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Influence of Pressure Level based Parameters on Lightning and Rainfall over Nepal

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ABSTRACT: Lightning and rainfall based activities are the major weather events which create a lot of damage to humans, crops and infrastructure in recent years. Nepal is one of the prone countries for these types of weather events. The present study was done from the satellite datasets such as LIS-TRMM, GPCC and ECMWF era-interim reanalysis data. The lightning flash rates were retrieved from LIS-TRMM satellite for the duration of 20 years (1995-2014). We made use of some pressure level based atmospheric parameters such as K Index(ki), Lifted Index(LI), Total totals Index(TTI), Humidity Index(HI), Convective Available Potential Energy(CAPE) and Total precipitable water(TPW) for studying their impact on lightning and rainfall. The seasonal analysis reveals that most lightning activity was seen during the pre-monsoon period (80–100 flash/sq. km/yr) over the Far western and Mid western regions of Nepal. High rainfall activity was observed during Monsoon season. The region between Pokhara and Katmandu receives high rainfall during Monsoon and Pre-monsoon season when compared to other regions. The results of this study also indicates the importance of satellite products in analyzing the Lightning and rainfall activities.

Keywords: Thunderstorm, lightning, rainfall.

I. INTRODUCTION

Thunderstorms usually occur in cumulonimbus clouds with lightning and thunder followed by rain, speedy winds, sometime with hails [1]. The Lightning activity which occurs in these clouds leads to great damages to humans, live stock and agriculture. These activities lead to huge damages to electric poles, communication sector which creates economic losses. In agricultural sector, crops were exposed to intense winds and rainfall. In aviation sector, flight cancelation and delays occur due to this type of events. These are worldwide happening events that can occur at any moment of time [2]. Majority of the lightning activity occur in the tropical regions. Countries like Sri Lanka, India, Bhutan, Bangladesh and Nepal are frequently affected to extreme thunderstorms during pre-monsoon season. Nepal is a high altitude located country which lies 4000 m above the sea level. It has the Tibetan Plateau to its north and Indo-Gangetic Plains to its south. It has complex topography such as Himalayas on north and tropical lowlands in south [3]. From this, we can clearly understand that it has various climatic changes [4]. Usually, high lightning activity is seen in pre-monsoon season which decreases gradually as monsoon season approaches [5]. A lightning study by [6] reveals that lightning activity is initiated in March month which reaches peak phase in May month and it descents slowly in June due to the Monsoon onset.

More number of thunderstorms occurrences was observed in central and western parts of Nepal because of local systems. These local systems are often linked with intense land surface heating triggered with NorWester's leading to high instability. This Instability is associated with warm moist air from lower levels to the dry cold air in upper levels of the atmosphere. This is the major convective process which helps for the formation of intense thunderstorms. These types of thunderstorms and lightning activity are observed in Indian subcontinent and its neighboring countries [1]. 140 lightning deaths were recorded only in 2013 academic year (National Emergency Operation Center of Nepal). This is one of the occasions where everybody felt the need of lightning studies. Lightning and thunderstorm activities are influenced by regional topography and different atmospheric parameters like temperature, relative humidity, wind shear etc. [7]. As Nepal is situated at the foot hills of Himalayas, the warm moist air from Bay of Bengal flows towards these foot hills which is triggered with topographic uplifts [8].

Rainfall is also one of the frequently observed convective processes seen over India and Nepal during thunderstorm occurrences. Rainfall related to these local convective systems are having great significance as they have adverse effects on agriculture. A study showed that a group of stability indices were calculated from satellite data for real-time monitoring of thunderstorm [9]. From the motivation of above research works, we made an attempt to analyze the lightning activity and rainfall over Nepal. For this, we have taken some pressure level based atmospheric parameters to check their influence on lightning and rainfall. This approach of studying the parameters associated with lightning and rainfall will help us to understand the dynamics behind it. With the usage of satellite data, we can have a better understanding of these parameters on lightning and rainfall. The lightning and rainfall activities were studied using LIS TRMM satellite data and GPCC precipitation data. These pressure level based atmospheric parameters were calculated from ERA-Interim ECMWF re-analysis data.

