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ASSESSING THE SPATIO-TEMPORAL VARIABILITY IN THE FREQUENCY AND MAGNITUDE OF FLASH FLOODS AND THEIR DRIVING MECHANISMS: EVIDENCE FROM HAOR REGION OF BANGLADESH

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Abstract

There are a limited number of studies addressing the spatiotemporal variability of pre-monsoon flash floods and their driving forces in Bangladesh. This study examines long-term trends in temperature, rainfall, and the frequency and magnitude of flash floods in the five most vulnerable *haor* districts of northeastern Bangladesh. Temperature, rainfall, and surface water level datasets, up to 2018, were collected from the Bangladesh Meteorological Department (BMD) and the Bangladesh Water Development Board (BWDB). Based on the normal distribution of these datasets observed in quantile-quantile (Q-Q) plots, regression models were used to analyze the long-term temperature trends. The models predict a gradual rise in maximum temperature, ranging from 1.06% to 1.94% over decadal periods. Additionally, an average annual rainfall increase of 4.1% at Sreemangal and 2.28% at Sylhet stations are forecasted. Analysis of historical data from the past sixty years shows a relatively lower peak river stage in tidal rivers compared to non-tidal river stations during pre-monsoon months. The frequency of peak surface water levels at six non-tidal and ten tidal river monitoring stations was estimated using Gumbel's probability estimation method. Frequency analysis suggests a high probability of flash floods across most floodplain areas, with a return period of five to ten years, based on flood danger levels established by government agencies. Furthermore, MODIS satellite imagery (with cloud cover <10%) from the peak flood months (March to May) between 2004 and 2017 was analyzed to assess the extent of flash floods in the study area. Geospatial analysis revealed temporal variations in peak flood extents across different locations. While no clear trends were observed in the frequency of flash floods, their magnitude has significantly increased in recent decades, potentially leading to greater losses in agriculture and property. The increased vulnerability to flash floods in the region can be attributed to several factors, including a rise in pre-monsoon heavy rainfall in the upstream hilly regions of Assam and Meghalaya, high sediment loads in Transboundary Rivers, drainage congestion, poorly designed and maintained flood control structures, and the absence of a reliable flash flood warning system.

Keywords: Climate change, Flash flood, Frequency analysis, Haor, Hazards, Tidal River.

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Introduction

Flash flood generally occurs in low-lying areas shortly after a heavy rainfall event which can also occur in the downstream areas from the source of the precipitation. Earlier studies reported the occurrence of frequent flash floods due to changes in rainfall patterns and intensity in peninsular, east, and northeast India and Myanmar, creating food insecurity and flood risk (Boori *et al.,* 2017; Guhathakurta *et al.,* 2011). High drainage densities, topographic relief, along with heavy rainfall have increased the frequency of flash floods and their risk potential in Western Nepal (Pangali Sharma *et al.,* 2021; Pokharel *et al.,* 2020). Along with climate change effects, encroachment and excessive interventions in the flood plains and flood-prone areas, destruction of forests and hill slopes development and other manmade activities has significantly increased the frequency of flood and therefore increased risks to humans, property, and the economy in different parts of Malaysia and the Brahmaputra basin of India (Bhattacharyya and Bora, 1997; Maqtan *et al.,* 2022; Mohamad *et al.,* 2012; Muhammed *et al.,* 2022; Weng, 1997). To combat the flood-induced losses, the local and regional agencies undertook various conventional approaches to controlling floods, including structural interventions, many of which were found less effective or entirely ineffective in the long run. For instance, the authorities in the Brahmaputra basin adopted various flood control measures since the early fifties, which became non-operational over time (Bhattacharyya and Bora, 1997). Another example is the breach of the Kosi embankment in Nepal resulted from the high sediment content of the Kosi River, which proved ineffective in controlling floods in Bihar (Dixit, 2009).

Bangladesh is considered one of the most vulnerable countries to climate-induced hazards and disasters (Ali *et al.,* 2013; Khan and Islam, 2018; Sammonds, 2021). Lack of adequate institutional capacities, infrastructural development, and climate variability results in significant damage to agriculture and fish production in the north-eastern *haor* region of Bangladesh (Sammonds, 2021; Hossain, 2013; Hossain *et al.,* 2017; Kamruzzaman and Shaw, 2018; Suvra, 2021). Pre-monsoon (March to May) flash floods often result from excess rainfall in the upstream hilly areas of Asam and Meghalaya in India and enter the Haor areas through the transboundary rivers within 5-6 hrs (Dey *et al.,* 2021; Roy *et al.,* 2017; Sarker and Rashid, 2013). Therefore, the emergency response system was often unsuccessful in reducing the adverse impacts of the sudden intense flood (Rahman *et al.,* 2011). These climate impacts significantly hinder the economic growth, livelihood improvement, environment, and public health of the *haor* communities (Suvra, 2021; Sadeque, 2018). Bangladesh Water Development Board took the initiative to erect low-height submersible embankments, drainage channels, and sluices and regulators to delay pre-monsoon floods and to reduce the damage to agriculture crop productions since 1960 (Suvra, 2021; Khan, 2010; Rahman and Salehin, 2013).

In Bangladesh, no comprehensive studies were conducted regarding how the magnitude and frequency of flash floods vary spatially over different temporal scales in the NE *haor* districts; tectonically, *haor* is a bowl-shaped large depression (Banglapedia, 2021). There is also a significant gap in understanding the influences of the key driving forces and their characteristics which is a significant constraint for the early preparedness and emergency response to reduce the adverse impacts in flash flood vulnerable areas. Earlier, the flood danger levels at and nearby the river stations were set by the Flood Forecasting and Warning Center (FFWC) of the Bangladesh Water Development Board (BWDB), based on the riverine peak floods during the monsoon period (June to October) (Roy *et al.,* 2019). The flood danger level indicates the threshold above which flood may potentially overflow the floodplain areas and affect the lives, properties, and crop production (Rahman *et al.,* 2011). Although pre-monsoon flash flood causes significant damage to crop cultivation and properties, there are neither any scientifically well-defined danger levels, particularly for flash floods, nor any reliable early warning system considering the flash flood magnitudes, elevation of the submersible embankments, and floodplains. There is also a lack of regional collaboration to establish hydro-meteorological networks to strengthen the flash flood early warning system. Therefore, this study is aimed at assessing the long-term variability of the frequency and magnitude of flash floods spatially in the *haor* districts of Bangladesh. A further aim was to explore how the variations in climate conditions and human interventions contribute to the vulnerability of flash floods. Finally, this study attempted to elucidate any technical gaps that need to be addressed to improve the flash flood warning system. That information will be beneficial to identify flash flood danger levels and to adopt efficient warning systems in vulnerable areas.

