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RELATIONSHIP BETWEEN MANNING ROUGHNESS COEFFICIENT AND FLOW DEPTH IN BANGLADESH RIVERS

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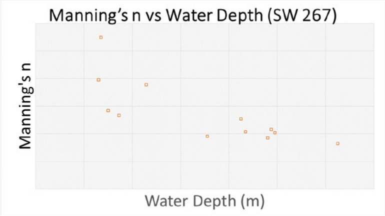
Graphical abstract



Abstract

Manning's n is the most widely used resistance coefficient for open channel flows. There are several factors that affecting the variation of roughness coefficient in open channels such as surface roughness, bed material, channel alignment, shape irregularity and vegetation. The prediction of the variation of the roughness coefficient in a natural waterway becomes more complex and challenging task to hydraulics engineers until now. The main emphasis of this research is the assessment of the Manning coefficient of riverside roughness, which is used in hydraulic simulations and to explore the link between the coefficient of Manning and water depth The aim of this study was to investigate the correlation/relationship between flow depth and Manning's n for several selected rivers in Bangladesh. This research represents graphically the connection between roughness coefficient of Manning and water depth of year 2019 based on the collected data's (cross section, discharge, stream width) from Bangladesh Water Development Board (BWDB). The main focus of this research was to establish the regression equations by graphically plotting calculated Manning's n versus flow depth. The relationship between the two variables in the stations is shown to be directly proportional, while some are inversely proportional, by changing water depth and computing Manning roughness coefficient. It can be seen that most stations have more than one behavior, i.e., the connection between these parameters is directly related in certain periods all through the year, while it is inversely proportional with others. The findings prevail that the Manning's n varied from 0.01 s/m1/3 to 0.14 s/m1/3 for a comparable depth of 1m to 20m at all the stations being studied here and 6th order polynomial equation observed R2 is between 0.9288 and 0.9943 for most of the stations being studied here which may provide an efficient prediction evaluation in estimating Manning roughness coefficient.

Keywords: Manning's n, water depth, natural channel/waterway, Bangladesh river, regression equation.

1.0 INTRODUCTION

The amount of discharge calculation on waterways is one of the essential challenges for hydraulic engineers. The evaluated respondents of the survey of channel capacity are as aged as hydrology itself. Attempted solutions to the question of channel capacity are as old as hydraulic engineering itself, going all the way back to the significant achievements of early pioneers who designed and constructed irrigation and supply channels with little theoretical knowledge, which performed surprisingly well, and some of which survive to this day. Antoine Chezy, Robert Manning and Darcy-Weisbach are the pioneer researchers that have been developed the resistance equation in open channels. These very basic equations have inherent importance, but they are also significant because they support more sophisticated model is used to simulate progressively changing stable and unstable flows, where they represent the frictional gradient that permits for restriction to flow through streams and rivers. Manning's condition is quite possibly the most usually utilized conditions for deciding the pace of stream in an open channel with uniform stream [1]. This equation expresses the equilibrium between the prime motivator (gravity) and the flow resistance, which is represented by Manning's roughness coefficient '*n*'.

In numerical modellings, this roughness parameter is usually employed to investigate waterways hydraulic behavior [2] and to produce simulations for construction of flood zoning maps, water systems and other uses such as bridges and dams. According to Kopecki, Schneider, and Tuhtan (2017), regardless of the hydraulic model's dimensionality (1D, 2D, etc.), all of them must be calibrated by adjusting one value to the Manning's coefficient in order to reproduce water surface elevations that are close to field measurements [3].

Nevertheless, selecting a suitable coefficient can be difficult, requiring practical expertise as well as specific and local perceptions, which can lead to numerous values being achieved in a certain channel study [4, 5]. This is owing to the fact that perhaps the roughness coefficient is impacted by a variety of elements, since rivers move under a variety of different and challenging problems [6, 7]. Various intruding factors, such as, channel irregularities and alignment, changes in the geomorphology of the channel bed as a result of material deposition or deterioration, vegetation impacts, surface quality and the movement of soluble and/or subsurface sediments, can all affect the coefficient [8]. Furthermore, due to fluctuations in water levels, the roughness coefficient varies in cross-sectional area; the lower the water profundity, the more prominent the coefficient esteem, as the impacts of stream base imperfections are more evident. Because of the relevance and complexity of calculating the roughness coefficient, numerous writers have proposed formulae to quantify it, which have been distributed in the specific writing. Prajapati, Vadher, and Yadav (2016) used Manning's Equation, the empirical relations of Limerinous, Strickler, Meyer-Peter, and Muller, and the Cowan table to find roughness coefficients [9]. The findings correspond to those recorded at the Garudeshwar station on the Purna River in India. Researchers concluded that the roughness coefficient calculated using Manning's formula would be the most accurate, with an error margin of less than 1%.

