Approaching model of Manning’s coefficient due to an Effect of density and height of vegetation in open channel

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Abstract. The presence of vegetation growing in the channel can cause increasing the Manning’s coefficient. The magnitude of Manning’s coefficient is depended on the characteristic and type of vegetation. The purpose of the research is to study and model the effect of density and height of vegetation on Manning’s coefficient in open channel. The study was conducted in open channel with 15.5 m length, 0.5 m width and 1.0 m height. At the centre part of the channel is planted with Elephant grass (Pennisetum Purpureum). The effect of different density and height of vegetation were run with fixed discharge to measure the velocity and water profiles in order to obtain Manning's coefficients. The effect of those variables on the developed model was evaluated using statistical analysis of variance and paired t-test with significance level of 0.05. The results showed that Manning’s coefficient is increasing as increasing density and height of vegetation. If compared to un-vegetated channel, Manning’s coefficient increase in between 4.92-54.07%. Based on statistical analysis, it is found that $F_{\text{calculation}}=367.776 > F_{\text{critic}}=19.452$, $t_{\text{calculation}}=12.298$ and $22.464 > t_{\text{critic}}=2.571$ and $R^2=0.967$, showing that the density and height of vegetation significantly influence on the Manning’s coefficient with strong correlation variables in the model.

1. Introduction

Mostly irrigation channel or any other water bodies in Indonesia and Aceh specifically, the vegetation can be found growing on the channels. A lot of type and kind of vegetation grow in the channel, for example, water grass (Acorus Gramineus), water hyacinth (Eichhornia Crassipes), watercress (Ipomoea Aquatica Forsk), elephant grass (Pennisetum Purpureum) and jeringau or sweet flag (Acorus Calamus) [9].

The presence of vegetation in the channel on one side can prevent slope stability of channel from erosion, but on the other side, the existence of plants in the channel can increase the flow resistance making increase loss energy in the channel. A lot of articles has been fully published by [2-5,10] related to flow resistance due to the presence of vegetation. The results of the study indicated that the presence of plants either flexible, stiff or rigid characteristic, and either submerged or partially submerged vegetation in the water, may increase the flow resistance and increase the Manning’s coefficient. And even, [3] has completely published values of Manning’s coefficient for types of shrubs and woody vegetation.

However, the prediction of the vegetation resistance is very complex since there are many different species with their unique characteristics changing during the season, may vary significantly from place to place, and may also change in time [9]. This inhomogeneous character of the vegetation in the field

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make hardly to take into account in a model of the equation. Moreover, the difference of type dan characteristic of vegetation might result in different flow resistance, although these vegetations are equally flexible, rigid or stiff vegetation [4,9]. Due to the importance of vegetation effect in the channel roughness, therefore, it is necessary to do further research by studying for different characteristic and type of vegetation in the channel to make the more reliable approach of manning’s coefficient model in general application.

The objectives of this research is to study the effects of vegetation density and height of Elephant grass (Pennisetum Purpureum) on Manning’s coefficient, develop the approaching model and test statistically the effect of those two variables on Manning’s coefficient.

This research is a continuation of research as mentioned in [6,9]. These studies were laboratory experimental based, and both research used Elephant grass (Pennisetum Purpureum) as vegetation in the channel. [9] has published research about the effect of vegetation height on flow resistance, resulting in increasing flow resistance in the channel as increase of vegetation density, which was indicated by increasing of vegetated Manning’s coefficient (n_v) in between 0,0083-0,0196. Furthermore, [6] has also published a similar study by examining the effect of vegetation density on flow resistance in the channel, resulting in increasing n_v as increasing vegetation density in between 0,0141-0,0207. These showed that both effect of vegetation height and density separately gave an effect on manning’s coefficient. In fact, in nature, sometimes it is found that the vegetation in the channel are grown in different height and density, therefore it is necessary to study the combination of two condition of vegetation height and density. This is the primary object of this research.

2. Manning’s coefficient

2.1. Original Manning’s equation
One the most commonly used equations governing open channel flow is known as the Manning’s Equation. It was introduced by the Irish Engineer Robert Manning in 1889 as an alternative to the Chezy equation. The Manning’s equation is an empirical equation that applies to uniform flow in open channels and is a function of the channel velocity, flow area and channel slope [1].

Flow velocity is dependent on the amount of friction between the water and the stream channel. Smoother channels will have less friction and, therefore, faster flow. Channel roughness contributes to turbulence, which dissipates energy and reduces flow velocity. The following equation is the Manning Equation, which is used to calculate average flow velocities in open-channel systems:

\[ V = \frac{1}{n} R^{2/3} S^{1/2} \]  
\[ (1) \]

In this equation, V is the average flow velocity, R is the hydraulic radius, or the ratio of the cross-sectional area of the stream divided by the perimeter of the channel in contact with water (wetted perimeter), S is the slope of the water surface, and n is the Manning roughness coefficient. From the mathematics, it follows that a greater n-value will result in a smaller value for flow velocity.

