An analytical study of Heat Wave occurred over Bangladesh during pre-monsoon of 2021

Md. Abdul Mannan[1], Fatima Akter[2], Md. Bazlur Rashid[1], Md. Monowar Hossain[1], SK. Omar Faruque[1], Sharif Shameem Ara[1], Afruza Sultana[1], Sushmita Barua[1], Samarendra Karmakar[3] and Md. Abdul Mannan Chowdhury[4]

[1]*Bangladesh Meteorological Department, Dhaka, Bangladesh*
[2]*Department of Meteorology, University of Dhaka, Dhaka, Bangladesh*
[3]*National Oceanographic and Maritime Institute, Dhaka, Bangladesh*
[4]*Department of Physics, Jahangirnagar University, Savar, Dhaka, Bangladesh*
Corresponding author: mannan_u2003@yahoo.co.in, mamannanbmd2015@gmail.com

Abstract

Heat wave is a period of excessively hot weather accompanied by high humidity. It endanger human health and makes the human body not to adapt with the environment, causes aggravation of disease, even death. Heat wave (HW) mainly occurs during the pre-monsoon season in Bangladesh. In the recent times it appears in other seasons also. HW also becomes more common in Bangladesh and deserves broad analysis especially synoptic analysis. To proceed on this aspect HW condition has been searched utilizing the recorded maximum temperature data from 43 stations of Bangladesh Meteorological Department (BMD) during pre-monsoon season (March to May) of 2021. Considering the operational definition of BMD, the HW events are calculated. Considering all of these conditions, the pre-monsoon season of 2021 can be treated as one of the most potential HW period, as there are several HWs during this season. To understand the cause of this HW, the parameters of sea level pressure, wind flow, relative humidity and lifted index (LI) associated with the events of occurred during 21-27 March, 11-15 April, 24-30 April and 15-24 May 2021 have been checked. Analysis depicts that the presence of thermal low over western side of Bangladesh, anticyclonic circulation over the Bay of Bengal, presence of high humidity at lower tropospheric level over Bangladesh and negative magnitude of LI are well recognized conditions for formation, intensification and persistence of HW in Bangladesh. The result of this study may be useful to the operational forecasters.

Key Words: Heat wave, lifted index, pre-monsoon and lifted index.

1. Introduction

A heat wave (HW) is a period of excessively hot weather, which may be accompanied by high humidity. A heat wave is usually measured relative to the usual weather in the area and relative to normal temperatures for the season. The impact of heat wave is multifaceted, and the main effects of it are as follows:

i. It endangers human health and makes the human body cannot adapt the environment, so this will cause for the occurrence or aggravation of the disease, even death;
ii. It stain the city's water and electricity supplies;
iii. It affects plant growth and reduce crop yields;
iv. It exacerbating droughts;
v. Heat wave often makes people agitated, and even may appear the phenomenon of mental disorder. It's easy to cause public disorder, accident casualties and poisoning, fire and other events.

There is no universal definition of Heat Wave (HW). Most of the definitions are based on the persistence of maximum, minimum or mean surface air temperature above a threshold value that is based on the upper tail of the temperature distribution over a region [1]. Some of the definitions may even consider surface humidity levels as humidity can worsen a HW effect. Vaidyanathan et al. [2] provided a HW definition considering four core variables- the heat metric (viz., maximum/minimum/mean temperature, diurnal temperature difference etc.), duration, thresholds type and threshold intensity.

Della-Martha et al. [3] defined HW as the number of consecutive 3-day periods in summer that exceed the long-term daily 80th percentile of daily maximum temperature. Srivastava et al. [4] defined the event if the maximum temperature at a grid point is 3°C or more than the normal temperature, consecutively for 3 days or more. Mishra et al. [5] considered HW as the period during which the daily maximum temperature stayed above the empirical 99th percentile consecutively for six or more days. Ganguly et al. [6] defined HW as the mean annual consecutive 3-day warmest night-time minima event. Apart from temperature, large scale circulation has also been used to define HW. Lee et al. [7] calculated HW index over Korea as the difference in the 200 hPa vorticity between the average over 25°-30°N, 110°-130°E and the average over 35°- 45°N, 120° - 140°E. Australian Bureau of Meteorology defines the HW using Excess Heat Factor (EHF) [8, 9, 10], which depends on Excess Heat and Heat Stress. Both the maximum and minimum temperatures are used in this assessment. Daily mean temperature averaged over a 3-day period against its climatological value is used to characterize excess heat, while maximum and subsequent minimum averaged over a 3-day period and the previous 30 days characterizes heat stress.

The definition specified by India Meteorological Department (IMD) for station data has been widely used in many studies [11-17]. The criteria set by IMD is as follows: When maximum temperature of a station reaches ≥ 40°C for plains and ≥ 30°C for hilly regions,

a. Based on departure from normal: HW- maximum temperature departure from normal is 4.5°C to 6.4°C, Severe HW (SHW)- maximum temperature departure from normal is ≥ 6.5°C;
b. Based on actual maximum temperature: HW- actual maximum temperature is ≥ 6.5°C; SHW- actual maximum temperature is ≥ 47°C;
c. Criteria for coastal stations: HW- When maximum temperature departure ≥ 4.5°C and actual maximum temperature ≥ 37°C

Heat waves are generally caused by quasi-stationary anticyclonic circulation anomalies or atmospheric blocking [18-21], and/or land-atmosphere feedbacks (in transitional climate regions). The land-atmosphere feedbacks can act as an amplifying mechanism through reduction in evaporative cooling, but also induce enhanced persistence due to soil moisture memory [22].

