Nowcasting of Hailstorm by using BAF Doppler Weather Radar

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Abstract

With the advent of modern meteorological instrument and Numerical Weather Prediction Model a significant improvement has been taken place in the field of weather forecasting. But, some of the micro scale severe weather event, such as hailstorm, is still difficult to be predicted completely and accurately. However, Dual-Polarization Doppler Weather Radar is one of the effective nowcasting tool to determine hail. During pre-monsoon period we often experience Thunderstorm/ Nor'wester with hailstorm over Bangladesh and neighbourhood. Before induction of Doppler Weather Radar in Bangladesh Air Force (BAF), it was difficult for BAF meteorologist to predict accurately about which thunder cloud will be associated with hail. In this paper, a total 32 hailstorm cases have been analyzed using Jashore Doppler Weather Radar reflectivity product. It is found that during pre-monsoon season if the radar reflectivity product shows 50dBz or more, then there is a good chance of occurrences of hailstorm. This chances increases (along with intensity and size of hail) with increasing of the dBz (60 to 70dBz). Thus, Doppler Weather Radar can be utilized to provide early warning about hailstorm with a lead time ranging from half an hour to two hours or more depending upon the intensity and place of origin. With my five years' experience working with Doppler Weather Radar at Jashore, it can be said that hailstorm can be predicted by watching the Radar reflectivity product with more than 85% of accuracy. Therefore, this study will help meteorologists to nowcast hailstorm events with more confidently using BAF Doppler Weather Radar. Eventually, warnings may be issued with a considerable lead time (depending upon the place of origin and movement) before hail strikes, thus allowing pilots to avoid threatening air space, people to seek shelter, and properties to be protected.

Keywords: Hailstorm, Doppler Weather Radar, Radar Reflectivity-dBz, Nowcasting, Nor'wester.

1. Introduction

Bangladesh experiences a high frequency of thunderstorms during the pre-monsoon season (March, April and May) which have a great destructive potential and characterized by tornadic violence, often accompanied with high magnitude squalls, torrential rain and hail. The thunderstorms with high magnitude hail cause an extensive damage to life and property in the areas through which they traverse (Quadir et al., 2020). For the Indian subcontinent, the South Asian monsoon alerts the hailstorm climatology and about 75% of hailstorms on the eastern side (around Bangladesh) occur in the month of April through June, generally before monsoon onset (Cecil & Blankenship, 2012). Hailstorms can bring severe damages to buildings, crops, vehicles, and other personal properties. As hailstorm has a short duration and small spatial scale, its detection and nowcasting are always demanding subjects. Currently, the most accurate hail forecasting methods rely on weather radars due to the fact that they could generate high-resolution volume data by scanning at multiple elevations. Commonly in radar-based severe weather forecasting, corresponding radar parameters should be extracted from the radar images (Shi et al., 2020). Forecasting of hailstorms is similar to the forecasting of the occurrence of severe convective storms. Beyond that, it is difficult to distinguish between a hail-producing storm and a storm that produces severe winds and tornadoes. This is because often a severe convective storm that produces large hail also produces tornadoes and strong winds. Hail being a very short term and localized phenomena, its prediction well in advance to inform all stakeholders for adequate preventive measures is a major challenge for even the most technologically advanced and hail affected countries like as US. (Bal, Saha S., et al., 2014).

Prediction of hailstorm has always been a challenge for meteorologists. With the induction of Doppler Weather Radars in BAF and their continuous (24/7) surveillance, severe weather as well as hailstorm detection has become possible. Therefore, this study has been undertaken to predict hailstorm events with greater accuracy and issue meteorological warning with a considerable lead time (depending upon the place of origin and movement) before hail strikes. This will allow pilots to avoid potentially dangerous airspace, people to seek shelter, and property to be protected.

1.1 Hailstorms: Facts and Figures

Hail is a type of precipitation in the form of hard, rounded pellets of irregular lumps of ice formed due to deposition of ice over the condensation nuclei as the hailstones cycle travels through strong convective clouds (Kulkarni et al., 2015). Hailstorms are the result of four atmospheric factors which are characterized as: (a) Strong convective instability creating strong updrafts (b) Abundant moisture at low levels feeding into the updrafts (c) Strong wind shear aloft, usually veering with height, enhancing updrafts (d) Some dynamical mechanisms that can assist the release of instability such as air flow over mountain ridges (Bal, Saha S., et al., 2014). The formation of large hail is a result of a broad range of interacting scales of motion and physical processes. However, the size of the hailstones is also strongly dependent on the strength of updrafts and the microstructure of the storm system. This includes the source, location, and size of the ice particles (hail embryos) suitable for initiation of the rapid stages of hail particle growth; the time needed to grow large hailstones relative to the time constraints provided by the storm system; the nature of hail particle growth in the optimum temperature, liquid-water content, and updraft velocity regions; and the rapidity of hailstone melting processes (Figure 1).

