Simulation of a Thunderstorm over Bangladesh using WRF Model and its impacts – a case study

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Abstract

Using the well-known WRF-ARW model, we attempt to simulate a thunderstorm event that occurred at Dhaka on 29 April 2018. The model is configured with WSM 3-Class Simple Ice Scheme microphysics option, Yonsei University Scheme as PBL parameterization, Revised MM5 Scheme for the surface layer, Unified Noah Land Surface Model as a land surface model, Rapid Radiation Transfer Model Scheme for both short wave radiation and longwave radiation and Kain-Fritsch (new Eta) Scheme as cumulus physics option. The model is then compiled for 48 hours using the 1°×1° six-hourly GFS data on a single domain of 10 km horizontal resolution and 38 vertical layers. The model's performance was evaluated by examining various meteorological parameters such as MSLP, wind pattern, vertical wind shear, two-meter height temperature and RH along with their vertical cross-section, convective available potential energy, Convective Inhibition and K-Index. For the validation of model-simulated MSLP, Temperature, and RH at 2-m height, and rainfall were compared with the observed value of BMD. It was revealed that the model's simulated outcome is good enough to forecast thunderstorm occurrences throughout Bangladesh, notably in Dhaka and its surrounding areas.

Keywords: Thunderstorms, ARW-ARW, Wind Pattern, CAPE, K-Index.

1. Introduction

Due to geographical location Bangladesh experiences a high frequency of thunderstorms which have a great destructive effect on life and property. Thunderstorm is the most common natural disturbance which locally called 'Kal Boishakhi' in pre-monsoon season. Mainly in this season the time of severe thunderstorms which are occurred with squall, lightning, gusty winds and moderate to very heavy rain accompanied by thunder and lightning swept across the country at time. Not only that the frequency of thunderstorms has tendency to increase at most places in Bangladesh (S. Karmakar et al., 2021). Thunderstorms arise when layers of warm, moist air rise in a large, swift updraft to cooler regions of the stratosphere. There the moisture contained in the updraft condenses to form gigantic cumulonimbus clouds and finally rainfall. Columns of cooled air then sink earthward, striking the ground with strong downdrafts and horizontal winds. At the same time, electrical charges gather on cloud particles. Romatschke and Houze (2011) examined the precipitating convective system over south Asia during pre-monsoon season and opined that strong day time heating of land during the pre-monsoon season produced conditionally unstable conditions satisfactory for intense convection. According to Habib (2009), TS is ranked 3rd in the list of hazards that affect Bangladesh. The monthly frequency of thunderstorms increases from March to May in Bangladesh with maximum frequency in Sylhet region (Mannan et al., 2018). About 170-183 thunderstorms occur over northeastern Bangladesh in the pre-monsoon season of 1980-2016 (Karmakar and Mannan, 2014). Unstable atmospheric conditions are more favorable for thunderstorm which find in our country in pre-monsoon. Prediction of thunderstorm is very important for exact forecast. For the accurate prediction of such high impact weather events, such as thunderstorm, mesoscale models are essential. Bahar et al. (2019) took an attempt to find out the characteristics of thunderstorm events which occurred at Mymensingh (24.75°N and 90.40ºE), Bangladesh during pre-monsoon season of 23 May, 2015 using Weather Research and Forecasting (WRF) model version 3.8.1. They simulate some parameters and state that simulated parameters were favorable for the formation of thunderstorm and very much supportive for the system genesis and intensification. According to them the WRF model-simulated parameters suggest that the thunderstorm event can be predicted for upcoming thunderstorms events. Litta et al. (2012) used high resolution WRF model for judgment a severe thunderstorm. Their results of these analyses demonstrated the capability of high resolution WRF-NMM model in the simulation of severe thunderstorm events and determined that the 3 km model improve upon current abilities when it comes to simulating severe thunderstorms over east Indian region. They use the WRF-NMM model with Ferrier microphysical scheme appears to reproduce the cloud and precipitation processes more realistically than other schemes. Karmakar and Dewan (2015) simulated of thunderstorms during the pre-monsoon season 2014 with the help of WRF Model. Rajeevan et al. (2010) simulated the features associated with a severe thunderstorm event over Gadanki using WRF model and examined its sensitivity to four different microphysical schemes validated with many observations. Prediction, forecasting and research of thunderstorm during pre-monsoon season is insufficient in country. Thunderstorm forecasting is very difficult with exact location and time. The main objective of the present study is to simulate the TS over Bangladesh using WRF model to identify the possible synoptic conditions and the thermo-dynamical reasons responsible for occurring of such events.

