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Seasonal Waterlogging Variation in the Sylhet City Corporation Area, Bangladesh- an Integrated Geospatial Approach

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ABSTRACT

Waterlogging is considered a severe environmental hazard in the Sylhet city corporation (SCC) area of northeast Bangladesh adversely affects the local socio-economic development. The integrated geospatial approach presents a worthy alternative to the conventional mapping of waterlogged surface areas. The remote sensing-based water index technique was used for delineating pre-monsoon and post-monsoon waterlogged areas of SCC in 2020 and 2021. Seasonal deviations of the waterlogging were determined by overlaying the waterlogged sites emanated from the pre-monsoon and post-monsoon periods under the GIS environment. Results show that waterlogged areas for pre-monsoon and post-monsoon seasons in 2020 are 2.25 sq. km and 4.12 sq. km, respectively, whereas 2.22 sq. km and 3.90 sq. km in 2021. Hence, the seasonal variations in waterlogged areas in 2020 and 2021 are 1.87 sq. km and 1.68 sq. km, respectively. This analysis also demonstrates that waterlogging in SCC is utterly driven by the high seasonal variations that mainly depend on the amount of rainfall besides the local flood-prone geologic settings and climate change.

Keywords: Seasonal Waterlogging, Sylhet City Corporation, Geospatial Technique, Remote Sensing, Bangladesh

1. Introduction

The geographical position of Sylhet is in the northeastern region of Bangladesh within the Himalayan foothill. The area has a typical tropical monsoon with a humid subtropical climate. The monsoon generally starts from May to September. It is quite hot and humid with hefty rains almost every day, while the short dry season begins from the end of October to February, and it is torrid and relatively clear (Ahmed & Kim, 2003). Almost 80% of the annual average precipitation of 3334 mm occurs in this entire area between May and September (Choudhury et al., 2012). The area is located within the territory of hills and basins, which comprise one of the most distinct regions in Bangladesh. Northeastern Bangladesh is also significantly exposed to environmental hazards, such as waterlogging (Sarker & Rashid, 2013).

Sylhet City Corporation (SCC) was formed on April 9, 2001, and is located in the center of the Sylhet district beside the Surma River. The city has a high population density with nearly 500,000 inhabitants in about 27 square kilometers (Bhuiyan & Siddiqui, 2015; Iqbal, 2017). During the Monsoon season, water-logging significantly disrupts daily life in Sylhet. Evidence suggests that the city's socio-economic development and sustainable urban growth are consistently affected by waterlogging and seasonal flooding. This location is predominantly settled in the flood-prone zone with severe monsoonal floods (Ali, 2002; Nchito, 2007).

Sylhet City Corporation has been encountering tremendous waterlogging problems. Associated with the annual monsoon season emerges the chronic waterlogging situation that drowns homes, farmlands, ponds and streets, orchards and grasslands, and so on (Hossain et al., 2022; Roy et al., 2022). Loss of grain crops and irrigated crop production get harmed due to severe waterlogging (Bakker et al., 2007; Hossain & Uddin, 2011; Solaiman et al., 2007). It also results in devastating impacts on livelihoods, health, sanitation, basic services (such as food and drinking water), infrastructure, etc. (Awal & Islam, 2020). Besides, longer-term consequences of waterlogging include unemployment, reduced production levels, social disruption (school, housing, health, markets, women's mobility), and loss of earnings for low-income workers. It is an enduring circumstance that usually takes up to seven months to downsize (FSC and Partners, 2014; Mirza & Ahmad, 2005).

Waterlogging is referred to when the near-surface soil in a certain area is entirely saturated with water (Sujatha et al., 2000). It appears when water's assemblage rate via rainfall or other sources transcend the total drainage and infiltration of a catchment or when floodwater dips an area (Mancuso & Shabala, 2010). However, in aspects of Bangladesh, rivers repeatedly get blocked totally or somewhat by siltation so that the water exceeding the jam has no path of emptying. Likewise, when monsoonal rains fall, they get confined by a perimeter (polder) and no place to pass, ending in stationary flooding defined as 'water logging' (FSC and Partners, 2014). Waterlogging may be considered a seasonal phenomenon, which indicates that it remains only in one season or can prevail throughout the year (Sharma et al., 2009).

