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Preliminary Modelling of Hydrological Performance for Green Roof Drainage Layer using Response Surface Methodology

Salinah Dullah[1], Hidayati Asrah[1,*], Movierawanna Bernard[1], Jane Ann Jumi[1]

[1] Faculty of Engineering, Civil Engineering Programme, University Malaysia Sabah, 88400 Kota Kinabalu, Sabah Malaysia

ABSTRACT

Response Surface Methodology modelling is used in this study to investigate experimental result for waterproofing and drainage layers with slope ranging from 0% to 6% test beds with three types layers of drainage, rubber crumbs, oil palm shells and polyform. The aim of this study is to determine the accuracy and effectiveness of RSM through investigating the hydrological performance of green roofs. Nine sets of experimental data were used to analyse, and the input parameters include type of material drainage layer, slopes, and water absorption of the materials. The output variables were hydrograph and peak runoff, peak attenuation, and water retention for each material. It was proven that the mathematical equations developed by the RSM model can predict the output response, with ANOVA analysis being used to determine the level of significant effect of the input parameters on the green roof hydrological performance. RSM model's 2D contour plot and 3D surface plot expecting to revealed slope and water absorption. This modelling showed significant effect on peak runoff, peak attenuation, and water retention. It is proven that the RSM can be used to investigate various factors affecting green roof hydrological performance.

Keywords:
Green roof; Drainage layer; Hydrological performance; Response surface methodology

1. Introduction

Sustainability in urban development has become well known due to climate change, scarcity of natural energy resources and urbanization [1-3]. Reduction of energy consumption through lowering cooling and heating loads, increase the building values, enhancement quality of stormwater mitigation, lower air temperatures, urban air quality improvement, noise pollution reduction, and attenuate the effect of urban heat island are well known advantages when using green roof [4]. Green technology has been introduced to meet with the needs for environmental sustainability but there are numerous challenges in implementing green roofs especially in Malaysia [5]. It was found there was no specific general guidelines and design rules for the green roof concept in the country. This happened due to lack in professional and experts for green roof implementation in Malaysia. Its complexity which can be costly due to its maintenance and installation may also contribute to

* *Corresponding author.*
E-mail address: hidayati@ums.edu.my

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another limitation factor. Despite providing benefit to the environment, it can however be susceptible to fire if it is not monitored scientifically which may lead to failure [6,7].

Green roof installation benefits the environment by increasing biological diversity, reducing the effects of urban energy absorption, lowering building thermal temperature changes, lowering maintenance and operational costs from an economic standpoint, and providing social spaces where people have access to the open spaces on the roof [8]. The use of a green roof as a spatial expansion in a building is not only for aesthetic reasons, but also to address attempts to address environmental issues [8]. Green roof materials act as insulators in cold climates, reducing heat loss from inside to outside. As a result, installing green roofs on buildings is one of the most suitable and effective ways of protecting the environment that is aligned with United Nations Sustainable Development aims [9].

Modelling software, particularly Response Surface Methodology (RSM), is one of the tools that have been widely used for stimulation without needing to prepare an actual prototype. This paper relatively focused on the effectiveness of RSM in Minitab software through hydrological performance of green roof drainage layers rubber crumb, oil palm shells and polyfoam. Based on Ewadh [10] study, the prediction on the parameter optimization can be obtained through RSM. Its statistical modelling prediction could also reduce massive laboratory work. Slope and water absorption were classified as input parameters. Meanwhile, peak runoff, peak attenuation, and water retention capacity were the output parameters. Mathematical equations generate by RSM is used to predict the outcome response, with assistance of ANOVA analysis. It determines the level of significant effect of the input parameters. 3D surface and 2D contour plots in the model revealed that slope and water absorption which indicating the effect on water retention, peak attenuation and peak runoff.

1.1 Green Roof

Green roofs usually classified according to growing media thickness, vegetation type, accessibility, maintenance types and origin [11-13]. Spengen *et al.,* [14] and Mentens *et al.,* [15] separate green roof two categories, artificially and natural. The upper layer is vegetation layer comprising of a thick growing substrate with a depth of 150 mm and plants, meanwhile the overall layers of a green roof are often similar in extensive and intensive roofs [17,18].

Substrate layer are usually top soil or garden soil. It is the physical support for the plants, where it provides nutrients and should have the capacity to retain water. Following by the filter layer which usually geotextiles membranes. It allows water to cross but not of the substrate small particulates that could clog the cavities in the drainage layer. Next, drainage layer must be able to retain water when it rains, while ensuring good drainage & aeration of the substrate and roots. The waterproofing layer protects the building from the roots and water [19,20].

As shown in Figure 1 is the cross-section of a representative extensive green roof system including typically used layers. The drainage layer is placed over a root barrier that covers the roofing membrane. The water retention fabric is optional and the media depth and plant material vary depending on design specifications [21]. A typical GR is constructed by placing a drainage course, growing substrate, and vegetation on top of a roof’s waterproof membrane [22].

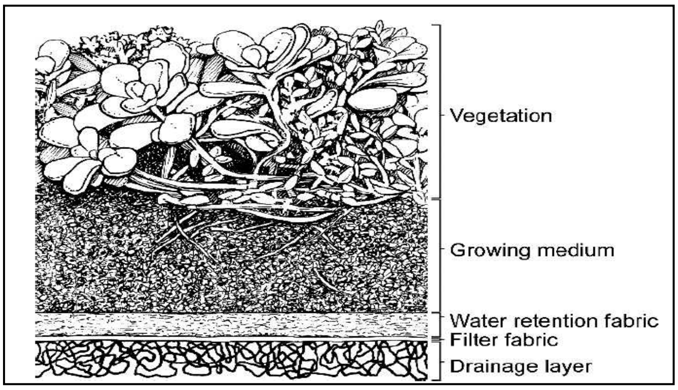


Fig. 1. Cross-section area of extensive green roof [19,21]

Asman *et al.,* [19] summarized as shown in Table 1, green roof content six layers and this layer knows as vegetative, substrate (usually soil), water retention fabric, filter, drainage and waterproofing. Based on her findings, it was stated numerous previous researchers concluded that depth and types of substrate mostly effected the water retention capacity and vegetation types and cover are insignificant [19,23]. Asman [19] also mentioned studied done by Voyde *et al.,* [24] using two substrate depths 50 mm and 70 mm showing influence the stormwater discharge with no significant effect on stormwater for depth over 70 mm

Table 1
Example of green roof layers as defined by different authors [16,19,20]

Green roof layers	References
Vegetative layer Soil layer Webbing/ geotextile filter Drainage material	[26]
Vegetation Growing medium Water retention fabric Filter fabric Drainage layer	[27]
Vegetation layer Substrate layer Filter layer Drainage layer Waterproofing layer	[28]

. Moreover, numerous studies were conducted over decades experimenting varies thickness in extensive green roof and it is shown in Table 2. Based on the findings, depth of vegetative layer ranging between 50 to 130 mm. However, 50 mm of the substrate layer and maximum depths around 150 mm in height are the common measurement [19].