2. Model description

Numerical Weather Prediction (NWP) refers to the simulation and prediction of the atmosphere with a computer model and Weather Research Forecasting (WRF) is a set of software for this. Weather Research and Forecasting (WRF) is a next generation mesoscale numerical weather forecasting community model. It has the potential to simulate the meteorological phenomena ranging from meters to thousands of kilometers. Advance Research WRF (ARW) is a dynamic solver which is compatible with the WRF system to simulate the broad spectrum of meteorological phenomena. The WRF model version is 3.4.1 has been used during the present study. WRF Model consists of three major components: i. WRF preprocessing system, ii. Weather Research Forecasting Version-3 and iii. Advanced Research WRF post processing.

2.1 Data and Methodology

Global Forecast System (GFS) data have been used as input to the WRF model which data is prepared by NCEP. In this study, GFS Operational data from 0000 UTC of 28 May, 2018 to 0000 UTC of 30 April, 2018 was used. The WRF Model was run at 10 km × 10 km resolution on a single domain. The covered area was 15°- 30°N and 75°-100°E and central point of the domain 22.5°N, 87.5°E over Bangladesh. The grid size was taken 105 × 105. The model was run for 48 hours. Results from ARW were needed to be processed for analysis and visualization by GrADS which is extensively described below. The model performance was evaluated by analyzing the different predicted parameters like Lifted Index (LI), K-index (KI), Total Totals Index (TT), Convective Available Potential Energy (CAPE), Convective Inhibition (CIN) and Rainfall distribution. To validate the model performance, model simulated values of parameters were compared with observational data obtained from Bangladesh Meteorological Department (BMD) and other sources by Geographic Information System (GIS) and ArcGIS. Causality data of the event collected from five daily newspapers: The Daily Star, The Daily Ittefaq, The Daily Jugantor, The Janakantha and The Prothom Alo. Collected data were compiled after cross-check for avoid over lapping.

3. Result and Discussions

Atmospheric thermodynamic conditions derived from model simulation and the upper air observation at Dhaka on 0000 UTC of 29 April, 2018 is given in Table 1. Analysis says that the SI and LI were negative and low for both simulated and observed. This is the marginal unstable to large instability of the atmospheric condition (Meteorologist Jeff Haby). K-index is a measure of thunderstorm potential based on vertical temperature lapse rate, moisture content of lower atmosphere, and the vertical extent of moist layer. The model predicted K-index is found 37°C and the observed K-index is found 35.3°C which is the Moderate convective potential of the atmospheric condition (Meteorologist Jeff Haby).

Table 1: Model simulated and observed thermodynamic indices at Dhaka

Sl.	Parameter	Date and time	
		29 April, 2018	
		0000UTC (Simulated)	0000UTC (Observed)
1.	SI	-	-2.11
2.	LI	-6	0.94
3.	SWEAT	-	363.14
4.	KI	37	35.30
7.	TT	48	49.00
8.	CAPE	2165	0.00
9.	CIN	2	0.00
12.	PWAT	43	40.53

The model generated TT is found 40°C on the other hand the observed TT is found 39.8°C which is supported for likely thunderstorm formation (Met. Jeff Haby). The magnitude of CAPE of the model simulated value indicated moderately unstable. This condition was sustained till 1200 UTC of 30 April, 2018. SWEAT index reached its highest magnitude at 0000 UTC of 31 March, 2018. PWAT were high and above of 40 mm during the observed period. Therefore LI, KI, CIN, CAPE and PWAT were very much favorable for the occurrence of the event. These thermodynamic indices indicate to favorable condition for occurring moderate to very heavy thunderstorm with its associated features. Analysis suggests the favorable condition for the formation of the event

3.1. Analysis of rainfall

From the spatial analysis of rainfall (Figure-1), it is found that a significant amount of rainfall is simulated over northern parts and then central part of the country. Model has also simulated a small amount of rainfall all over the country. From the observation of BMD it was depicted that significant rainfall was in the eastern parts and then central-eastern part and other parts had a very small amount of rainfall.