Generally, waterlogged area mapping has been executed using a conventional approach such as land survey, but these procedures are neither cost-effective nor time-efficient for regional studies (Adewumi et al., 2016; Mahmud et al., 2017). The remote sensing (RS) techniques combined with the Geo-information system (GIS) offer an excellent choice to traditional approaches in monitoring and evaluating the magnitude of Spatio-temporal divergences in waterlogged spaces (Chowdary et al., 2008). Earlier researches have revealed the benefit of RS and GIS approaches in detecting and observing waterlogged areas (Bouwer et al., 1990; Weiers et al., 2004). A very few research reports have been found about detecting waterlogging regions and adaptation schemes in the different areas of Bangladesh, mainly concentrating on seasonal variation of waterlogging (Awal & Islam, 2020). Most of those researches focused on some southern districts of Bangladesh (Rahman & Shozib, 2021), and no research has been found concentrating on Northeastern Bangladesh. This paper could pioneer its originality for assessing the seasonal divergence of waterlogging area detection for Northeastern Bangladesh using the integrated geospatial approach, especially for emerging cities like SCC.

This current study has attempted to pinpoint waterlogged areas for both pre-monsoon and post-monsoon seasons in the area of SCC for 2020 and 2021. Therefore, to determine the seasonal change in waterlogging by delineating the waterlogged places derived with an integrated geospatial approach.

2. Materials and Method

2.1. Study Area

Sylhet City Corporation is a 27 sq. km metropolitan area of Sylhet Sadar Upazila in Sylhet district, located in between 24°51′ N and 24°55′ N latitudes and in between 91°50′ E and 91°54′ E longitudes. This area is about 27.36 sq. km, with approximately half a million people living here. The city corporation area consists of 27 wards and 207 mahallas (ward and mahallah is a smaller administrative unit of Bangladesh). The study area shows elevated topography where most of the region lies above 35m from sea level (BBS, 2011).

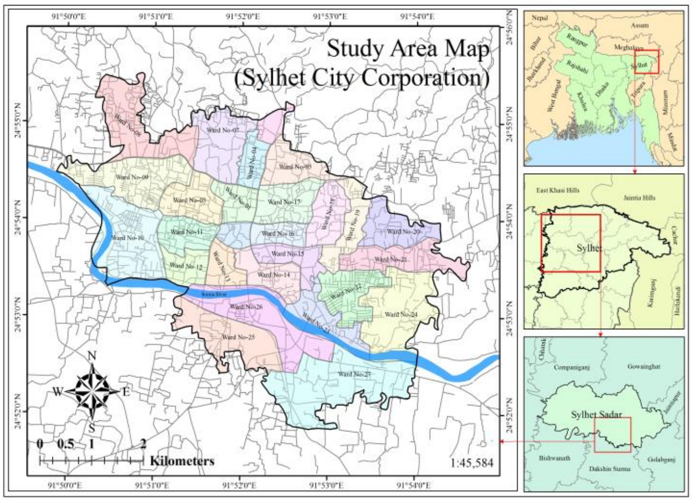

Figure 1 Location map of the study area.

An extensive literature review was conducted at every stage of this research work. The study area map was designed using the information obtained from Sylhet City Corporation's government website. The Sentinel 2 satellite images of 2020 and 2021 were collected from the USGS Earth Explorer website (Table 1), where the multispectral satellite images of April and October represent pre-monsoon and post-monsoon seasons. Satellite images were pre-processed using ENVI 5.3 software for radiometric and atmospheric correction. The waterlogged surface area delineation and visualization were performed using ArcGIS 10.5 software. The rainfall data were accumulated from the Meteorological Department of Bangladesh (BMD) to observe the rainfall pattern for this study. A constructive flow chart of this study is illustrated in Figure 2.

Table 1 Sentinel 2 datasets that have been used in this study.