The understanding on the relationship between resistance coefficient and the river flow behavior is still unknown especially in Bangladesh rivers. Thus, this research is significant.

The aim of the study is to calculate Manning's roughness along Bangladesh's different rivers (stations of rivers) showing in figure 1 using streamflow data obtained by the Bangladesh Water Development Board (BWDB), so that a database may be created that can be utilized in future hydraulic simulations.

Furthermore, the regression equations and the graphs are established to develop relationship between the Manning value with water depth.

2.0 METHODOLOGY

Manning's roughness coefficient 'n' is used to calculate the roughness characteristics of the streams in this study.

Roughness coefficient of Manning 'n':

For discharge, Manning's formula is: [8, 11]

$$n = \frac{AR^{\frac{2}{3}}S^{\frac{1}{2}}}{Q} \qquad (1)$$

Where, R is the hydraulic radius (m), A is the cross-sectional area (m^2), S is the energy line slope = 0.000063 which is same for all selected rivers being studied and Q is the river flow rate/discharge (m^3/s).

Data about several Bangladeshi rivers have been obtained in the research. Bangladesh is known to have six seasons, and the cyclical fluctuation of river flow occurs all over the year. Data on stream flow including outflow, cross sectional zone, stream width were obtained/acquired from Bangladesh Water Development Board (BWDB). The river's surface water slopes were also fixed with the BWDB observer data, which fluctuates primarily between 0.000014 and 0.00008 [10].

Table 1 Details information on the selected rivers in Bangladesh.

	Station
Surma-Meghna	SW267
Turag	SW301
Gorai-Madhumati-harighata-baleswara	SW99
Mohananda	SW211.5
Kushiyara	SW173
Gumati-Burinadi	SW110
Gorai-Madhumati-harighata-baleswara	SW101
Khowai	SW158.1
Old Brahmaputra	SW230.1
Sangu	SW247
Surma-Meghna	SW266

