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A Study of Bank Line Shifting of the Selected Reach of Jamuna River Using Multi-Variant Regression Model

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ABSTRACT

Jamuna river is a morphologically very dynamic river. It carries a vast sediment load from the erosive foothills of Himalaya mountain. The length of the Jamuna River is 220 km. For this research work Jamalpur district is selected to assess morphological changes using hydrodynamic, Artificial intelligence and google satellite images. First, the hydrodynamic model was calibrated and validated at Kazipur station for the years 2018 and 2019 respectively. Then, left overbank maximum discharge, water level, velocity, the slope was extracted from HEC-RAS 1D at 300 m interval interpolated cross-section. Then, this cross-section was exported as a shapefile. In google earth, the erosion rate was measured corresponding to this interpolated cross-section. The results of the hydrodynamic model were given as input variable and erosion rate as an output variable in Machine learning and deep learning technique. Calibration and validation of the regression model was done for the years 2018 and 2019 respectively. This research work can be helpful to locate the area which are vulnerable to bank erosion.

1. Introduction

River erosion occurs generally in monsoon period of Bangladesh. Hydraulic forces and geotechnical instability are the main factor to initiate river erosion. River erosion means loss of

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land which is the reason of the shifting the course of river channel. It initiates the development of the floodplain. It is additionally significant from the geomorphological viewpoint [1,2]. Center for Environmental and Geographic Information Services (CEGIS), (2018) reported that between 1973 and 2017, the net erosion was about 93,302 ha along the 220 km long Jamuna River and predicted bank erosion for 15 erosion-prone areas [3].A large number of individuals have been separated from their unique living spots due to intense riverbank erosion in Bangladesh. About 285 locations, 85 built-up areas including 204 km of riverbank line of Bangladesh are vulnerable to river erosion [4]. Bangladesh is flat and deltaic country which is very vulnerable to the flood. The three major rivers are morphologically very dynamic. The Brahmaputra-Jamuna River carries tremendous amounts of silt from the erosive lower regions of the Himalayan foredeep. Different researcher interprets wide range value of suspended load ranging from 500-1200 Mt/year. Bangladesh Water Development Board (BWDB) estimated the sediment load in two rivers such as Jamuna and the Ganges in 1960s. They found that most of the sediment is in silt size and only 15-25 percent is sand size [5]. As of now, CEGIS has fostered an interesting device for anticipating the riverbank disintegration one year in front of the Padma, the Jamuna and the Ganges dependent on time-series dry season satellite pictures. This expectation is a probabilistic methodology and CEGIS has been foreseeing the disintegration weak areas along the two banks of these streams since 2004 for three unique probabilities (30%, half and 70%). The overall precision of this device goes from 70% to 80% which can be considered as exceptionally extraordinary contemplating the weakness in fluvial interaction [6]. But according to Nardi et al., (2013) it has a relative degree of inaccuracy [7]. That is why hydrological and morphological assessment is an important part in river management study. So, the present research work plan is to predict of bank erosion of Jamuna river by output results of hydrodynamic model.

According to Atkinson et al. (2003), Land use, presence of meandering appearance, Soil characteristics and shear stress are the controlling parameters of the soil erosion [8].Other factors such as hydro-dynamic conditions maximum_minimum discharge, riverbed slope, water level, water velocity, river bank slope have also been reported to affect the erosion rate [1,9].The bank erosion measure is firmly identified with the soil arrangement of the riverbanks. Erodibility is a kind of measure that indicates the resistance of soils to erosion. This factor is dependent upon the arrangement of silt, clay and sand. River bank consisting of sand and silt can be effortlessly disintegrated because of the characteristics of the soil. This soil also can be also easily transported by stream. Riverbank consisting of different soil layers are very sensible to river erosion and this kind of bank structure is very familiar in Jamuna river. Non-cohesive soil has less clay content. The shear strength of this kind of soil is also low which can be easily separated by low hydraulic actions [10,11]. Zhang et al. (2020) introduced soft computing techniques in the braced excavations to determine the maximum lateral displacement. Four Deep learning technique were introduced and the performance of these model were evaluated based on RMSE, R^2, bias factor and MAPE. Though all four methods showed promising results but ensemble method showed very accurate result comparing to other three models [12]. Zhang et al. (2021) also used some methods of soft computing techniques to predict the settlement of surfaces due to the construction of the tunnel. Then he evaluated model predictions and found that Extreme Gradient Boosting method gave more accurate results than other soft computing methods he used in the case study [13]. Zhang Goh (2016) modeled pile drivability using neural network models (BPNN) and Multivariate adaptive regression splines (MARS). They compared two models based on models predictions result and found that MARS can be effectively used to predict different parameters during pile driving [14]. Zhang et al. (2020) used two ensemble learning methods for the prediction of undrained shear strength of clays which is soft in nature. They found that Extreme gradient Boosting method performed very accurately than other models they used and this developed model can be very useful for geotechnical Engineers to estimate different parameters of clay soils [15]. Zhang at el. (2021) did review about the application of deep learning in the field of Geotechnical Engineering. He specifically described four major algorithms of the Deep learning category with their applications in Geotechnical field [16]. Zhang et al. (2020) used an Extreme gradient Boosting and random forest regression model to determine the factor of safety in clayey soil in braced excavation [17]. Thus in the field of Geotechnical Engineering, the application of Extreme gradient Boosting method can be effectively used. Saadon et al. (2020) used the Nonlinear AutoRegressive model with eXogenous inputs and QR factorization parameter which is also known as the NARX-QR Factorization model. This model predicts the bank erosion rate of Sg. Bernam,Selangor, Malaysia. Hydro-dynamic conditions and soil characteristics were the input variables in that model. A straight least-squares procedure was followed to measure riverbank erosion rates. Important and dominant independent variables were introduced as input parameters. fourteen models were run under the NARX-QR Factorization model. The model performance analysis shows that Models 1 and 9 has the most noteworthy and the highest R^2 at about 76% and 89%, respectively [18]. Despite the fact that erosion of river bank is a common event, the early warning and the prediction of riverbank erosion is troublesome. Therefore different methodologies have been introduced and followed. The main issue concerning riverbank erosion is the identification of the areas which are vulnerable to bank erosion. So that forecasting of riverbank erosion will be easy and this forecasting will be helpful for a river restoration and river tarining projects. Different procedures have been followed to predict the erosion rate of river bank. Analysis of historical maps on GIS is a one kind of method that is used to estimate bank erosion rates. However, the best approach to predict and estimate riverbank erosion is to use the combination of bank stability methods and hydrodynamic models [7]. Of these two methods, the latter is too complex to be applied. The latter method requires more data variables. Generally the excess shear stress approach (Eq. 1) is followed in the prediction of hydraulic erosion of river banks which is consisting of cohesive soils. The relationship is developed by Partheniades (1965). He makes a relationship between hydraulic erosion and magnitude of excess shear stress ($\tau_a - \tau_c$) (Eq. 1):

