Spatial and Temporal Distributions of Outgoing Longwave Radiation over Bangladesh: 1991 – 2020

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Abstract

The pattern of Outgoing Longwave Radiation (OLR) was investigated by studying monthly OLR data collected from polar-orbiting satellites operated by the National Oceanic and Atmospheric Administration (NOAA). The study focused on analyzing OLR data recorded from January 1991 to December 2020 over Southeast Asia, particularly in Bangladesh. From a meteorological perspective, Bangladesh experiences four distinct seasons - winter, pre-monsoon, monsoon, and post-monsoon. This study presents an analysis of monthly, seasonal, and yearly variations of OLR in Bangladesh. The monsoon season exhibits the lowest OLR values, while the winter season shows the highest. The highest monthly average value of 280 W/m² was recorded in November, whereas the lowest monthly average value of 203 W/m² was found in July. The western side of Bangladesh showed higher OLR values than the eastern side. In 1997, a higher number of rainy days resulted in a lower amount of OLR (242 W/m²), while in 2009, fewer rainy days were associated with a higher amount of OLR (254 W/m²). Additionally, the study found that the Rajshahi division experiences the highest amount of OLR, while Sylhet experiences the lowest. Moreover, the study reveals a negative relationship between rainfall and OLR in Bangladesh.

Keywords: OLR, Rainfall, Temperature, Sensor HIRS-2, 3, 4.

1. Introduction

Outgoing Longwave Radiation (OLR) is considered a fundamental climate variable acknowledged by the World Meteorological Organization (WMO) and holds considerable importance in regulating the Earth radiation budget (Schreck et al., 2018). The solar radiation reaching the Earth is referred to as Incoming Shortwave Radiation (ISR), whereas the energy released into space by the Earth surface, oceans, and atmosphere is quantified as Outgoing Longwave Radiation (OLR) (Dewitte and Clerbaux, 2017). The OLR data is utilized for climatological investigations (Knapp et al., 2018) and to understand how natural factors such as clouds and water vapor, along with man-made greenhouse gases (GHGs), absorb longwave radiation emitted from the Earth surface and subsequently re-radiate a portion back into space as OLR (Wild et al., 2015). Since any short-term flux imbalance indicates a warmer/colder overall climate (Rajab et al., 2018).

The Asian monsoon region climate variability has a significant impact on global climate variation (Li et al., 2004). As a part of the Asian monsoon, the study of Bangladesh regional climate variability and features is very important. Bangladesh experiences a distinct monsoon climate, with a pronounced wet season and dry season. Due to monsoon disturbances, it receives rainfall above average amounts (Ahasan et al., 2010). Floods caused by monsoon weather disruptions have a disastrous effect on a country socioeconomic well-being (Lim et al., 2011).

OLR values have a tremendous effect on the investigation of precipitation and floods (Chinthalu et al., 2018). OLR values are frequently used in this respect as a measure for convection in tropical and subtropical regions, whereby cloud top temperature changes are a predictive factor for convection (Schreck et al., 2018). Analyzing OLR data can offer valuable information about the timing, intensity, and fluctuations of monsoon rainfall. By examining OLR patterns, researchers can detect the monsoon's onset and withdrawal, a critical aspect of agricultural planning, water resource management, and flood forecasting in the region. OLR pattern can contribute to understanding long-term trends in the energy balance of the atmosphere. It aids in evaluating the impact of climate change on the radiative characteristics of the atmosphere and its consequences for the overall climate system in Bangladesh.

Since the early days of meteorological satellites (Arkin et al., 1989), the OLR has been estimated or observed using a wide variety of satellite equipment and algorithms, as it is a fundamental and vital characteristic of the Earth energy balance for investigating many fields of atmospheric science (Pushpanjali et al., 2020; Prasad and Verma, 1985; Arkin et al., 1989). Over the Indian subcontinent, the large-scale, as well as regional-scale characteristics of the annual and seasonal OLR patterns have been examined by the datasets retrieved from NOAA polar-orbiting satellites (Haque and Lal, 1991). In the study of large-scale deep convective activity, OLR, rainfall and the moisture budget have mostly been utilized as markers of convection in the past (Murakami, 1980). An analysis of the spatial and temporal distribution of Outgoing Longwave Radiation (OLR) was conducted for Iraq. The study utilized the AIRS dataset spanning from January 2007 to December 2016, providing insights into the monthly, seasonal, and annual variations in the retrieved OLR data (Rajab et al., 2017).