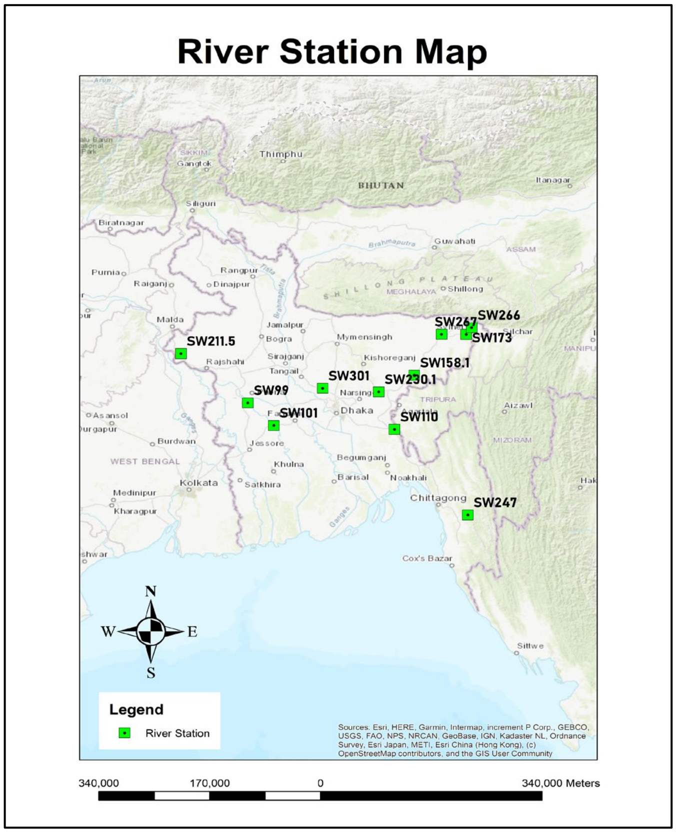


Figure 1 River Station Map

3.0 ANALYSIS RESULTS

The stream is not defined by nature, but it is sensitive to changes in mark geometry and parameters due to the reciprocal interaction between the stream and the bed. The stream's defense is solely based on grain aggressiveness, and a single viciousness concern for all deliveries is thought to be sufficient to demonstrate the stream's safety. The problem is that the bed design changes as stream conditions change, making determining the water resistance of waterways complicated [26]. Utilizing streamflow data from BWDB, the Manning formula (Equation: 1) was used to compute ''n'' for the rivers suggested in Table 1. For the year of 2019, Table 2, 3, 4 displays the computed values of Manning roughness coefficient "n" corresponding to water depth over the year of the respective stations of rivers of Bangladesh using and showing the value of discharge, velocity and area.

Table 2 Summaries of measured water depth and calculated Manning's n at SW267, SW301, SW99, SW211.5 stations.

	SW 267					**SW301**				
Month	**Discharge (m^3/s)**	**Velocity (m/s)**	**Area m^2**	**Water Depth (m)**	**Manning's n(s/$m^{1/3}$)**	**Discharge (m^3/s)**	**Velocity (m/s)**	**Area m^2**	**Water Depth (m)**	**Manning's n(s/$m^{1/3}$)**
January	37	0.29	127.58	3	0.06	17.64	0.2	88.20	3.92	0.10
February	17.54	0.19	92.31	2.6	0.08	15.88	0.14	113.42	3.71	0.14
March	13.33	0.14	95.21	2.7	0.11	18.98	0.22	86.27	3.5	0.08
April	48.63	0.34	143.02	3.45	0.05	28.59	0.18	158.83	4.27	0.12
May	562.83	0.81	694.85	8.68	0.04	36	0.22	163.63	4.5	0.10
June	1061.62	0.97	1094.45	9.6	0.04	40.43	0.27	149.74	4	0.07
July	1898.84	1.3	1460.64	12.5	0.033	502.94	1.22	412.24	8.5	0.03
August	1025.48	0.9	1139.42	9.9	0.04	608.99	0.99	615.14	9	0.03
September	864.28	0.84	1028.90	9.75	0.04	497.39	0.92	540.64	8.5	0.04
October	566.58	0.65	871.66	8.5	0.05	508.85	0.82	620.54	9	0.04
November	478	0.77	620.77	7.1	0.04	221.15	0.61	362.54	7	0.05
December	93.8	0.29	323.44	4.58	0.08	35.77	0.18	198.72	4	0.11
	SW99					**SW211.5**				
Month	**Discharge (m^3/s)**	**Velocity (m/s)**	**Area m^2**	**Water Depth (m)**	**Manning's n(s/$m^{1/3}$)**	**Discharge (m^3/s)**	**Velocity (m/s)**	**Area m^2**	**Water Depth (m)**	**Manning's n(s/$m^{1/3}$)**
January	89.49	0.49	182.63	2.9	0.03	43.38	2	21.69	12.24	0.02
February	9.33	0.07	133.28	2.3	0.20	12.39	1.8	6.88	11.79	0.02
March	4.45	0.03	148.33	2	0.42	8.17	2.1	3.89	11.52	0.02
April	6.81	0.05	136.2	2.15	0.26	5.97	1.85	3.23	11.35	0.02
May	5.55	0.04	138.75	2.1	0.33	32.61	2	16.31	12.11	0.02
June	36.08	0.12	300.67	3.85	0.16	35.33	1.9	18.59	12.37	0.02
July	2474.01	1.95	1268.72	7.7	0.02	1209.19	8.8	137.41	18.53	0.01
August	3061.97	2	1530.98	8.3	0.02	1256.42	8.7	144.42	18.45	0.01
September	4582.62	2.26	2027.70	9.5	0.02	167.89	8.6	19.52	18.34	0.01
October	4979.04	2.29	2174.25	10	0.02	1250.66	10.3	121.42	20.7	0.01
November	606.75	0.85	713.82	7.9	0.04	236.56	4.4	53.76	14.51	0.01
December	451.69	0.82	550.84	6.48	0.04	80.48	3.4	23.67	13.03	0.01

Table 3 Summaries of measured water depth and calculated Manning's n at SW173, SW110, SW101, SW158.1 stations.

