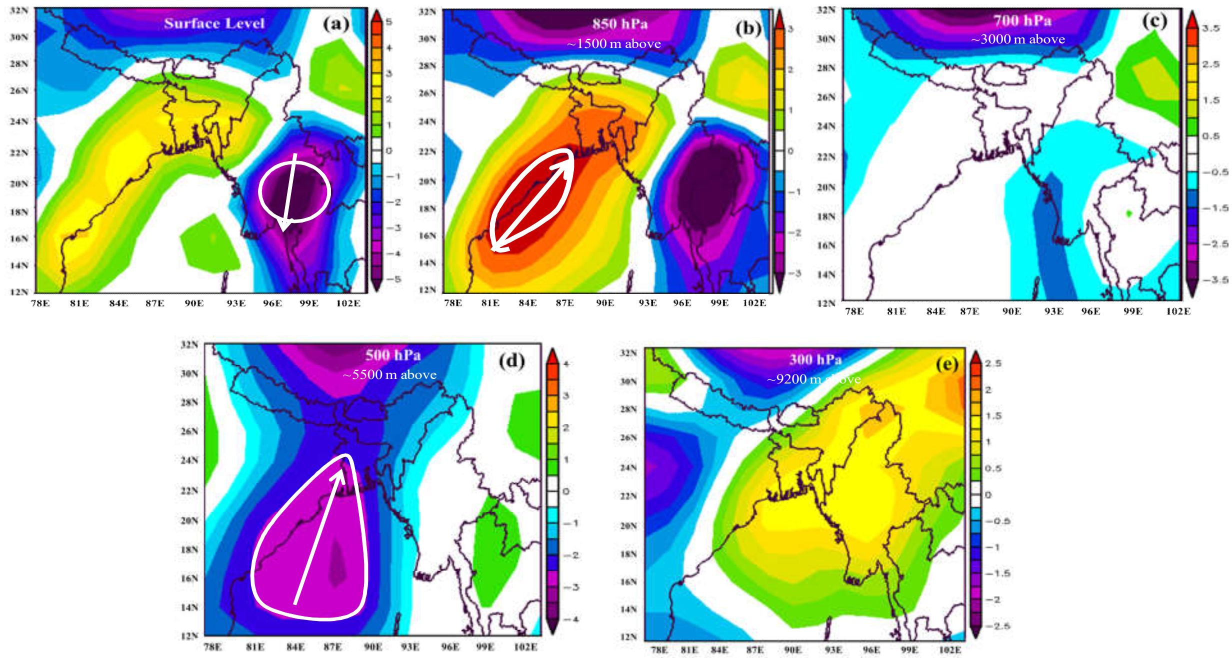


**Figure 5**. Analyzed GCM results of temperature anomaly (a) surface, (b) 850hPa, (c) 700hPa, (d) 500hpa, and (e) 300hPa level of atmosphere.

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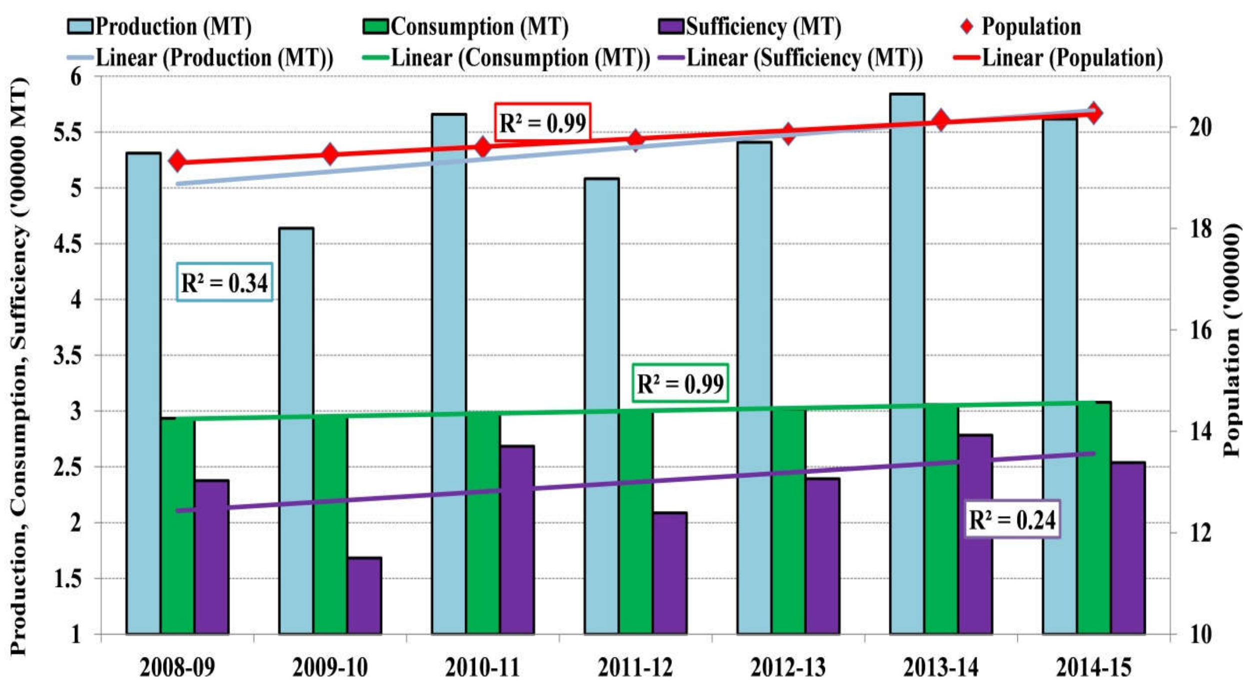


**Figure 6**. Rice grain production, consumption and sufficiency in Satkhira.

## Conclusions

Synoptic features of 52 cyclones have been studied using the results of 3 clusters. Disaster Preparedness Centre (AIT), Bangladesh Bureau of Statistics (BBS), and NCEP–NCAR reanalysis data have been used to assess the upper atmospheric temperature anomalies related to severe cyclone events in the southern part of Bangladesh mainly over BB. The climatological anomaly of air temperatures for clusters at different levels of atmosphere showed the dominance of relatively cooler air temperatures in the southern zone of Bangladesh. But just a few km above, the whole vertical atmospheric column showed increased temperature especially from 850 to 300 hPa levels. These warmer zones at relatively upper atmosphere could make unstable situation through the thermal instability interacting with the surface layer. Finally, the whole of Bangladesh was dominated by positive anomaly values up to 300 hPa level implies formation of a deep warmer zone over this region. The larger warmer air mass at upper atmosphere creates profound influence to develop huge instability throughout the whole atmospheric column that may led to extreme weather phenomenon like severe cyclone.

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