$$E=k(\tau a-\tau c)^a \tag{1}$$

where "E" is erosion rate and the unit is expressed in meters per second, "k" is an erodibility factor which expressed in cubic meter/Newton second, "τ_a" is shear stress which is applied by flow in Pascal, and "τ_c" is critical stress in Pascal . These parameters can very significantly. But

Asrhaf, M. (2018) predicted bank erosion for a river consisting of silt and sand materials which is not cohesive in nature. So he modified the erodibility co-efficient by making relationship with the observed data. He got good results to predict erosion rates of riverbank but the maximum river discharge is about 7000m^3/sec [19] where for jamuna river every year discharge reaches 50000m^3/sec in monsoon period [20]. Herein, The results of an 1D hydrodynamic model will be used for the determination of river bank erosion rate. Instead of the excess shear stress approach left over bank discharge will be used to predict bank erosion rate of Jamalpur district by Machine learning and Deep learning technique. In the past, several studies have been carried out to predict bank erosion of Jamuna river. Center for Environmental and Geographic Information Services (CEGIS) predicts river bank erosion one year earlier by the probabilistic approach but did not predict with hydrodynamic model [6]. Khan, M. (2015) worked on bank erosion using 2D morpho-dynamic model MIKE21C. He simulated Model by introducing revetment in the bank and found that this intervention reduced near bank velocity. A correlation related to hydraulic erosion was established between average discharge prevailing during monsoon and shear stress applied by the erosive action of flow. He used hydrodynamic model but did not predict bank erosion [21].

The river reach will be considered from upstream of Bhadurabad to Sirajgonj station(Fig. 1). In this study, a research work has been conducted to estimate bank line erosion of the Jamalpur district along Jamuna river which will be helpful to locate the area which are vulnerable to river bank erosion.

2. Research significance

This research work aims to develop a model which will predict bank line shifting using variables of hydro-dynamic conditions. This procedure can be helpful to predict bankline shifting of alluvial braided river like Jamuna using hydro-dynamic modeling tools. The model results will be useful primarily for river training purposes. The early warning and identification of the area that is vulnerable to riverbank erosion is very important. It can be useful to protect different land use that is facing at hydro-geological risks.

3. Methods

3.1. Study area

The study area [Fig. 1] is located in northeast and north central region of Bangladesh. The projected river reach has started from Bhadurabadh station and ended at Sirajgonj station. The total length of this River is 220 Km. This river is mainly a braided river. The soil formation is mainly consisting of sandy types and small amount of clayey soil. The average width of the river varies from 6 km to 10 km including with floodplain.