The combination of heat and high humidity may cause discomfort, heat stroke or even death to humans and animals. This heat related incidences have been studied extensively by various authors [23-26].

The impacts of recent heat waves are of particular concern since these events are expected to become more frequent, intense, and of longer duration for much of India over the course of the 21st century [27]. The fact that extreme heat events tend to come just before the onset of monsoon rains also raises an interesting question about land-atmosphere interactions. This is a dry time of year in much of India, and both the approach of summer solstice and the presence of typically clear skies lead to high downwelling solar radiation at the surface.

This suggests that extreme heat waves could, in part, be a product of local heating through enhanced sensible heat flux from a hot and dry surface. A significant contribution of local heating to the onset and/or intensification of heat waves has been found for major heat events in Europe in 2003 [28,29] and in Russia in 2010 [30], among others. Impacts of depleted soil moisture on the occurrence of heat wave during 1961-2013 are also found over India [31]. Extreme heat events appear to be associated with late monsoon rains, inadequate pre-monsoon rains, or low rain in neighboring regions leading to advection of dry heat into India [32]. Longer (duration) and warmer heat waves over India are found to be linked with El Niño years as well [33].

In Bangladesh, mortality rates increase by about 20% during heat waves [34]. However, the frequency, location or strength of atmospheric circulation patterns associated with heat waves [1, 34-36] could also change as emissions increase.

Heat waves in Bangladesh occur during the pre-monsoon season, between April and June (AMJ). This season is characterized by hot weather, thunderstorms and intense but sporadic convective precipitation, which depends on southerly winds from the Bay of Bengal for its supply of moisture [37]. Heat waves are associated with stronger-than-normal westerly winds, which import hot, dry air from northern India, weakening the advection of moisture from the south and suppressing rainfall. The association of heat waves with dry conditions also extends to seasonal and interannual timescales. Anomalously dry soil moisture conditions and low accumulated precipitation occur for up to 60 days in advance of a heat wave. Inter-annually, variations in seasonal precipitation and soil moisture are related to the frequency of heat-wave days, with drier than normal years associated with higher heat-wave frequencies [34]. Considering the importance of the prediction, recorded HW of pre-monsoon season has been chosen for this study.

2. Data used and Methodology

To get the records of HW over Bangladesh during pre-monsoon season of 2022, daily records of maximum temperature from BMD weather stations have been collected. The HW conditions have been searched on the basis of the records of maximum temperature (MaxT) with other conditions as given in Table 1. Spatial maps has been prepared to locate the coverage area of different intensities of HW its progression over Bangladesh territory.

For further checking, NCEP reanalysis data has also been utilized. To know the physical cause of the formation, intensification and progression of HW, daily NCEP 6-hourly reanalysis data of sea level pressure, surface wind, surface relative humidity and lifted index over a wide region surroundings of Bangladesh of pre-monsoon season 2021 have been analyzed. The result has been accomplished accordingly in chapter four.

Table 1: Classifications of HW utilized for analysis

Types	MaxT (°C) as commonly utilized	MaxT (°C) as utilized for calculation	Deviation of MaxT (°C) from the normal
Mild Cold Wave	36.0-38.0	36.0 – 37.9	+2.0 (°C) or more
Moderate Cold Wave	38.0 – 40.0	38.0 – 39.9	+4.0 (°C) or more
Severe Cold Wave	40.0 – 42.0	40.0 - 41.9	+5.0 (°C) or more
Very Severe Cold Wave	> 42.0	> 42.0	+6.0 (°C) or more

3. Analysis and discussions

3.1 Heat wave in Bangladesh during pre-monsoon season of 2021

As per the record of BMD there were five individual HW spells in Bangladesh during the season, but the long and significant HW were recorded during 21-27 March, during 11-15 April 2021and 24-30 April 2021 and 15-24 May 2021 as depicted in Fig. 1. Spatial deviation depicts these events were exceptionally located mainly over southwest, south parts with their coverage over central and eastern parts. Details of these events are discussed in the following sections.