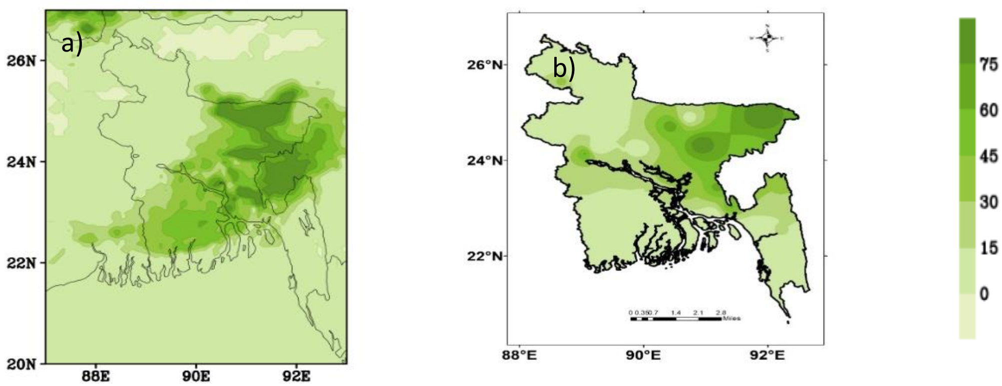

Figure1: a) Model-simulated rainfall of 29 April, 2018 based on the initial condition of 0000 UTC of 28 April, 2018 and b) Observed rainfall of 29 April, 2018.

3.2 Analysis of Mean Sea Level Pressure

The analysis of Mean Sea Level Pressure of 0000, 0300 and 0600 UTC of 29 April, 2018 based on the initial condition of 0000 UTC of 28 April, 2018 which is shown in figure 2. The analysis shows that model simulate a low pressure area will extend up to central and southern part of the country. On the other hand, observed value from BMD indicate that Sea level pressure was low in Dhaka and its adjoining central and southern parts of Bangladesh. At 0000 UTC, there is a low-pressure area with below 1011 hPa over West Bengal and major part of Bangladesh. The area of this low is reduced and found to lay over West Bengal and southwestern part of Bangladesh extended to Barisal and Dhaka region. At this time the pressure is found to be 1009-1010 hPa over southwestern part of Bangladesh with a trough extending to Dhaka and Barisal.

From the simulation of Mean Seal Level Pressure on 0000 UTC of 29 April, 2018 at Dhaka (Figure-3), it is clear that the prediction is very similar with observation. So, the simulation of WRF was supportive and appropriate.

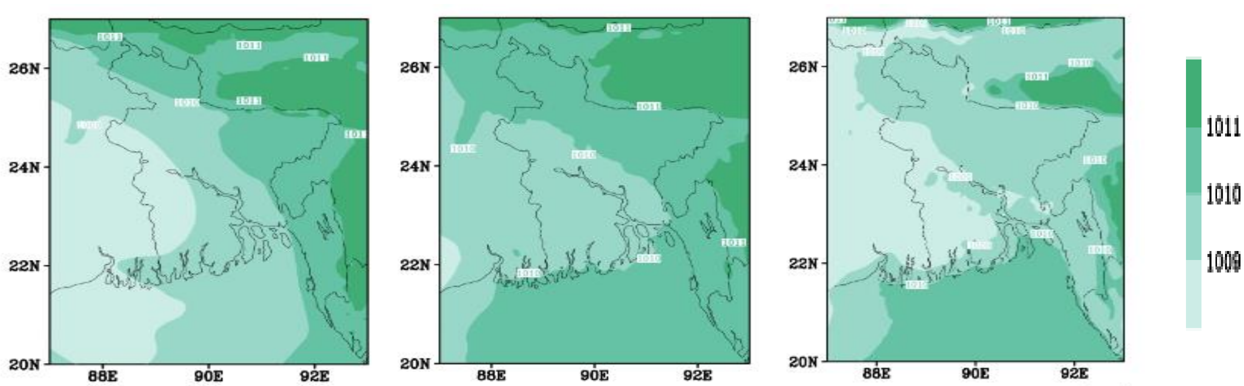

Figure 2: Model simulated Mean Sea Level Pressure (MSLP) of 0000, 0300 and 0600 UTC of 29 April, 2018 based on the initial condition of 0000 UTC of 28 April, 2018.