Table 2
Example thickness of extensive green roofs layers as defined by different authors [16,19]

Green roof layers	Thickness, d (mm)	References
Vegetative Layer	50-130	[29]
Substrate Layer	50-150	[29]
	50	[25,28,30-34]
	150	[17,18]
	< 150	[15,35]
	≤ 150	[25,37,38]
Drainage Layer	40	[28,33]

1.2 Design Method

Asman *et al.,* [19] had gathered information on design method, which she concluded there are initial design consideration must be taken account before designing the green roof system and this consideration compromises many factors as shown in Table 3 [19].

Table 3
Initial design consideration [19,20,38]

Local Requirements	Green roofs should be designed following applicable city, state and federal building codes. Owner and design team should beforehand meet with local code officials, including the fire department, before starting the designing work.
Structural Support	The structural support of a building should be adequate in order to hold the weight of the green roof. The roof must first be verified by a structural engineer or architect that it will support the weight of the green roof system.
Quality Control	Green roof system should be designed to manage the Water Quality Volume (WQV) as defined in Chapter 2, section 1 of the Iowa Stormwater Management Manual (Unified Sizing Criteria) – green roof can be routed into additional practices such as rain gardens to meet WQV requirements.
Quantity Control	Green roof systems should be designed to safely convey large storm events through internal or external drainage systems.
Waterproofing System	Considerations must be given to the type of waterproofing system and the manufacturer's long team maintenance and warranty requirements. Each manufacturer has unique warranty requirements that must be met with the system's design.
Wind Uplift	Careful consideration should be given to the design wind speed for systems that are not altered or mechanically attached to the roof deck. ANSI/RP14
Public Access	Consideration must be given to accessibility and occupancy requirements if the green roof will be accessible to the public.
Plant Materials	Plants must be drought tolerant and able to withstand extreme temperatures. Extensive green roofs are primarily planted with sedum species, while semi-intensive and intensive green roofs are able to support a limited number of native plants.
Maintenance	Maintenance varies depending on the green roof design; the owner and designer should develop a maintenance plan that complies with the manufacturer's warranty. NOTE: some manufacturers require maintenance to be completed by a 3rd party contractor during the initial green roof establishment period.

Asman *et al.,* also stated that Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau, FLL 2008 Green Roofing Guidelines are common standard design used in Germany [3,19] and summarised the green roof standard used by ASTM and ANSI as shown in Table 4 [19]:

Table 4
Green roof standard design accordance to ASTM and ANSI [19,20,38]

Standard		Description
ASTM	E2396	Standard Test Method for Saturated Water Permeability of Granular Drainage Media (Falling Head Method) for Green Roof Systems
	E2397	Standard Practice for Determination of Dead Loads and Live Loads Associated with Green Roof Systems
	E2398	Standard Test Method for Water Capture and Media Retention of Geocomposite Drain Layers for Green Roof Systems
	E2399	Standard Test Method for Maximum Media Density for Dead Load Analysis of Green Roof Systems (includes tests to measure moisture retention potential and saturated water permeability of media, total porosity, and air content of media)
	E2400	Standard Guide for Selection, Installation and Maintenance of Plants for Green Roof Systems
ANSI	ANSI/SPRI RP-14	Wind Design Standard for Vegetative Roofing Systems
	ANSI/SPRI VF-1	External Fire Design Standard for Vegetative Roofs
	ANSI/GRHC/SPRI VR-1 2011	Procedure for Investigating Resistance to Root Penetration on Vegetative Roofs

1.3 Past Modelling Study of Hydrological Performance

Though, green roof well known to provide varies advantages to urban development in sense of cost expenses in management, installation and operation green roof are more costly compared to conventional roof [39]. Due to funds constraint, model mathematical were introduced as an alternative to coped this limitation and many studies had been conducted ever since.

According to Baek *et al.,* [39] a few study groups have conducted green roof simulation by developing Low Impact Development (LID) modelling tools , which later was known as such SUSTAIN and stormwater management model (SWMM). In order to increase the efficiency of the model, Baek *et al.,* [39] had introduced new modelling tool (SWMM-H) which is a combination of SWMM and HYDRUS-1D models. The HYDRUS-1D model enables the soil water flow to be simulated mechanically and predict the water flow according to degree of soil saturation through soil physics theory. Coupling of SWMM and HYDRUS-1 models was done as the applicability of SWMM in detailed green roof simulations is limited and the conceptual and computational framework to simulate the hydrological and hydraulic processes of stormwater in urban areas. The competency of this model to simulate soil moisture was analysed using rainfall-runoff data from a pilot-scale green roof system and compared to that of SWMM. The findings concluded that the new modelling tool improved green roof simulations more than that of SWMM. The model can be used in other LID infrastructures like rain gardens and bioretention as it can do a better simulation of soil hydrology and hydraulics in a green roof system.

Paithankar and Taji [40] has also investigated the hydrological performance of green roofs using SWMM. The findings had proven green roofs capability to enhance the runoff retention through a storage layer that mitigate altered peak flow [40]. Various parameters must be taken into consideration during the evaluation such as the site-specific conditions, vegetation characteristics, physical properties of layers [40]. Other parameters like climate parameters involving temperature, evaporation, evapotranspiration are important and beneficial to be included in the investigation of green roofs performance on the catchment scale [40].