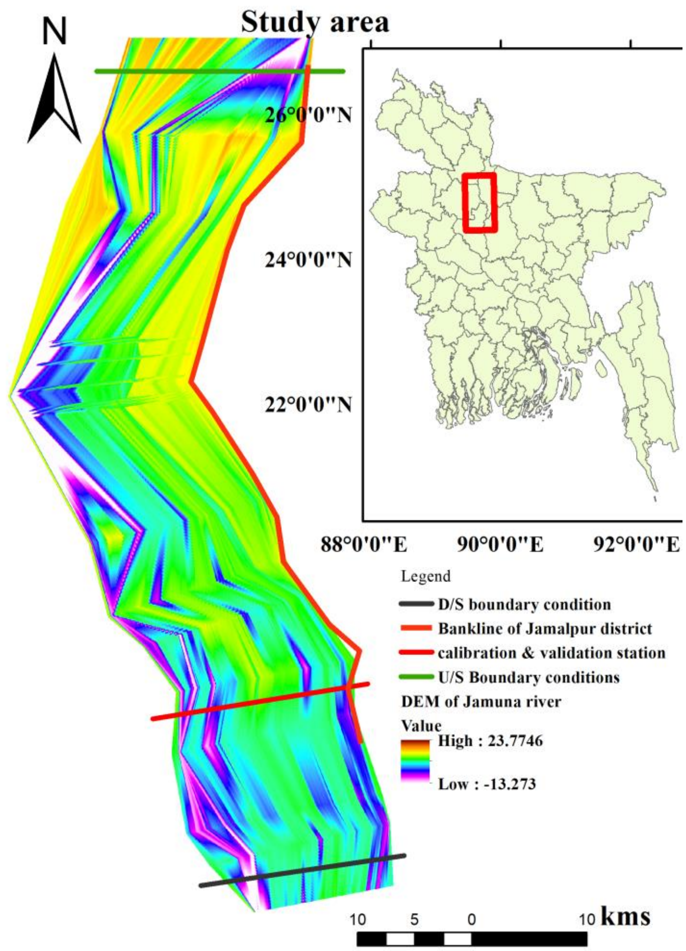

Fig. 1. Study area showing Jamuna river reach.

3.2. Data collection

Cross-section was collected from Bangladesh Water Development Board (BWDB) for the year 2018 (Table.1). 15 cross-sections were collected for the study area from #13-#7.Stage hydrograph at Bahadurabad, Kazipur and Sirajgonj station, flow hydrograph at Bahadurabad of 2018-2019 were also collected from Bangladesh Water Development Board (BWDB). Google sate images was used to estimate bank erosion rate of the Jamlapur district (Table.1). Merit DEM was used for the graphical representation of the river in the HEC-RAS geometry editor.

Table 1
Data collection.

Data type	Source	Data collection	Period
Discharge	BWDB	Bahadurabad	2018-2019
Water level	BWDB	SW49A,SW49, SW46.9	2018-2019
Cross-section	BWDB	RMJ #13-#7	2018
Google Satelite Iamges	Google Earth Engine	Bahadurabad	2018-2019
MERIT DEM	http://hydro.iis.u-tokyo.ac.jp/~yamadai/MERIT_DEM/	Jamuna River	

3.3. Model setup

The DEM is originally in Geographic co-ordinate (Lat-Long) system. For the transformation of the coordinate system, ARC-GIS 'Define Projection' Tool needs to use and set to WGS 1984 UTM 46N projection. Cross-section derivate DEM was inserted in RAS Mapper. According to BWDB cross-section shapefile, cross section was drawn in RAS Mapper. Then in Geometric editor, the geometric data was saved. In unsteady flow data window, discharge was given in Bhadurabadh station and stage hydrograph was given in Sirajganj station which is shown in Fig. 2.

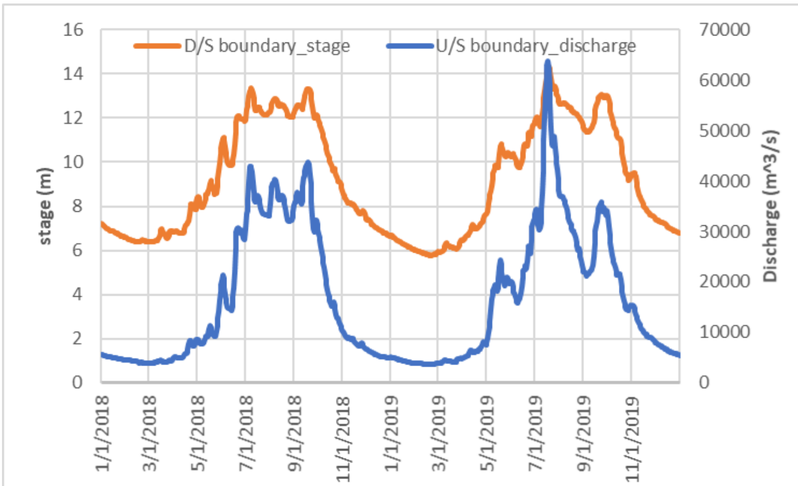

Fig. 2. Boundary conditions.

After running the model, the hydrodynamic model was calibrated and validated for the water level with manning's 'n' at the Kazipur station for the year 2018 and 2019 respectively. After calibration and validation of the hydrodynamic model, the results of an 1D hydrodynamic model were used for the determination of river bank erosion rate. Instead of the excess shear stress approach LOB discharge, Max_ Min WL, slope, velocity of HEC-RAS model was used to predict bank erosion rate of Jamuna river at Jamalpur district by Machine learning and Deep learning technique. At 300 m interval 5 variables were extracted from HECRAS 1D model. Using this output data and bank line shifting, the Machine learning model was calibrated using the data of 2018 and will predict the bank line shifting for the year 2019 which is represented in flow chart (Fig. 3).