A study by Center for Environment and Geographic Information Services (CEGIS) shows that about 373 Haors cut across Kishorenganj, Netrokona, Sunamganj, Sylhet, Habiganj, Mymensingh, and Brahmanbaria districts of Bangladesh (CEGIS, 2012). As many as 28 Upazilas under the five most vulnerable Hoar districts were considered for this study. Those include eleven Upazilas from Sunamganj, three from Habiganj, four from Netrokona, four from Kishoreganj, and six from Brahmanbaria (Table 1; Fig. 1).

Table 1. Locations of the study area.

Name of the districts	Name of the upazilas
Sunamganj	Sunamganj Sadar, Tahirpur, South Sunamganj, Bishwambapur, Jamalganj, Derai, Sulla, Chahtak, Dowarabazar, Dharmapasha and Jagannathpur
Habiganj	Azmiriganj, Lakhail, Baniachong
Netrokona	Khaliajuri, Komlakanda, Modon, Mohanganj
Kishoreganj	Itna, Mithamoin, Astagram, Nikli
Brahmanbaria	Nasirnagar, Nobinagar, Sarail, Ashuganj, Brahmanbaria Sadar, Bancharampur

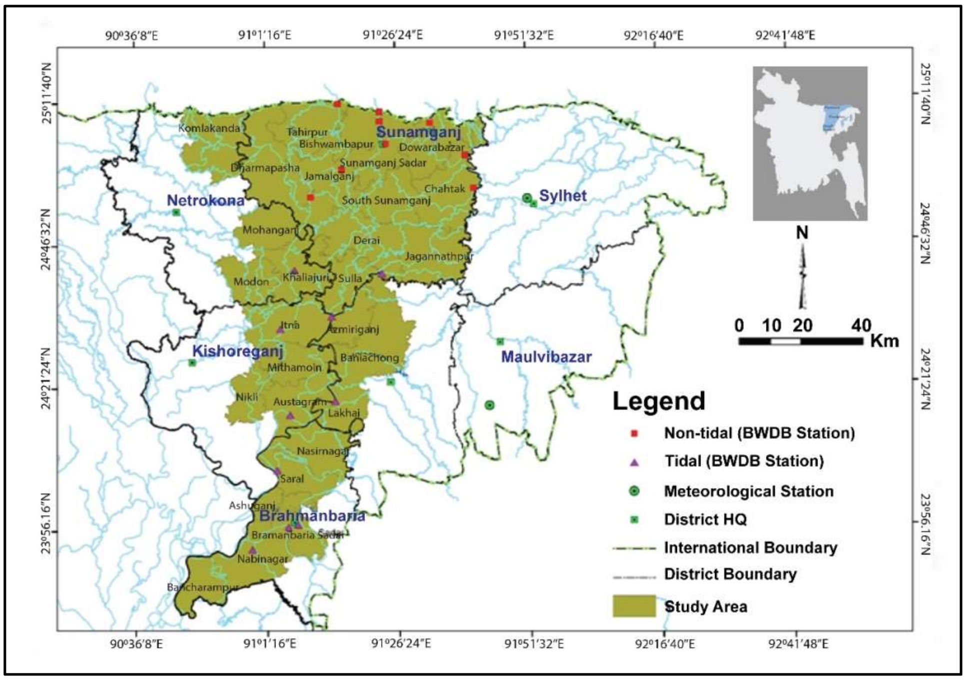


Fig. 1. Location map of the study area.

Materials and Methods

Available temperature datasets of up to 2018 were collected from the Bangladesh Meteorological Department (BMD). Trend analyses were conducted at nearest station Id 10704 (Sreemangal) and station Id 10705 (Sylhet) to see the annual trend of the maximum and minimum temperature values over decadal-scale periods. The mean annual maximum and minimum temperature datasets distribution was normal in the quantile-

quantile (Q-Q) plots. So linear regression models were run to examine the long-term trends of temperature. Future temperature projections were performed using the Statistical Downscaling Model (SDSM) based on observed data from 1991 to 2015. Climate projections were performed for three-time slices: 2023-37, 2043-57, and 2073-87, and for two Representative Concentration Pathways (RCP) scenarios: RCP 4.5 and RCP 8.5 (Wikipedia, 2024).

Available rainfall data for stations 10704 (Sreemangal) and 10705 (Sylhet) were collected from the BMD. Cumulative annual rainfall data from 1991 to 2018 were examined for trend analysis for these locations.

Available surface water level data (1950-2018) were collected from BWDB. The Gumbel and generalized extreme value (GEV) distributions provided the most reliable estimates among the available methods tested to assess the frequency analysis of pre-monsoon flash floods. Therefore, the frequency of peak surface water levels of different monitoring stations was estimated using Gumbel's probability estimation method up to a one-hundred years return period (Smail and Myrtene, 2004). A total of six non-tidal and ten tidal river stations were considered for frequency analyses. Log-normal distributions of surface water level frequency analysis results showed that the distributions were normal enough in the quantile-quantile (Q-Q) plots. Although slight curviness was noticed at stations 268, 131.5, and 33, no significant heteroscedasticity influenced the outcomes.

Available Moderate Resolution Imaging Spectroradiometer (MODIS) satellite images for the peak flood months (March to May) from 2005 to 2017 were studied to evaluate the flash flood extents in those areas. Bangladesh transverse Mercator (BTM) projection was used to transfer locations from 3D to 2D space. Finally, unsupervised classification was carried out using the isodata clustering techniques to classify pixels that represent water bodies. Flash flood extents were determined based on the areas inundated by water. Finally, trend analyses were conducted to study the long-term trends of flash floods in those *haor* regions.