More significant studies done by other researchers such as Stovin *et al.,* [41] that contribute in developing a conceptual hydrological flux model through understanding the influence of both climate and roof configuration on the long-term retention performance of green roof systems. The findings suggested that the retention capacity of a green roof is factored by its physical configuration, local climate which include the rainfall characteristics and restoration of retention capacity associated with evapotranspiration during dry weather periods. The model content a function that connects the evapotranspiration rates with substrate moisture content and is validated against observed runoff data. It also found reasonable relationship between local climatic conditions and retention performance of green roofs. Concluded that roof configuration affects the retention performance as roofs with lower moisture holding capacity retain less water compared to deeper retentive substrates.

Vijayaraghavan [42] other researchers interested in this modelling concepts and discovered the relation of green roofs in many parameters. It stated that retention potential of green roof can be influenced by factors such as type of vegetation and coverage, depth and types of growing medium, storage capacity and type of element drainage, volume of rainfall and time of previous dry period and green roof slope. The efficiency of green roofs in reducing total runoff volume and flow rate had been studied by many researchers but stormwater response performance for a wide range of soil depth have not been evaluated [43].

In a modelling study by Feitosa and Wilkinson [43], an evaluation of stormwater runoff attenuation response was done for different soil depths (5, 10, 20, 40, 80 and 160mm), planted with succulent Sedum species and using rainfall registers from Auckland New Zealand. HYDRUS-1D version 4.16 was used in this modelling study for modelling water flow in variably saturated porous media. It was discovered deeper soils are not guaranteed as the most effective solution although having better capability in rainfall peak attenuation as greater soil depth comprises a greater structural load that is likely to overcome the design load of existing roofs, causing a need for structural upgrade [43].

Numerous studies conducted over the decades by many scholars firmly proves that with proper precaution and assumption modelling study are useful and able to predict the interrelationship between factors, which allow to assess the effect of different parameters.

1.4 Response Surface Methodology (RSM)

Optimization tool such as Response Surface Methodology (RSM) has been widely utilised for modelling, optimizing and identifying the interrelationship between investigated factors and observed results [10]. RSM is a mixture of mathematical and statistical techniques for modelling or assessing the effects of a few factors. RSM is applied for acquiring estimation of the factors that produce the required estimations of the reaction. Analysis of variance (ANOVA) is used to evaluate the degree of accuracy of the established model which is based on the responses used in the investigation. RSM is used in this study as it was stated in Ewadh [10] that RSM provides the best prediction on the parameters optimization and help in reducing the huge amount of laboratorial work due to its statistical modelling prediction.

In one of studies conducted by Kostic *et al.,* [44], a study model was developed to investigate the background flow rate using basic mathematical relations among influential parameters, that are easy to use and provide high prediction accuracy. This model was developed using RSM and Kostic *et al.,* [44] had proven it was able produce favourable results in hydrologic forecasting, geotechnical analysis, concrete production and analytical chemistry. The model was derived to prediction flow according to temperature and rainfall data. The main benefits of this model were due to its simple and explicit mathematical expression as it enables easy and quick estimation of a flow rate using input factors of only rainfall and temperature. However, it was also stated that the sensitivity analysis performed could also be used for assessment of other controlling factors such as evapotranspiration and different watershed properties (vegetation, soil type, topography, etc.). Zhan *et al.,* [45] also stated in the modelling process, parameter identification, model calibration and uncertainty quantification are such important steps as these steps need to be considered so that the results are credible.

RSM consist of a few design strategies which are full factorial design (FFD), central composite design (CCD), Box-Behnken design (BBD) and Doehlert design (DD). Selecting a suitable design strategy will give significant impact on making a response surface and also on the accuracy of the established model. These methods are provided in many computers software such as MATLAB (Mathworks), Minitab (Minitab Inc.), Statistica (Stat Soft) and Design Expert (State-Ease Inc.) [10]. In this study, RMS was used as green roof simulations to investigate the accuracy and effectiveness of RSM through investigating the hydrological performance of green roofs, peak runoff, peak attenuation, and water retention.

2. Methodology

2.1 Data Set

The analysis was performed using Minitab 18 Software, which developed the Response Surface Methodology (RSM) model equations. The input parameters used were the test bed slope and water absorption of the materials. The output variables were hydrological performance such as peak runoff, peak attenuation, and water retention. The RSM was modelled using experimental data from Asman *et al.,* [16] whereby the waste materials used for drainage layer were rubber crumbs, oil palm shells, and polyfoam. The modelled were tested on varies roof slopes: 0%, 2%, and 6% and the hydrological performance were monitored. Once the RSM model has been completed and verified, the hydrological performance according to drainage layer characteristics were determined and the effect of the input parameters (slope and water absorption) and the output parameters were then investigated. Table 5 shows a series of data sets for each hydrological performance which were analyses for RSM modelling. The abbreviations used as shown in Table 5 are as follows:

i. RC (rubber crumb)
ii. OPS (oil palm shells)
iii. PF (polyfoam)

Table 5
Details of data used in the Modelling for Peak Runoff, Peak Attenuation and Water Retention [16]

Materials	Slope (%)	Water Absorption (%)	Peak Runoff (mm)	Peak Attenuation (mm)	Water Retention (mm)
RC	0	3.37	5.67	11.93	26.87
OPS	0	8.87	8.55	9.05	22.78
PF	0	0.38	6.22	11.38	23.93
RC	2	3.37	8.50	9.10	25.47
OPS	2	8.87	10.49	7.11	13.60
PF	2	0.38	9.32	8.28	20.08
RC	6	3.37	8.86	8.74	21.92
OPS	6	8.87	11.66	5.94	9.32
PF	6	0.38	10.10	7.50	16.02

2.2 Response Surface Methodology (RSM) Modelling

The RSM modelling software used is Minitab 18, where mathematical and statistical methods are used to analyses the problems and the optimization occurs as the output variables are influenced by the input parameters. The hydrological performance of green roof will be developed by using Central

Composite Design (CCD) since it is easier to use, most popular and is desirable in the design of hydrology process. CCD was often developed through a sequential experimentation. It consists of factorial points, central points and axial points. In CCD, the alpha number that will be used is $\alpha = 0.05$ and a full quadratic model will be applied for each response. Table 6 shows the parameters to be investigated, A (slope) and B (water absorption). The predicted output variables are the peak runoff, peak attenuation, and water retention for each material. The variance analysis for fitting the information to the second order and contour plots will help to characterize the response surface. The Minitab will usually compute the linear, quadratic and interaction terms in the model.