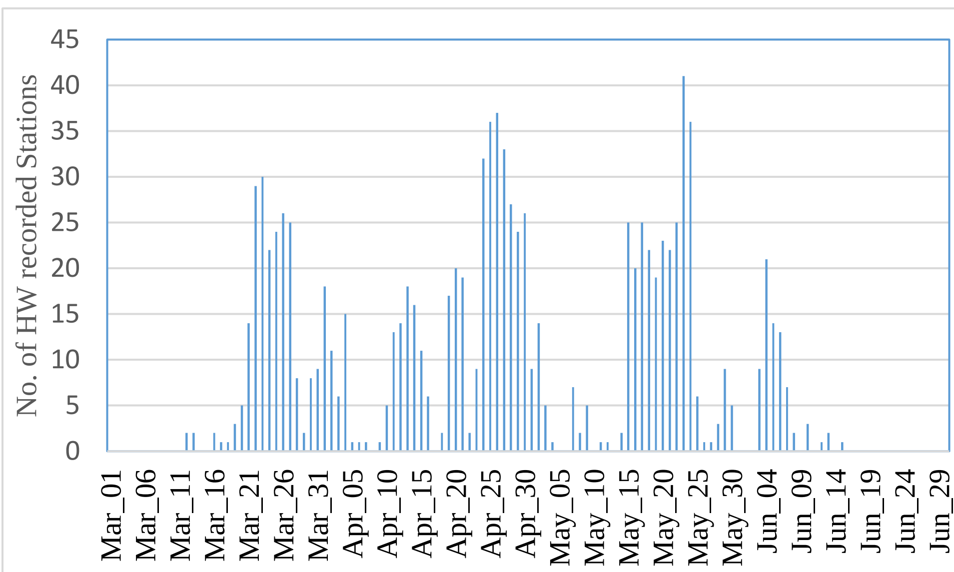

Fig. 1: Temporal distribution of the no. of HW recorded stations of BMD

3.2 Heat wave during 21-27 March 2021

A prolonged heat wave situation was observed over Bangladesh during 21-27 March 2021. It initiated on 20 March at isolated places over Khulna division and then at Dhaka Division. It covered Dhaka and Khulna divisions on 21 March. Then it covered and persisted over Dhaka, Khulna and most part of Chattogram, Barishal divisions during 22-27 March 2021. During this period the highest maximum temperature of 39.3°C was recorded at Sitakunda. Analysis of mean Sea Level Pressure (MSLP) indicate that a thermal low appeared in the southwestern and southern part of Bangladesh and its adjoining areas covering central part of Bangladesh, which oriented east-west direction during this period and finally settled over Gangetic West Bengal and adjoining southwestern part of Bangladesh (Fig. 2). Following this low and weak anticyclonic flow over East-central Bay of Bengal there were high moisture content at surface level over southern and central parts of Bangladesh (Fig. 3).

Following this low and weak anticyclonic flow over central Bay of Bengal, which facilitate incurring moisture from the Bay of Bengal and there were high moisture content at surface level over southern and central parts of Bangladesh (Fig. 4). Due to the presence of high insolation and high moisture facilitated by the heat low over land mass area and low level anticyclonic flow over the Bay of Bengal, warm and unstable atmosphere persisted over the central to southern part of Bangladesh (Fig. 5). The presence of anticyclonic flow was continued during 21-27 March 2021, which was supported the heat wave to be active during the observed period.

3.3 Heat wave during 11-15 April 2021

This spell of HW was recorded during 11-15 April 2021. It initiated on 10 April over Rajshahi region and then covered Rajshahi division, most parts of Khulna, Dhaka and Barishal divisions and the regions Rangamati and Feni on 14 April. At this stage the highest maximum temperature reached to 39.7°C, which was recorded at Rajshahi. Then the situation stated to diminish and finally concentrated only over Jashore and Kushtia region on 15 April.

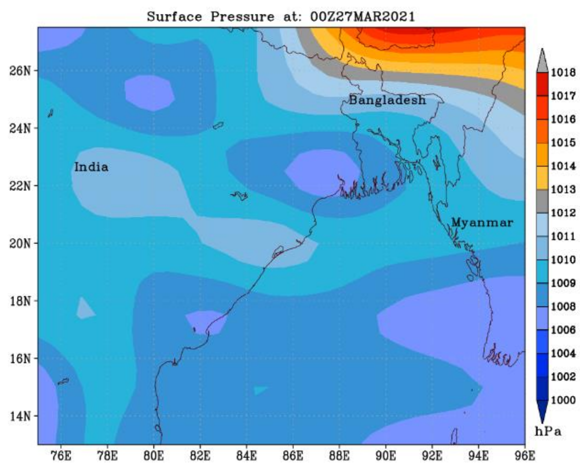

Fig. 2: Spatial distribution of MSLP over Bangladesh and adjoining area

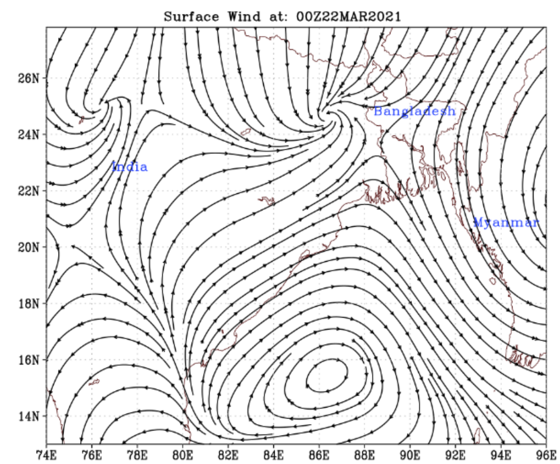

Fig. 3: Wind flow at surface level over Bangladesh and adjoining area

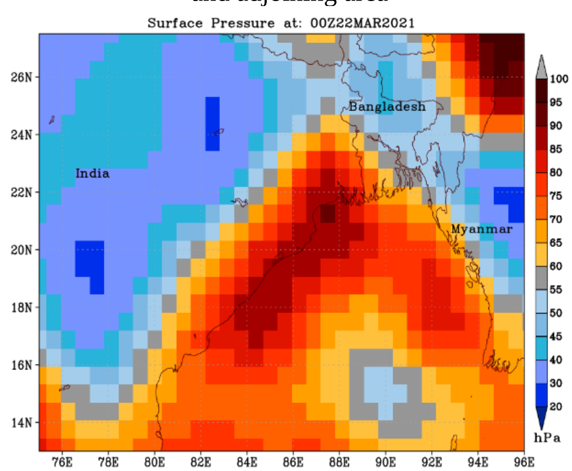

Fig. 4: Spatial distribution of relative humidity at surface level over Bangladesh and adjoining area