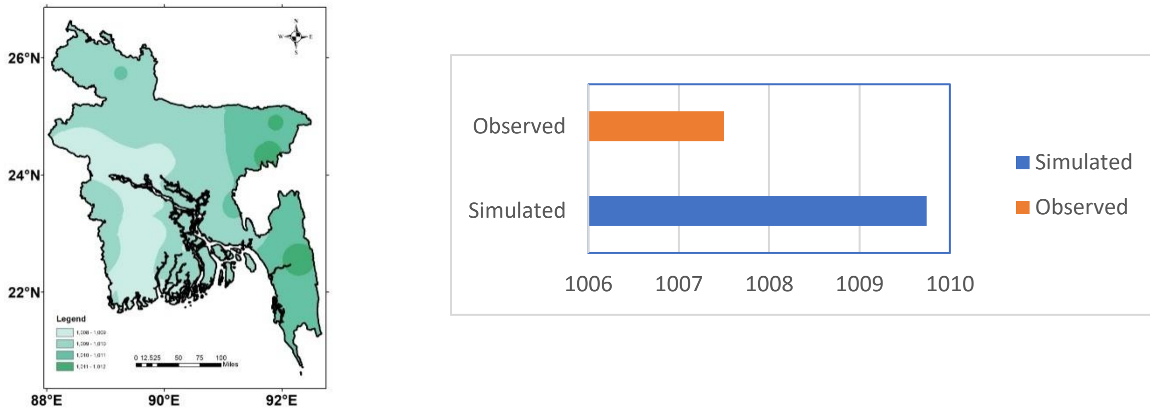

Figure 3: Compare between model simulated and observed Mean Seal Level Pressure on 0000 UTC of 29 April, 2018 at Dhaka

3.3. Analysis of Relative humidity and vertical cross section of RH

The analysis of relative humidity at 2m height on 0000UTC of 29 April, 2018 based on the initial condition of 0000 UTC of 28 April, 2018 is sown in figure 4. It is found that the model simulated relative humidity at 2m height the ranges 80% to 95% over eastern, central and southern parts of Bangladesh except western part and this high relative humidity is conducive for strong convection [1].

Comparison between model simulated and observed RH on 0000 UTC of 29 April, 2018 shown in figure 5, it is clear that the predicted RH is lower than observed.

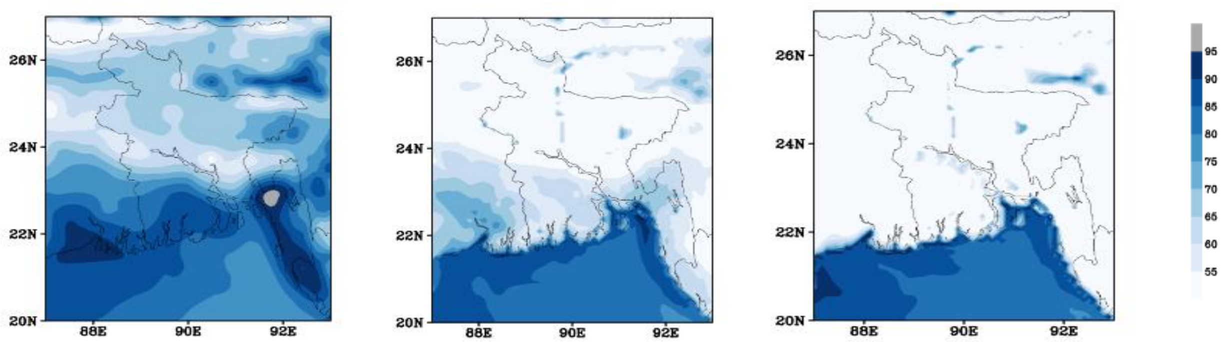

Figure 4: Model simulated Relative Humidity (RH) of 0000, 0300 and 0600 UTC of 29 April, 2018 based on the initial condition on 0000 UTC of 28 April, 2018.