Table 6
Factor and factors level adopted for RSM [16]

Factors	Code	Factors Level	
		Low	High
Slope (%)	A	0	6
Water absorption (%)	B	0.38	8.87

2.3 Verification of the RSM Models

Based on the modelling analysis, it was performed at significance level of $\alpha = 0.05$. This significance level indicates a 5% risk of concluding that a difference exists when there is no actual difference and is used to identify the experimental input parameters (slope and water absorption). The green roof hydrological performance, which includes peak runoff, peak attenuation, and water retention capacity, was used as an output variable. The efficiency of the experimental input parameters to the output variables was determined using Analysis of Variance (ANOVA). The test parameters on the test results, based on their significant effect on the output, are indicated by the P – values obtained from the analysis. If the P – value obtained is less than 0.05 ($P<0.05$), the parameter is statistically significant; if the P – value obtained is greater than 0.05 ($P>0.05$), it is statistically insignificant. The Minitab software generates mathematical equations based on the ANOVA. The predicted peak runoff, peak attenuation, and water retention values of the GR hydrological performance is calculated using these mathematical equations. In terms of coded factors, Eq. (1) depicts the entire quadratic model.

$$Y = \beta o + \beta 1A - \beta 2B - \beta 11A2 + \beta 22B2 - \beta 12AB \quad (1)$$

Where,
Y = Predicted response,
$B0$ = Intercept,
$B1$, $B2$ = Interaction effect coefficient,
$B12$, $B13$ = Quadratic effect coefficient,
A, B = Factors or independent variables.

Thereafter, using the plotted fitted line of predicted value against the experimental value generated by the software, regression analysis was performed. The value for R – squared is calculated based on the graph. The model theory is effective if the R-squared value is close to 1.0.

2.4 Relationship between Slope and Water Absorption on RSM Model

The effects of the slope and water absorption to the peak runoff, peak attenuation and water retention as green roof hydrological performance was then investigated in the analysis. According to the contour plot, the darker the green in the graph, the higher the output values will be. The desired output values will be investigated in terms of the input parameters' effects on the output values. In the 2D contour plot, the x – axis represents the water absorption value and the y – axis represents the slope value for each green roof hydrological performance contour plot.

2.5 Optimization of Slope and Water Absorption on RSM Model

The graph generated by Minitab software was used to optimize the slope and water absorption of the materials in the model. The graph depicts the highest and lowest slope values, as well as the water absorption of drainage layer waste materials, resulting in minimum and maximum peak runoff and peak attenuation.

4. Results and Discussions

4.1 Model Validation: Analysis of Variance (ANOVA)

The ANOVA test is used to determine the significance of survey or the outputs of experiment. In Minitab, ANOVAs compare the response variable means at different factor levels to determine the importance of one or more factors. The P – value generally determines the significance of the parameters used for the input which affects the output. The significance level of 0.05 was used in this analysis.

4.1.1 Peak runoff

The results from Table 7 indicate that the linear outcome of the input parameters which consist of the slope and water absorption of the materials to the peak runoff variables are statistically significant ($P<0.05$). In terms of the quadratic form, the input parameters of slope and water absorption of the materials are found to be statistically significant to the peak runoff as well. As for the 2 – way interaction between the two input parameters, they are found to be statistically insignificant to the peak runoff as had been proven by the model ($P>0.05$). The lowest P – value of P = 0.002 ($P<0.05$), is the main parameter that has led to a more linear effect on the peak runoff than the water absorption in which the P – value is P = 0.012.

Table 7
ANOVA for peak runoff using RSM Model

Source	P-Value
Model	0.006
Linear	0.003
Slope	0.002
Water Absorption	0.012
Square	0.010
Slope*Slope	0.011
Water Absorption* Water Absorption	0.012
2-Way Interaction	0.548
Slope* Water Absorption	0.548

4.1.2 Peak attenuation

Table 8 shows the ANOVA for Peak Attenuation using the Minitab RSM model. The linear outcome of the input parameters, which include the slope and water absorption, to the peak attenuation variables is statistically significant (P<0.05). The input parameters of slope and material water absorption are found to be statistically significant to the peak attenuation in the quadratic form since the P – values for both parameters are less than 0.05. The two-way interaction between the two input parameters is found to be statistically insignificant to peak attenuation, as the model has proven (P>0.05). By comparing the two factors, the slope, has the lowest P – value of P = 0.002 (P<0.05), is the main parameter that has resulted in a more linear effect on the peak runoff than the water absorption, P – value with P = 0.012.

Table 8
ANOVA for peak attenuation using RSM model

Source	P-Value
Model	0.006
Linear	0.003
Slope	0.002
Water Absorption	0.012
Square	0.010
Slope*Slope	0.011
Water Absorption* Water Absorption	0.012
2-Way Interaction	0.548
Slope* Water Absorption	0.548

4.1.3 Water retention

Table 9 shows the ANOVA for Water Retention using the Minitab RSM model. Based on the result shown in the table, the linear effect for slope has P = 0.015 (P<0.05) which is found to be statistically significant to water retention variables. However, for the water absorption, it is found to be statistically insignificant to the water retention variables since the P – value is greater than 0.05 which is P = 0.068. In the quadratic form, it can be seen in the table that only the P – value for Slope*Slope is statistically insignificant to water retention since the P – value is P = 0.321. Meanwhile, quadratic effect for water absorption is statistically significant (P = 0.027 < 0.05). The two-way interaction between the two input parameters is found to be statistically insignificant to water retention, as the model has proven (P>0.05). By comparing the two factors, the slope, has the lowest P – value of P = 0.015 (P<0.05), is the main parameter that has resulted in a more linear effect on the water retention than the water absorption in which the P – value is P = 0.068.