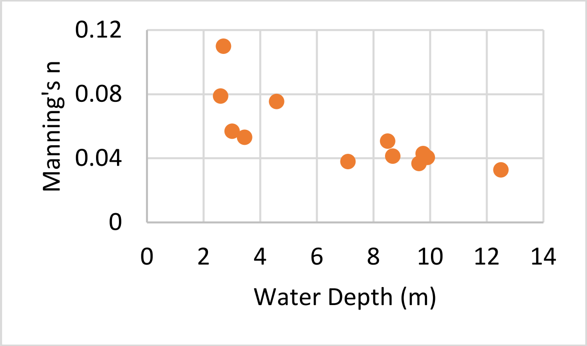
	SW173					**SW110**				
Month	**Discharge (m^3/s)**	**Velocity (m/s)**	**Area m^2**	**Water Depth (m)**	**Manning's n(s/$m^{1/3}$)**	**Discharge (m^3/s)**	**Velocity (m/s)**	**Area m^2**	**Water Depth (m)**	**Manning's n(s/$m^{1/3}$)**
January	149.44	0.47	317.96	7.85	0.07	29.98	0.45	66.62	1.75	0.03
February	112.56	0.37	304.22	7.5	0.08	23.13	0.41	56.41	1.67	0.03
March	106.67	0.4	266.68	7.6	0.08	22.54	0.41	54.98	1.66	0.03
April	231.67	0.61	379.79	8.2	0.05	46.29	0.66	70.14	2.03	0.02
May	563.45	0.92	612.45	11.1	0.04	48.01	0.68	70.60	1.95	0.02
June	818.85	1.07	765.28	12.45	0.04	29.21	0.45	64.91	1.8	0.03
July	1579.96	1.26	1253.94	15.15	0.04	397.02	0.91	436.29	5.65	0.03
August	1734.99	1.29	1344.95	15.6	0.04	43.51	0.64	67.98	1.7	0.02
September	1083.49	1.09	994.03	13.6	0.04	50.96	0.66	77.21	1.95	0.02
October	741.93	0.91	815.31	12.75	0.05	43.27	0.54	80.13	2.1	0.02
November	899.89	1.12	803.47	12.4	0.04	39.91	0.45	88.69	2.15	0.03
December	365.25	0.72	507.29	9.55	0.05	29.98	0.45	66.62	1.75	0.03

	SW101					**SW158.1**				
Month	**Discharge (m^3/s)**	**Velocity (m/s)**	**Area m^2**	**Water Depth (m)**	**Manning's n(s/m$^{1/3}$)**	**Discharge (m^3/s)**	**Velocity (m/s)**	**Area m^2**	**Water Depth (m)**	**Manning's n(s/m$^{1/3}$)**
January	12.13	0.29	41.83	1.29	0.03	24.19	0.9	26.88	1.06	0.01
February	20.05	0.29	69.14	1.42	0.03	22.57	0.87	25.94	1.08	0.01
March	20.25	0.33	61.36	1.54	0.03	40.7	0.81	50.25	1.44	0.01
April	11.6	1.67	6.95	2.01	0.01	61.68	0.93	66.32	2.3	0.01
May	18.8	3.26	5.77	2.22	0.004	38.24	0.87	43.95	1.56	0.01
June	177	1.74	101.72	2.86	0.01	36.56	0.85	43.01	1.46	0.01
July	2730	2.44	1118.85	7.1	0.01	107.48	0.95	113.14	2.96	0.01
August	1970	2.7	729.63	7.41	0.01	59.97	0.9	66.63	2.18	0.01
September	2730	1.84	1483.70	7.45	0.02	60.9	0.89	68.43	2.22	0.02
October	4160	2.74	1518.25	7.44	0.01	73.21	0.93	78.72	2.34	0.02
November	893	1.66	537.95	4.34	0.01	50.59	0.87	58.15	1.8	0.01
December	220	1.32	166.67	2.73	0.01	26.15	0.88	29.72	1.38	0.01

Table 4 Summaries of measured water depth and calculated Manning's n at SW230.1, SW247, SW266 stations.