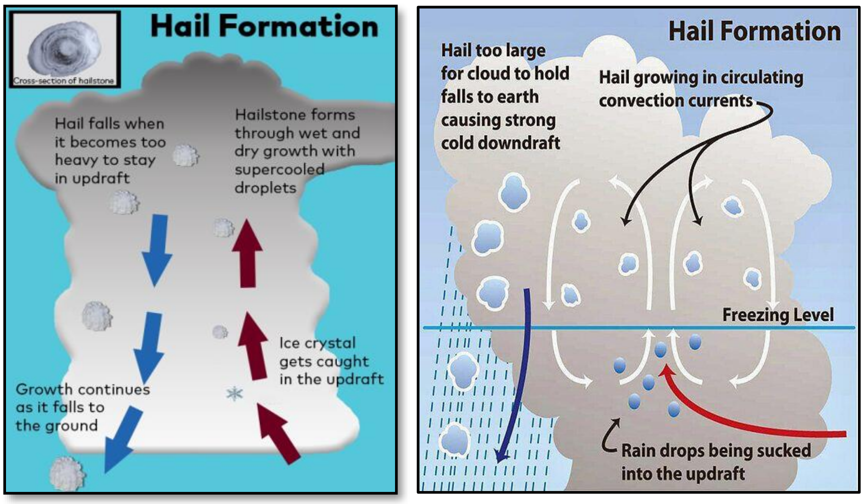

Figure 1: Formation Mechanism of Hail *(Source: https://www.dtn.com/)*

1.1.1 Hail Characteristics and Damage Potential

The damages caused by hails are determined by its characteristics that include the size and number of hailstones that fall per unit area and the strength of winds during a hail fall. The association between intensity and the damage depends greatly on the target such as crop, livestock or property. Some delicate-leaf crops such as tea and tobacco suffer damage from small hailstones, whereas other crops such as maize may not be damaged unless hailstones are of size more than 2 cm. The extent of hail damages also varies with stage of a given crop. A specific type of hailstorm may not cause much damage during vegetable phase growing season but the same storm can be very destructive during flowering and seed/fruit development. Hailstones range in size from pellets to golf balls or even larger. Semi-quantitative estimates of the severity of damages by hails of different sizes borne out of hailstorms of different intensities are given in Table 1 and Figure 2 (Bal, Saha, et al., 2014).

Table 1: Hailstorm intensity scale (*source: www.noaa.gov and www.torro.org)*

Size code	Typical hail diameter (mm)	Equivalent shape	Intensity category	Typical damage impacts
H0	< 8.4	Pea	Hard hail	No damage
H1	8.4 to 15.2	Marble	Potentially damaging	Slight damage to plants, crops
H2	15.2 to 20.3	Coin or grape	Potentially damaging	Significant damage to fruit, crops, vegetation
H3	20.3 to 30.5	Nickel to quarter	Severe	Severe damage to fruit and crops, damage to glass and plastic structures, paint and wood scored
H4	30.5 to 40.6	Golf ball	Severe	Widespread glass damage, vehicle bodywork damage
H5	40.6 to 50.8	Tennis ball	Destructive	Wholesale destruction of glass, damage to tiled roofs, significant risk of injuries
H6	50.8 to 61.0	Baseball	Destructive	Aircraft bodywork dented, brick walls pitted
H7	61.0 to 76.2	Grapefruit	Very destructive	Severe roof damage, risk of serious injuries
H8	76.2 to 88.9	Softball	Very destructive	Severe damage to aircraft bodywork
H9	88.9 to 101.6	Softball	Super hailstorms	Extensive structural damage. Risk of severe or even fatal injuries to persons caught in the open
H10	>101.6	Softball and up	Super hailstorms	Extensive structural damage. Risk of severe or even fatal injuries to persons caught in the open

Figure 2: Hail stones produced under varying intensities of hailstorm (*source: www.noaa.gov and www.torro.org)*

1.1.2 Severe Hailstorm Events of the World

The chronological sequence of some of the severe hailstorm events that happened across continents in the recent recorded history is presented in Table2 (Bal, Saha, et al., 2014).