Table 9
ANOVA for water retention using RSM model

Source	P-Value
Model	0.040
Linear	0.025
Slope	0.015
Water Absorption	0.068
Square	0.054
Slope*Slope	0.321
Water Absorption* Water Absorption	0.027
2-Way Interaction	0.279
Slope* Water Absorption	0.279

4.2 Mathematical Equations

The experimental results from Asman *et al.,* [16] were used as comparison values to ensure the equation's accuracy. The Minitab RSM model generates a mathematical equation for the output variable, which includes peak runoff, peak attenuation, and water retention. The equation applies to water absorption which ranging from 0.38% to 8.87% and slopes ranging from 0% to 6%. The model's equations can be used to predict the hydrological performance of green roofs, including peak runoff, peak attenuation, and water retention. Eq. (2), Eq. (3) and Eq. (4) are the mathematical models equation used to predict the hydrological performance of the green roofs. Meanwhile, Table 10, 11, and 12 show the comparison between the experimental value and the model's prediction value, and the percentage error for the output (Peak runoff, Peak attenuation and Water retention).

$$Peak\ runoff\ \text{(mm)} = 6.659 + 1.725\text{A} - 0.599\text{B} - 0.1865A2 + 0.0890B2 + 0.0095\text{AB} \quad (2)$$

$$Peak\ attenuation\ \text{(mm)} = 10.941 - 1.725\text{A} - 0.599\text{B} + 0.1865A2 - 0.0890B2 - 0.0950\text{AB} \quad (3)$$

$$Water\ retention\ \text{(mm)} = 22.19 - 2.41A + 3.347B + 0.236A2 - 0.3907B2 - 0.1106AB \quad (4)$$

Where , A = Slope (%), B = Water Absorption (%)

Based on Table 10, the largest error among the forecasted responses from Eq. (2) is 2.48%, while the smallest error is -3.72%. The highest error for the peak runoff hydrological performance of green roofs is when rubber crumbs were used as a drainage layer at a 2% slope and 3.37% water absorption capacity. Meanwhile, the smallest error for the peak runoff is when the oil palm shells were used as a drainage layer at a 2% slope and 8.87% water absorption capacity.

Table 10
Comparison of predicted and actual value for peak runoff

Materials	Slope (%)	Water absorption (%)	Peak runoff (mm)		Error (%)
			Actual	Predicted	
RC	0	3.37	5.67	5.65	0.35
OPS	0	8.87	8.55	8.35	2.38
PF	0	0.38	6.22	6.44	-3.60
RC	2	3.37	8.50	8.29	2.48
OPS	2	8.87	10.49	20.88	-3.72
PF	2	0.38	9.32	9.14	1.93
RC	6	3.37	8.86	9.09	-2.61
OPS	6	8.87	11.66	11.47	1.60
PF	6	0.38	10.10	10.06	0.44

Table 11 shows that the largest error among the predicted responses from Eq. (3) is 5.50%, while the smallest error is -3.14%. The highest error for the peak attenuation hydrological performance of green roofs is when oil palm shells were used as a drainage layer at a 2% slope and 8.87% water absorption capacity. Meanwhile, the smallest error for the peak attenuation is when the oil palm shells were used as a drainage layer at a 6% slope and 8.87% water absorption capacity.

Table 11
Comparison of predicted and actual value for peak attenuation

Materials	Slope (%)	Water absorption (%)	Peak runoff (mm)		Error (%)
			Actual	Predicted	
RC	0	3.37	11.93	11.95	-0.17
OPS	0	8.87	9.05	9.25	-2.25
PF	0	0.38	11.38	11.16	1.97
RC	2	3.37	9.10	9.31	-2.32
OPS	2	8.87	7.11	6.72	5.50
PF	2	0.38	8.28	8.46	-2.17
RC	6	3.37	8.74	8.51	2.64
OPS	6	8.87	5.94	6.13	-3.14
PF	6	0.38	7.5	7.54	-0.59

Table 12 shows that the largest error among the forecasted responses from Eq. (4) is 7.21%, while the smallest error is -12.46%. The highest error for the water retention hydrological performance of green roofs is when oil palm shells were used as a drainage layer at a 0% slope and 8.87% water absorption capacity. Meanwhile, the smallest error for the water retention is when the oil palm shells were used as a drainage layer at a 2% slope and 8.87% water absorption capacity.

Table 12
Comparison of predicted and actual value for water retention

Materials	Slope (%)	Water absorption (%)	Peak runoff (mm)		Error (%)
			Actual	Predicted	
RC	0	3.37	26.87	29.03	-8.05
OPS	0	8.87	22.78	21.14	7.21
PF	0	0.38	23.93	23.41	2.18
RC	2	3.37	25.47	24.41	4.16
OPS	2	8.87	13.60	15.30	-12.46
PF	2	0.38	20.08	19.45	3.16
RC	6	3.37	21.92	20.82	5.04
OPS	6	8.87	9.32	9.27	0.56
PF	6	0.38	16.02	17.18	-7.21

4.3 Regression Analysis

Figure 2(a), 2(b) and 2(c), displayed fitted line graph from the regression analysis for hydrological performance of green roofs, which include peak runoff, peak attenuation, and water retention, using the equations generated by ANOVA.