	SW230.1					**SW247**				
Month	**Discharge (m^3/s)**	**Velocity (m/s)**	**Area m^2**	**Water Depth (m)**	**Manning's n(s/m$^{1/3}$)**	**Discharge (m^3/s)**	**Velocity (m/s)**	**Area m^2**	**Water Depth (m)**	**Manning's n(s/m$^{1/3}$)**
January	50.37	0.2	251.85	**0**	**0**	3.13	0.28	11.179	0.64	0.02
February	51.89	0.22	235.86	5	0.12	2.33	0.33	7.061	0.57	0.02
March	55.5	0.19	292.11	5.12	0.11	2.23	0.35	6.371	0.55	0.02
April	70.01	0.2	350.05	5.42	0.13	2.43	0.26	9.346	0.65	0.02
May	82.42	0.22	374.64	5.86	0.13	2.15	0.25	8.600	0.63	0.02
June	154.32	0.31	497.81	6.18	0.12	303.82	0.72	421.972	8.11	0.04
July	149.01	0.31	480.68	7.78	0.10	169.86	0.69	246.174	5.03	0.03
August	134.32	0.27	497.48	7.7	0.10	664	1.14	582.456	12.2	0.04
September	120.5	0.29	415.52	7.22	0.11	281.51	0.86	327.337	8.82	0.04
October	80.54	0.31	259.81	7.22	0.10	17.72	0.39	45.436	1.54	0.03
November	20.69	0.12	172.42	6.2	0.09	10.43	0.3	34.767	1.21	0.03
December	50.37	0.2	251.85	4.95	0.19	3.13	0.28	11.179	0.64	0.02

	SW266				
Month	**Discharge (m^3/s)**	**Velocity (m/s)**	**Area m^2**	**Water Depth (m)**	**Manning's n(s/m$^{1/3}$)**
January	13.82	0.6	23.03	1.9	0.02
February	5.9	0.61	9.67	0.55	0.01
March	5.77	0.58	9.95	0.5	0.01
April	28.7	0.71	40.42	1.15	0.01
May	662.78	0.75	883.71	8.45	0.04
June	877.59	0.89	986.06	8.35	0.04
July	1858.48	1.18	1574.98	11.75	0.03
August	1619.96	1.15	1408.66	10.75	0.03
September	952.4	1.01	942.97	9	0.03
October	500.38	0.63	794.25	6.7	0.05
November	630.16	0.74	851.57	6.9	0.04
December	110.2	0.24	459.17	4.9	0.10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0.04
0
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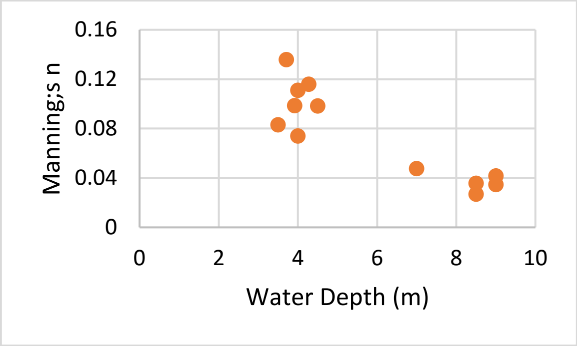
Water Depth (m)

(a)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0.08
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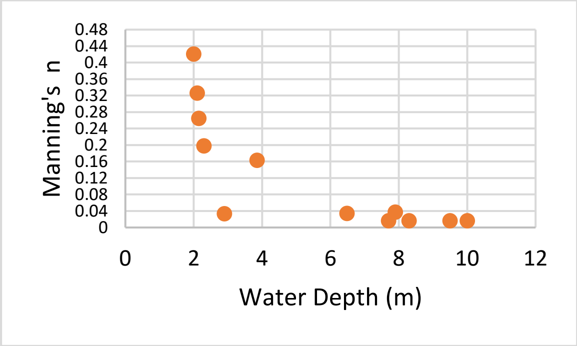
Water Depth (m)

(b)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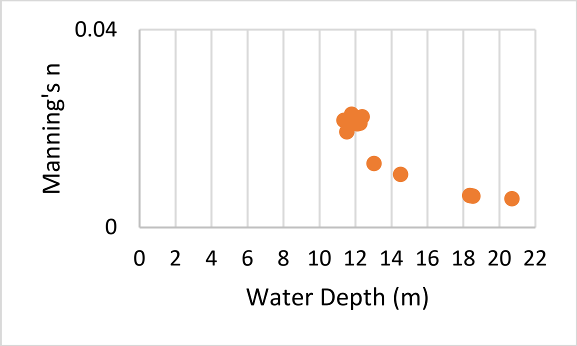
Water Depth (m)