II. DATA AND METHODOLOGY

In this study, the complete analysis was done on the Nepal region which extends from 21-27 N and 85-95 E. We have collected lightning flash rate density from Lightning Imaging Sensor (LIS) onboard TRMM satellite (https://ghrc.nsstc.nasa.gov/home) [10]. Later, we have collected temperature, relative humidity, CAPE, TPW data from the ERA-Interim ECMWF Re-analysis data from the website (http://apps.ecmwf.int/datasets/data/interim_full_daily/). We also collected 0.5 degree precipitation dataset from Global Precipitation Climatology Centre (GPCC) (https://www.esrl.noaa.gov/psd/) [11]

Methodology: By using temperature and relative humidity datasets from ERA-Interim ECMWF Re-analysis data, we calculated dewpoint temperature parameter. Using temperature and dewpoint temperature data at different pressure levels, we computed different parameters using the Formula given below.

(a) k-index (ki): The k-index calculation is performed using temperature and dew point temperature terms which are obtained at different pressure levels as shown below. [12]:

$$ki = (te_{850} - ted_{500}) + ted_{850} - (t_{700} - ted_{700}) \quad (1)$$

where te is the temperature; ted is the dew point temperature.

If ki values are below 288K there is no thunderstorm occurrence.

If ki values are ranging between 288-303K then there is a chance of 20-60% thunderstorm occurrence.

If ki values are ranging between 304-313K then there is a chance of 60-90% thunderstorm occurrence.

If ki values are above 313K there is 90% chance for thunderstorm occurrence.

(b) Total Totals Index (TTI):

This index is estimated by using the formula shown below [13]

$$TTI = te_{850} + ted_{850} - 2te_{500} \quad (2)$$

When TTI values are greater than 44K there is high chance for thunderstorm possibility.

(c) Lifted Index (LI):

This Index valuation is done to check the stability of the lower troposphere. LI values lesser than -2 are a good indication of severe thunderstorm occurrence. So, LI is calculated as [14].

$$\text{Lifted index (LI)} = T_{500} - T_{parcel} \quad (3)$$

(d) Humidity Index (HI):

Humidity Index HI is calculated by the formula shown below.

$$HI = (T\text{-}Td)_{850} + (T\text{-}Td)_{700} + (T\text{-}Td)_{500\text{-}} \quad (4)$$

Where T is the air temperature; Td is the dew point temperature; the suffix values 850, 500, 700 indicate the pressure levels. If HI values are lesser than 30 K it's an indication for high moisture availability [15].

(e) Convective available potential energy (CAPE):

CAPE is determined by the below formula defined by [16]

$$CAPE = \int_{Z_f}^{Z_n} g\left[\frac{T_{v,parcel} - T_{v,env}}{T_{v,env}}\right] dz \quad (5)$$

Where $T_{v,parcel}$ and $T_{v,env}$ represents the virtual temperature of the parcel and environment respectively. Z_f and Z_n denotes the level of free convection and neutral buoyancy. When CAPE values ranges between 2000J/kg to 2500J/kg there is high chance for severe thunderstorm.

III. RESULTS AND DISCUSSION

According to Department Of Hydrology and Meteorology (DHM) the climate of Nepal country has four seasons. (i) Winter Season: it comprises of December, January and February months (DJF), (ii) Pre-monsoon Season: it comprises of March, April and May months (MAM), (iii) Summer Season: it comprises of June, July, August and September months (JJAS), (d) Post-monsoon Season: it comprises of October, November months (ON). As we know that thunderstorms are linked with cumulo-nimbus clouds which creates lightning and thunder associated with rainfall and winds. The monthly lightning flashes data from LIS-TRMM satellite, GPCC monthly gridded precipitation dataset and ERA-Interim ECMWF re-analysis data were collected at 0.5 degree resolution for the period 1995 – 2014. The Results of these datasets were presented below:

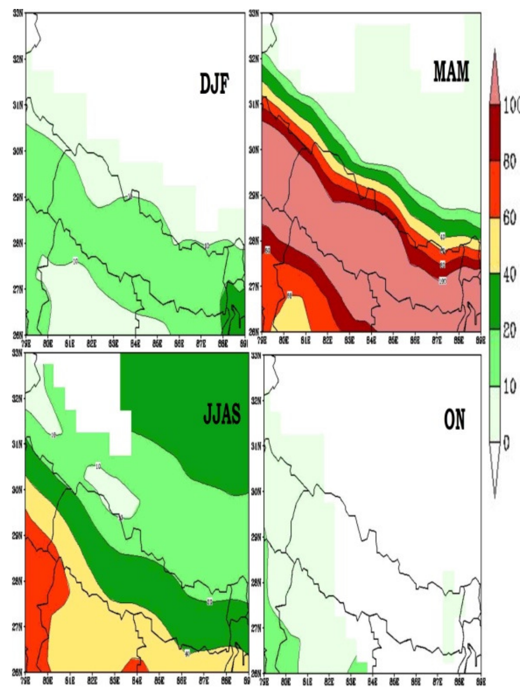

Fig. 1. Spatial distribution of Mean lightning flashes for Winter, Pre-Monsoon, Monsoon and Post-Monsoon seasons over Nepal region for the time period 1995-2014.

During winter season, the mean lightning flashes were ranging between 10 to 20 throughout the Nepal as shown in Fig. 1. During pre-monsoon season the whole Nepal country is affected with severe lightning flashes. Almost every region in Nepal country has recorded 80-100 mean lightning flashes throughout pre-monsoon season every year during 1995-2014 as shown in Fig. 1.

Western region was having more lightning flashes than Eastern region. From Fig. 1 we observed that the eastern, central and western regions of Nepal were having a mean of 20-40 flashes per year during Monsoon season. The Mid western and Far western regions (Dipayal) were having a mean values ranging from 40-60 flashes/year as observed in Fig. 1. The Nepal country experiences very less lightning Flashes nearly 10 flashes per year were recorded during post-monsoon season as seen in Fig. 1. From this we can understand that, Nepal is affected with more lightning flashes in pre-monsoon season during 1995-2014.

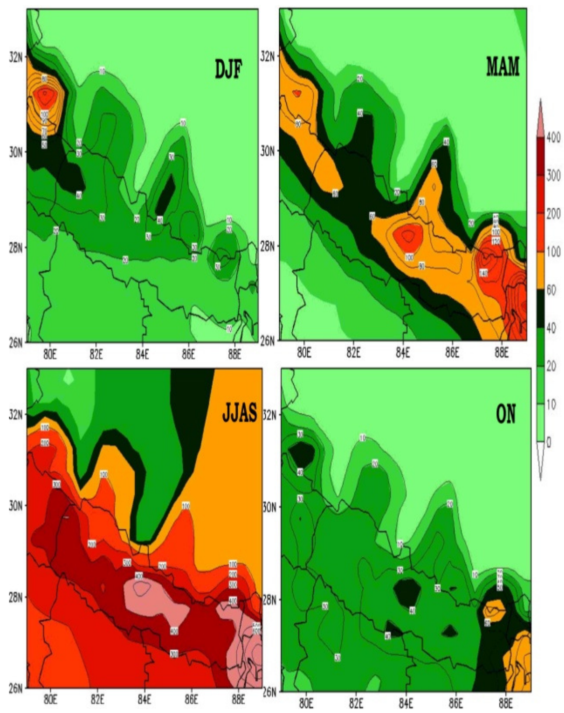

Fig. 2. Spatial distribution of Mean Rainfall for Winter, Pre-Monsoon, Monsoon and Post-Monsoon seasons over Nepal region for the time period 1995-2014.

During winter season, the mean rainfall was ranging between 10 to 20mm mean rainfall in Eastern and Central regions of Nepal. The Mid-western and Western regions has recorded a mean rainfall of 20-40mm whereas Far western region has recorded 40-60mm mean rainfall especially near Dipayal as shown in Fig. 2. During pre-monsoon season, the Eastern region records high mean rainfall values ranging from 100-150 mm. The Central and western regions records 60-100 mm mean rainfall values. The Mid-Western and Far Western regions receives 40-60mm mean rainfall. The region between Pokhara and Katmandu receive ~100mm rainfall during pre-monsoon season was observed in Fig. 2. The whole Nepal country receives good amount of rainfall during Monsoon season as shown in Fig. 2. A mean of 200-500mm of rainfall is usually observed during Monsoon season as seen in Fig. 2. The region between Pokhara and Katmandu receives >=400mm mean rainfall during Monsoon season was observed in Fig. 2.