In MATLAB, the regression model was chosen under Machine learning and Deep learning technique. Five input variables and one output variable have been processed using MATLAB. Then all model types were selected under regression learner. After that, all models were run. After running about 19 models under the Artificial and machine learning model, four statistical parameters for each model were used to evaluate the model performance. It was found that the Linear regression model is not suitable to predict bank erosion rate as R^2 was found near 0. So, the linear regression model types cannot be used to predict bank erosion. Similarly, Tree and Support Vector Machine type regression model cannot suitable for the prediction of bank line shifting as the statistical parameters are in a very poor range. Support Vector Machine type regression model cannot be used to predict bank erosion using five variables of hydro-dynamic conditions near the river bank as the value of R^2 is about 0. The value of RMSE for three regression models such as Linear, Tree and SVM varying from 50-60 except fine tree regression model. The range is not good. The value of MSE, MAE are also not in minimal acceptable range for the specified three regression model such as Linear, Tree and SVM (Table. 2).

From the Table.02, the values of four statistical parameters such as RMSE,R^2,MSE,MAE of the Ensemble and Gaussian type Regression learner model are in good range except few parameters. From 19 regression models, Exponential Gaussian Process Regression performed very good results as RMSE,R^2,MSE,MAE is 21, 0.86, 450 and 9 respectively. Then this model was exported to validate the model for the year 2019 using five hydro-dynamic variables but it was found that the output of this model remains constant even using different five input variables. So, Ensemble Boosted Tree regression model was chosen for the prediction of bank line shifting of the Jamalpur district as this model responses based upon different input variables. The RMSE, R^2, MSE, MAE is 32, 0.70, 1060 and 15 respectively which can be said that these values are in good range (Table. 2).

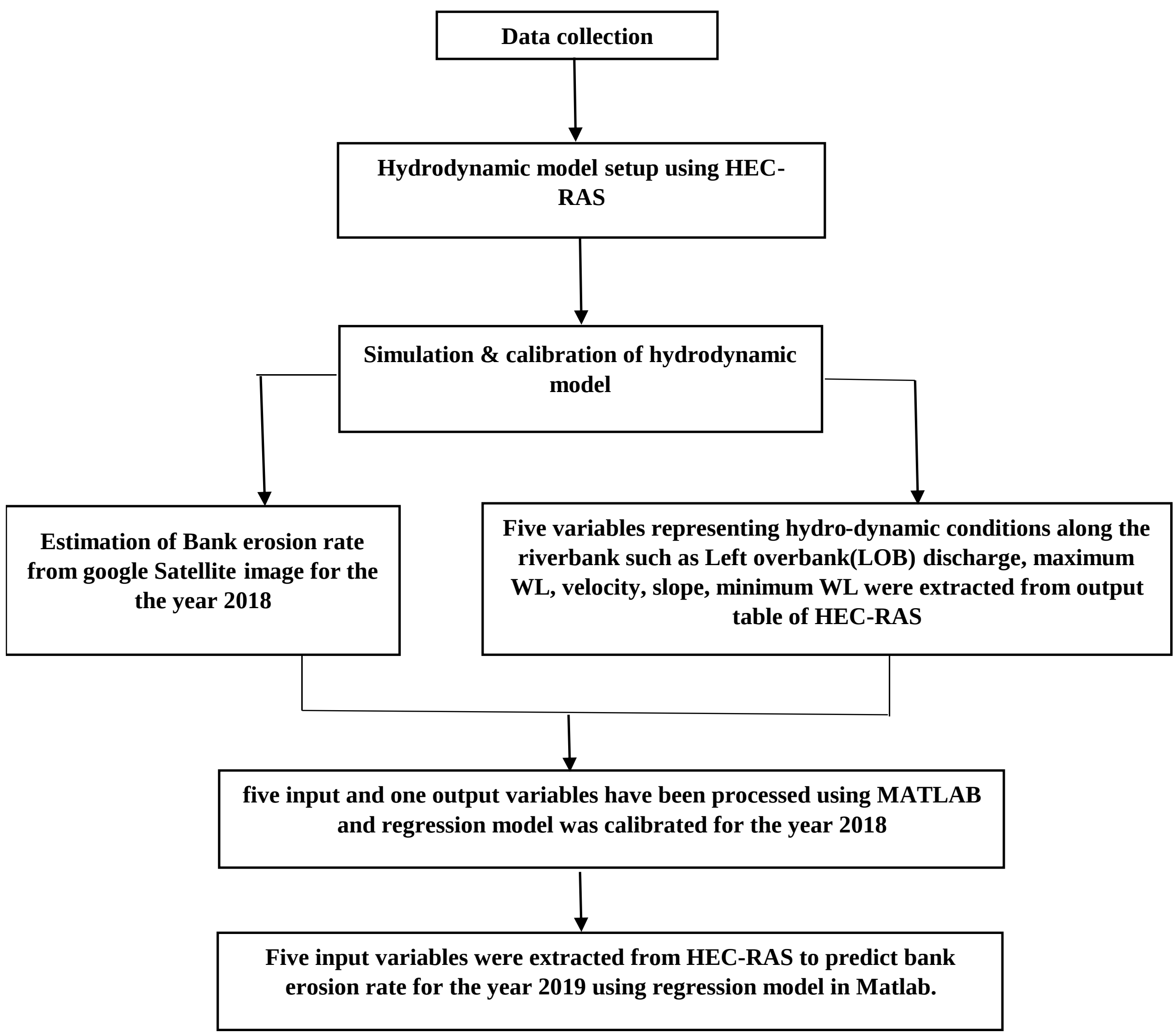

Fig. 3. Flowchart of model setup and prediction of the bank erosion.