Results and discussions

Long-term variations of meteorological condition: Halder *et al.* (2023) examined the temperature and rainfall patterns in the Guwahati City of Assam using data from 1970 to 2019, which showed an increase in the seasonal and annual min-max temperature over the years. Results showed that the monsoon and winter rainfall decreased, but the pre-monsoon rainfall has increased over the past 50 years. Marak *et al.* (2020) studied the spatial and temporal rainfall variations in the Umiam and Umtru watersheds of Meghalaya using gridded rainfall data from 1901 to 2018. Results showed no definite patterns of the annual minimum and maximum rainfall spatially. However, the high-intensity rainfall is increasing at the seasonal and annual scales. Overall, the increases of the pre-monsoon rainfall in Assam and the ratio of high-intensity rainfall in Meghalaya increase the likelihood of frequent and high-magnitude flash floods due to the rapid movement of the flood water through the transboundary rivers in the study area.

Temperature trends: The mean maximum annual temperature varied between 31.62°C and 29.88°C in Sreemangal, whereas values ranged between 31.47°C and 29.12°C in Sylhet (Fig. 2). A comparatively higher mean annual maximum and a lower mean annual minimum temperature were found at Sreemangal compared to Sylhet station. However, both maximum and minimum temperature datasets at Sylhet show relatively higher variability than those at the Sreemangal station. Although a strong correlation (R = 0.88) was noticed between the mean annual maximum temperatures at both locations, the correlation was relatively weaker between the minimum temperature datasets at a 95% confidence interval.

The given models in Fig. 2 predict an average increase of the mean maximum and minimum temperature of 1.06% and 0.92%, respectively in Sreemangal at every decadal-scale time. On the other hand, a comparatively higher increase in mean annual maximum (1.88%) and minimum (1.94%) values were found in Sylhet within the same time frame. In addition to the trend analysis, monthly mean maximum and minimum temperatures were studied to predict the mean monthly temperature fluctuations in the study area. In every case, higher-order polynomial functions produced the best-fit models with explanatory power of at least 89% with respect to the observed data points (Equations 1-4). The maximum temperature was predicted to be highest in July and August. In contrast, the lowest temperature was predicted to be in January at both stations.

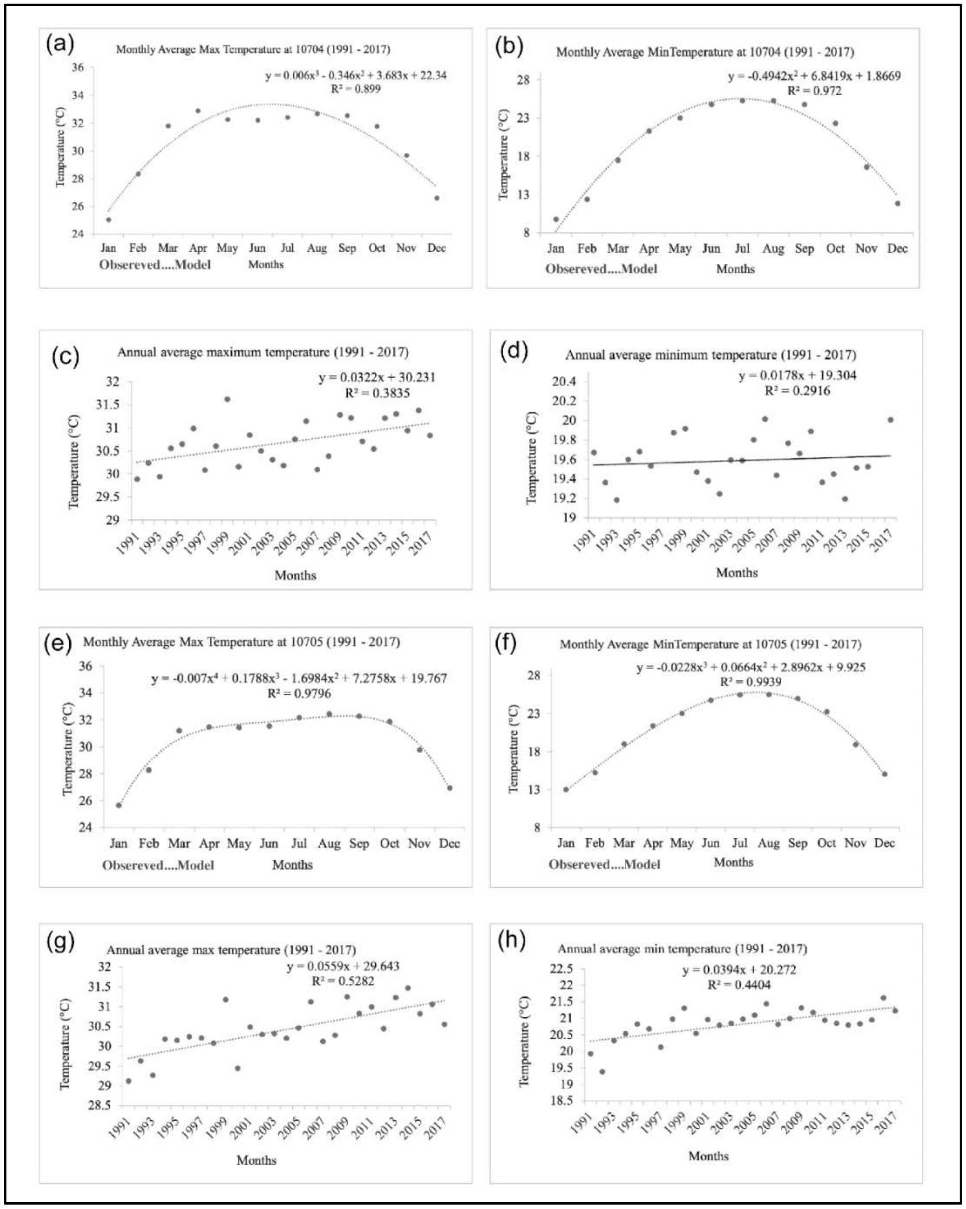
The following models were chosen for the given locations.