2.2. The Manning’s coefficient
The Manning’s coefficient (n) as in the equations 1 is normally derived from the roughness of materials forming channels. In fact, [1] stated that in nature the flow resistance is influenced by many factors, so the total Manning’s coefficient can be obtained using the equation 2 below.

\[ n = (n_0 + n_1 + n_2 + n_3 + n_4)m_5 \]  
\[ (2) \]
In some cases, the values of \( n_1, n_2, n_3 \) can be ignored due to not significant and \( m \) is 1 for straight channel, so Equation 2 is dominated by the base roughness of channel and due to vegetation, as in Equation 3.

\[
n = n_0 + n_v
\]

where: \( n_0 \) = base roughness; \( n_v \) = the variation of channel surface; \( n_s \) = shape variation of channel section; \( n_e \) = obstacles due to the structure; \( n_i \) = due to vegetation; and \( m \) = correction factor for channel bend.

For specific case, [3] has published specific formula in determination of resistance due to shrubs and woody vegetation, as in Equation 4. This formula as a base to calculated the Manning’s coefficient.

\[
n = n_0 \left[ 1 + \left( \frac{C_D \sum A_i}{2gAL} \right) \left( \frac{Kn}{n_0} \right)^{2/3} \left( \frac{A}{P} \right)^{4/3} \right]
\]

where: \( A_i \) = individual vegetated area (m²), \( A \) = channel area (m²), \( C_D \) = drag coefficient of vegetation; \( g \) = gravity (m/det²); \( Kn \) = conversion Manning’s equation (m¹/³/d); \( L \) = length of channel (m); \( n_0 \) = base roughness of channel; \( P \) = wetted perimeter (m).

3. Research method

3.1. Experimental design
Experiments were conducted in a 15.5 m long, 0.5 m wide and 1.0 m deep glass-walled flume. The slope of flume is set with fixed slope of 0%. Discharge of 5.53 l/s is conducted through one V-notch gate to maintain a constant water level of 45 cm. Bed flume was layered uniformly with fine sand with 15 cm thick. At the center of 3 m long of flume is planted with Elephant grass (*Pennisetum Purpureum*).

![Figure 1. Variations of vegetation height.](image)

![Figure 2. Variations of vegetation density.](image)

The vegetation is set in the channel with a density (VD) of 0, 6, 12, 18, 30 and 42 veg/m² and combined with vegetation height (VH) of 0, 9, 27, 36, 45 and 54 cm. For more detail, the setting of vegetation in the channel can be seen in figure 1 and 2.
3.2. Series of Measurements
The series of measurements under fixed discharge are run on the flume with a different variation of vegetation density and height. Totally, there are 36 series of measurements and analysis in this research, completely shown in the Table 1. The velocity of flow was measured using microcurrent meter at upstream, centre and downstream of flume. The velocity was measured at the bottom, 0.2h, 0.6h, 0.8h and surface level to obtain the profile of velocity distribution and the mean velocity. The slope of energy was measured using point gate at every 0.50 m as long 14 m of channel. And the manning’s coefficient was analyzed based on these parameters using the method below.

**Table 1.** The series of experimental design.

| Vegetation Density in (veg/m²) | Vegetation Height in (cm) |
|--------------------------------|---------------------------|
| 0                              | (Sₜ, Vₘₙ, n)ₜ₁,1          |
| 6                              | (Sₜ, Vₘₙ, n)ₜ₂,1          |
| 12                             | (Sₜ, Vₘₙ, n)ₜ₃,1          |
| 18                             | (Sₜ, Vₘₙ, n)ₜ₄,1          |
| 30                             | (Sₜ, Vₘₙ, n)ₜ₅,1          |
| 42                             | (Sₜ, Vₘₙ, n)ₜ₆,1          |

3.3. Analysis of measurement data
There are 3 locations that be an object of measurements to analyze the distribution and mean velocity, namely: at the upstream, at the middle and the downstream of the channel. The velocity distribution is measured using a current meter on the flow surface, depth of 0.2h, 0.6h, 0.8h and a channel base. The mean velocity is calculated using the Equation 5 as below.

\[ V_m = \frac{V_p + 3V_{0.2h} + 2V_{0.6h} + 3V_{0.8h} + V_d}{10} \]  

(5)

where: \( V_m = \) mean velocity (m/s); \( V_p = \) velocity at the surface (m/s); \( V_{0.2h} = \) velocity at depth 0.2h (m/s); \( V_{0.6h} = \) velocity at depth 0.6h (m/s); \( V_{0.8h} = \) Velocity at a depth of 0.8h (m/s); \( V_d = \) velocity at the base (m/s).