Table 2
performance evaluation of different regression model.

SL	Regression Model types	RMSE	R^2	MSE	MAE
1.	Linear Regression(linear)	53	0.11	2820	30
2.	Linear Regression (Interactions linear)	53	0.12	2785	32
3.	Linear Regression (Robust linear)	59	-0.08	3429	20
4.	Linear (Stepwise Linear)	54	0.09	2892	30
5.	Tree (Fine Tree)	37	0.56	1400	13
6.	Tree (Medium Tree)	52	0.15	2700	13
7.	Tree (Coarse Tree)	52	0.15	2700	27
8.	Support Vector Machines (Linear)	57	-0.03	3290	14
9.	Support Vector Machines (Quadratic)	57	-0.01	3200	19
10.	Support Vector Machines (Cubic)	52	0.14	2740	19
11.	Support Vector Machines (Fine Gaussian)	55	0.06	2980	17
12.	Support Vector Machines (Medium Gaussian)	57	-0.01	3205	18
13.	Support Vector Machines (Coarse Gaussian)	59	-0.08	3450	20
14.	Ensemble (Boosted Tree)	32	0.70	1060	15
15.	Ensemble (Bagged Tree)	42	0.44	1785	18
16.	Gaussian Process Regression (Squared Exponential)	85	0.80	612	12
17.	Gaussian Process Regression (Matern 5/2 GPR)	23	0.83	542	10
18.	Gaussian Process Regression (Exponential GPR)	21	0.86	450	9
19.	Gaussian Process Regression (Rational Quadratic GPR)	24	0.83	556	10

4. Results and discussions

4.1. Simulation, calibration and validation

Hydrodynamic model was calibrated and validated for the year 2018 and 2019 at the Kazipur station with the water level which is shown in Fig. 4. The manning's roughness co-efficient was adjusted to calibrate the hydro-dynamic model. Model simulated water level showed a very good agreement with the observed water level for the manning's roughness as 0.029. For the hydro-dynamic model, the coefficient of correlation(R^2) was found 0.98 for calibration and validation (Fig. 5).

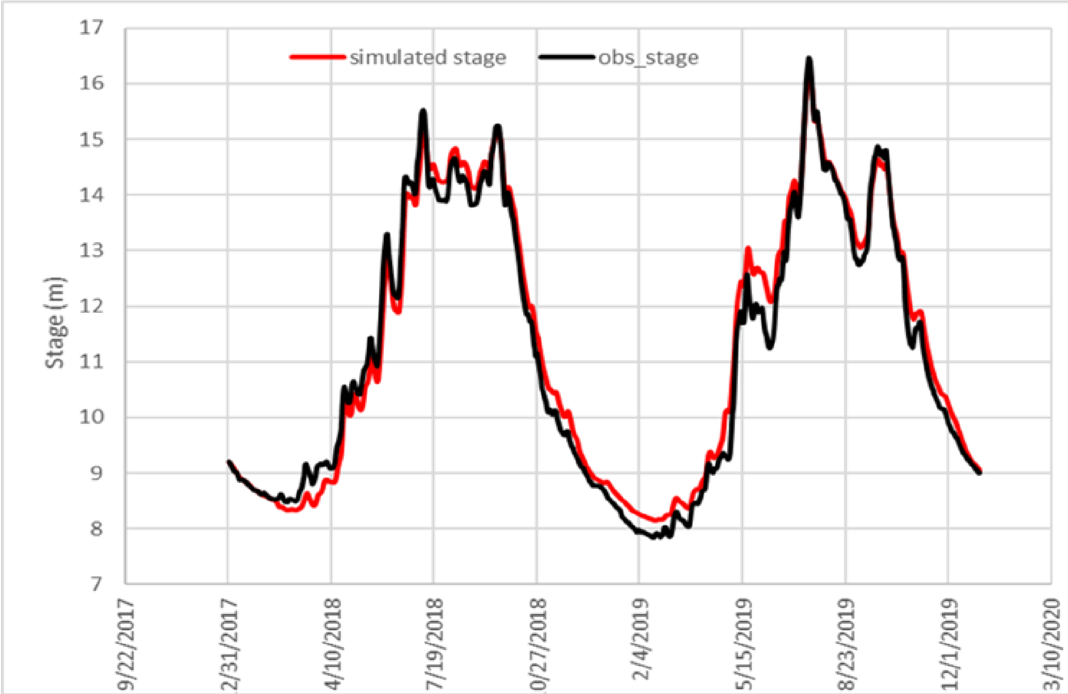

Fig. 4. stage hydrograph at Sirajganj station.