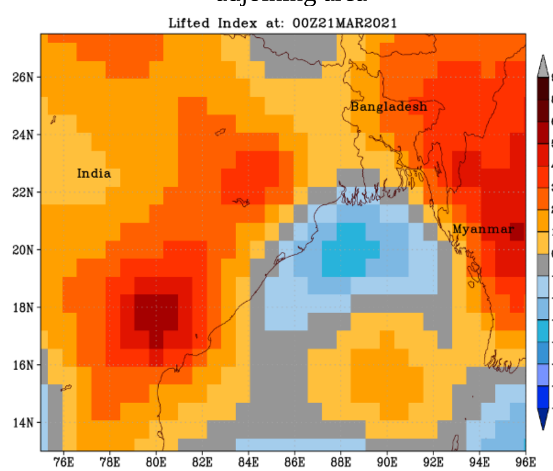

Fig. 5: Lifted Index over Bangladesh and adjoining area

Analysis of MSLP indicate that an extended thermal low persisted over Bihar, West Bengal with its extension over southwestern part of Bangladesh. The central and southern parts of Bangladesh were under its influence (Fig. 6). An anticyclonic system at surface level over central part of the Bay of Bengal was present during this period and act a source of moisture flow from the Bay of Bengal to Bangladesh and adjoining area, created confluence over northern part of Bangladesh and its nearby places (Fig. 7). Due to this synoptic situation high humidity was at surface level over Bangladesh during this period as displayed in Fig. 8. Accordingly, the surface atmosphere was very much unstable due to absorption of high heat energy as estimated through lifted index and shown in Fig. 9.

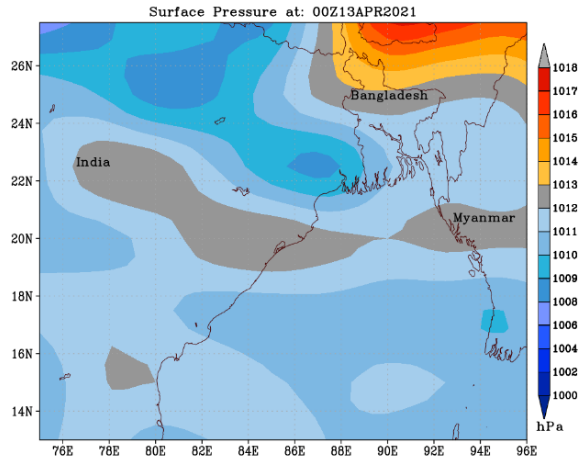

Fig. 6: Spatial distribution of MSLP over Bangladesh and adjoining area

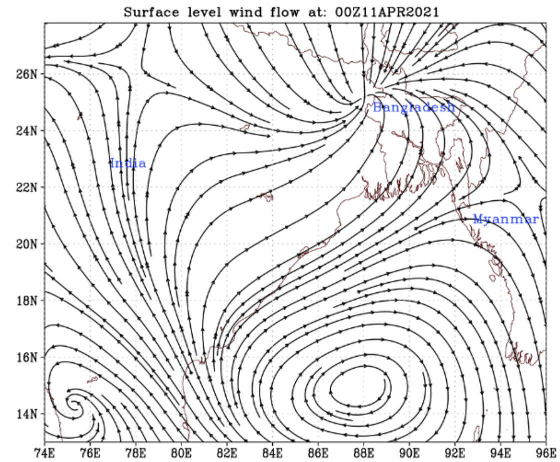

Fig. 7: Wind flow at surface level over Bangladesh and adjoining area

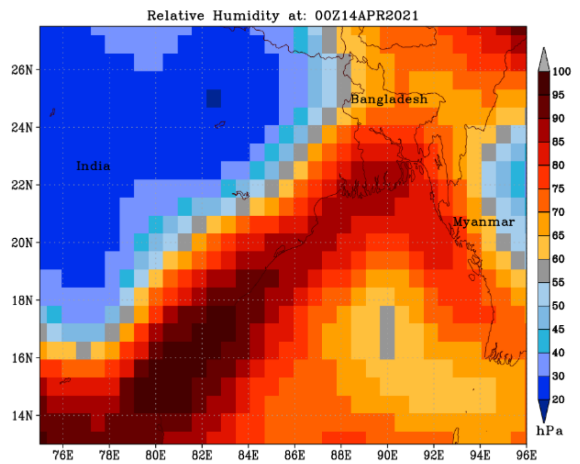

Fig. 8: Spatial distribution of RH over Bangladesh and adjoining area

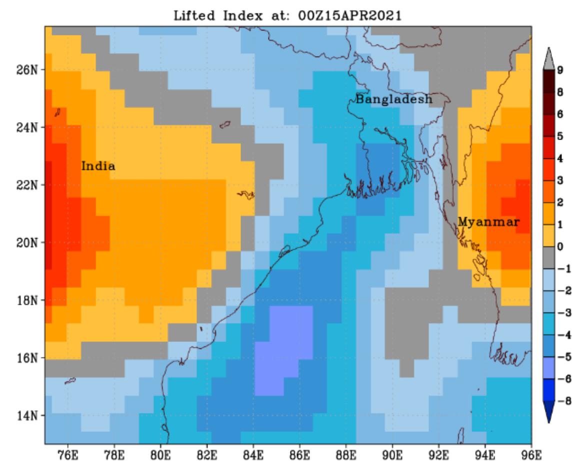

Fig. 9: Lifted Index over Bangladesh and adjoining area

3.4 Heat wave during 24-30 April 2021

This spell of HW was initiated on 23 April over Khulna region and then extended over most parts of the country except Chattagram and Cox's Bazar regions on 26 April. During this period the severity of HW reached to the highest