During Post-Monsoon season, except eastern region all regions receive a mean of 20-60mm rainfall. The Eastern region receives a mean of 60-100mm mean rainfall as seen in Fig. 2 during 1995-2014.

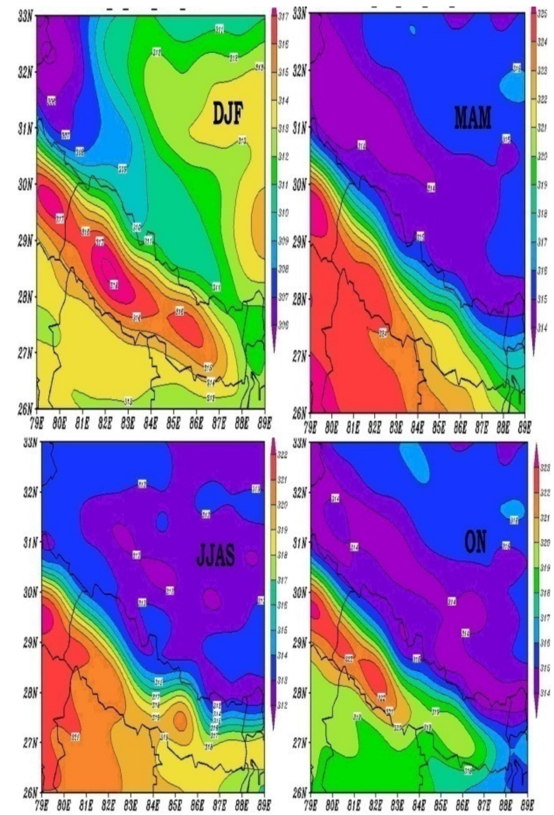

Fig. 3. Spatial distribution of Mean ki values for Winter, Pre-Monsoon, Monsoon and Post-Monsoon seasons over Nepal region for the time period 1995-2014.

During winter season, the mean ki values were ranging between 312 to 318K over all regions of Nepal. The Far-western and Mid-Western regions record 316-318K mean ki values during 1995-2014. This threshold values are good enough for thunderstorms. During Pre-Monsoon season, the mean ki values were ranging between 319 to 324K over all regions of Nepal. The Far-western and Mid-Western regions record 324K mean ki values during 1995-2014. This threshold values indicate that intense thunderstorms may occur. During Monsoon season, the mean ki values are ranging from 313K to 322K which is reasonable a good indication for thunderstorm occurrence. The Mid-western and Far Western regions has recorded a mean ki values of 321-323 K. During Post-Monsoon season, the mean ki values are ranging from 318K to 322K which is reasonable a good indication for thunderstorm possibility. Out of all seasons, Pre-monsoon season has higher ki values which is a clear indication for the occurrence of intense thunderstorms. The other seasons also indicated good thresholds for thunderstorm formation as seen in Fig. 3 during 1995-2014.

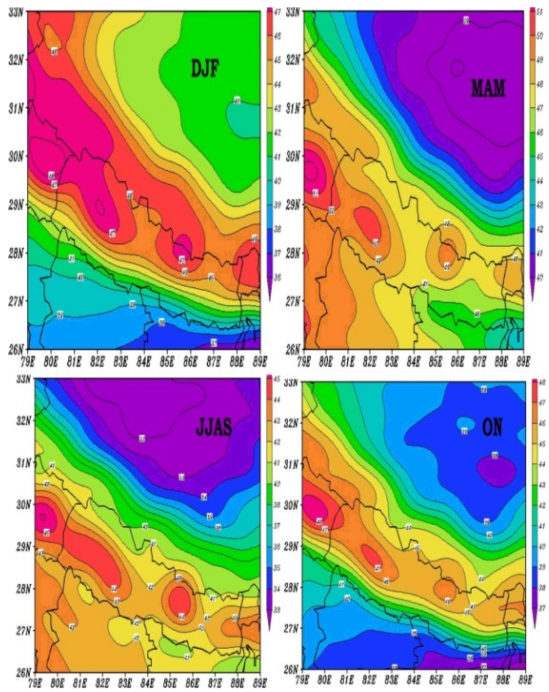

Fig. 4. Spatial distribution of Mean TTI values for Winter, Pre-Monsoon, Monsoon and Post-Monsoon seasons over Nepal region for the time period 1995-2014.