Sl. no.	Acquisition Date	Tile No.	Datum	Projection	Zone	Resolution
1	06/04/2020	T46RCN	WGS84	UTM	46N	10m
2	28/10/2020	T46RCN	WGS84	UTM	46N	10m
3	16/04/2021	T46RCN	WGS84	UTM	46N	10m
4	23/10/2021	T46RCN	WGS84	UTM	46N	10m

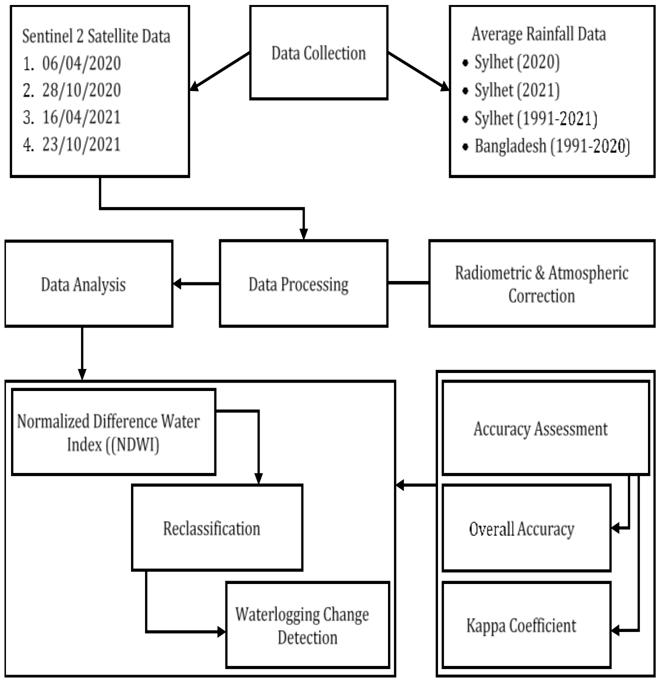

Figure 2 A flowchart showing the stepwise methodologies followed in the study.

Generally, the waterlogged places show intense contrast with the adjoining places on the satellite images. Optic sensors' visible and infrared domains can efficiently determine these spectral parcels of waterlogged areas. The static water sites seem dark blue to black, relying on the water depth, while the wet places appear as a dark grey to light grey on the multispectral images. The land/water edge is often perplexing in a single near-infrared (NIR) band, and therefore, two-band instead of single-band data such as green and NIR bands can be utilized in such cases. Thus, rationing of the two band data carries the advantage of the contrast in the reflectance of separate wavelengths in improving a particular feature from the multispectral satellite data (Chowdary et al., 2008; Santosa, 2016).

So, in this investigation, the most used water index algorithm Normalized Difference Water Index (NDWI), produced by McFeeters (1996), was utilized. NDWI was employed in multispectral imagery to outline waterlogged places by suppressing them from terrestrial vegetation features. The waterlogged areas derived for both pre-monsoon and post-monsoon seasons were used in geoprocessing analysis to pinpoint the seasonally waterlogged places. This index is calculated as follows:

$$NDWI = (\rho Green - \rho NIR) / (\rho Green + \rho NIR)$$

Where ρGreen represents the spectral reflectance in the Green band and ρNIR is for the near-infrared (NIR) band. The ranges of NDWI vary from -1 to +1, in which negative values resemble the vegetation cover, and positive values represent the water features. Because of the NIR band's high reflectance compared to the Green Band, Water features reveal a positive value (McFEETERS, 1996). The NDWI threshold value estimation is likely to vary with different data acquisition dates and requires to be specified for each data independently.

In this study, the threshold value of NDWI was specified for individual satellite images based on the visible rendition of raw data (Table 2). Finally, the kappa statistics and overall accuracy were carried out for validation. One hundred seventy-five points were randomly selected to apply accuracy assessment following the Google Earth photos. Verification was conducted to observe the accuracy level of waterlogged places in the study areas and their seasonal variations (Abbas & Jaber, 2020; Foody, 2020).

Table 2 Threshold values for temporally different satellite images.

Year	Seasons	NDWI Threshold Value
2020	Pre-monsoon	≥ 0.05
	Post-monsoon	≥ 0.1
2021	Pre-monsoon	≥ 0.05
	Post-monsoon	≥ 0.1

3. Result and Discussion

The pre-monsoon and post-monsoon surface waterlogged places in the study area for 2020 and 2021 are delineated practicing RS and GIS approaches. Permanently waterlogged areas are those where the ground remains waterlogged throughout the year. During April (peak of the dry season), water bodies on satellite images may be considered permanently waterlogged areas after subtracting the areas under ponds and rivers. On the other hand, seasonal inundation occurs due to intensive rainfall throughout the monsoon season. So water bodies on the satellite images during October (just after the monsoon season) may be considered seasonally waterlogged areas.