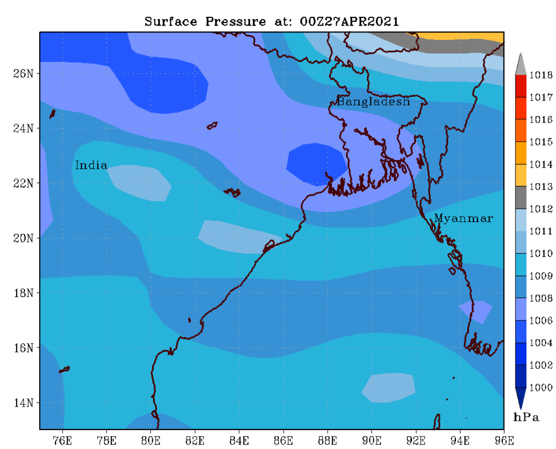

Fig. 10: Spatial distribution of MSLP over Bangladesh and adjoining area

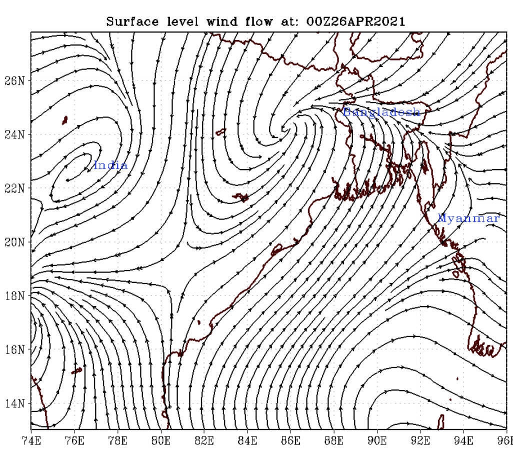

Fig. 11: Wind flow at surface level over Bangladesh and adjoining area

on 25 April, the maximum coverage was on 26 April and the highest maximum temperature reached to 41.2°C at Jashore. Then the situation started to weaken and finally concentrated only over Sylhet, Rajshahi, Jashore and Kushtia regions on 03 May.

Analysis of MSLP indicate that the thermal low pressure extended from northwest persisted over Bihar, West Bengal with its extension upto southeastern part of Bangladesh covering central and southern parts of Bangladesh during this period. The central and southern parts of Bangladesh were under its influence (Fig. 10). Due to the presence of this thermal low over WB and adjoining area of India and anticyclonic system over the BoB, moisture incursion was in continuous over Bangladesh during this period as in Fig. 11. As a result, higher RH at surface level continued over Bangladesh as displayed in Fig. 12. By reasons of high RH, insolation and higher temperature, low level atmosphere was highly unstable and LI was negative as indicated in Fig. 13.