Numerous studies have demonstrated that satellites have utilized Outgoing Longwave Radiation (OLR) as a reliable method for detecting deep convection. Using the Tropical Rainfall Measuring Mission (TRMM) and Global Precipitation Climatology Project (GPCP), the novel OLR-based heavy precipitation index is validated (Sukumaran and Strodal, 2013). Prasad and Bansod, 2000, analyzed the relationship between OLR and interannual rainfall of the southwest summer monsoon for 306 stations over India and found a negative relationship between them. By studying pentad OLR climatology over the South American sector, Kousky, 1988 estimated a threshold value of 240 W/m2 for identification of convective rainfall. Smith and Rutan, 2003, have been monitoring the Earth radiation balance using Earth-orbiting satellites. The diurnal variation of the OLR is influenced by a combination of factors, including surface temperature, cloud cover, humidity at different atmospheric levels, and other related elements (Comer et al., 2007; Stephens et al. 2012). This variation is controlled by the climate system response to the diurnal variability of Indian Summer Rainfall. The relationship between monsoonal rainfall and satellite-derived OLR data from 1974 to 1996 over India has been investigated by Prasad and Bansod, 2000. An equation based on multiple linear regression was formulated to forecast the Indian summer monsoon rainfall utilizing OLR data (Prasad et al., 2000).

Although there may be limited research solely dedicated to OLR patterns in Bangladesh. Integrating OLR data into meteorological and climatological studies can provide valuable insights into the country weather patterns, monsoon behavior, extreme events, and the effects of climate change. This research aims to examine the spatial and temporal patterns of outgoing longwave radiation over the last three decades (1991-2020) and establish a correlation between OLR and rainfall.

2. Materials and Methods

2.1 Data

2.2.1 OLR data from NOAA

The Climate Data Record (CDR) provides monthly mean High-Resolution Infrared Radiation Sounder (HIRS) OLR flux data at the Earth's top atmosphere under all-sky conditions. This data covers the entire globe starting from January 1979 to the present and is updated monthly. It is plotted on a 2.5°×2.5° resolution with 10,368 total grids over the globe. The HIRS level 1b dataset from the TIROS-N to NOAA-19 series satellites was used to produce the data set. HIRS-2 (High-Resolution Infra-red Sounder), HIRS-3, and HIRS-4 sensors are used to observe the OLR. The study utilized monthly mean OLR-CDR data (Version 2.2-1) from January 1991 to December 2020.

2.2.2 Rainfall data from BMD

Normal monthly rainfall is collected from the Bangladesh Meteorological Department (BMD) and then seasonal rainfall is estimated. The rain gauge station locations of BMD over Bangladesh are shown in Figure 1.

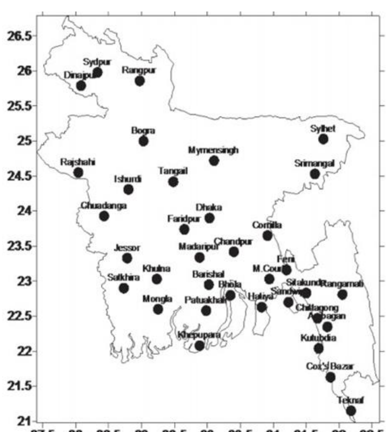

Figure 1: The locations of BMD rain gauge stations for calculation of normal monthly rainfall (Devkota, 2006).

2.2 Methodology

The analysis began by accessing OLR data from NOAA CDR. To find out the 30 years of pattern, the OLR data were averaged at each grid point for monthly mean. The monthly mean, seasonal mean, and yearly mean have been analyzed from the OLR data from the years 1991-2020. After that, OLR data was extracted by using divisional latitude and longitude through the GrADS.