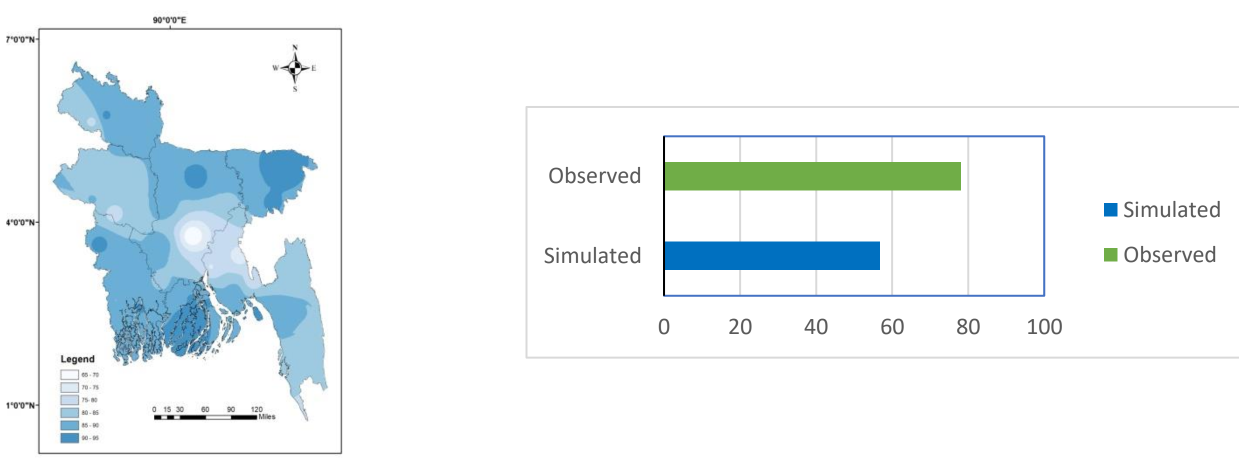

Figure 5: Compare between model simulated and observed RH on 0000 UTC of 29 April, 2018.

Vertical cross section may be a supportive indicator. The high amount of moisture is responsible for buoyant of air parcel, which may create a severe thunderstorm. Model simulating vertical cross section of RH was considered along 24.9°N on 0000, 0300 and 0600 UTC of 29 April, 2018 based on the initial condition of 0000 UTC of 28 April, 2018. The model simulated a vertical column of RH of 60-100% over central and its adjoining southern and eastern parts of Bangladesh up to 850 hPa. A column of RH 40-60% was simulated of this zone from 800 hPa to 300 hPa (Figure-6). Predicted RH was very supportive for cloud formation. The WRF model captured the system very well.

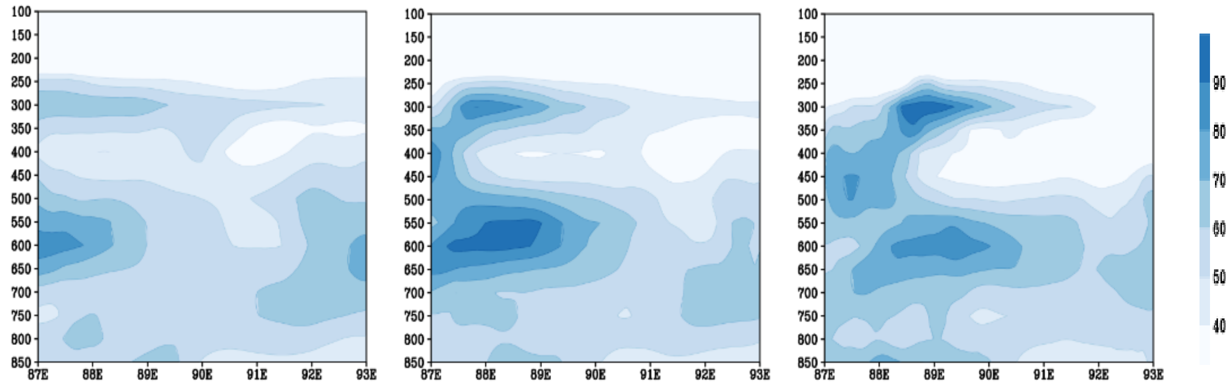

Figure 6: Model simulated Vertical Cross Section of Relative Humidity on 0000, 0300 and 0600 UTC of 29 April, 2018 based on the initial condition on 0000 UTC of 28 April, 2018.