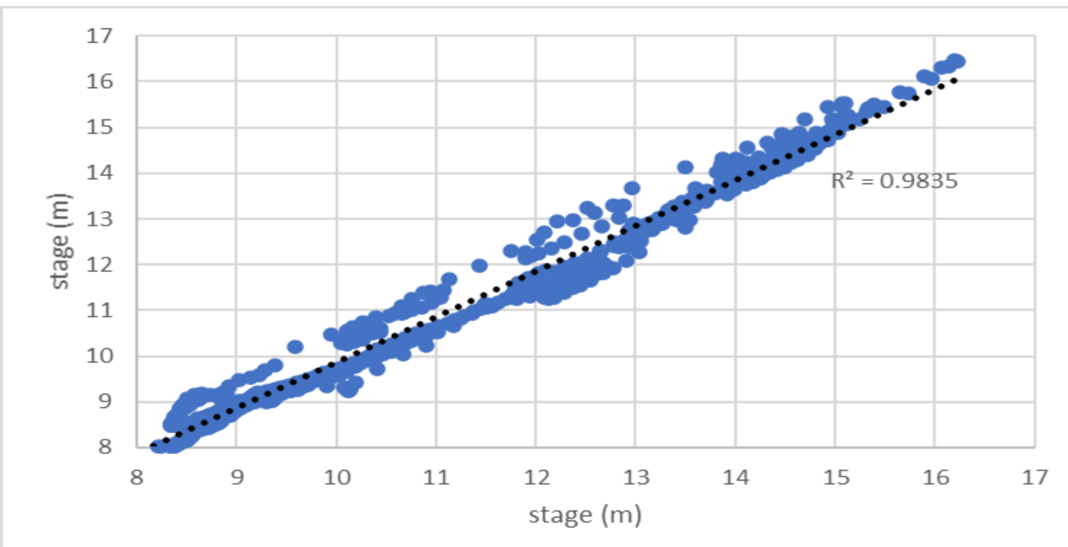

Fig. 5. scatter plot at Sirajganj station.

4.2. Estimation of bank line shifting

To determine bank line erosion, google satellite image was used. In HECRAS, the cross-section was interpolated in 300 m distance. Then, this cross-section shapefile was exported and imported in Google Earth explorer. The bank line shifting corresponding to this interpolated cross-section for the year 2018 was estimated which is shown in Fig. 6. As the bank is very erosive in nature, the maximum erosion was found 350 m/yrs. and in some location, it was found that the bank line is stable. It was found that the location of bank erosion varies from year to year.

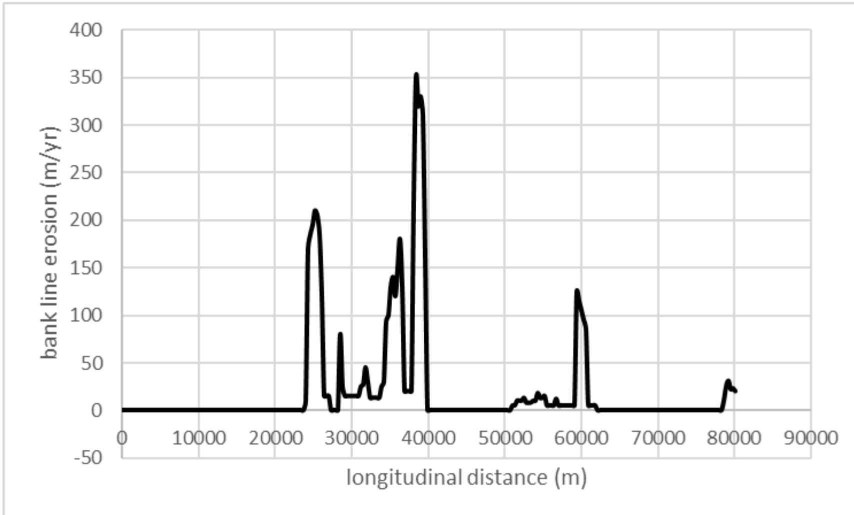

Fig. 6. bank erosion rate for Jamalpur district for the year 2018.

4.3. Calibration and validation of regression model

To predict bank line erosion rate, MATLAB was used. Regression learner under Machine learning and deep learning technique was used to predict bank line erosion rate. About 19 regression model was run and out of 19 regression model one regression model was chosen based upon responses of the model with varying input variables. The R^2 and RMSE was found 0.70 and 30 respectively which indicates that this regression model will be used to predict bank line erosion for the Jamalpur district. But the overall fit is not very accurate. For R^2=0.7, the minimum leaf size, number of learners and learning rate was 8,32 and 0.1 respectively. Then these parameters were changed gradually and finally for 4, 20 and 0.4 respectively this regression model gave accurate results which was found by comparing with previous statistical parameters. The R^2 value was found 0.8 and the values of other three statistical parameters such as RMSE, MSE, MAE are 25, 700 and 10 respectively. So, parameter optimization was done for more accurate results. After parameter optimization of the model, the responses of the regression model are presented in the Fig. 7.