Model for the mean monthly maximum temperature at station 10704:

$$Y = 0.0062x^3 - 0.346x^2 + 3.6839x + 22.348;\ R^2 = 0.8997 \quad \text{(Equation 1)}$$

Model for the mean monthly minimum temperature at station 10704:

$$Y = -0.4942x^2 + 6.8419x + 1.8669;\ R^2 = 0.972 \quad \text{(Equation 2)}$$



Source: Temperature data from Bangladesh Meteorological Department (BMD).

Fig. 2. Monthly and annual average maximum and minimum temperature from 1991 to 2017 at the Sreemangal station 10704 (a to d) and Sylhet station10705 (e to h).

Model for the mean monthly maximum temperature at station 10705:

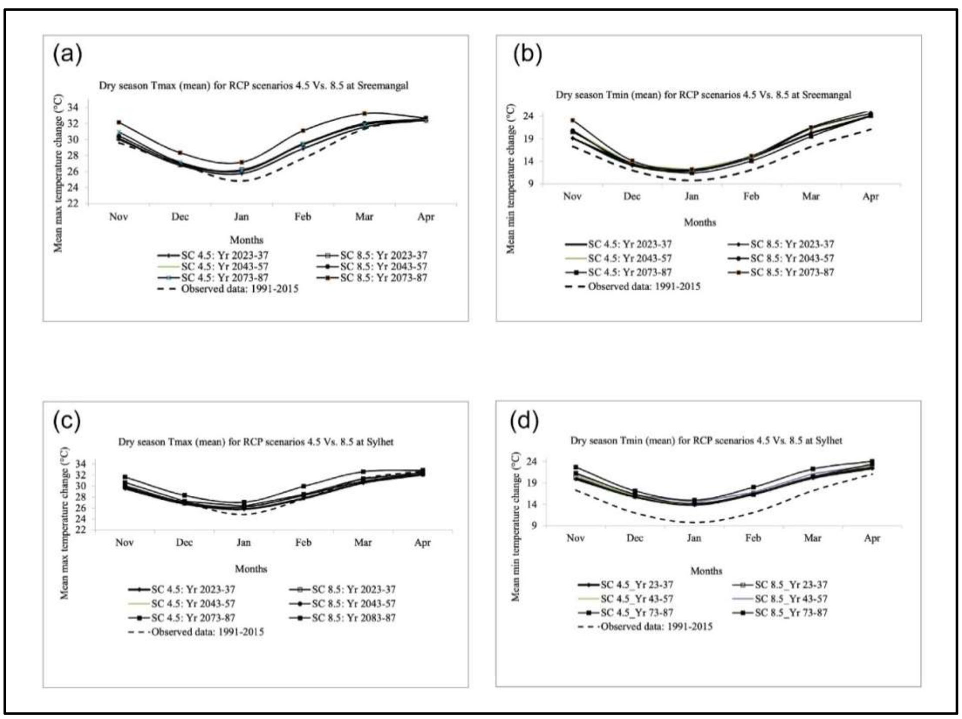
$$Y = -0.007x^4 + 0.1788x^3 - 1.6984x^2 + 7.2758x + 19.767;\ R^2 = 0.9796 \qquad \text{(Equation 3)}$$

Model for the mean monthly minimum temperature at station 10705:

$$Y = -0.0228x^3 + 0.0664x^2 + 2.8962x + 9.925;\ R^2 = 0.9939 \qquad \text{(Equation 4)}$$

Where x and y are the time (in years) and mean monthly temperature (in °C), respectively, the value of R^2 represents the model's explanatory power.

Both RCP scenarios 4.5 and 8.5 at both stations predicted a higher temperature during the winter months (Fig. 3). Therefore, a gradual rise of temperature over decadal scale time may pose significant threats to agriculture and fisheries production over longer time intervals.



Source: Temperature data from BMD.

Fig. 3. Representative Concentration Pathways (RCP) scenarios of dry season temperature forecast using Statistical DownScaling Model (SDSM) at the Sreemangal station 10704 (a to b) and Sylhet station10705 (c to d).

Rainfall condition: Annual cumulative rainfall at Sylhet station (Id: 10705) shows higher variability than that at the Sreemangal station (Id: 10704). The minimum and maximum rainfall varied between 1741mm and 3813mm in stations 10704 and 3100 mm and 5944 mm in station 10705. The median annual rainfall of 3891 mm at station 10705 was considerably higher than that at station 10704 which is 2266 mm. A moderately strong positive correlation was noticed (correlation coefficient 0.62) between the cumulative annual rainfalls at those two locations.

No noticeable differences were observed in the intensity of pre-monsoon rainfall at any of those stations. However, a slight increase in annual rainfall was noticed in both locations. At station 10704, the following regression model showed an average of 4.1% increase in the annual rainfall over a decadal scale period.

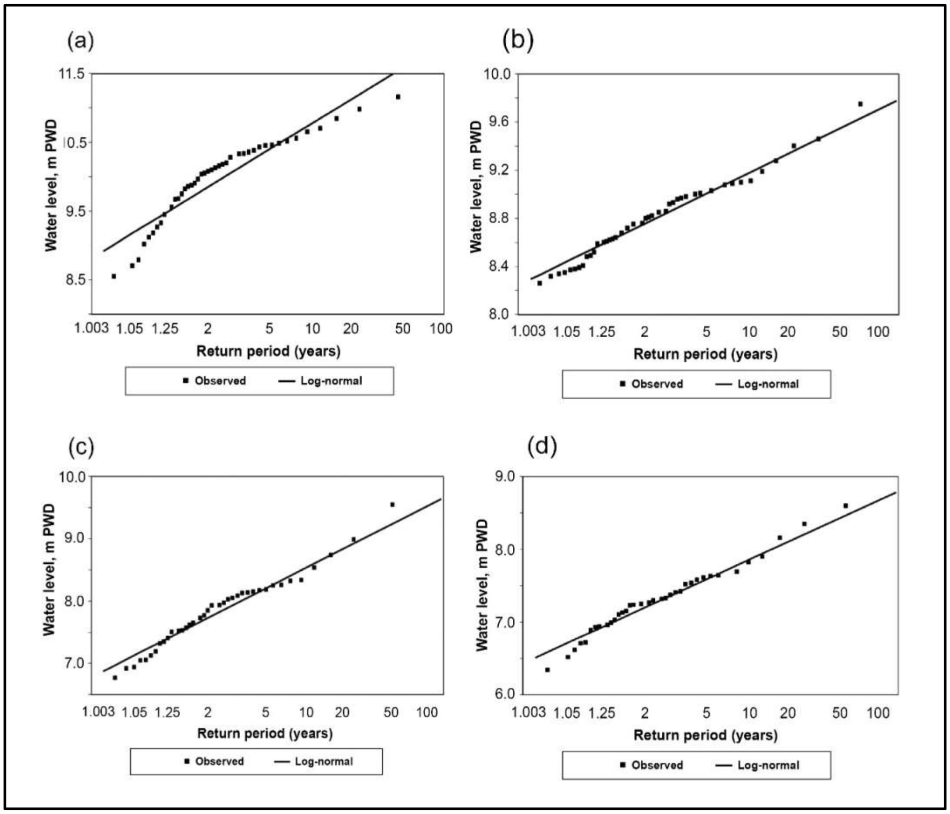
$$\text{Rainfall (in mm)} = f\,(\text{Number of years}) \times 9.27 + 2261 \qquad \text{(Equation 5)}$$