3. Results and Discussions

3.1 Monthly Outgoing Longwave Radiation

During the winter season, which spans from December to February, Figure 2(a) illustrates that the OLR is relatively high in December. This is attributed to clear

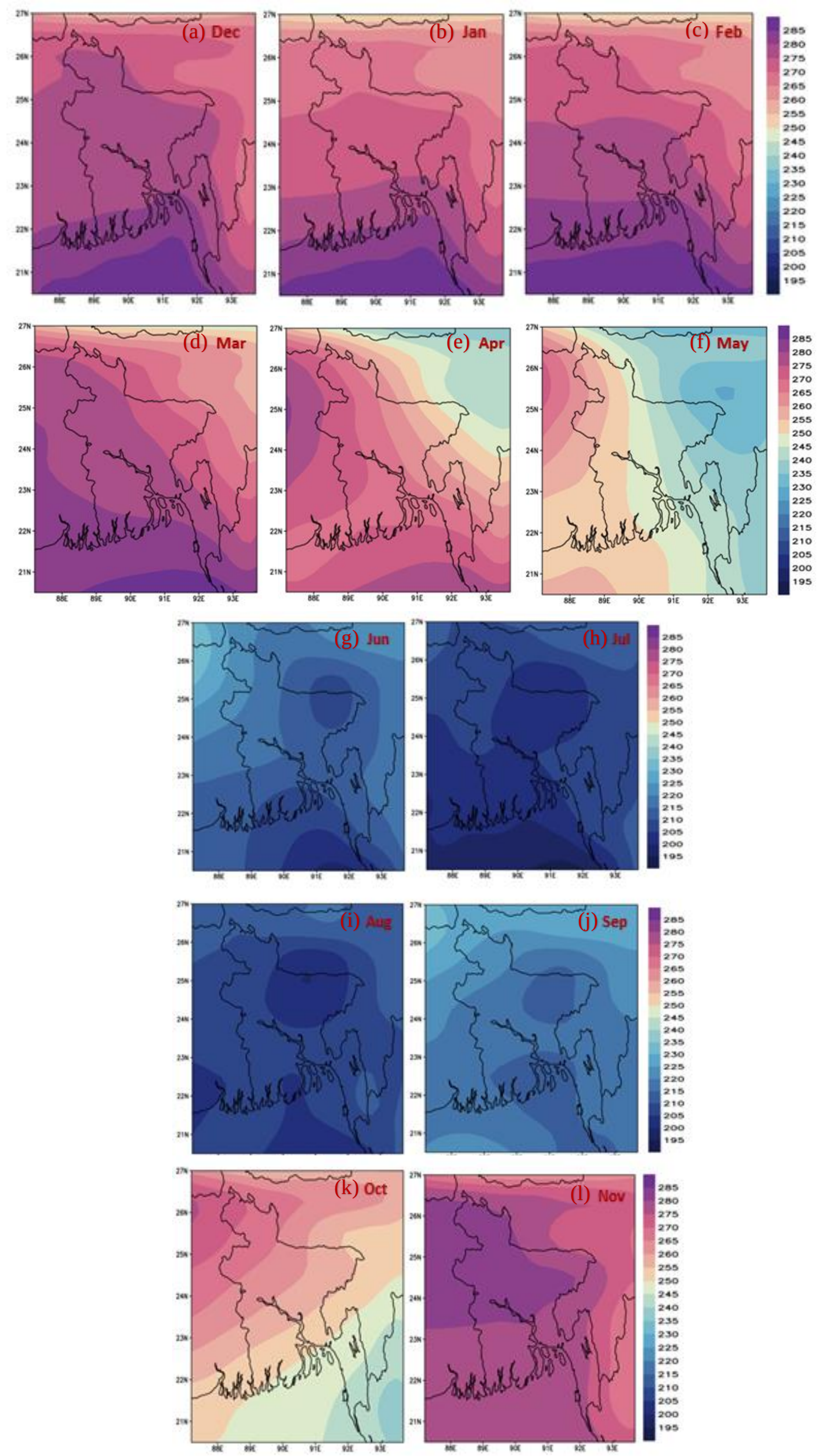

Figure 2: Monthwise (Jan- Dec) Climatology of OLR (W/m²) for the years (1991-2020), e.g. a) December, b) January, c) February, d) March, e) April, f) May, g) June, h) July, i) August, j) September, k) October, l) November.