It is clearly visible from the map in Figure 3 that in 2020 the center part of the city corporation area held most of the water permanently in the pre-monsoon season. On the other hand, the waterlogging areas were detected throughout the city after monsoonal rainfall in the post-monsoon period. After incorporating pre-and post-monsoon waterlogged areas, it is noticeable that most northern parts of the Surma River and western past of the SCC become inundated after the monsoon season and, thus, these parts can be assumed as seasonally waterlogged areas. The same scenario was observed in 2021 with a slight variation.

Waterlogged areas in the SCC area, along with temporal variations, have been estimated by the geoprocessing analysis (Table. 3). It is observed that waterlogged areas in the area of SCC in 2020 for pre-and post-monsoon seasons are 2.26 km2 and 4.12 km2, respectively, where their area coverage enhances 1.87 km2 due to monsoon rainfall. The percentage of waterlogged area changes from 8.43% in pre-monsoon to 15.44% in post-monsoon, and the seasonal divergence is 7.02%. Similarly, in 2021, the corresponding waterlogged areas for pre-monsoon and post-monsoon seasons are 2.22 km2 and 3.90 km2, and the variation is 1.68 km2. The percentage of area coverage jumps up to 14.64% from 8.33%, with a deviation of 6.31% due to monsoon rainfall.