(c)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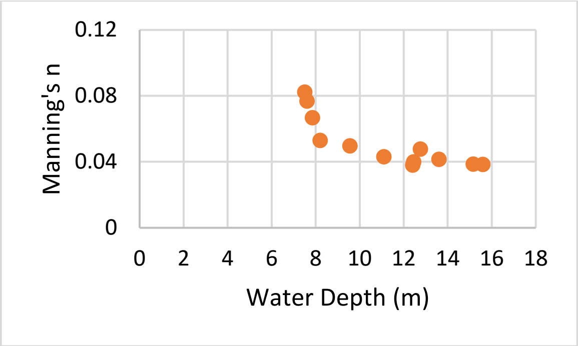
Water Depth (m)

(d)


Manning's n
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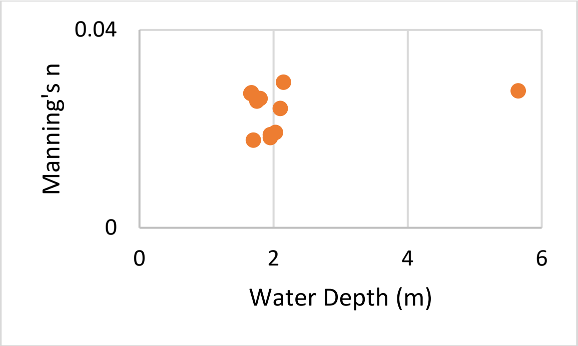
0.04
0
0 2 4 6 8 10 12 14 16 18
Water Depth (m)

(e)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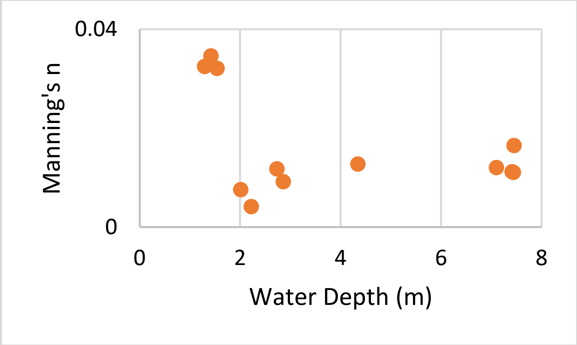
0
0 2 4 6
Water Depth (m)

(f)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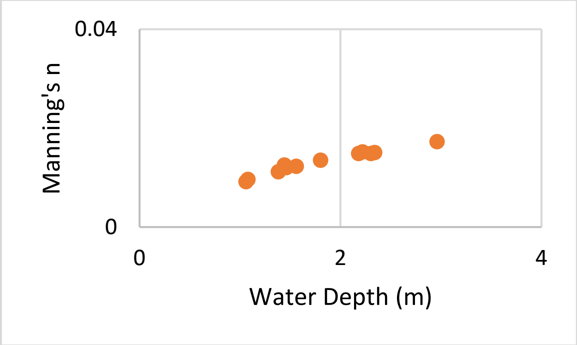
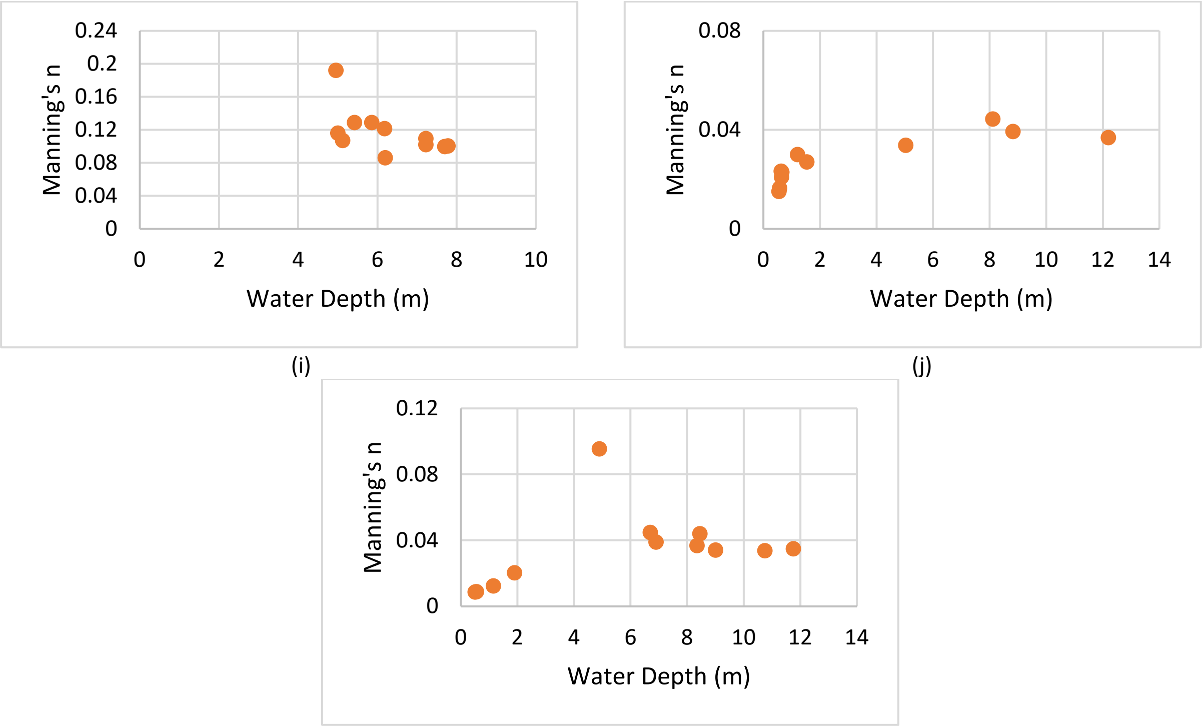
0.04
0
0 2 4 6 8
Water Depth (m)