Table 2: Severe hailstorms in the world during the recent recorded history (*source: http:// en.wikipedia.org/wiki/List_of_costly_or_deadly_hailstorms*)

Date	Location	Incident
02 Sep 1960	California, USA	Golfball to baseball sized hail occurred in parts of southern California, Boulevard and in Riverside County.
30 Jul 1979	Colorado, USA	A violent forty-minute hailstorm bombed Fort Collins with hail up to grapefruit size. Two thousand homes and 2500 automobiles were severely damaged, and about 25 people were injured.
12 Jul 1984	Munich, Germany	Tennis ball sized hail fell on Munich and surrounding areas. It was the greatest loss event in the history of the German insurance industry: 2,00,000 cars were damaged and reported severe losses in monetary terms.
18 Jan 1985	Queensland, Australia	Alate afternoon supercell thunderstorm swept in from the west dropping hailstones as large as 6 cm over parts of the Brisbane city. A wind gust of over 180 km/h was recorded at Brisbane airport. This rate as the 5th most costly insured event in Australia since 1968.
01 Nov 1985	Transvaal, South Africa	Major hailstorm struck central Pretoria and surrounding areas. Damage estimated at 400 million of south African currency
14 Apr 1986	**Gopalganj, Bangladesh**	**At least 92 people were killed in Gopalganj by some of the heaviest hailstones ever recorded, which were the size of grapefruits and weighed around one kilogram each.**
07 Sep 1991	Alberta, Canada	A single hailstorm damage costing about 342 million US dollar. Thirteen additional hailstorms occurred between 1981 and 1998 causing an estimated 600 million US dollar in damage in the Calgary area alone.

14 Apr 1999	New South Wales, Australia	20,000 properties and 40,000 vehicles were damaged during the storm with more than 25 aircraft damaged at Sydney airport. At $ 1.5 billion, it was the costliest hailstorm to hit an Australian populated city. Largest stone measured was 9.5 cm.
10 Apr 2001	Missouri, USA	The costliest hailstorm (damage estimated at more than $ 2.0 billion) in US history struck the I-70 corridor of eastern Kansas, across Missouri, into south-western Illinois.
19 Jul 2002	Henan, China	25 dead and hundreds injured.
28 & 29 Jun 2006	Baden-württemberg Germany	Super-cell thunderstorms, severe damage by grape fruit sized hail stones, causing € 150 million damage and more than 100 injuries
23 Jul 2010	Vivian, USA	The largest hailstone of all time, measuring 20 centimeters in diameter- larger than a bowling ball - and weighing about 0.9 kg was recorded
28 Apr 2012	St. Louis, Missouri, USA	Series of hailstorms amount to second costliest in US history at estimated $ 1.6 billion in insured losses.
28 Jul 2013	Southern Germany	A super cell dropped hailstones with a diameter of up to 8 centimeters. Around 70 people were injured by large rain amounts, downbursts, lightning strikes and the hail. Reported as the second most expensive hailstorm in the history of Germany after the Munich hailstorm of 12th July 1984.

1.2 RADAR Technology in Hail Forecasting

Protection against violent hailstorms is possible only when we are capable to forecast those well in advance. However, it is difficult to forecast a hailstorm, since its occurrence is sporadic and confined to very limited areas in a thunderstorm. Efforts to detect and measure hail have been underway for many years. While hail formation continues to elude scientists, sophisticated radar has been developed that can detect the presence of hail before it falls to the ground (Bal, Saha, et al., 2014). A microwave pulse is sent out from the radar transmitter. The pulse strikes raindrops/ hailstones and a fraction of its energy is reflected back to the radar unit (Figure 3). The radar itself does not delineate between rain and snow. On Doppler radar, hail generally sends a return signal that looks like extremely heavy rainfall. Dual-polarization radar technology can help to tell the difference between hail, ice pellets and rain, and even determine hail size.