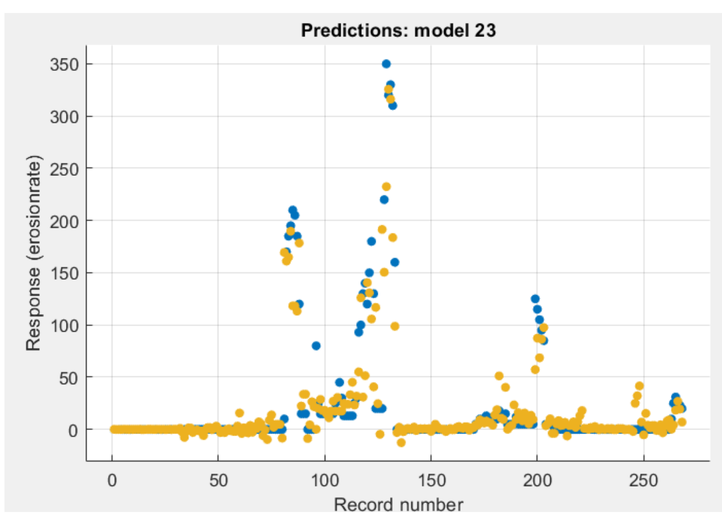

Fig. 7. calibration graph for bank line erosion prediction.

The calibrated regression model was used to predict the bank erosion rate for the Jamalpur district for the year 2019. The validation is shown in Fig. 8. and also indicates that there is a satisfactory agreement between observed and simulated bank erosion rate. Then this model also used to predict bank erosion rate for the year 2017 and it has found that the pattern of bank line shifting differs to year to year which reflects the actual scenario of the Jamuna river bank (Fig. 9).

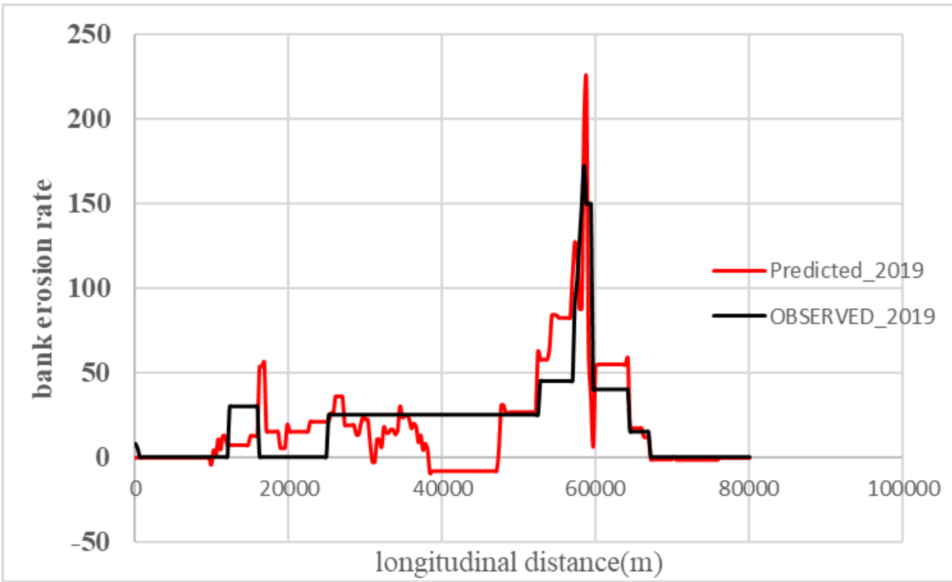

Fig. 8. validation of the regression model for bank line erosion.

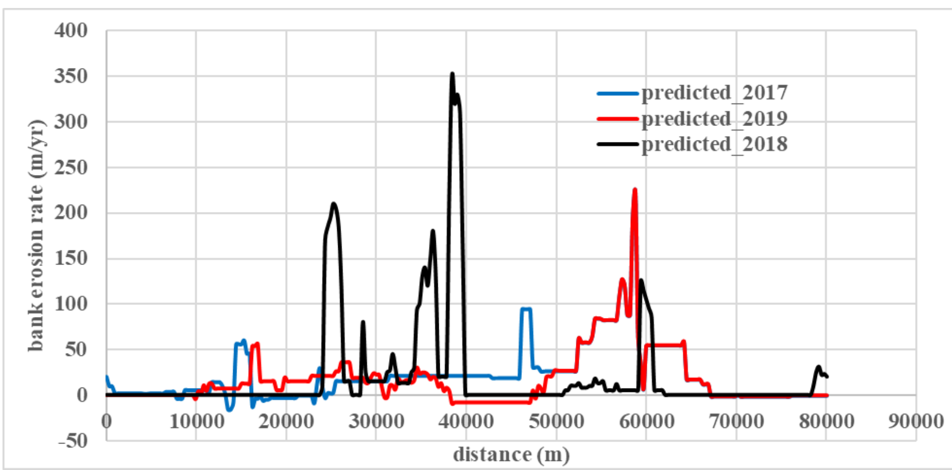

Fig. 9. Prediction of bank line shifting using best regression model.

5. Conclusions

This research work developed a bank erosion prediction model using five input variables of hydro-dynamic conditions along the river bank. 19 regression model was run and these regression models were evaluated comparing with four statistical parameters such as R^2, RMSE, MSE & MAE. After that, the performed regression model was validated and it was found that Ensemble Boosted Tree responses differently with different input variables. But the overall fit was not very accurate. Then parameter optimization was done and the value of R^2, RMSE, MSE, MAE was found 0.80, 25, 700 and 10. After that, this regression model was used to predict bank erosion rate for the year 2019 and comparing with observed bank erosion rate, it can be said that this model can be effectively used to predict bank erosion rate. In Jamuna river, if any location faces any erosion that location will be eroded about 250-600 meter in a year. So, if we predict any location that is vulnerable to river erosion, this model can be helpful to give early warning. This model also predicted the bank erosion rate for the year 2017 and it was found that the model response differently based upon on the input variables which is familiar with the real scenario of the Jamuna river bank.