(g)


Manning's n
0.04
0
0 2 4
Water Depth (m)

(h)



(i) (j)

(k)

Figure 2 Relationship between Manning's n and water depth at various station of (a) SW267; (b) SW301; (c) SW99; (d) SW211.5; (e) SW173; (f) SW110; (g) SW101; (h) SW158.1; (i) SW230.1; (j) SW247; (k) SW266.

By observing Table. 2, 3, 4 and figure 2, varying the water depth and computing the Manning roughness coefficient, it was demonstrated that it was directly proportionate in certain cases and inversely proportional in others. The cross-segment shape and range of water profundity may clarify why there is definitely not a solitary principle for the connection between these two factors. When the part has two characterized beds, one larger and one smaller, the connection is straightforwardly related when the water is streaming in the larger bed and contrarily related when the water is streaming in the smaller bed, as expected. This indicates that the influence of variation surface roughness on the river (bed materials: gravel or boulders) and its floodplains (plants or vegetation). The impacts of riverbed morphology on the Manning's n values were more visible in shallow flow depth [8]. The values of manning's n are between 0.08 and 0.14 at SW301 that most of them are at 4m water depth, whereas most of them are between 0.02 and 0.03 at 2m water depth for SW110. For good correlation, 6th order polynomial regression analysis is observed here. From the table 2, 3 and 4, all the stations being studied here, the Manning roughness coefficient varied from 0.01 **s/m$^{1/3}$** to 0.14 **s/m$^{1/3}$** for a corresponding depth 1m to 20m, except the station SW99 for the flow rate of water is high.

Table 5 Correlation between the variety of Manning coefficient and water profundity

Station No.	Straightforwardly Proportional	Proportional in opposite
SW267	Yes	Yes
SW301	Yes	Yes
SW99	Yes	Yes
SW211.5	No	Yes
SW173	Yes	Yes
SW110	Yes	Yes
SW101	Yes	Yes
SW158.1	Yes	No
SW230.1	Yes	Yes
SW247	Yes	Yes
SW266	Yes	Yes

Straightforwardly and oppositely proportional, both cases are justified in all stations except station SW211.5 and SW158.1. Table 5 shows that, with the exception of SW158.1, the relationship among both Manning roughness coefficient and water depth was always inverse of all stations, which might be due to the lack of two beds which means compound channel in most of these stations' cross-sections.