On the other hand, an approximately 2.28% increase in the annual rainfall was predicted for similar time frames at station 10705. The linear regression model is given below-

$$\text{Rainfall (in mm)} = f\,(\text{Number of years}) \times 8.89 + 3876.8 \qquad \text{(Equation 6)}$$

Pre-monsoon Flood Frequency analyses: Locations of the BWDB tidal and non-tidal river stations are shown in Fig. 1. Among the six non-tidal river stations considered, the highest and lowest peaks of surface water levels were predicted as 13.46 m PWD at station 131.5 and 8.72 m PWD at station 72B, respectively over a one-hundred-year return period (Table 2 and Fig. 4).

A total of ten tidal river stations located in the southern part of the study area were considered for frequency analysis (Fig. 1). Relatively lower peak river stages were predicted for the tidal rivers compared to the non-tidal rivers within a one-hundred-year return cycle (Table 2 and Fig. 4). In addition, the variability of the probable higher river stages is statistically higher in the non-tidal river stations. The possible highest and the lowest peaks of tidal river stages were predicted for station 72 and station 298, respectively, up to a return period of 50 years. However, a noticeably higher positive slope for stations 271 and 272.1 was resulted from a significant rise in water level at the Upper Meghna River. The maximum surface water peaks were predicted in station 271 at and beyond fifty-year time intervals. Finally, frequency analysis results indicate high chances of very high magnitude flash flood events at most river stations, especially at Jadukata (Id: 131.5) and upper Meghna River (Ids: 271 and 272.1) within a fifty-year return period.



Source: Surface water level data from Bangladesh Water Development Board (BWDB).

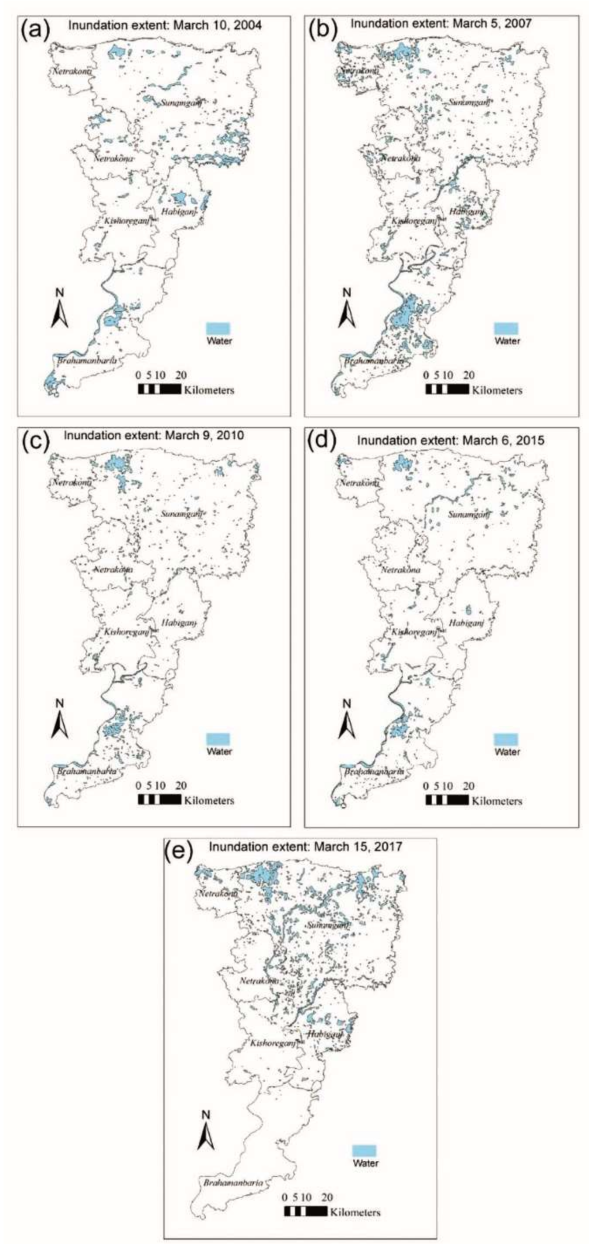
Fig. 4. Frequency analyses of pre-monsoon non-tidal surface water level at stations (a) 268 and (b) 269, and tidal surface water level at stations c) 72 and d) 271.

Results show that the surface water danger levels currently being practiced by the FFWC for monsoon flood lie below two years pre-monsoon flood return period at the surface water stations in Dhanu-Boulai Ghorutrautra and Jadukata rivers and Anderson Khal (canal). The danger level lies below the 5-10 years flood return period at several stations in Surma-Meghna and Lower Meghna rivers (Table 2). Therefore, heavy rainfall in the upstream hilly areas results in frequent flash floods in the floodplain communities, ultimately affecting the agriculture production of the study area.

Table 2. Frequency analyses results during the pre-monsoon period at the non-tidal and tidal river stations in the study area.