skies and low temperatures observed during this month. The southern region of Bangladesh recorded the highest monthly OLR value, reaching up to 285 W/m². The coldest month of the year is January when the temperature is lowest than the other month. But due to winter fog in January, [Figure 2(b)] OLR value is less than the December OLR value. During February [Figure 2(c)], the lowest OLR value, ranging between 270-275 W/m², was observed in the northern region of Bangladesh, while the majority of the country experienced OLR values ranging from 275-285 W/m².

The pre-monsoon season starts in March and ends in May. In this season, Norwester occurs frequently over Bangladesh. Temperatures start increasing through March and April which are the warmest months of the year. Due to the high temperature, the convective system was active there, and this resulted in a lower OLR value.

In March [Figure 2(d)], the mean OLR is found to decrease towards the northeastern part as the temperature is gradually increasing. Norwester occurs from cumulonimbus clouds and creates heavy rainfall with thunderstorms. Consequently, during the months of April [Figure 2(e)] and May [Figure 2(f)], there is a noticeable decline in the average OLR. In May [Figure 2(f)], the mean OLR decreases significantly from 260 W/m² to 240 W/m².

The monsoon season commences in June and concludes in September, constituting the southwest summer monsoon, which is a component of the Asian summer monsoon (Ahasan et al., 2014). As the monsoon arrives in June [Figure 2(g)], extensive deep convective clouds disperse across the sky, leading to a rapid reduction in OLR. During July [Figure 2(h)] and August [Figure 2(i)], the peak of the monsoon season is observed. This period is characterized by intense rainfall originating from convective clouds, resulting in a continued decrease in OLR. OLR decreases from 210 W/m² to 195 W/m² [Figure 2(h) and 2(i)] here.

In September, the OLR was found to increase gradually. As monsoon withdrawal starts to occur this month and the season starts to change, cloud formation decreases. As a result, OLR increases to 210-215 W/m² [Figure 2(j)]. October and November are two months made post-monsoon season. The northern side of OLR was found higher than the southern side due to the hilly region on the southeastern side. From [Figure 2(k)] and [Figure 2(l)], the OLR value is higher in November compared to October.

3.2 Seasonal Outgoing Longwave Radiation

The pre-monsoon, monsoon, and post-monsoon circulations in Bangladesh are influenced by the country humid and warm climate. As a result, it is frequently affected by tropical storms and heavy rain. The hottest months (March-September) correspond with the rainy season, whereas the coldest months (December-February) are drier and colder.

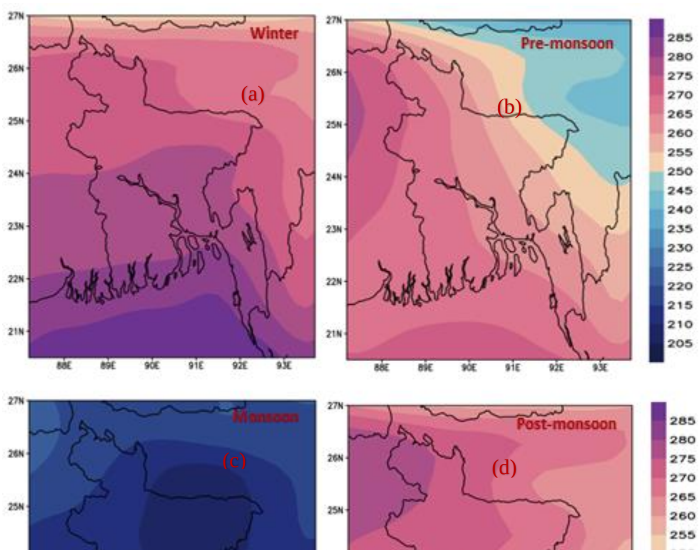

Figure 3: Seasonal distribution of OLR (W/m²) for the years (1991-2020), e.g., a) Winter b) Pre-monsoon, c) Monsoon, d) Post-monsoon.