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Conflicts of Interest

The authors declare no conflict of interest.

Authors Contribution Statement

AH, MAM: Conceptualization; AH: Data curation; AH: Formal analysis; AH, MAM: Investigation; AH: Methodology; AH: Software; MAM: Supervision; AH: Validation; AH,MAM: Visualization; AH: Roles/Writing – original draft; AH: Writing – review & editing.

References

[1] Hooke JM. An analysis of the processes of river bank erosion. J Hydrol 1979;42:39–62. https://doi.org/10.1016/0022-1694(79)90005-2.

[2] Bridge JS. Rivers and floodplains: forms, processes, and sedimentary record. John Wiley & Sons; 2009.

[3] CEGIS. Prediction of river bank erosion along the Jamuna, the Ganges, and the Padma River, Prepared for BWDB, Dhaka, Bangladesh. Center for Environmental and Geographic Information Services; 2018.

[4] Islam MDF, Rashid ANMB. Riverbank erosion displacees in Bangladesh: need for institutional response and policy intervention. Bangladesh J Bioeth 2011;2:4–19.

[5] Centre for Environmental and Geographic Information Services (CEGIS), Impact of Climate Change on Morphological Processes in Different River of Bangladesh 2010.

[6] Center for Environmental and Geographic Information Services (CEGIS), River Erosion Prediction Model. https://www.cegisbd.com/DivisionInfo?Div=MOR n.d.

[7] Nardi L, Campo L, Rinaldi M. Quantification of riverbank erosion and application in risk analysis. Nat Hazards 2013;69:869–87. https://doi.org/10.1007/s11069-013-0741-8.

[8] Atkinson PM, German SE, Sear DA, Clark MJ. Exploring the Relations Between Riverbank Erosion and Geomorphological Controls Using Geographically Weighted Logistic Regression. Geogr Anal 2003;35:58–82. https://doi.org/10.1111/j.1538-4632.2003.tb01101.x.

[9] Abam TKS. Factors affecting distribution of instability of river banks in the Niger delta. Eng Geol 1993;35:123–33. https://doi.org/10.1016/0013-7952(93)90074-M.

[10] Raudkivi AJ. Loose boundary hydraulics. CRC Press; 1998.

[11] Roslan ZA, Naimah Y, Roseli ZA. River bank erosion risk potential with regards to soil erodibility. River Basin Manag VII Wessex Inst Technol UK 2013:289–297.

[12] Zhang W, Zhang R, Wu C, Goh ATC, Lacasse S, Liu Z, et al. State-of-the-art review of soft computing applications in underground excavations. Geosci Front 2020;11:1095–106. https://doi.org/10.1016/j.gsf.2019.12.003.

[13] Zhang WG, Li HR, Wu CZ, Li YQ, Liu ZQ, Liu HL. Soft computing approach for prediction of surface settlement induced by earth pressure balance shield tunneling. Undergr Sp 2021;6:353–63. https://doi.org/10.1016/j.undsp.2019.12.003.

[14] Zhang W, Goh ATC. Multivariate adaptive regression splines and neural network models for prediction of pile drivability. Geosci Front 2016;7:45–52. https://doi.org/10.1016/j.gsf.2014.10.003.

[15] Zhang W, Wu C, Zhong H, Li Y, Wang L. Prediction of undrained shear strength using extreme gradient boosting and random forest based on Bayesian optimization. Geosci Front 2021;12:469–77. https://doi.org/10.1016/j.gsf.2020.03.007.

[16] Zhang W, Li H, Li Y, Liu H, Chen Y, Ding X. Application of deep learning algorithms in geotechnical engineering: a short critical review. Artif Intell Rev 2021;54:5633–73. https://doi.org/10.1007/s10462-021-09967-1.

[17] Zhang W, Zhang R, Wu C, Goh ATC, Wang L. Assessment of basal heave stability for braced excavations in anisotropic clay using extreme gradient boosting and random forest regression. Undergr Sp 2022;7:233–41. https://doi.org/10.1016/j.undsp.2020.03.001.

[18] Saadon A, Abdullah J, Muhammad NS, Ariffin J. Development of riverbank erosion rate predictor for natural channels using NARX-QR Factorization model: a case study of Sg. Bernam, Selangor, Malaysia. Neural Comput Appl 2020;32:14839–49. https://doi.org/10.1007/s00521-020-04835-5.

[19] Ashraf M, Shakir AS. Prediction of river bank erosion and protection works in a reach of Chenab River, Pakistan. Arab J Geosci 2018;11:145. https://doi.org/10.1007/s12517-018-3493-7.

[20] Pal PK, Rahman A, Yunus A. A Study on Seasonal Variation of Hydro-Morphodynamic Parameters of Jamuna River. Int J Eng Res 2017;6:307–11.

[21] Khan M. Modeling the bank erosion of selected reach of Jamuna river 2015.