3.4. Analysis of vorticity

Vorticity is a clockwise or counter clockwise spin in the troposphere**.** A wind flow through a vorticity gradient will produce regions of Positive Vorticity Advection and Negative Vorticity Advection. Positive Vorticity Advection (PVA) contributes to rising air. Vertical positive vorticity contributes to upper-level divergence in the PVA region and thus rising air while horizontal vorticity is important to severe weather.

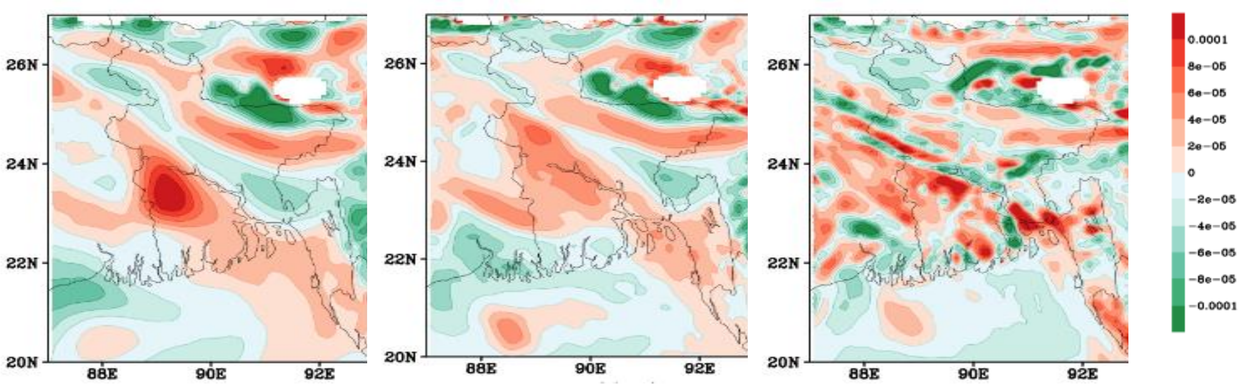

Figure 7: Model simulated Vorticity at 850 hPa level on 0000, 0300 and 0600 of 29 April, 2018 based on the initial condition on 0000 UTC of 28 April, 2018.

Vertical vorticity was predicted and analyzed at 850 hpa level on 0000 UTC of 29 April, 2018 based on the initial condition of 0000 UTC of 28 April, 2018 are shown in figure 7. A well -organized rotary zone of positive vorticity of $(2\text{-}10)\times10^{-5}$ s^{-1} was found over southwestern and northeastern part of Bangladesh mainly Jashore and its adjacent areas and negetive vorticity of $(8\text{-}10)\times 10^{-5}$ s^{-1} was found over Mymensingh and adjacent areas. Estimated negetive magnitude of $(2\text{-}8)\times10^{-5}$ s^{-1} was found in central mainly Dhaka and its adjacent areas. Positive vorticity and negetive vorticity govern downdraft and updraft [3]. For Ts formation, updraft and downdraft was the precondition [2].

4. Casualities of the event

Almost all over the country were affected by this event (Table-2). Highest number of deaths found at Sirajganj then Magura. Same as highest number of injuries found in Sirajganj. Durnal distribution of fatalities and Distribution of fatalities on the basis of gender are shown is figures 8 and 9. Number of death and injury also found high among male. Highest number of death found in the morning for this event. Number of death and injury also found high among male. So, it can be said that male and morning time are more vulnerable which is a good agreement with Rahman et al. (2019) and Farzana et al. (2019).