3.3.1. Slope of energy
Loss of energy can be calculated using the Bernoulli equation [1]. This value is obtained from the measurement of water depth and velocity in upstream (\( H_u \)) and downstream (\( H_d \)). The total energy losses can be written as in the equation below. Then the slope of energy (\( S_f \)) can be calculated by the Equation 7, where \( L \) is the length of the vegetation channel.

\[ H_u + \frac{V_u^2}{2g} = H_d + \frac{V_d^2}{2g} + h_f \]  

(6)

\[ S_f = \frac{h_f}{L} \]  

(7)

3.3.2. The Manning’s coefficient
The coefficient of Manning (\( n \)) is obtained by arranging equation 1 to be as equation below, where \( V_m \) is mean velocity.

\[ n = \frac{1}{V_m} R^{2/3} S_f^{1/2} \]  

(8)
The value of \( n \) in Equation 8 is the total Manning’s coefficient produced by channel roughness (\( n_a \)) and vegetation roughness (\( n_v \)) as in Equation 3. Then the Manning’s coefficient of vegetation can be obtained using Equation 9.

\[
n_v = n - n_a
\]  

(9)

3.4. Model development

3.4.1. Regression model

In this research, multiple linear regression is applied in developing the model. The dependent variable is Manning’s coefficient of vegetation (\( n_v \)) and independent variable are vegetation height \( (V_H) \) and density \( (V_D) \), so the model can be formulated as in equation 10. The coefficient of matrix \((\beta_0, \beta_1, \text{and } \beta_2)\) is obtained using least square method and concisely is written as in equation 11.

\[
n_v = \beta_0 + \beta_1 V_H + \beta_2 V_D
\]  

(10)

\[
\begin{bmatrix}
n \\
\sum V_{H} \\
\sum V_{D} \\
\sum D_{H} \\
\sum D_{D}
\end{bmatrix}
\begin{bmatrix}
\beta_0 \\
\beta_1 \\
\beta_2
\end{bmatrix}
= \begin{bmatrix}
n \\
\sum V_{H} \\
\sum V_{D} \\
\sum D_{H} \\
\sum D_{D}
\end{bmatrix}
\]  

(11)

3.4.2. Statistical test of regression model

**Coefficient of determination \((R^2)\).** This parameter is to see whether or not there is a statistically significant relationship between the dependent variable and the variable added to the equation. The value of \( R^2 \) is in the range of 0-1. The more \( R^2 \) tend to 1, the stronger correlation between independent and dependent variable in the model.

**Analysis of variance (Anova).** Anova is applied to test the effect of vegetation height and density on Manning’s coefficient in the model regression. These variables are tested using two ways anova method with the confidence level \((\alpha) = 5\%\). If \( F_{\text{calc}} > F_{\text{stat}} \) then reject \( H_0 \) and accept \( H_a \) it can be concluded that the vegetation height and density influence the Manning’s coefficient. On the other hand, If \( F_{\text{calc}} < F_{\text{stat}} \) then accept \( H_0 \) and reject \( H_a \), it can be concluded that the vegetation height and density do not influence Manning’s coefficient.

**T-test.** This test is applied to measure the contribution the vegetation height or density in the model. These variables are tested using two-tailed test with the confidence level \((\alpha) = 5\%\). If \( t_{\text{calc}} > t_{\text{stat}} \) then reject \( H_0 \) and accept \( H_a \) it can be concluded that the vegetation height or density influence the Manning’s coefficient. On the other hand, If \( t_{\text{calc}} < t_{\text{stat}} \) then accept \( H_0 \) and reject \( H_a \) it can be concluded that the vegetation height or density do not influence Manning’s coefficient.

4. Results and discussions

4.1. The profile of velocity distribution and mean velocity

The velocity on various vegetation height and density has been measured and collected at the downstream, centre and upstream in every depth as mentioned in above method. A part of measurement is depicted figure 3 and 4. Figure 3 is the distribution of velocity profile for various vegetation height on vegetation density of 42 veg/m². Meanwhile, figure 4 is the distribution of
velocity profile for various vegetation density on vegetation height of 45 cm. As seen in both figure that the velocity decreases with increase in height and density of vegetation. The profile of velocity distribution can draw the mean velocity in the channel. The presence of plants in the channel make water flow to be blocked, and arise backwater flow. This condition makes the increasing flow resistance, so at the block layer due to vegetation will decrease the mean velocity.

The higher density and height of vegetation, the slower mean velocity in the channel, or it can be explained that the mean velocity tend to decrease as increase the density and height of vegetation, as can be seen in table 2. If compared to un-vegetated channel, the velocity is reducing by 11.87-25.42%. Surely, this condition will affect flow system in the channel.