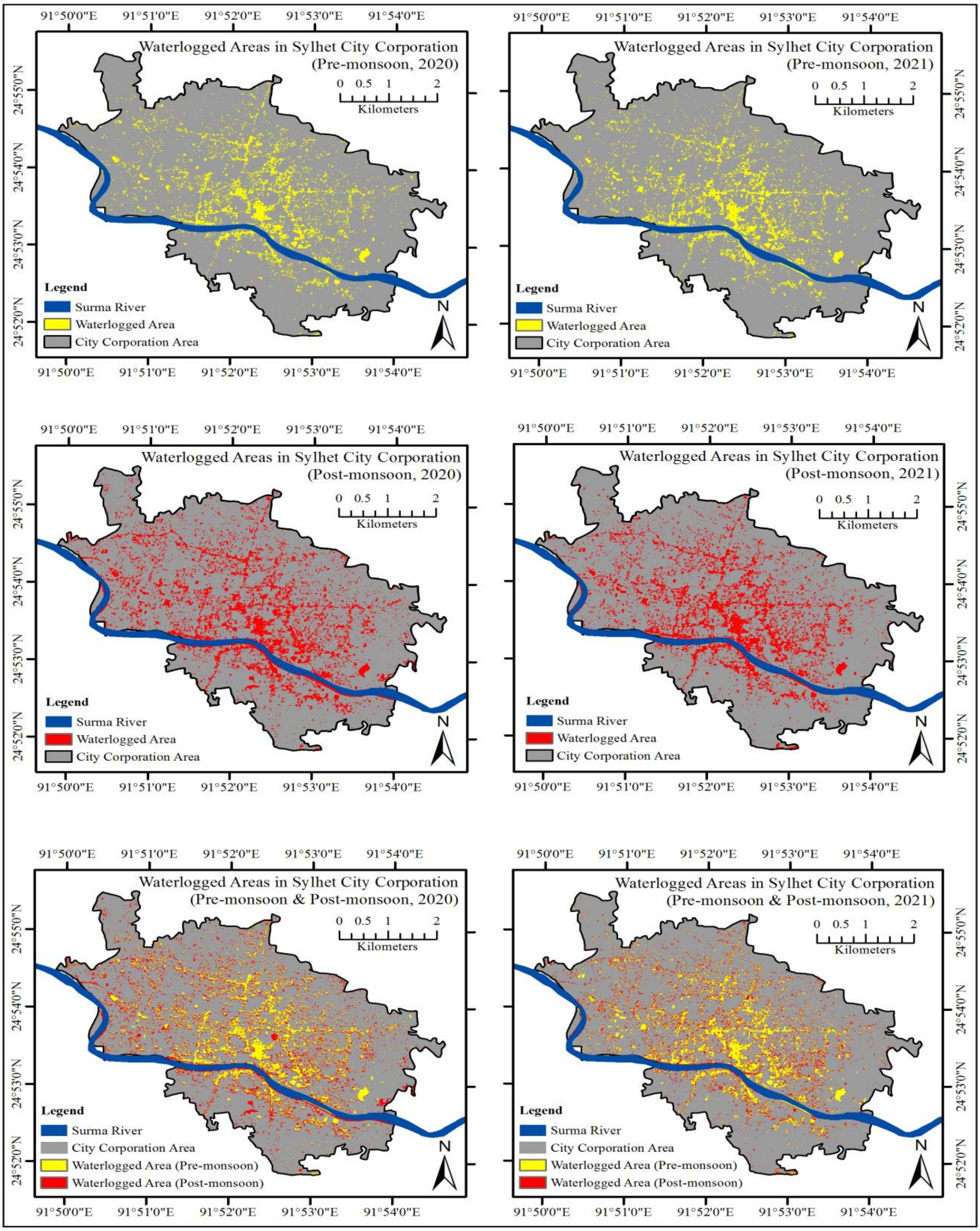

Figure 3 Maps are displaying waterlogged areas in Sylhet City Corporation during pre-monsoon and post-monsoon seasons, and integrated waterlogged map for both seasons in 2020 and 2021.

Table 3. Variations in waterlogged areas between pre-monsoon and post-monsoon seasons for 2020 and 2021 in Sylhet City Corporation area.

Year	Pre-monsoon		Post-monsoon		Seasonal Variation		Average Rainfall
	Km²	%	Km²	%	Km²	%	Mm
2020	2.25	8.43	4.12	15.44	1.87	7.02	421
2021	2.22	8.33	3.90	14.64	1.68	6.31	350

The waterlogging in the northeastern part of Bangladesh is mainly affected by rainfall. It is apparent from Sylhet district's monthly average rainfall distribution compared to the national monthly average, where the regional average is remarkably higher than the national rainfall average (Figure 4).

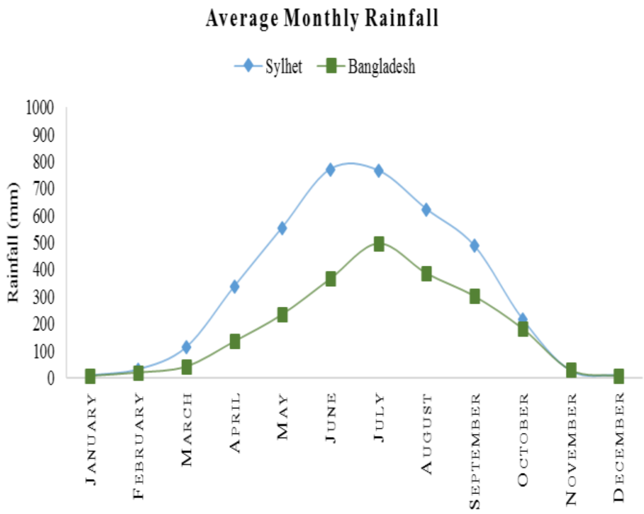

Figure 4. Average monthly rainfall of Sylhet district and the total national average. (Data source: Bangladesh Meteorological Department)

Moreover, the influence of rainfall on the waterlogging scenario in SCC can also be explained by the average rainfall of the years 2020 and 2021 with the average rainfall. In 2020 and 2021, the average rainfall of the Sylhet region was 421mm and 350mm (Table 3). The rainfall in the monsoonal period (May, June, July, and August) of 2020 was much higher than the monsoonal rainfall of 2021 (Figure 5). As a result, the waterlogging area in the post-monsoon of 2020 was found at about 4.12 km2. On the other hand, in 2021, the waterlogging area in the post-monsoon season was 3.90 km2 (Table 3). Therefore, this comparison clearly showed that the variation of rainfall influences the variation in seasonal waterlogging of the area of SCC.