During winter season, the mean TTI values were ranging between 45 to 47K over most regions of Nepal. The Far-western and Mid-Western regions record ~47K mean TTI values during 1995-2014. This threshold values are good enough for heavy thunderstorms. During Pre-Monsoon season, the mean TTI values were ranging between 46 to 51K over all regions of Nepal. The Far-western and Mid-Western regions record ~49-51 K mean TTI values during 1995-2014. This threshold values indicate that intense thunderstorms may occur. During Monsoon season, the mean TTI values are ranging from 41K to 44K which indicates very good chances for the thunderstorm occurrence. The Mid-western and Far Western regions has recorded mean TTI values of 43-44 K. During Post-Monsoon season, the mean TTI values are ranging from 45K to 48K which is reasonable a good indication for moderated thunderstorm possibility. Out of all seasons, Pre-monsoon season has higher TTI values which is a clear indication for the occurrence of severe intense thunderstorms as seen in Fig. 4 during 1995-2014.

During winter season, the mean LI values were ranging between 5 to 7K over most regions of Nepal which is a good indication for less thunderstorm activity during 1995-2014. During Pre-Monsoon season, the mean LI values were ranging between 1 to 2K over all regions of Nepal during 1995-2014. These threshold values indicate that very less chances for the thunderstorm formation. During Monsoon season, the mean LI values are ranging from -0.9K to -1.5K which indicates a good chances for the thunderstorm occurrence especially in Eastern, Central and Western regions of Nepal. During Post-Monsoon season, the mean LI values are ranging from 2.5K to 4.5K which indicates that very low chances for thunderstorm formation as seen in Fig. 5 during 1995-2014.

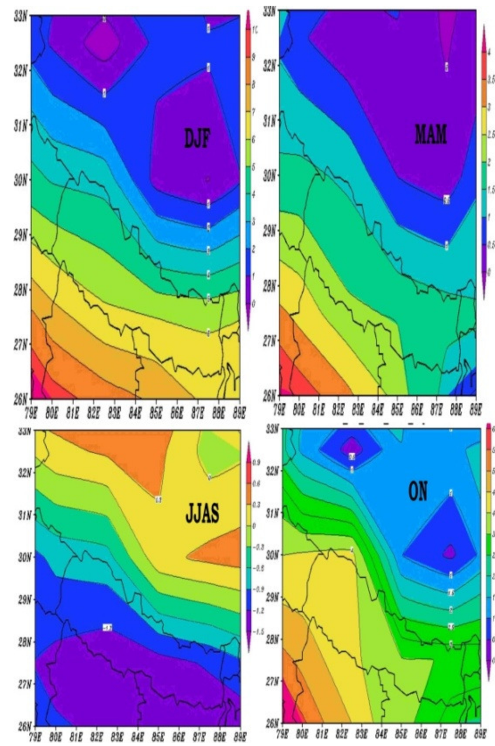

Fig. 5. Spatial distribution of Mean LI values for Winter, Pre-Monsoon, Monsoon and Post-Monsoon seasons over Nepal region for the time period 1995-2014.