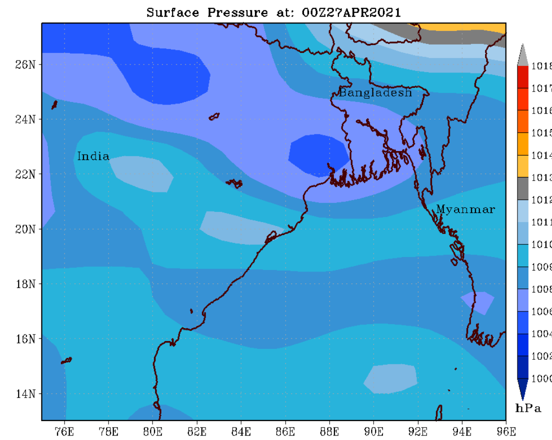

Fig. 10: Spatial distribution of MSLP over Bangladesh and adjoining area

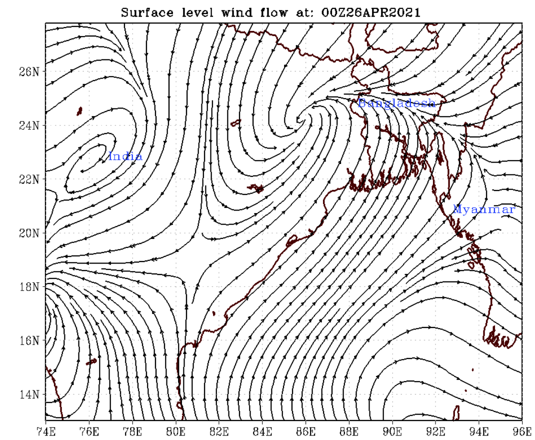

Fig. 11: Wind flow at surface level over Bangladesh and adjoining area

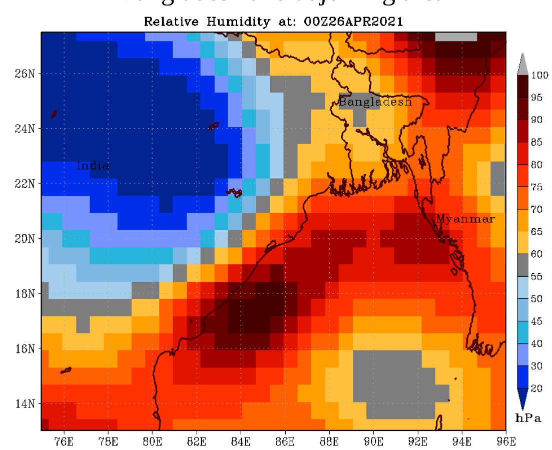

Fig. 12: Spatial distribution of RH over Bangladesh and adjoining area

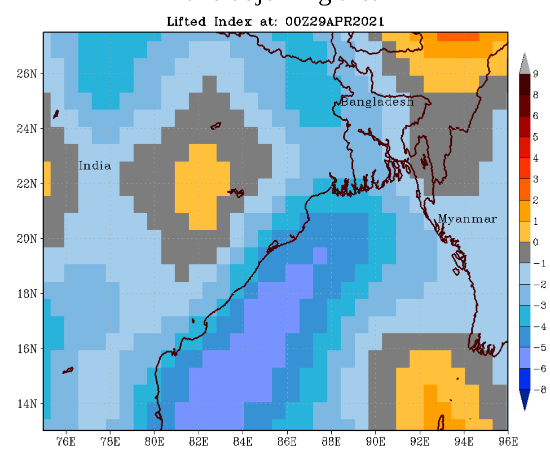

Fig. 13: Lifted Index over Bangladesh and adjoining area

3.5 Heat wave during 15-24 May 2021

This spell of HW was initiated first on 14 May over Jashore and Mongla regions, then continued over Khulna, Barishal, Sylhet divisions, most parts of Dhaka and Chattogram divisions upto 22 May and finally covered whole Bangladesh except Teknaf and Kutubdia upa-zillas on 23 May. During this period the severity of HW reached to the highest on 17 and 23 May with the maximum temperature of 39.4°C was recorded at respectively Jashore and Rangamati. Then the HW situation started to improve and finally concentrated only over Sylhet, Rajshahi and Pabna regions on 25 May.

During this period thermal low pressure persisted from Bihar, West Bengal of India to Assam across Bangladesh and the whole Bangladesh were under its coverage (Fig. 14). This HL and anticyclonic circulation (ACC) over the BoB facilitated high amounts of moisture incursion incessantly over Bangladesh and adjoining areas during this period as in Fig. 15. As a result, very RH at surface persevered at lower level over Bangladesh in Fig. 16. By this reason high

RH, higher temperature continued and consequently lower troposphere was unstable as displayed through LI, which was negative as indicated in Fig. 17.