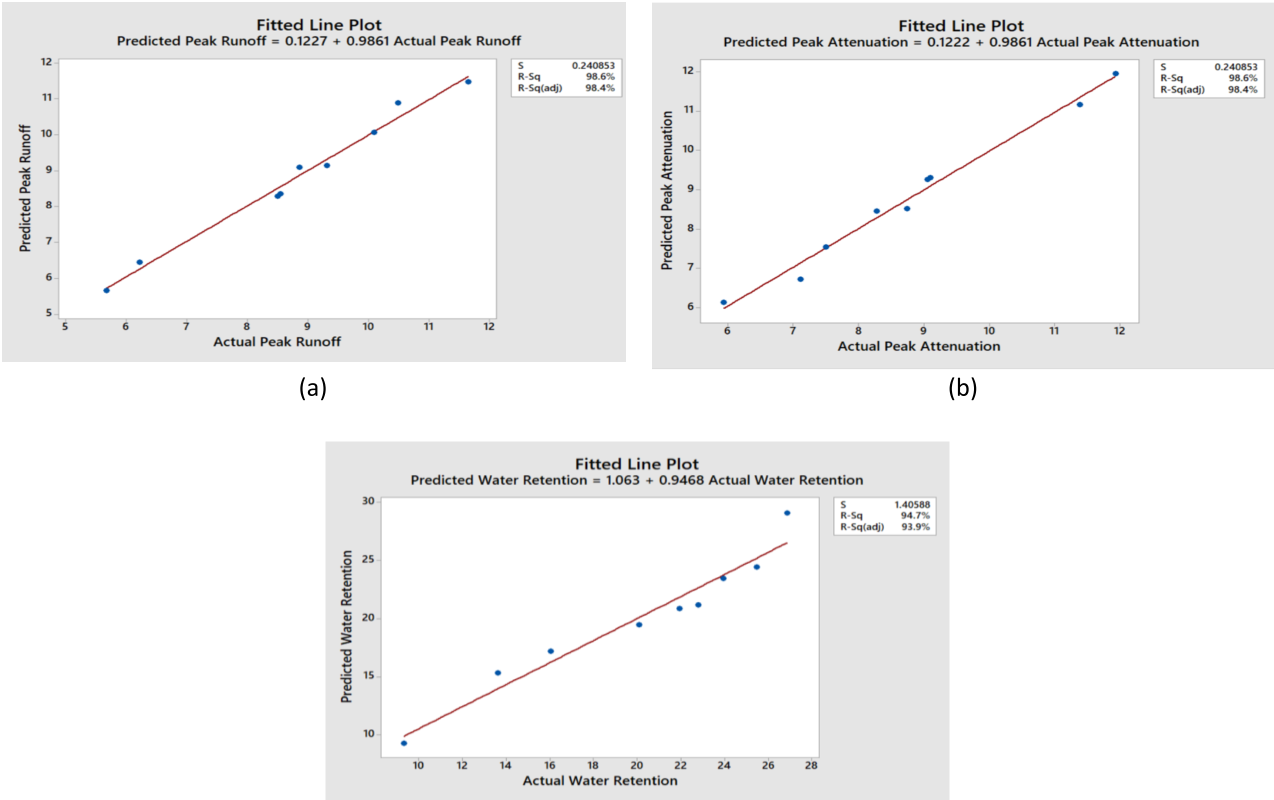


Fig. 2. Fitted line plot (a) predicted and actual peak runoff (b) predicted and actual peak attenuation (c) predicted and actual water retention

The summary model of regression analysis for all GR hydrological performance models is shown in Table 13. It shows that R – squared values for each green roof hydrological performance are greater than 0.900, which is closer to 1.0. Peak runoff and peak attenuation have the highest R – squared values of 0.986, while water retention has the lowest at 0.947. As a result, the predicted and actual values have good connections, and the regression model matches the data well.

Table 13
Regression analysis for green roof hydrological performance

Hydrological properties	R-squared value
Peak runoff	0.986
Peak Attenuation	0.986
Water retention	0.947

4.4 Hydrological Performance
4.4.1 Peak runoff

According to Figure 3 and 4, the contours are curved because the model contains quadratic terms that are statistically significant. It was observed that the lower the slope and the water absorption of the materials, the values for peak runoff are also reduced. From the contour plot, the minimum peak runoff is achieved when the slope is at a range of 0% - 0.3% and the water absorption is within the range of 0% - 6.9%. Meanwhile, the peak runoff is at maximum when the slope is at a range of 3% - 6% and the water absorption of the materials is at a range of more than 8%. As a result, when the slope increases, peak runoff rises with it, and water absorption increases with it. According to Asman *et al.,* [16] experimental data, the greater the peak runoff, the faster (shorter) the runoff time for water to discharge from the green roof test beds. This is due to the growing slope of the GR as well as the properties of the materials employed as a drainage layer, which are primarily concerned with water absorption to assess the hydrological performance, peak runoff.

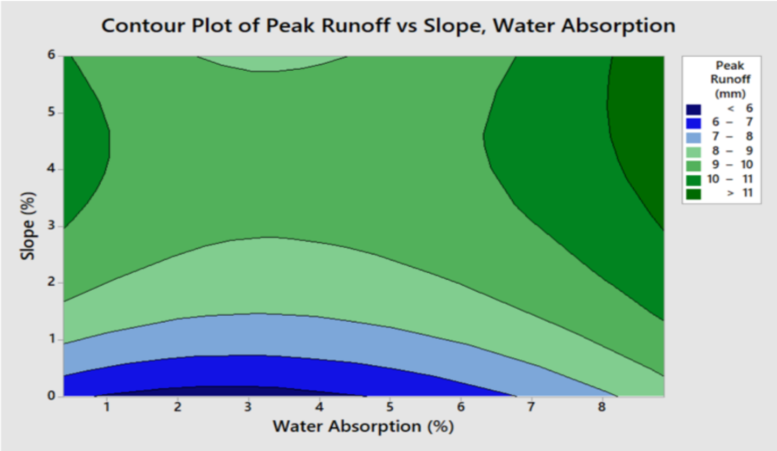


Fig. 3. Contour plot of peak runoff, slope and water absorption

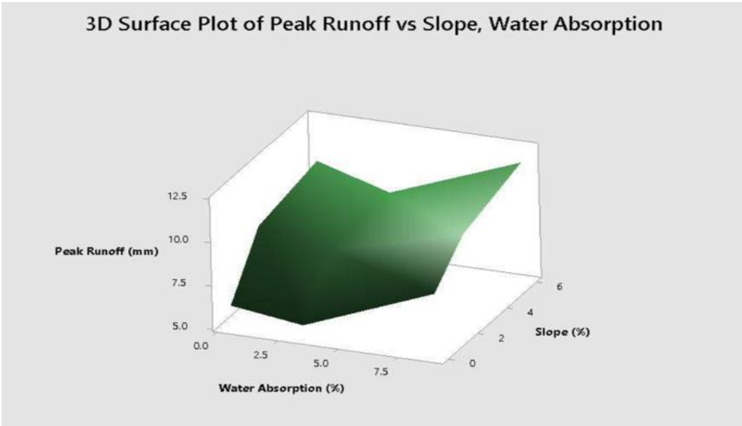


Fig. 4. Surface plot of peak runoff, slope and water absorption

4.4.2 Peak attenuation

As shown in Figure 5 and 6, the contours are curved because the model incorporates statistically significant quadratic term. Based on the observation, peak attenuation is at its highest when the slope value is at a range of 0% - 0.1% and the water absorption is within the range of 0% - 6%. Based on the contour plot, the minimum peak attenuation is achieved when the slope is at a range of 2% - 6% and the water absorption is in the range of more than 7.5% (>7.5%). Meanwhile, the peak attenuation is at maximum when the slope is at a range of 0% - 0.1% and the water absorption of the materials is at a range of 0% - 6%. As a result, when the slope is lower, peak attenuation and water absorption increases. According to Asman *et al.,* [16] experimental data, the higher the peak attenuation value, the more flow reduction and ability to attenuate the peak flow. This is mainly due to the water absorption capacity of the materials and the slope itself since it is likely to have influenced on the peak runoff as well as the peak attenuation. To conclude, as the slope decreases, the peak attenuation value increases.