Figure 3 illustrates the variation between seasons, indicating higher values during winter, lower values during monsoon season, and slightly elevated values in pre-monsoon and post-monsoon periods.

During the monsoon season, the OLR exhibits lower values primarily because of frequent overcast or cloudy skies and reduced emissivity. Within the monsoon period, the lowest OLR value (205 W/m²) [Figure 3(c)] was observed in the northeastern region and the southwestern region. Cherrapunji is situated on the windward side of the Khasi hills, and it receives a substantial amount of rainfall from both the Bay of the Bengal branch of the monsoon and the Sylhet region, which is located nearby. Due to this proximity and the heavy rainfall received from these weather systems, Sylhet experiences the highest amount of rainfall (BMD) and, as a consequence, exhibits the lowest amount of OLR. As the sky in the monsoon season is mostly covered with clouds and the highest amounts of rainfall, radiation has to be low followed by OLR declination at its best.

During the pre-monsoon period [Figure 3(b)] and post-monsoon period [Figure 3(d)], there was a moderate to slightly higher OLR observed. This can be attributed to the elevated temperatures and high emissivity during these seasons. In the winter season [Figure 3(a)], cloud formation is less than in any other month. So, a high amount of OLR has been found in Bangladesh. In the winter season, the presence of sunny days with minimal cloud formation results in an elevation of OLR distribution.

During the winter season, the Rangpur area exhibits the highest amount of OLR, while the northeast part of the country experiences the lowest amount. However, when comparing the monsoon season to the winter season, all radiation balance components have lower magnitudes in the monsoon due to reduced solar radiation caused by cloudy weather conditions.

3.3 Mean OLR during 1991-2020

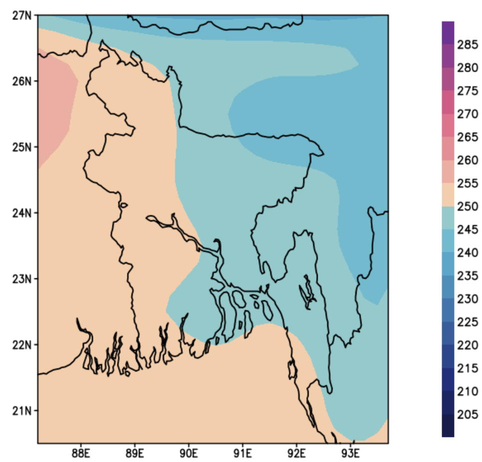

Figure 4: Pattern of OLR (W/m²) for the years (1991-2020).

Figure 4 illustrates the mean (1991-2020) of Outgoing Longwave Radiation (OLR) over Bangladesh and the OLR value found from 240-255 W/m². The western region of the country exhibited the highest OLR, ranging from 250 to 255 W/m², and was characterized by extensive hot weather. On the other hand, the eastern region had the lowest OLR, ranging from 240 to 245 W/m². The absence of a hilly area and change in topography and elevation have made the OLR increase in the Western region more than most other parts of Bangladesh. The main hilly tracts lie in the southeast or eastern frontier part of Bangladesh. So, the temperature never increases that much in these areas. As a result, more cloud formation with high amounts of rainfall made the OLR stay in a minimal number than the northern part.

3.4 Time Series of Outgoing Longwave Radiation (1991-2020)

Figure 5 presents a climatological time series covering the last 30 years. In 1997, the lowest amount of OLR (242 W/m²) was recorded, which can be attributed to the highest number of rainy days during that year.