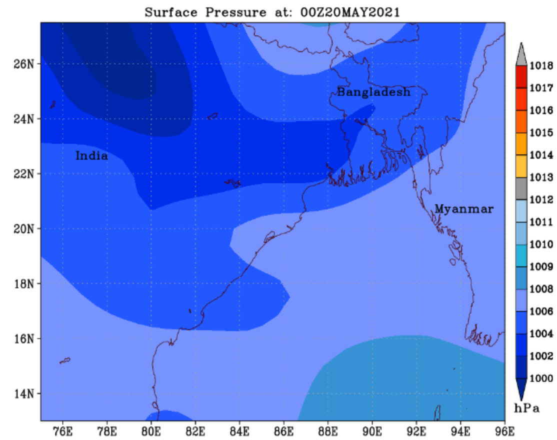

Fig. 14: Spatial distribution of MSLP over Bangladesh and adjoining area

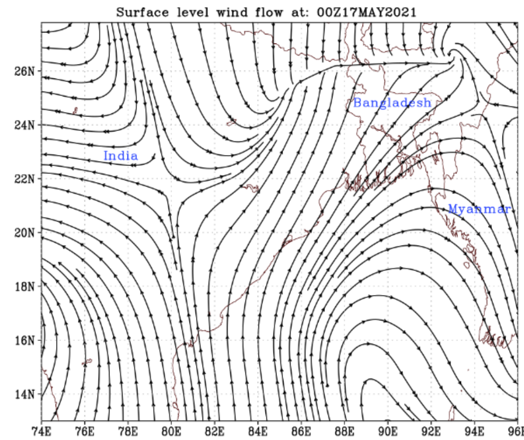

Fig. 15: Wind flow at surface level over Bangladesh and adjoining area

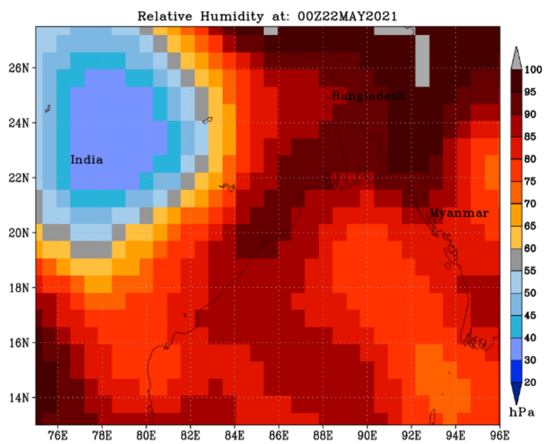

Fig. 16: Spatial distribution of RH over Bangladesh and adjoining area

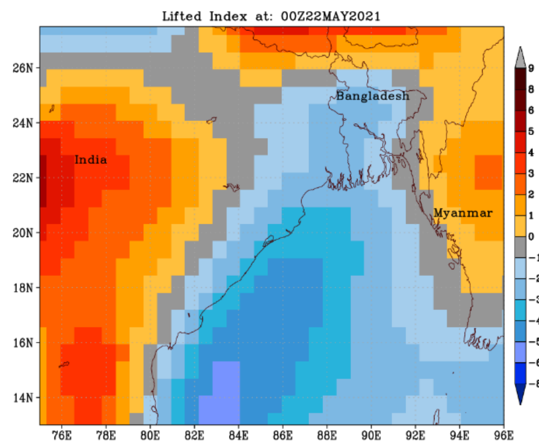

Fig. 17: Lifted Index over Bangladesh and adjoining area

4. Conclusion

Prediction of HW is very challenging to the meteorologists. To do this meteorologists need to know the physical processes of HW, which can be understood through synoptic analysis. Efforts has therefore been made to analyze six hourly NCEP derived reanalysis data. Analysis reveals that presence of trough over Bangladesh and adjoining areas from HL are one of the pre-requisite condition during the HW days over Bangladesh. But there should be wind flow from the Bay of Bengal in conjugation with, which might the enforced from anticyclonic circulation. Due to this moist flow over Bangladesh and adjoining area, existence of high humidity traps more heat energy in the lower troposphere. This situation also makes the lower troposphere unstable as derived through LI. As all of the selected cases have found to be with the favourable situation of the distribution of SLP, wind flow, RH and LI, these elements may be recognized as the favourable conditions of HW process over Bangladesh. Some other synoptic process may also be responsible with these, but these demand more research.

References

1. Perkins, S. E., 2015: A review on the scientific understanding of heatwaves–their measurement, driving mechanisms and changes at the global scale, Atmos Res., 164-165, 242–267.

2. Vaidyanathan, A., Kegler scott, R., Saha, S. S., and Mulholland, J.A., 2016: A Statistical Framework to Evaluate Extreme Weather Definitions from A Health Perspective: A Demonstration Based on Extreme Heat Events, Bulletin of the American Meteorological Society, 97(10), 1817-1830, doi:10.1175/BAMS-D-15-00181.1.

3. Della-Marta, P.M., Luterbacher, J., Weissenfluh, H. von, Xoplaki, E., Brunet, M., and Wanner, H., 2007: Summer heat waves over western Europe 1880–2003, their relationship to large-scale forcings and predictability, Clim Dyn, 29, 251–275, DOI: 10.1007/s00382-007-0233-1.

4. Srivastava, A.K., Rajeevan, M., and Kshirsagar, S.R., 2009: Development of a high resolution daily gridded temperature data set (1969–2005) for the Indian region, Atmos. Sci. Lett., 10, 249–254, doi:10.1002/asl.232.

5. Mishra, V., Ganguly, A.R., Nijssen, B., and Lettenmaie, D. P., 2015: Changes in observed climate extremes in global urban areas, Environ. Res. Lett., 10, 024005. https://doi.org/10.1088/1748-9326/10/2/024005.

6. Ganguly, A.R., Steinhaeuser, K., Erickson, D.J., Branstetter, M., Parish, E.S., Singh, N., Drake, J.B.,and Buja, L., 2009: Higher trends but larger uncertainty and geographic variability in 21st century temperature and heat waves, PNAS, September 15, vol. 106, no. 37: 15555–15559, doi: 10.1073_pnas.0904495106

7. Lee, H.J., Lee, W.S., and Yoo, J. H., 2016: Assessment of medium-range ensemble forecasts of heat waves, Atmos. Sci. Lett., 17, 19–25. doi:10.1002/asl.593.

8. Nairn, J., and Fawcett, R., 2013: Defining heatwaves: Heatwave defined as a heat impact event servicing all community and business sectors in Australia, CAWCR. Technical Report No 060.

9. Nairn, J., and Fawcett, R., 2015: The Excess Heat Factor: A Metric for Heatwave Intensity and Its Use in Classifying Heatwave Severity, Int. J. Environ. Res. Public Health, 12, 227-253; doi: 10.3390/ijerph120100227

10. Perkins, S.E., and Alexander, L.V., 2013: On the Measurement of Heat Waves, J. Clim., 26, 4500–4517, doi: 10.1175/JCLI-D-12-00383.1.

11. De, U.S. and Mukhopadhyay, R.K., 1998: Severe heat wave over Indian subcontinent in 1998 in a perspective of global Climate, Current Science, 75, 12, 1308-1311.

12. Chaudhury, S.K., Gore, J.M., and Sinha Ray, K.C., 2000: Impact of heat waves over India, Curr Sci., 79:153–155

13. Pai, D.S., Thapliyal, V., and Kokate, P.D., 2004: Decadal variation in the heat and cold waves over India during 1971–2000, Mausam, 55, 281–292.