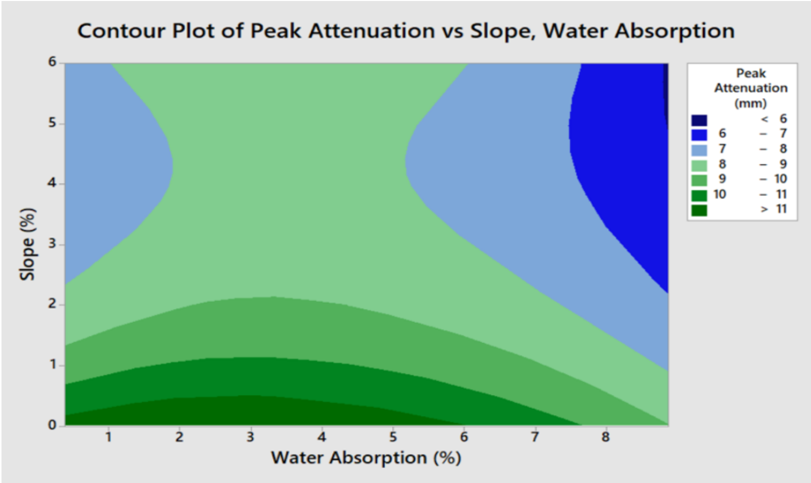


Fig. 5. Contour plot of peak attenuation, slope and water absorption

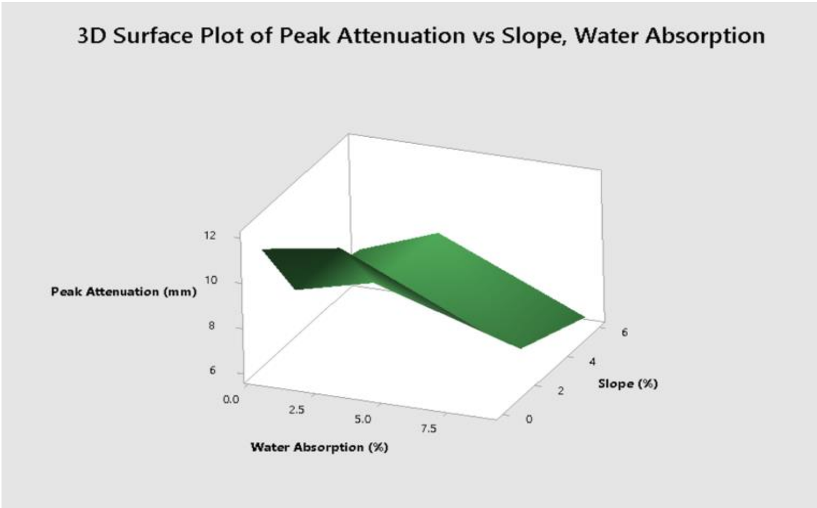


Fig. 6. Surface plot of peak attenuation, slope and water absorption

4.4.3 Water retention

The contours are curved because, as demonstrated in Figure 7 and 8, the model includes statistically significant quadratic factors. According to the findings, when the slope value is between 0 and 2.5% and the water absorption is between 1.0 and 7.0%, the maximum water retention occurs. Based the finding, the minimum water retention is achieved when the slope is at a range of 4% - 6% and the water absorption is in the range of more than 8.0% (>8.0%). Meanwhile, the water retention is at maximum when the slope is at a range of 0% - 2.5% and the water absorption of the materials is at a range of 1.0% - 7.0%. As a result, the water retention increases as the slope and water absorption decreases. According to Asman *et al.,* [16] experimental data, the higher the water retention value, the greater the water absorption capacity of the materials and the slope itself, which is likely to have influenced peak runoff as well as peak attenuation. In general, retention values are determined by the properties of the green roof, with the slope and water absorption of the materials being the primary determinants of the percentage of precipitation stored in the test bed.