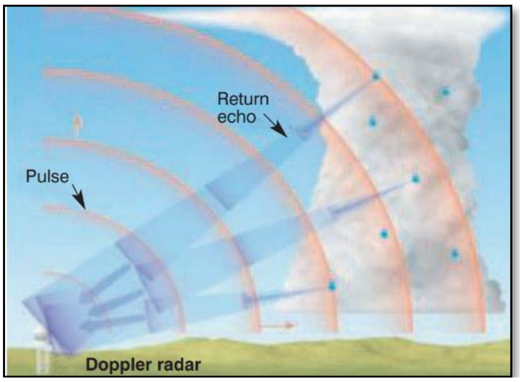

Figure 3: A microwave pulse and return echo

A number of studies have been carried out about forecasting of hailstorm that occurred over India and Bangladesh. A study using differential reflectivity radar values found that it could detect hail quite well at Colorado USA (Depue et al., 2007). Pradhan et al. (2012) studied hailstorm occurrence over Kolkata on 06 May, 2007 at 1002 UTC using DWR. The size of hails was about 2 cm and the hailstorm lasted for 10 minutes. Authors found some typical signature of the system in the DWR observations as a very long "Anvil" ahead of the main cloud and extended up to a distance of 100 km towards east of Kolkata. Vertical extent of the cloud was only 8 km and the RADAR reflectivity was lying in the range of 53.3 dBz to 56.7 dBz (Pradhan et al., 2012). "Prediction of Hailstorm during Pre–monsoon Period over Bangladesh Using NWP Model" studied by Syeda Sabrina Sultana et al. (2021). Her model generated result showed that 700 to 200 hPa level had the highest concentration of cloud microphysical properties and reflectivity was also high above 60dBz on those levels (Das et al., 2021). "Winter hailstorms signatures by C-band polarimetric radar at Delhi" studied by Devajyoti Dutta et al. (2016). He found that the hailstorms over the study region were classified into two types with and without large CAPE. Although ZH is higher for all events, the ZDR differs for the two categories. The events with small CAPE and strong shear produce storms with larger ZDR (rain mixed with small hail), while those with large CAPE and weak shear produce smaller ZDR (strong hail) (Dutta et al., 2016). "Unusual Hail storms during May 2002 in Chennai and its suburbs-A study using data from single Doppler Weather Radar" studied by R. Suresh et al. (2004). He concluded that the hail warning conditions/ thresholds on echo top of 45 dBz exceeding freezing level by more than 1.4km, vertically integrated liquid (VIL) of 43kg/m^2 or more, VIL density of 3.5 g/m^3 and reflectivity of more than 55 dBz at 3 km height (Suresh & Bhatnagar, 2004).

2. Data and Methodology

Doppler Weather Radar data from Bangladesh Air Force (BAF) Base Jashore and Chattogram for Pre-monsoon months (March, April and May) for the period of 2019 to 2022 have been used. A total 32 cases of Hailstorm events have been considered for this study for the period of 2019 to 2022 especially during Pre-monsoon months (March, April and May). Some early hailstorm cases in the month of February are also taken. Dates of occurrences of Hailstorm over BAF Bases have been collected from the recorded registers. Hailstorm events over the country (except BAF Bases) and neighborhood are collected from newspapers/electronic or print media.

Figure 4: A typical Radar Base Reflectivity product of BAF Radar

The Radar base reflectivity product is a display of echo intensity (reflectivity) measured in dBZ (decibels). "Reflectivity" is the amount of transmitted power returned to the radar receiver after hitting precipitation. The colors represent the strength of returned energy to the radar expressed in values of decibels (dBZ). The color scale is located at the lower right of each image. As dBZ values increase so does the intensity of the rainfall/precipitation. Value of 20 dBZ is typically the point at which light rain begins. The higher value of dBz indicate higher rain intensity. As per US National Weather Service (NWS), the values of 60 to 65 dBZ is about the level where 1" (2.5 cm) diameter hail can occur. However, a value of 60 to 65 dBZ does not necessarily mean a hailstorm. It depends on season and cloud microphysical properties. In Bangladesh, during pre-monsoon season, if base reflectivity shows greater than 50-55dBz, then there is a chance of hailstorm. But, during monsoon season 50-55dBz echo gives only rain. In this study, only Radar Base Reflectivity products have been used to determine hail potential during Pre-Monsoon period.