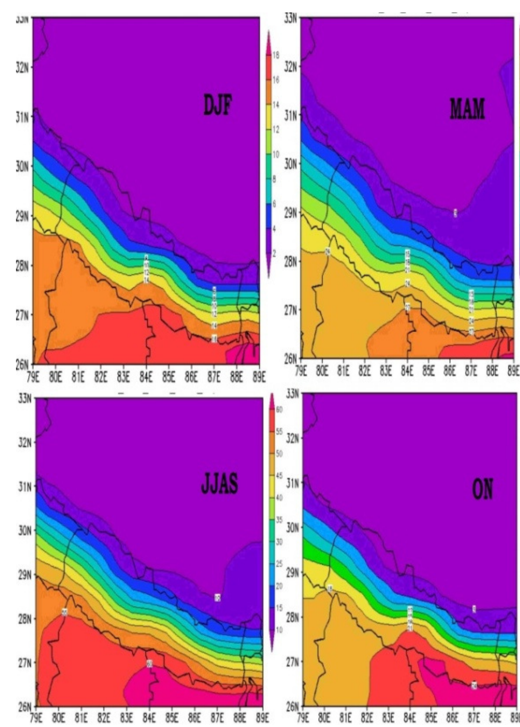

Fig. 6. Spatial distribution of Mean TPW values for Winter, Pre-Monsoon, Monsoon and Post-Monsoon seasons over Nepal region for the time period 1995-2014.

During winter season, the mean TPW values were ranging between 8 to 16mm over most regions of Nepal during 1995-2014. During Pre-Monsoon season, the mean TPW values were ranging between 18 to 27mm over all regions of Nepal during 1995-2014. During Monsoon season, the mean TPW values are ranging from 25 to 55 mm which indicates a good amount of moisture required for precipitation as seen in Fig.6. During Post-Monsoon season, the mean TPW values are ranging from 9 to 21mm during 1995-2014. Out of all seasons, Monsoon season has higher TPW values which are a clear indication for the high moisture availability for the convection to take place as seen in Fig. 6 during 1995-2014.

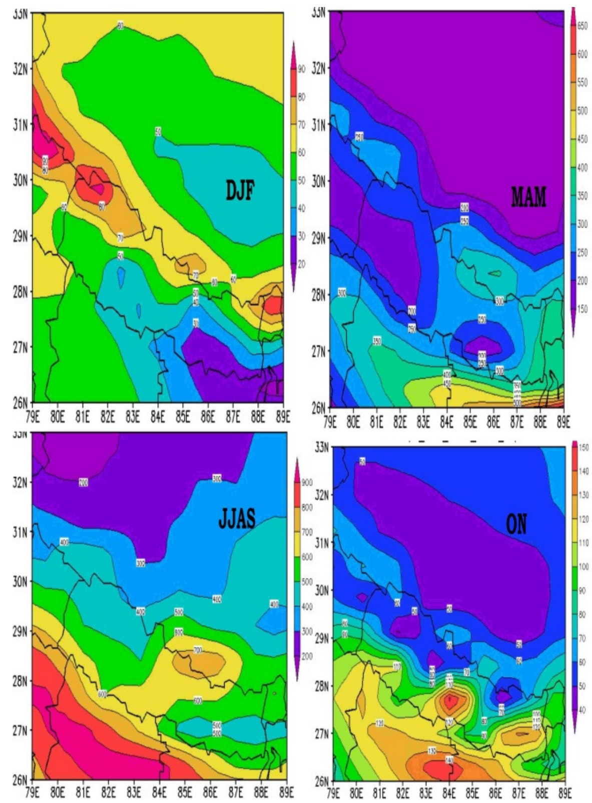

Fig. 7. Spatial distribution of Mean CAPE values for Winter, Pre-Monsoon, Monsoon and Post-Monsoon seasons over Nepal region for the time period 1995-2014.

During Winter season, the mean CAPE values were ranging between 20 to 60 J/Kg over most regions of Nepal. The Far-western and Mid-Western regions record ~40 – 60J/Kg mean CAPE values during 1995-2014. This threshold values are a indication of no instability in the atmosphere. During Pre-Monsoon season, the mean CAPE values were ranging between 150 to 300 J/Kg over all regions of Nepal during 1995-2014. During Monsoon season, the mean CAPE values are ranging from 400 to 800J/Kg which indicates a very less chances for the thunderstorm occurrence. During Post-Monsoon season, the mean CAPE values were ranging from 80 to 120J/Kg as seen in Fig. 7 during 1995-2014.