Conversely, in 2009, a value of 254 W/m² of OLR was observed due to the smallest number of rainy days recorded in that particular year. According to time series, OLR values fluctuate between 242 W/m² and 254 W/m², with less fluctuation in the second decade. The highest variation occurred between 1996 and 1997 when the variance in OLR values was 9 W/m².

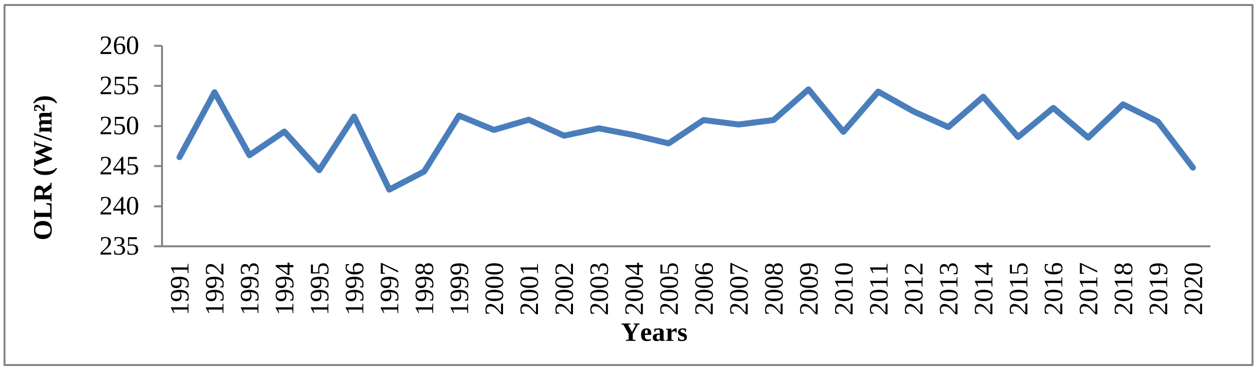

Figure 5: Time series of OLR during 1991-2020

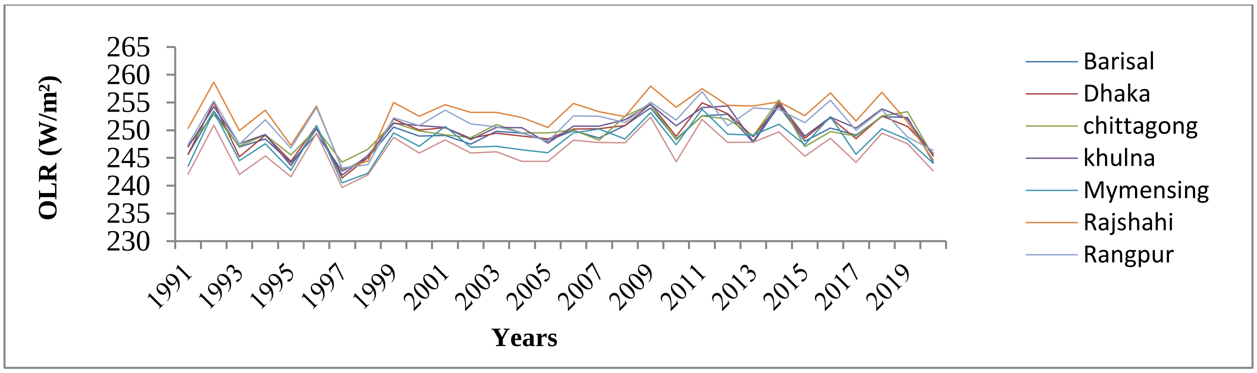

Figure 6: Divisional time series of OLR for the years 1991-2020

Figure 6 shows, the divisional OLR patterns from 1991-2020 in Bangladesh. Sylhet experiences the lowest OLR while Rajshahi experiences the highest. The variations in OLR distribution between divisions mainly occur from their distinct geographical and climatological characteristics. The presence of the Shillong Plateau acts as an impediment to the southerly or southwesterly monsoon winds, leading to higher rainfall in the Sylhet division. As a result, Sylhet receives a constant low OLR over the years. Rangpur receives the highest OLR and Chittagong receives the lowest OLR in the winter season.