3. Results and Discussion

3.1 Case-1: Hailstorm over Rajshahi, Natore and Kushtia. On 17 February 2019 early morning hailstorm occurred over Rajshahi, Natore and Kushtia districts. Jashore Doppler Weather Radar image shows echo reflectivity 63 dBz (pink colour), 67 dBz (pink and black colour) and 68.5 dBz (black colour) are observed over Rajshahi, Kushtia and Narore districts respectively (Figure 5). The hailstorm has caused damage to crops in Rajshahi and Kushtia (report of Dhaka Tribune). It has caused damage to the mango blossoms and a huge number of mangoes fell down from the trees in various locations of Rajshahi. Meanwhile, the rain has caused damage to many crops in the region. Mainly onion farmers are the ones who have been mostly affected for it. 17mm of rain was recorded during the 38-minute storm. The report of ‘Kalerkantho’ (on 17 February 2019) says, the sudden hailstorm in three upazilas of Natore has caused severe damage to various crops including rabi crops. Farmers said that hailstorm started suddenly in most parts of Naldanga, Singra and Sadarupazilas of the district around 5:30 am on Sunday. Ten to fifteen minutes of hail caused severe damage to various crops including mango, litchi, guava, onion, garlic, boro paddy, mustard, wheat, kalai, maize, vegetables, betel waste. Various birds have also died, including damage to homes. The farmers have been hit hard by the sudden hailstorm that has caused crop damage by borrowing crops. The tin shed has leaked

Figure 5: Radar Image and Hail damage pic

due to falling rock. Many dead birds are scattered around the house. Admitting the damage caused by the hailstorm, Deputy Director of the Department of Agricultural Extension Rafiqul Islam said that 2,084 hectares of land was affected by the hailstorm. (*News: Kalerkantho*)

3.2 Case-2: Hailstorm over Chuadanga. On 16 April 2019 night hailstorm heavy storm occurred over Chuadanga districts. Jashore Doppler Weather Radar image shows echo reflectivity 57.5 dBz (pink colour) over east-southeast of Chuadanga. It injured 11 people and caused severe damage to houses, plants and growing crops including paddy. However, no immediate account of the damage was available from the concerned departments. According to the Chuadanga Meteorological Department's first class observatory, the duration of the storm which started after 8 pm last night was four minutes. The speed of the storm was 60 kilometers per hour. Besides, there has been hail for an hour from 8:13pm at night. At this time 26 mm rainfall was recorded. (Figure 6) *(News: Prothom Alo)*

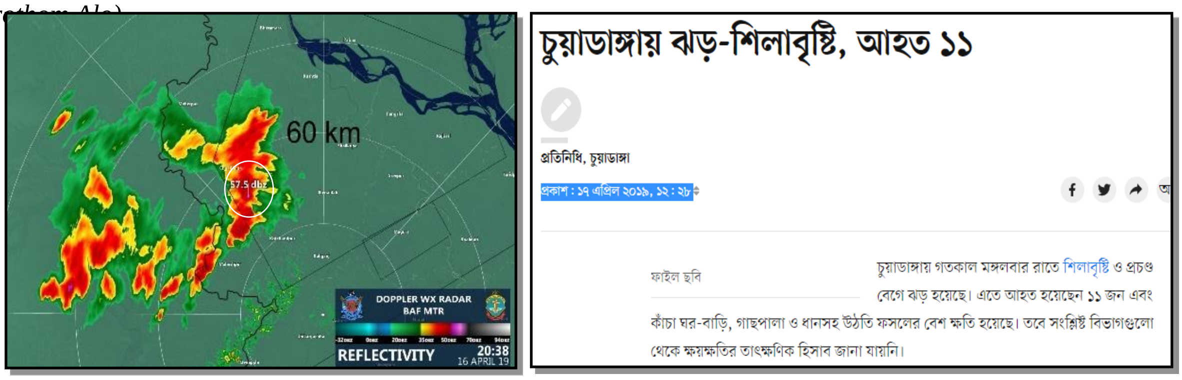

Figure 6: Radar Image and Hailstorm news pic over Chuadanga

3.3 Case-3: Hailstorm over BAF Base Bashar (Tejgaon) and Bangabandhu (Kurmitola). On 31 March 2019 evening hailstorm occurred over BAF Base Bashar and Bangabandhu (BAF BBD). Jashore Doppler Weather Radar image shows echo reflectivity 50 dBz (red colour) over west of the Bases. The cell was not that much intense (max reflectivity 50 dBz) in nature, but it produced hail (smaller in size) for the Bases (1220UTC-1222UTC over Bashar and 1218UTC -1223UTC over Bangabandhu) (Figure 7).