14. Pai, D.S., Smitha, A., and Ramanathan, A. N., 2013: Long term climatology and trends of heat waves over India during the recent 50 years (1961–2010), Mausam, 64(4), 585–604 .

15. Pai, D.S., Srivasatava, A.K., and Smitha, A., 2017: Heat and Cold waves over India, chapter 4 in Observed climate variability and change over the Indian region, Rajeevan, M., and Nayak, S. (eds.), Springer Geology, DOI: 10.1007/978-981-10-2531-0_4

16. Ray, K., Chincholikar, J.R., and Mohanty, M., 2013: Analysis of extreme high temperature conditions over Gujarat, Mausam, 64, 3: 467-474.

17. Ratnam, J.V., Behera, S. K., Ratna, S. B., Rajeevan, M., and Yamagata, T., 2016: Anatomy of Indian heatwaves, Sci. Rep., 6, 24395, doi: 10.1038/srep24395.

18. Xoplaki, E., J.F. Gonzalez-Rouco, J. Luterbacher, and H. Wanner, 2003: Mediterranean summer air temperature variability and its connection to the large-scale atmospheric circulation and SSTs. Climate Dynamics, 20(7-8), 723-739.

19. Meehl, G.A. and C. Tebaldi, 2004: More intense, more frequent, and longer lasting heat waves in the 21st century. Science, 305(5686), 994-997.

20. Cassou, C., L. Terray, and A.S. Phillips, 2005: Tropical Atlantic influence on European heat waves. Journal of Climate, 18(15), 2805-2811.

21. Della-Marta, P.M., J. Luterbacher, H. von Weissenfluh, E. Xoplaki, M. Brunet, and H. Wanner, 2007b: Summer heat waves over western-Europe 1880-2003, their relationship to large-scale forcings and predictability. Climate Dynamics, 29(2-3), 251-275.

22. Lorenz, R., E.B. Jaeger, and S.I. Seneviratne, 2010: Persistence of heat waves and its link to soil moisture memory. Geophysical Research Letters, 37, L09703.

23. Keatinge W R, G D Donaldson, E Cordioli, M Martinelli, A E Kunst, et al., 2000: Heat related mortality in warm and cold regions of Europe: observational study. Br Med J 321: 670 – 673.

24. Guest C S, K Wilson, A Woodward, K Hennessy, L S Kalkstein, et al., 1999: Climate and mortality in Australia: retrospective study, 1979-1990 and predicted impacts in five major cities in 2030. Clim Res 13:1–15. 13.

25. Kumar S, 1998: Indian heat wave and rains results in massive death toll. Lancet 351:1869.

26. Pan W H and Li L A, 1995: Temperature extremes and mortality from coronary heart disease and cerebral infarction in elderly Chinese. Lancet, 345,353-356.

27. Murari, K.K., Ghosh, S., Patwardhan, A., Daly, E., and Salvi, K., 2015: Intensification of future severe heat waves in India and their effect on heat stress and mortality, Reg. Environ Change, 15, 569–579; doi: 10.1007/s10113-014-0660-6 (2015).

28. Fischer, E. M., Seneviratne, S. I., Vidale, P. L., Lüthi, D. & Schär, C., 2007: Soil Moisture–Atmosphere Interactions during the 2003 European Summer Heat Wave. J. Climate. 20, 5081–5099, doi:10.1175/JCLI4288.1

29. Zaitchik, B. F., Macalady, A. K., Bonneau, L. R. & Smith, R. B., 2006: Europe's 2003 heat wave: a satellite view of impacts and land–atmosphere feedbacks. Int. J. Climatol. 26, 743–769, doi:10.1002/joc.1280.

30. Miralles, D. G., Teuling, A. J., van Heerwaarden, C. C. & de Arellano, V. G., 2014: Mega-heatwave temperatures due to combined soil desiccation and atmospheric heat accumulation. Nat. Geosci. 7, 345–349, doi: 10.1038/ngeo2141.

31. Rohini, P., Rajeevan, M. & Srivastava, A. K., 2016: On the Variability and Increasing Trends of Heat Waves over India. Scientifc Reports. 6(26), 153, doi: 10.1038/srep26153.

32. Ratnam, J. V., Behera, S. K., Ratna, S. B., Rajeevan, M. & Yamagata, T., 2016: Anatomy of Indian heatwaves. Scientifc Reports. 6, 24395, doi: 10.1038/srep24395.

33. Murari, K. K., Sahana, A. S., Daly, E. & Ghosh, S.,2016: The influence of the El Niño Southern Oscillation on heat waves in India. Met. Apps. 23, 705–713, doi:10.1002/met.1594.

34. Nissan, H., et al., 2017: Defining and predicting heat waves in Bangladesh. J. Appl. Meteorol. Climatol. 56 (10), 2653–2670.

35. Quesada, B., et al., 2012: Asymmetric European summer heat predictability from wet and dry southern winters and springs. Nature Climate Change.

36. Miralles, D.G., et al., 2014: Mega-heatwave temperatures due to combined soil desiccation and atmospheric heat accumulation. Nat. Geosci. 7 (5), 345–349.

37. Sanderson, M., and R. Ahmed, 1979: Pre-monsoon rainfall and its variability in Bangladesh: A trend surface analysis. Hydrol. Sci. Bull., 24, 277–287, doi: 10.1080/02626667909491867.