However, seasonal flooding also causes waterlogged areas (Huda et al., 2019; Shaibur et al., 2014). Several former studies showed that Sylhet metropolitan area is vulnerable to seasonal flooding (Talukdar et al., 2020). In addition to monsoon rainfall, riverbed rises due to siltation as stimulated by retardation of upstream river flow by human intervention, natural activity, and encroachment of river banks. Besides poorly executed infrastructure, unplanned urban drainage system, and climate change can be explained as the cause for waterlogging in the northeast of Bangladesh (Awal & Islam, 2020; Ayyam et al., 2019; Islam et al., 2020). The study revealed high accuracy and validated data, indicating transparent and essential observation. An analyzed value of 89% overall accuracy, more than 0.83 Kappa coefficient value where most studies referred to the value of kappa > 0.75 signify the higher accuracy rate (Abbas & Jaber, 2020; Foody, 2020; Islam et al., 2020).

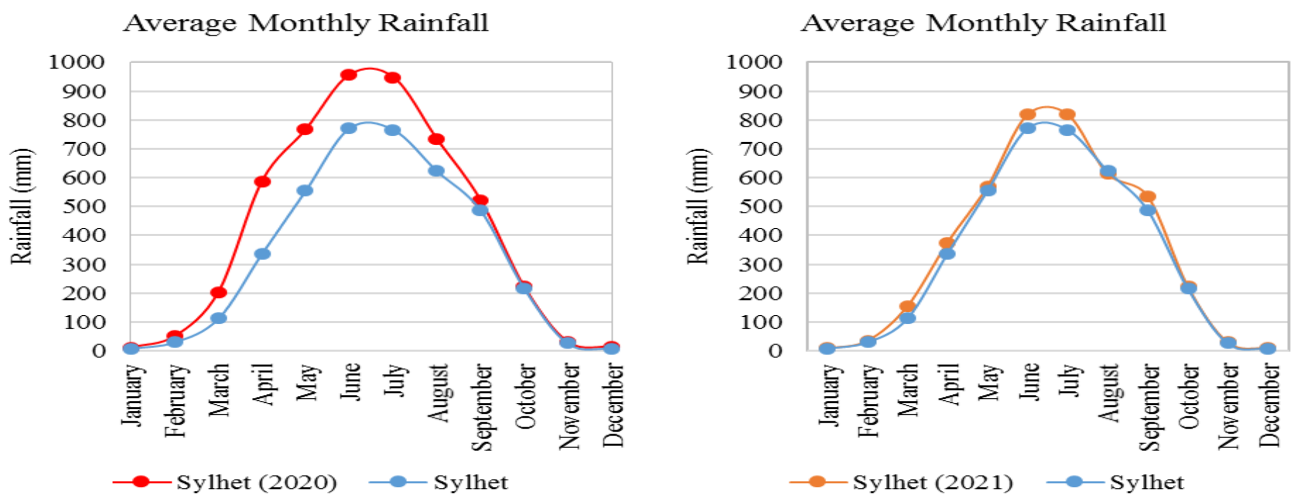

Figure 5. Comparison of monthly average rainfall for the years 2020 and 2021 with the average rainfall of Sylhet for the last 30 years (1991-2020). (Data source: Bangladesh Meteorological Department)

4. Conclusion

The northeastern portion of Bangladesh, particularly SCC, is inclined to waterlog because of heavy monsoon rainfall, hilly geologic settings, mismanagement in the drainage system, and unplanned rapid urbanization. About 7.02% and 6.31% of seasonal waterlogged area were increased in the year of 2020 and 2021 respectively. In addition, due to the difference of 71mm average annual rainfall between these years about 0.71% of seasonal waterlogged area less occurred in 2021 than in 2020. In this study, multispectral sentinel 2 satellite image data were successfully used to assess temporally and spatially distributed waterlogged locations to estimate the seasonal divergences. This research suggested that the variation in waterlogging zones likely to worsen under seasonal and annual rainfall variations. Reliable and detailed inspection of waterlogged places is vital in planning and enforcing curative measurements for optimal utilization of available land and water resources and sustainable urban development. Therefore, comprehensive research is required to assess the consequences of waterlogging on agricultural productivity, soil fertility, biodiversity, and drinking water and urban sanitation system in the northeastern hilly region of Bangladesh to find out the possible mitigation options. Furthermore, for immediate and short-term steps to solve the waterlogging problem, excavating silted-up rivers, canals, and sewage channels should be carried out, and establishing sustainable water discharge and drainage systems might be considered a long-term or permanent solution.

5. Acknowledgement

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6. Conflict of Interest

The authors declare that there is no conflict of interest with any financial, personal, or other relationships with other people or organizations related to the material discussed in the article.

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