Rivers' Name	Station ID	Water level (m PWD) in different Return periods (years)						Available data (Years)	Existing DL (in m PWD)
		2	5	10	20	50	100		
Non-tidal rivers									
Bhattakhal	33	9.96	10.60	11.03	11.43	11.96	12.35	1958-1981	-
Dhanu-Boulai	72B	7.23	7.63	7.89	8.15	8.47	8.72	1982-2018	5.31
Jadukata	131.5	10.62	11.38	11.88	12.36	12.99	13.46	1993-2009	8.53
Julakhali	333	9.62	9.89	10.07	10.25	10.46	10.64	1988-2009	-
Surma-Meghna (SM)	268	9.85	10.41	10.78	11.13	11.59	11.93	1960-2018	9.5
SM	269	8.75	9.03	9.21	9.38	9.60	9.77	1960-2018	8.25
Tidal rivers									
Anderson Khal	3A	6.31	6.78	7.09	7.38	7.77	8.06	1960-2009	5.5
Dhanu-Boulai Ghorutrautra (DBG)	72	7.73	8.24	8.58	8.90	9.32	9.63	1960-2009	6.31
DBG	73	7.47	7.94	8.25	8.54	8.93	9.21	1960-2009	-
Lower Meghna (LM)	270	7.48	7.90	8.17	8.43	8.77	9.03	1969-2009	8.5
Upper Meghna (UM)	271	7.24	7.93	8.38	8.82	9.38	9.8	1968-2018	-
UM	272.1	6.36	7.10	7.59	8.07	8.67	9.13	1965-2009	-
LM	272	6.81	7.36	7.73	8.08	8.54	8.88	1960-2009	-
Titas	295	6.52	7.12	7.52	7.90	8.40	8.77	1960-2009	-
Titas	297	6.16	6.70	7.06	7.40	7.85	8.18	1960-2009	-
Titas	298	6.06	6.54	6.86	7.17	7.57	7.87	1960-2018	-

Source: BWDB; DL=Danger Level; PWD=Power Works Datum



Source: MODIS satellite imageries.

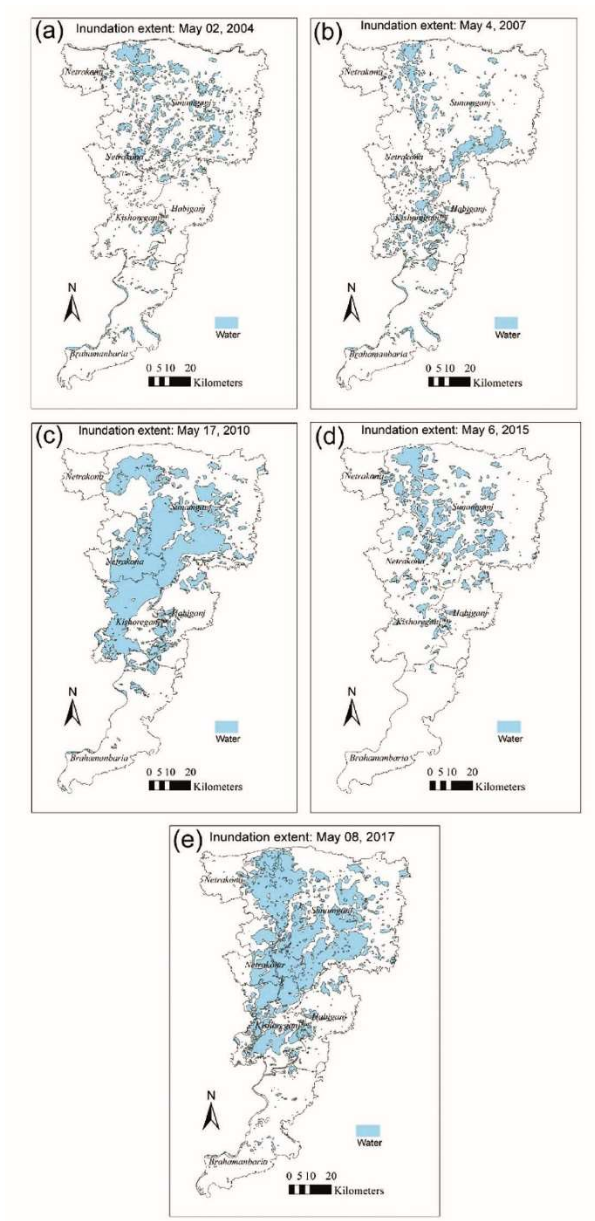
Fig. 5. Flash flood extents (% area inundated) in five *haor* districts in March of a) 2004, b) 2007, c) 2010, d) 2015, and e) 2017. Authors analyzed MODIS satellite images to generate the flood extent maps

Spatio-temporal trends of Flash flood inundation: The *haor* areas experienced significant floods in 1974, 1988, 1998, 2004, 2007, 2010, and 2017 (Rahman et al. 2011). Analysis of available satellite imageries for the pre-monsoon (March to May) from 2005 to 2017 reveals that the largest land area was inundated in the late of April to May. However, time-dependent variations of peak flood extents were noticed spatially from the same flash flood event (Fig. 5 and Fig. 6). In March, Brahamanbaria and Habiganj districts were found to be the most and the least inundated among the five Haor districts. On the other hand, Sunamganj areas became highly flooded in April. In general, the majority of the extreme flood events were found to take place in May. In May of 2006, 2007, 2010, and 2015, more than 15% of the land was flooded with water in several haor districts (Fig. 6). In May 2010, about 60%, 39%, 35%, and 15% of the land area of Kishorganj, Sunamganj, Netrokona, and Habiganj districs were flooded, respectively. Results showed about 58%, 23%, 19%, 10% and 7% areas in Sunamganj, Kishoreganj, Netrakona, Habiganj, and Brahamanbaria districts, respectively were inundated in 2017.

A slight annual decreasing trend of flash flood extents (i.e., the percentage of the area inundated) was observed in Brahamanbaria, Netrokona, and Sunamganj. However, no definite trends are observable in Habiganj and Kishoreganj in March. In April, flood extents slightly decreased in Brahamanbaria and slightly increased at Habiganj and Sunamganj districts. No definite patterns of changes were noticed in other two districts over the years. A gradual declination in flood extents was observed in all of the *haor* districts except Netrokona, where the trends of the flood extents appear to be relatively constant.