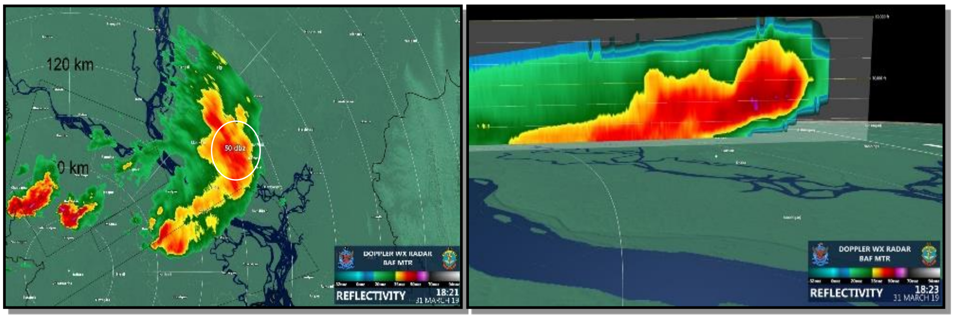

Figure 7: Radar Image with vertical cross section of the echo over Dhaka

3.4 Case-4: Hailstorm over Kaliganj and Jhenaidah. On 02 April 2019 evening hailstorm occurred over Kaligonj and Jhenaidah districts. At 1238UTC Radar image shows echo reflectivity 69dBz (black colour) over

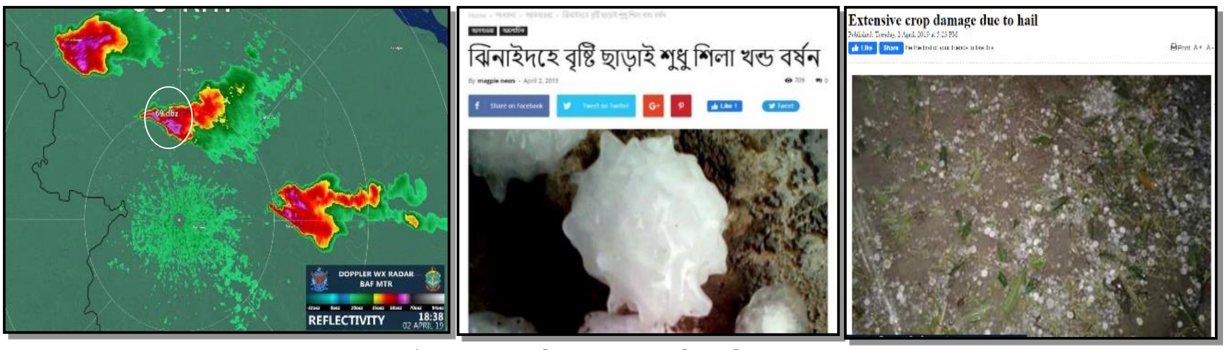

Figure 8: Radar Image and Hailstorm news pic

Kaliganj, Jhenaidah (Figure 8). Upazilas of Jhenaidah district, Kalbaishakhi rain and hail hit on 02 April 2019. It has affected the rural areas of every upazila of the district. The hailstorm has damaged brick field owners, mango orchard including field crops. It was very hot during the day. Local reporter said, that day he saw clouds in the northern sky. A few moments later, light rain with a gust of wind and later the hail began to fall. In this regard, GM Abdur Rauf, Director, Department of Agricultural Extension, Jhenaidah, said, “How much damage has been done in the last few days by storms, rains and rocks through our district, upazila and field level officials of the Agriculture Department. Work is underway to determine that. (*News: Shikshatathya.com*).

3.5 Cases 5 to 32: Rest of the cases (cases 5 to 32) are mentioned in the Summary of Results. Some of the radar reflectivity images as well as hailstorm devastation pictures are shown below (Figure 9 & 10):