Table.2: List of affected districts, number of death and injury

Sl.	Dist.	Number of Death	Number of Injury
1	Shirajganj	5	4
2	Magura	4	-
3	Naogaon	2	3
4	Sunamganj	1	-
5	Noakhali	2	2
6	Rangamati	1	-
7	Gazipur	2	5
8	B. Baria	1	3
9	Gopalganj	1	-
10	Dhaka	1	2

[Source:The Daily Star, The Daily Ittefq, The Daily Jugantor, The Janakantha and The Daily Inqilab of 30 April,2018]

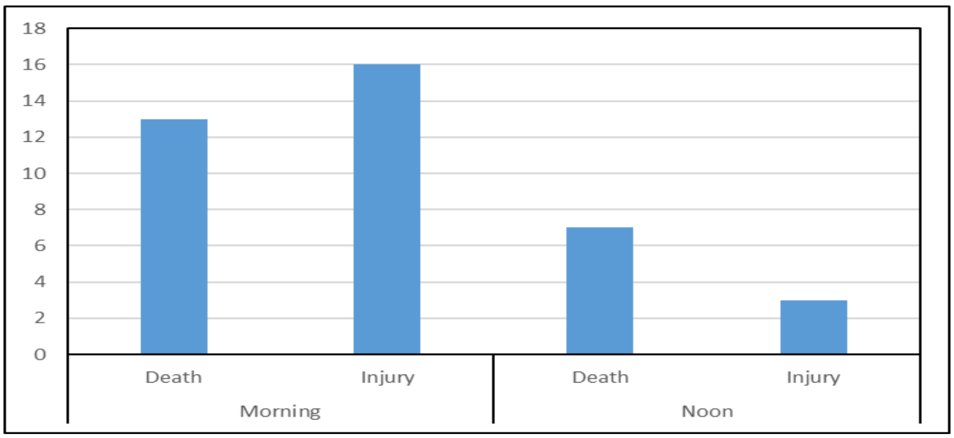

Fig.8. Durnal distribution of fatalities.

[Source:The Daily Star, The Daily Ittefq, The Daily Jugantor, The Janakantha and The Daily Inqilab of 30 April,2018]

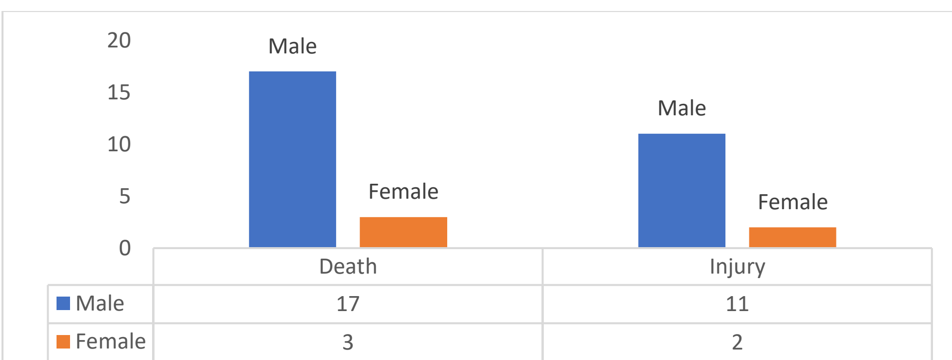

Fig.9. Distribution of fatalities on the basis of gender.

[Source:The Daily Star, The Daily Ittefq, The Daily Jugantor, The Janakantha and The Daily Inqilab of 30 April,2018]

5. Conclusion

1. On the basis of disscussions it can be concluded as follow-
2. Both simulated and observed thermodynamic indices are (CAPE, CIN, SI, LI, SWEAT, PWAT) near to similar.
3. Model simulated RH had a good agreement for thunderstorm. Not only that value is closely near to observed RH of BMD.
4. Model estimated rainfall is very close to observed rainfall.
5. Predicted vertical cross section of RH, Vorticity etc. indicated a thunderstorm event.
6. The performance of simulation of thunderstorm by WRF model is quite well and WRF model may be operationally used for predicting the TS and its thermodynamic features over Bangladesh even up to 48-hours advance.
7. Highest fatalities found at morning in this event
8. Male are more vulnerable than female
9. It is also recommended that similar study be extended for more number of cases for further modification of the model application.

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