Flash flood magnitude at different return intervals: Fig. 7 shows the intensity and frequency of high-magnitude pre-monsoon flash floods in April against different return periods in the selected Haor districts in north-eastern Bangladesh. Results indicate that the frequency of flash floods has not increased in the past 50 years, but the magnitude of the flood level has noticeably increased in those areas. Therefore, the earlier flood control structures, including the existing low-elevation embankments, would be unsuccessful in protecting agriculture, life, and properties from the possible upcoming floods with much higher magnitudes.

The submersible embankments' age dates from the early sixties to the present, and therefore the structural design varies significantly. The 2004, 2010, and 2017 flash floods noticeably damaged human life and property. During those years, the flood water overtopped most of the submersible embankments designed for floods with 1-10 year



Source: MODIS satellite imageries.

Fig. 6. Flash flood extents (% area inundated) in five Haor districts in May of a) 2004, b) 2007, c) 2010, d) 2015, and e) 2017. Authors analyzed MODIS satellite images to generate the flood extent maps.

return periods. Those infrastructural interventions were not very successful because of noticeable rise in pre-monsoon rainfall intensity during the recent decades in the upstream areas in Assam and Meghalaya, backdated design for the constructions of the earlier embankments including adequacy of design crest level, improper drainage systems, river sedimentation, erosion and breaching of the embankments during the flood flow, public cuts and breaches of the embankments, and the lack of regular operation and maintenance (Suvra, 2021; Mahtab *et al.,* 2018).

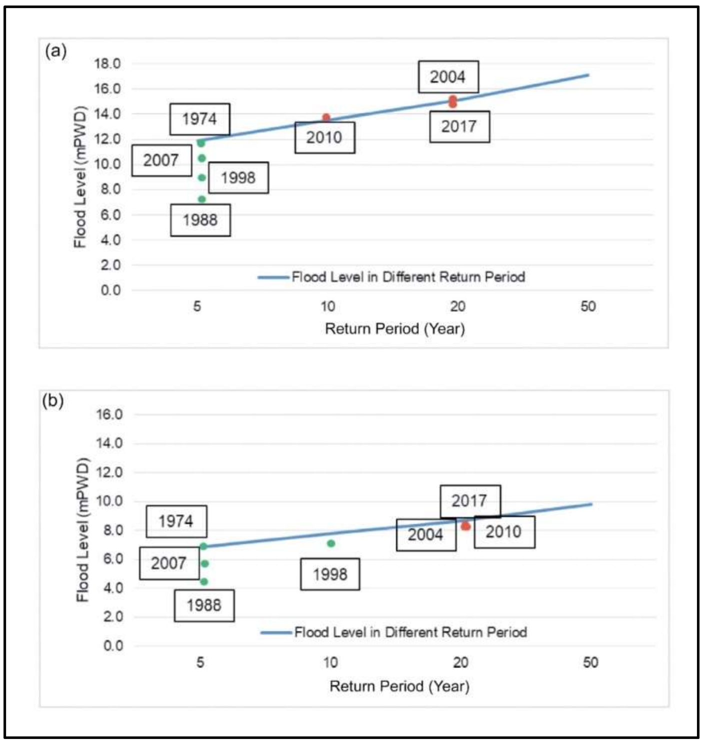


Fig. 7. Peak flood level versus different return periods in the month of April: (a) Sylhet-Sunamganj and (b) Sunamganj-Habiganj stations.

Conclusion

During recent years, an increase in the pre-monsoon heavy rainfall in upstream hilly areas in Assam and Meghalaya has substantially increased the likelihood of high-magnitude flash floods and hence the vulnerability of the losses of agriculture and properties in the northeastern *haor* region of Bangladesh. Results show that the frequency of flash floods did not show any specific trends of rise or fall in the past fifty years. However, the flash flood's magnitude has increased, ultimately inundating a significant portion of the *haor* region in recent decades. A variety of factors simultaneously influence the effectiveness of the flash flood management systems ranging from climate variability, siltation on the river beds, backdated design of the earlier embankments, the elevation of the flood control structures, including behavioral and institutional components such as public cuts, breaches, improper operation, and lack of proper maintenance of the flash flood embankments. The monsoon flood danger levels currently being practiced were found inadequate to implement the pre-monsoon flash flood warning system. Therefore, it is inevitable to adopt an efficient flash flood warning system incorporating an appropriate flash flood danger level and the redesigned elevations of the flood control structures through a rigorous cost-benefit analysis. There is also a great need to develop collaboration with the upstream regional authorities in Assam and Meghalaya to establish an effective hydro-meteorological networks with the view to strengthening the flash flood early warning system further.

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References

Ali, M. S., T. Mahjabin and T. Hosoda. 2013. Impact of climate change on floods of Bangladesh and introducing flood intensity index to characterize the flooding scenario. *Journal of Engineering*. pp 23-34.

Banglapedia, Asiatic Society of Bangladesh. 2021. https://en.banglapedia.org/index.php?title=Haor.

Bhattacharyya, N. N., A. Bora. 1997. Floods of the Brahmaputra River in India, *Water Int*. **22**: 222–229.

Boori, M. S, K. Choudhary, M. Evers and R. Paringer. 2017. A review of food security and flood risk dynamics in central dry zone area of Myanmar. *Procedia Engineering*. **201**: 231-238.

Center for Environment and Geographic Information Services. 2012. Master Plan of *haor* Area, Vol. 01, Summary Report, Government of the People's Republic of Bangladesh Ministry of Water Resources Bangladesh Haor and Wetland Development Board. pp. 1-3.

Dey, N. C., M. Parvez and M. R. Islam. 2021. A study on the impact of the 2017 early monsoon flash flood: Potential measures to safeguard livelihoods from extreme climate events in the *haor* area of Bangladesh. *International Journal of Disaster Risk Reduction*.

Dixit, A. 2009. Kosi Embankment Breach in Nepal: Need for a Paradigm Shift in Responding to Floods. *Economic and Political Weekly*. **44**(6): 70-78.