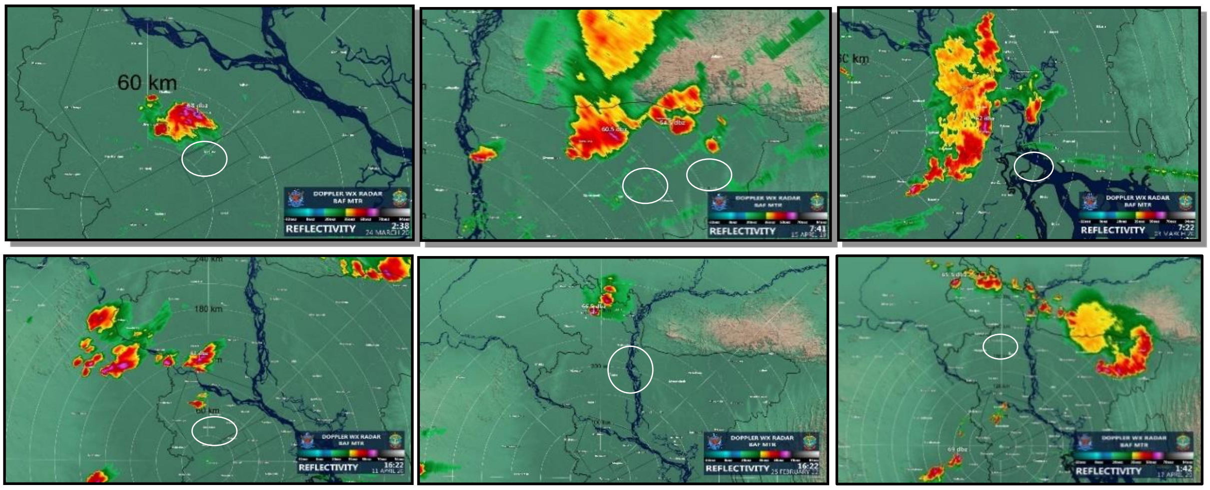

Figure 9: Radar Images of Hailstorm events over the

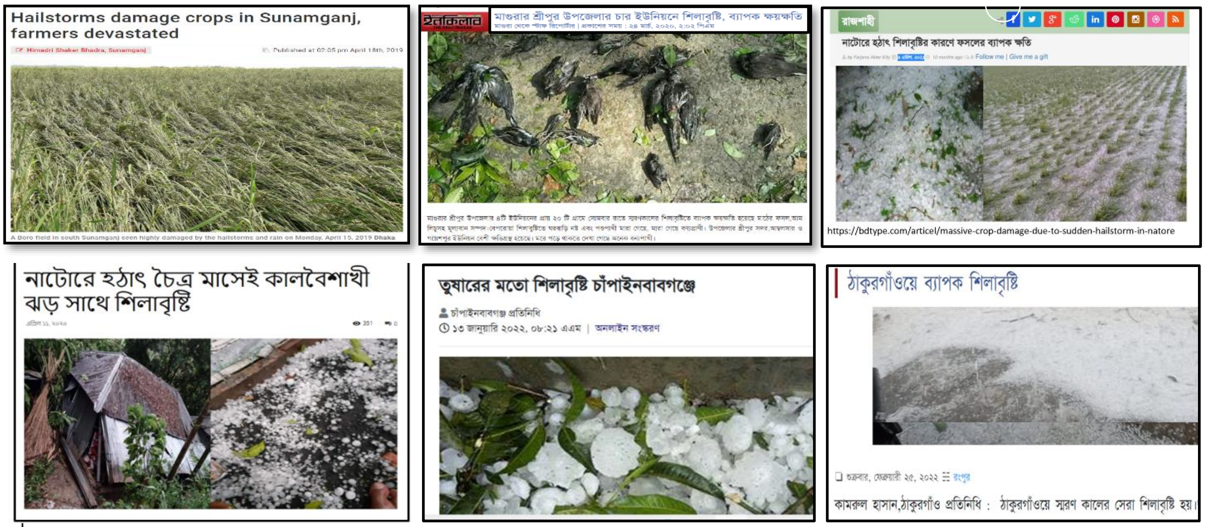

Figure 10: Hailstorm devastation pictures across the

3.6 Summary of Results

Table 3: Summary of 32 Hailstorm Cases (2019-2022)

Case No	Affected Place/Region	Date of Occurrence	Approximate Time of Occurrence (in UTC)	Damage/Impact	Radar Reflectivity (dBz)
01.	Rajshahi, Natore, Kushtia	17-02-2019	Sunday early morning (2240-2330 UTC)	Mango & lichi blossoms, various rabi crops	65-69
02.	Chuadanga	16-04-2019	1400 UTC -1500 UTC	11 injured, houses and crops	55-58
03.	BAF Base BBD	31-03-2019	1218 UTC -1223 UTC	Unknown	50-52
	BAF Base BSR	31-03-2019	1220 UTC -1222 UTC	Unknown	
04.	Kaliganj, Jhenaidah	02-04-2019	Evening	Brickfield, crops	60-69