The coefficient of determination (or square of the estimated correlation coefficient) R^2 is a widely used metric for assessing the appropriateness of an estimated regression function. The better the regression fits, the closer R^2 is to 1. Firstly, a linear regression analysis observed which provided R^2 value less than 0.20 for all the stations being studied. After the increasing order of regression analysis, the value became close to 1 of R^2 for 6th order. Again, 7th order analysis is also observed which provided less value than 0.70 for all the stations. From 6th order polynomial equation observed SW99, SW211.5, SW173, SW110, SW158.1, SW247 and SW266 stations get R^2 is significant close to 1, except 3 stations SW267, SW301, SW230.1. It may give an efficient evaluation in estimating Manning roughness coefficient depending on error evaluation criteria.

Table 6 Established regression equation on the Manning's n and water depth for selected Bangladesh rivers.

Station No.	Formulated Polynomial Equation	R^2 value
SW267	$y = 4E\text{-}05x^6 - 0.0018x^5 + 0.0317x^4 - 0.2839x^3 + 1.36x^2 - 3.2892x + 3.1986$	0.8013
SW301	$y = -0.0054x^6 + 0.1963x^5 - 2.907x^4 + 22.336x^3 - 93.887x^2 + 204.87x - 181.48$	0.8631
SW99	$y = 0.0003x^6 - 0.0123x^5 + 0.1959x^4 - 1.5875x^3 + 6.8543x^2 - 14.821x + 12.588$	0.9943
SW211.5	$y = -6E\text{-}06x^6 + 0.0006x^5 - 0.0229x^4 + 0.4908x^3 - 5.8519x^2 + 36.816x - 95.435$	0.9674
SW173	$y = 2E\text{-}05x^6 - 0.0013x^5 + 0.0379x^4 - 0.5879x^3 + 5.0826x^2 - 23.19x + 43.695$	0.9773
SW110	$y = 14.269x^6 - 217.64x^5 + 1299x^4 - 3968.8x^3 + 6622.6x^2 - 5763.6x + 2053.4$	0.9346
SW101	$y = -0.0006x^6 + 0.016x^5 - 0.1534x^4 + 0.7191x^3 - 1.7229x^2 + 1.9774x - 0.8231$	0.9347
SW158.1	$y = 0.0099x^6 - 0.1077x^5 + 0.4742x^4 - 1.083x^3 + 1.3513x^2 - 0.8653x + 0.2296$	0.9898
SW230.1	$y = 0.0688x^6 - 2.6812x^5 + 43.328x^4 - 371.45x^3 + 1781.4x^2 - 4531.3x + 4775.6$	0.7782
SW247	$y = -1E\text{-}05x^6 + 0.0005x^5 - 0.0071x^4 + 0.0476x^3 - 0.1482x^2 + 0.188x - 0.0495$	0.9876
SW266	$y = 9E\text{-}06x^6 - 0.0004x^5 + 0.0058x^4 - 0.0436x^3 + 0.1507x^2 - 0.1867x + 0.0729$	0.9288

4.0 CONCLUSIONS

Manning roughness coefficients in eleven selected rivers were computed based on the streamflow data obtained/acquired from Bangladesh Water Development Board (BWDB). The conclusions that can be drawn from the findings are discussed as follows:

- No standard relationship exists between the values of Manning and depth of water, so there are circumstances where such a relation is directly related to the same station as well as in other circumstances where it would be inversely related. As a result, when there are 2 beds, one more prominent and one more modest the connection between these factors is contrarily proportionate in the more modest bed, while the other is straightforwardly corresponding in the more noteworthy bed. Therefore, care must be taken for all rivers when utilizing a literary equation which just links the water depth mostly to coefficient, as the relationship is changing with time.
- In this work, a regression analysis was used to create 11 polynomial conditions for assessing the roughness coefficient of Manning of different rivers in Bangladesh based on water depth and validated using an error measurement parameter which may give an efficient evaluation in estimating Manning roughness coefficient depending on error evaluation criteria.
- The research shows that Manning's n ranged from 0.01 $s/m^{1/3}$ to 0.14 $s/m^{1/3}$ for a comparable depth of 1m to 20m at all of the stations investigated, and that the 6th order polynomial equation observed R^2 is between 0.9288 and 0.9943 for the majority of the stations investigated, suggesting that this equation can be used to estimate Manning roughness coefficient efficiently.

The values of slope of the roughness coefficient stations were not assessed in this study; nevertheless, it should be performed in future research to progress the confirmation of the Manning coefficient function of Bangladesh's rivers.

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