Guhathakurta, P., O. P. Sreejith and P. A. Menon. 2011. Impact of climate change on extreme rainfall events and flood risk in India. *J. Earth Syst. Sci*. **120**: 359-373.

Haldar, S., M. Choudhury, S. Choudhury and P. Samanta. 2023. Trend analysis of long-term meteorological data of a growing metropolitan city in the era of global climate change. *Total Environment Research Themes*.

Hossain, M. 2013. Flood damage and risk assessment model in the *haor* basin of Bangladesh. Publ. M.S. thesis. Bangladesh University of Engineering and Technology, Dhaka.

Hossain, M. S., A. A. Nayeem and A. K. Majumder. 2017. Impact of Flash Flood on Agriculture Land in Tanguar *haor* Basin. *International Journal of Research in Environmental Science*. **3**(4): 42-45.

Kamruzzaman, M., R. Shaw. 2018. Flood and Sustainable Agriculture in the *haor* Basin of Bangladesh: A Review Paper. *Universal Journal of Agricultural Research*. **6**: 40-49.

Khan, A. A. 2010. Impact of a submersible embankment project on *haor*-based livelihood. M.S. thesis. Institute of Water and Flood Management, Bangladesh University of Engineering and Technology, Dhaka.

Khan, R. H. and M. S. Islam. 2018. Comparative Study of the Changes in Climatic Condition and Seasonal Drought in North-Western Part of Bangladesh. *J. of Asiatic Society of Bangladesh*. **44**(2): 195-210.

Mahtab, M. H., M. Ohara and M. Rasmy. 2018. The Impact of Rainfall Variations on Flash Flooding in *haor* Areas in Bangladesh, *Water Conservation and Management*. **2**(2): 6-10.

Maqtan, R., F. Othman, W. Z. W. Jaafar, M. Sherif and A. El-Shafie. 2022. A scoping review of flash floods in Malaysia: current status and the way forward. *Nat. Hazards*. **114**: 2387-2416.

Marak, J. D. K., A. K. Sarma, and R. Bhattacharjya. 2020. Innovative trend analysis of spatial and temporal rainfall variations in Umiam and Umtru watersheds in Meghalaya, India. *Theor Appl Climatol*. **142**: 1397-1412.

Mohamad, S., N. M. Hashim, K. Aiyub and M. E. Toriman. 2012. Flash flood and community response at Sg. Lembing, Pahang. *Advances in Natural and Applied Sciences*. **6**: 19-25.

Muhammed, H. H., N. M. Nasidi, A. Wayayok. 2022. Impact of Climate Changes and Landuse/Land Cover Changes on Water Resources in Malaysia. In: *Environmental Degradation in Asia*, A. M. F. Al-Quraishi, Y. T. Mustafa and A. M. Negm, (ed.), Earth and Environmental Sciences Library.

Pangali Sharma T. P., J. Zhang, N. R. Khanal, F. A. Prodhan, L. Nanzad, D. Zhang and P. Nepal. 2021. Geomorphic Approach for Identifying Flash Flood Potential Areas in the East Rapti River Basin of Nepal. *ISPRS. Int. J. Geo-Inf.* **10**: p. 247.

Pokharel, B., S. Wang, J. Meyer, S. Marahatta, B. Nepal, Y. Chikamoto and R. Gillies. 2020. The east-west division of changing precipitation in Nepal. Int. J. Climatol, **40**(7): 3348-3359.

Rahman, M. Z., S. K. Shaha, M. Q. Hassan, A. S. M. Woobaidullah and M. S. Islam. 2011. Hydro-meteorological Study of Sunamganj Town and Surroundings for Forecasting Flash Flood Early Warning. *J. Asiat. Soc. Bangladesh, Sci*. **37**(1): 35-44.

Rahman, R. and M. Salehin. 2013. Flood Risks and Reduction Approaches in Bangladesh. In: *Disaster Risk Reduction Approaches in Bangladesh*, R. Shaw, F. Mallick, and A. Islam. (ed.), Disaster Risk Reduction. Springer, Tokyo.

Roy, B., A. K. M. S. Islam, G. M. T. Islam, M. J. U. Khan, B. Bhattacharya., M. H. Ali, A. S. Khan, M. S. Hossain, G. C. Sarker and N. M. Pieu. 2019. Frequency Analysis of Flash Floods for Establishing New Danger Levels for the Rivers in the Northeast *haor* Region of Bangladesh. *J. Hydrol. Eng*. **24**(4).

Roy, B., A. K. M. S. Islam and G. M. T. Islam. 2017. Recommending New Warning Levels for the River Systems of the *haor* Region of Bangladesh in Forecasting Flash Floods, 6th International Conference on Water & Flood Management.

Sadeque, A. Z. M. 2018. Indigenous Flood Coping Strategies towards Livelihoods: A Study in *haor* Area of North-East Bangladesh. Ph.D. thesis. Institute of Social Welfare and Research, University of Dhaka, Bangladesh.

Sammonds, P., M. Shamsudduha, B. Ahmed. 2021. Climate change driven disaster risks in Bangladesh and its journey towards resilience. *Journal of the British Academy*. **9**(s8): 55-77.

Sarker, A.A. and A. Rashid. 2013. Landslide and Flash flood in Bangladesh. In: *Disaster Risk Reduction Approaches in Bangladesh*, R. Shaw, F. Mallick and A. Islam (ed.), Disaster Risk Reduction. Springer, Tokyo.

Smail, M., and C. Myrtene. 2004. Estimating parameters of Gumbel distribution using the methods of moments, probability weighted moments and maximum likelihood. *Revista de Matemática: Teoría y Aplicaciones*. **12**: 151-156.

Suvra, K. 2021. *Haor* Regions- Importance, Problems, Strategy, and Future Development. *IOSR. Journal of Economics and Finance*. **12**(2): 35-48.

Weng Chan, N. 1997. Increasing flood risk in Malaysia: causes and solutions. *Disaster Prevention and Management*. **6**(2): 72-86.

Wikipedia, 2024. Retrieved October, 5, 2024, from

https://en.wikipedia.org/wiki/Representative_Concentration_Pathway#:~:text=Projections%20based%20on%20the%20RCPs,-

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