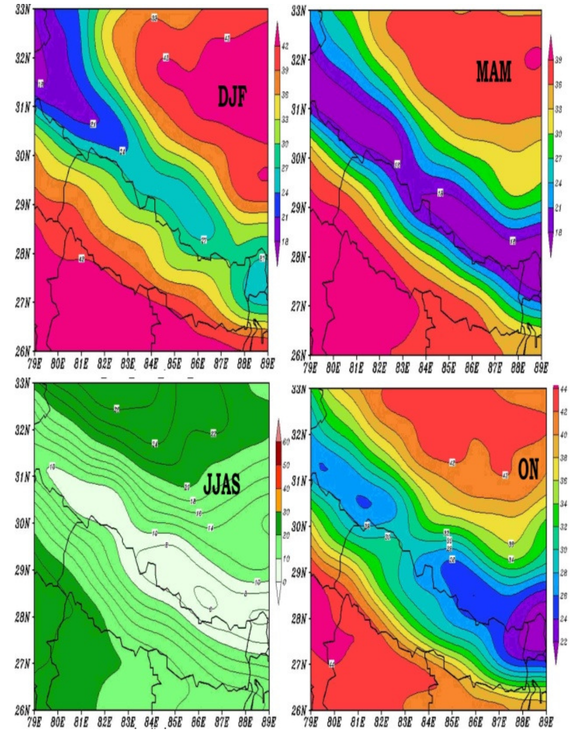

Fig. 8. Spatial distribution of Mean Humidity Index values for Winter, Pre-Monsoon, Monsoon and Post-Monsoon seasons over Nepal region for the time period 1995-2014.

During Winter season, the mean HI values were ranging between 30 to 42K over most regions of Nepal. The Far-western and Mid-Western regions record ~36 - 42K mean HI values during 1995-2014. These threshold values indicate very few chances for thunderstorm occurrence. During Pre-Monsoon season, the mean HI values were ranging between 27 to 39K over all regions of Nepal during 1995-2014. This threshold values indicate very few chances for thunderstorm occurrence. During Monsoon season, the mean HI values are ranging from 10K to 20K which indicates high chances for the thunderstorm occurrence. During Post-Monsoon season, the mean HI values are ranging from 30K to 42K which is reasonable a good indication for moderated thunderstorm possibility. Out of all seasons, Monsoon season has HI values below 30K which is a clear indication for the occurrence of severe intense thunderstorms as seen in Fig. 8 during 1995-2014.

IV. CONCLUSION

In this paper, an attempt is made to analyze the lightning activity and Rainfall over Nepal. The Pressure level based parameters which are calculated from ERA-INTERIM ECMWF Reanalysis data has helped us to analyze the thunderstorm related to lightning activity and rainfall.

During Pre-monsoon season, far western and mid western regions record high lightning flashes than other regions of Nepal. Almost 80-100 average Lightning strikes occurred during pre-monsoon season which is higher than other seasons.

Western region was having more lightning flashes than Eastern region. Least lightning activity was observed during Post-Monsoon season. The ki, TTI values were higher in pre-monsoon season when compared to other season.

During Monsoon season, the region between Pokhara and Katmandu records ~400mm mean rainfall. Even during pre-monsoon season, this region shows ~60mm rainfall. Whole Nepal country receives good rainfall throughout Monsoon season. Least Rainfall activity was observed during winter season. Negative values of LI less than -0.5 were observed during Monsoon season. High TPW values were also seen in Monsoon season. Actually CAPE values were showing fewer thunderstorms over NEPAL. HI values below 20K were observed during Monsoon season which is a good indication for convection to place.

Ki, TTI parameters were helpful in revealing the thunderstorm occurrence during pre-monsoon season whereas LI, TPW and HI parameters were useful in analyzing the thunderstorm related rainfall activity.

This study also reveals the importance of satellite based reanalysis data for thunderstorm related lightning and rainfall activities over Nepal.

V. FUTURE SCOPE

In future, by collecting recent 30 years data, we can fix the thresholds of above parameters over Nepal region. It helps us to study the convective climate more elaborately.

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Conflict of Interest. The authors confirm that there are no known conflicts of interest associated with this publication of this paper.

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