![Figure 3](image3.png) ![Figure 4](image4.png)

**Figure 3.** velocity distribution on variation of vegetation height (VH) and density (VD) of 42 veg per sq. m

**Figure 4.** velocity distribution on variation of vegetation density (VD) and height (VH) of 45 cm

| Vegetation density (VD) in veg/m² | Vegetation height (VH) in cm |
|-----------------------------------|-------------------------------|
| 0                                 | 0, 9, 18, 36, 45, 54          |
| 0                                 | 2,480, 2,480, 2,480, 2,480, 2,480 | 2,480 |
| 6                                 | 2,480, 2,185, 2,081, 2,047, 2,007 | 1,967 |
| 12                                | 2,480, 2,152, 2,038, 2,004, 1,964 | 1,924 |
| 18                                | 2,480, 2,109, 1,995, 1,961, 1,921 | 1,881 |
| 30                                | 2,480, 2,092, 1,978, 1,944, 1,904 | 1,864 |
| 42                                | 2,480, 2,078, 1,964, 1,929, 1,889 | 1,849 |

### 4.2. The manning’s coefficient due to vegetation density and height

As discussed above that the mean velocity tends to decrease as increase the density and height of vegetation. This clearly is shown in the figure 5. The graph tells us that how the mean velocity keeps decreasing as increasing the density and height of vegetation. Based on the analysis using equation 8, the total manning’s coefficient due to vegetation height and density are obtained. The results showed that total manning’s coefficient (n) tends to increasing as increasing density and height of vegetation. Maximum total manning’s coefficient is 0.040 and minimum is 0.0587. If compared with un-vegetated channel (n₀=0.0381), the manning’s coefficient increase 4.92% up to 54.07%.
Table 3. The Manning’s coefficients due to vegetation density and height.

| Vegetation density (VD) in veg/m² | Vegetation height (VH) in cm |
|-----------------------------------|-----------------------------|
| 0                                 | 0,000                       |
| 6                                 | 0,000                       |
| 12                                | 0,000                       |
| 18                                | 0,000                       |
| 30                                | 0,000                       |
| 42                                | 0,000                       |

In addition, using equation 9 the manning’s coefficient due to various vegetation height and density are obtained as tabulated in table 3 and clearly explained as in figure 6. The figure shows that the manning’s coefficient due to vegetated channel ($n_v$) increase as increase vegetation height and density. These values are inversely proportional to the velocity as seen in figure 5. As the greater vegetation height and density, the wider flow area which is block by vegetation making flow resistance increase, so that the velocity becomes decreased while manning’s coefficient becomes increased. An additional manning’s coefficient due to vegetation in the channel ($n_v$) should be considered in designing channel is in between (0,002-0,021)

![Figure 5. Mean velocity on variation of vegetation height and density](image1)

![Figure 6. The Manning’s coefficient on variation of vegetation height and density.](image2)

4.3. The approaching model development

The multiple linier regression is applied to develop the approaching model. The dependent variable is manning’s coefficient of vegetation ($n_v$) and independent variable are vegetation height ($V_H$) and density ($V_D$). Based on equation 12, the coefficient of matrix ($\beta_0$, $\beta_1$ and $\beta_2$) is obtained and the using equation 12, the approaching model can be developed as in equation 12.

$$n_v = -0.00107 + 0.01227 \cdot V_H + 0.00019 \cdot V_D$$

Based on statistical analysis, it is found that $F_{calculation}=367.776 > F_{critic}=19.452$, $F_{calc}> F_{stat}$ then reject $H_0$ and accept $H_a$, it can be concluded that the vegetation height and density influence the Manning’s coefficient. In addition, based on t-test, it is found that $t_{calculation}=12.298$ and $22.464 > t_{critic}=2.571$, $t_{calc}> t_{stat}$ then reject $H_0$ and accept $H_a$, it can be concluded that both vegetation height and density significantly effect on the manning’s coefficient. And lastly, it is obtained that determination
coefficient \( R^2 = 0.967 \), showing that the density and height of vegetation significantly strong correlate to the manning’s coefficient of the model.

5. Conclusion

The result of this research can be concluded that the presence of Elephant grass (Pennisetum Purpureum) with various vegetation height and density inside the channel can affect the mean velocity. The greater vegetation density and height result in the lower velocity in the channel. The mean velocity in the channel decrease of 11.87-25.42 % as the effect of vegetation density and height. This effect on increasing the total coefficient of manning (n) ranging from 0.040-0.0587, so that there is an additional vegetated manning’s coefficient (nv) in between (0.002-0.021), compared to the unvegetated channel \( (n_0 = 0.0381) \) or an increase 4.92% up to 54.07%. So it can be concluded that vegetation density and height in the open channel can affect the value of Manning coefficient. It is suggested that further research is required to include additional characteristics such as; diameter and leaf width of the vegetation or other types of vegetation so that the flow resistance due to the presence of vegetation can be modeled more general and perfect for the development of hydraulic science in the future.

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