05.	Bagerhat	26-02-2019	Tuesday morning	05 injured, houses	60-62
06.	BAF Base MTR	22-03-2019	1155 -1158UTC	Unknown	52-56
07.	BAF Base BBD	02-04-2019	0745-0752UTC & 0827-0835 UTC	Unknown	58-61
08.	BAF Base MTR	03-04-2019	1210 -1225UTC	Nothing significant	55-60
09.	BAF Base BBD	08-04-2019	0957 -1000UTC	Nothing significant	57-62
10.	BAF Base MTR	10-04-2019	0003 -0005UTC	Nothing significant	55-58
11.	Sunamgonj	15-04-2019	Monday Morning	Vast track of crops	56-61
12.	Madaripur, Faridpur(Vanga)	03-03-2020	Tuesday EM	Rabi crops, lichi & mango buds.	57-62
13.	BAF Base MTR	03-03-2020	1444 -1448UTC	Unknown	57-62
14.	BAF Base MTR	21-03-2020	1328 -1355UTC	Unknown	58-63
15.	Magura	24-03-2020	Monday Mid night	Mango & lichi pods, houses, killed wild animals & birds	63-68
16.	BAF Base BBD	02-04-2020	1201-1202UTC	Nothing significant	61-66
17.	Brahmanbaria	03-04-2020	Thursday at Afternoon	Mango blossoms, crops	62-67
18.	Cumilla(Homna)	05-04-2020	Sunday at Afternoon (0900UTC)	Rabi crops & vegetables	61-66
19.	Natore	11-04-2020	Saturday Late Afternoon/Evening	Rabi crops, mango, houses	56-61
20.	Thakurgaon	17-04-2020	Friday Late night	Various crops	61-66
21.	Naogaon, Natore&Tangail	22-04-2020	Wednesday Afternoon	Injured 50, IRRI crops, houses	62-68
22.	Brahmanbaria	23-04-2020	Thursday at Noon	Boro paddy (ripe)	60-65
23.	BAF BASE BBD	24-04-2020	0726- 0731UTC	Unknown	53-58
24.	Lalmonirhat	26-05-2020	Thursday Night at 1400UTC	Boro paddy, Maize, other crops.	61-65
25.	Rajshahi	13-03-2021	Saturday Afternoon	Chaitali crops and mango buds	63-68
26.	Rajshahi (Putia)	04-04-2021	Sunday at Afternoon	Boro paddy, crops	60-65
27.	Lalmonirhat and Rangpur	07-04-2021	1700 -1730UTC	Houses, boro paddy, crops	63-68
28.	Natore	09-04-2021	Afternoon	Various crops &boro paddy	63-68
29.	BAF BASE BBD	28-04-2021	1739 -1742UTC	Unknown	57-60
30.	Chapainawabganj & Naogaon	12-01-2022	1500 -1600UTC	Winter vegetables	65-70
31.	Thakurgaon	25 Feb 22	0930 -1000UTC	Record breaking, 17 injured, crops and properties	61-66
32.	Jhenidah	27 Feb 22	0930 -1000UTC	Severe Hailstorm (10/15 years record). Crops and properties damaged	66-71

4. Conclusion

Doppler Weather Radar is an excellent tool to predict (nowcast) hailstorm especially during Pre-Monsoon period. Radar reflectivity more than 50dBz (red color echo) during Pre-Monsoon period indicates the chances of hailstorm and the hail intensity and size increases with higher dBz (60dBz or more, that is pink or black color echo). As per the available records (2019-2022), the hailstorms are found to occur almost every region of Bangladesh except coastal regions. Hailstorms can cause severe damage to arable crops, orchard crops and farm structures apart from seriously injuring livestock, poultry and humans. With my five years' experience with Jashore Doppler Weather Radar, it can be said that prediction of hailstorm can be determined by seeing the Radar reflectivity images with more than 85% of accuracy. Doppler Weather Radar can provide early warning about hailstorm with a lead time ranging from half an hour to two hours or more depending upon the intensity and place of origin. BAF Doppler Weather Radar product can be potentially utilized to provide early warning to aviation sector, farmers and mass people to minimize damage from hailstorms. There is a need to have adequate Doppler Weather Radar coverage in the country to predict/forecast severe weather including lightning and hailstorms all over the country in order to alert farmers and mass people to minimize loss of lives and properties. In this study only Radar Reflectivity product is used. Dual-Polarization (volumetric) Doppler Radar data might give some additional information about hailstorms and severe weather. Therefore, in future the study may be carried out taking Dual-Polarization (volumetric) Doppler Radar data.

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