In figure 7, shows the OLR and rainfall have a reciprocal relation. The OLR is gradually decreasing in the middle of pre-monsoon which proves the occurrence of norwester. Due to the significant rainfall experienced during the monsoon season in Bangladesh, the OLR levels are observed to be at their lowest amount. The OLR value is minimum during monsoon corresponds to the highest amount of rainfall [Figure 7]. A similar negative association between OLR and rainfall was discovered by Lim et al. in 2011.

With the departure of the monsoon, the weather becomes warmer and the cloud cover diminishes. As hot sunny days arrive and humidity becomes low, OLR tends to increase again after the monsoon period. The winter season is normally dry in the country. Cloud formation is also less in this dry season. As a result, little amount of rainfall is

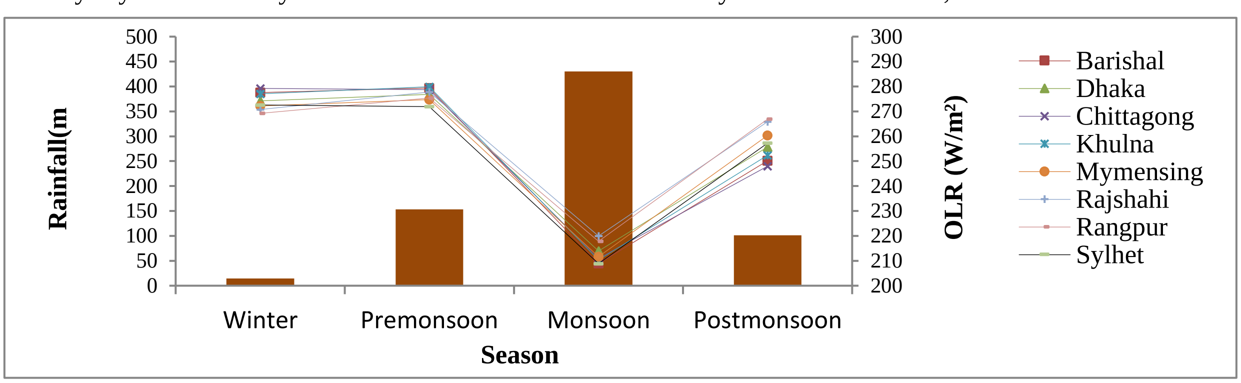

Figure 7: Comparison of a country average seasonal rainfall and divisional OLR distribution.

found in the season. The average rainfall of winter was approximately 15 mm while the OLR value was found at 269 W/m^2 – 276 W/m^2.

4. Conclusion

Over the last three decades (1991-2020), an examination of the NOAA CDR monthly data was conducted to analyze the attributes of OLR values. The months of January and December are the coldest, experiencing the lowest temperatures according to BMD. Though OLR is expected to be higher during those months, foggy conditions lead to a slight reduction in OLR. The seasonal distribution shows the OLR contributions to the season of Bangladesh. The monsoon season exhibits the lowest OLR values, whereas the winter season shows the highest. It indicates the OLR dependency on temperature and cloud formation. The average value of OLR was found to range from 240 W/m^2 to 255 W/m^2. The higher value of OLR was found on the western side of Bangladesh compared to the eastern side. This study also reveals that OLR value is gradually increasing which might be attributed due to the effect of climate change. In the first decade (1991-2000) average OLR value was 247 W/m^2 in Bangladesh, whereas in the second decade (2001-2010) average OLR value was 250.1 W/m2. But in the third decade (2011-2020), the average OLR value was 250.7 W/m2. The Highest OLR value 254.5 W/m2 was found in the year 2009 and the lowest OLR value 242 W/m2 was found in the year 1997. A negative correlation between OLR and rainfall has been observed across all seasons. Due to lower-latitudes, OLR plays a crucial role in cloud formation and rainfall patterns in Bangladesh. During the monsoon season, the highest amount of rainfall is observed alongside the lowest OLR values, while the reverse scenario is seen in winter.

Acknowledgment

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