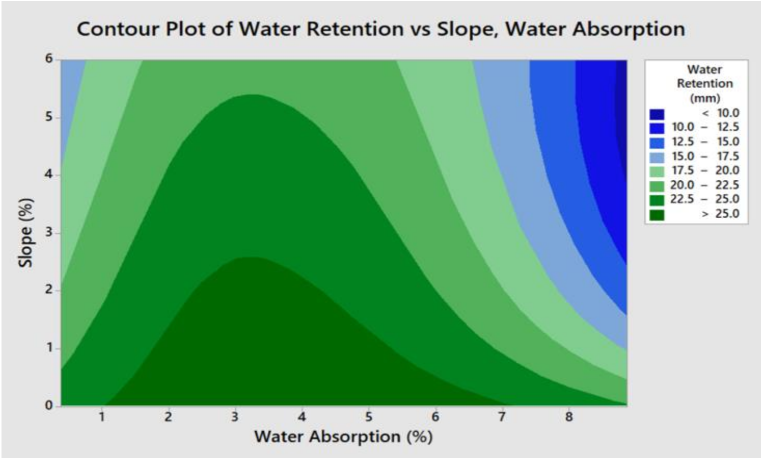


Fig. 7. Contour plot water retention, slope and water absorption

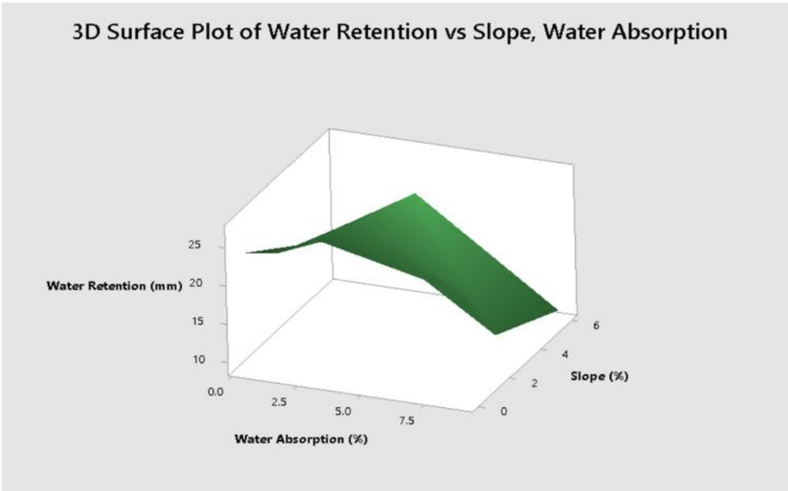
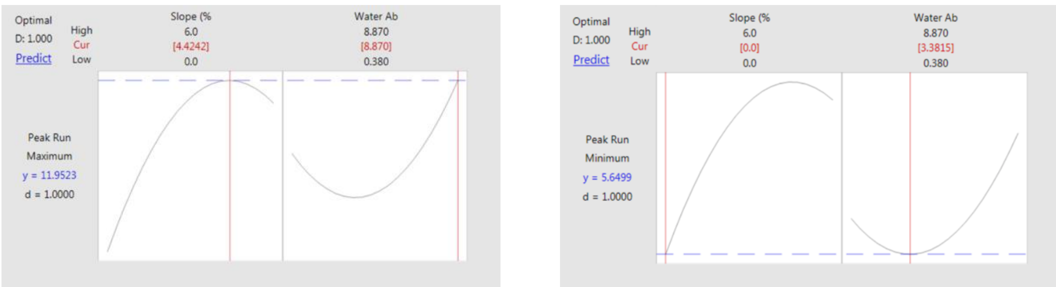


Fig. 8. Surface plot of water retention, slope and water absorption

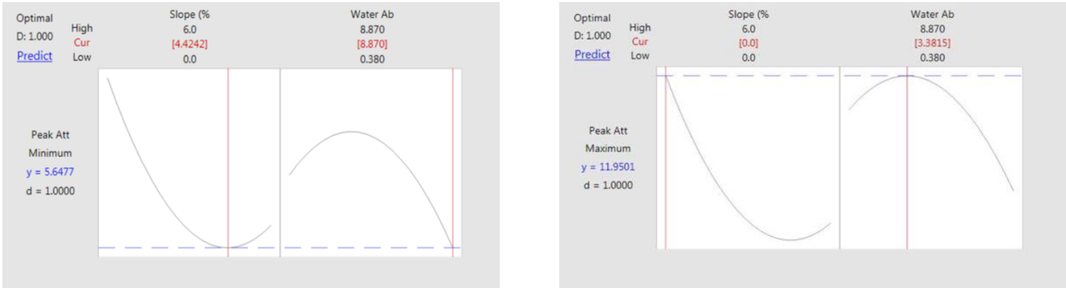
4.5 Optimization of Slope, Water Absorption of Drainage Layer Waste Materials on of Green Roof Hydrological Performance

The optimum value for slope and water absorption of the materials was computed using Minitab software to identify the minimum and maximum values for each of the hydrological performance, peak runoff, peak attenuation, and water retention. Figures 9, 10 and 11 show the graphs of the optimized data for each hydrological performance. Essentially, the Minitab optimization graphs show how the input variables influence the predicted responses.



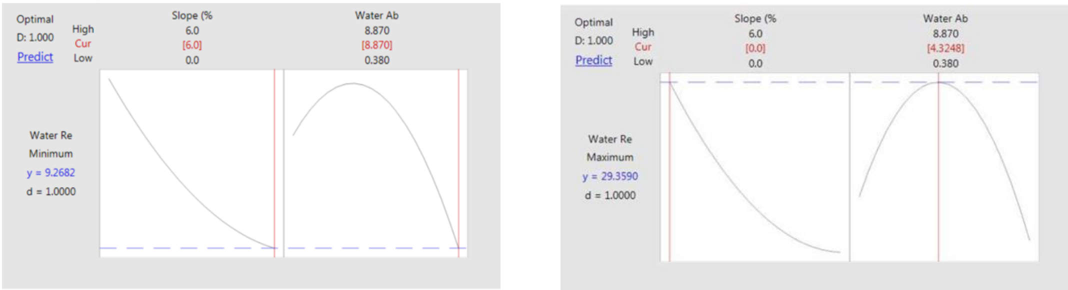
(a) (b)

Fig. 9. Optimization for (a) Minimum and (b) Maximum peak runoff



(a) (b)

Fig. 10. Optimization for (a) Minimum and (b) Maximum peak attenuation



(a) (b)

Fig. 11. Optimization for (a) Minimum and (b) Maximum water retention

According to Table 14, it shows that, the greater the value of peak runoff of the green roof system, the higher the value of slope and water absorption of the materials. Meanwhile, as the green roof slope increases, the peak attenuation decreases, and as the water absorption of the materials increases, the peak attenuation increases. However, if the slope and water absorption of the materials are higher, the water retention of the green roof system will be lower. As a result, the hydrological performance of green roofs is influenced by both slope and water absorption (peak runoff, peak attenuation, and water retention).

Table 14
Optimization result for green roof hydrological performance

Input parameters	Optimization	Peak runoff	Peak attenuation	Water retention
Slope	Minimum	0.0000	4.4242	6.0000
	Maximum	4.4242	0.0000	0.0000
Water Absorption	Minimum	3.3825	8.8700	8.8700
	Maximum	8.8700	3.3815	4.3248

5. Conclusions

In conclusion, RSM model with Minitab software, can be used to determine the hydrological performance of GR (peak runoff, peak attenuation, and water retention). The output variables (peak runoff, peak attenuation, and water retention) can be predicted using the desired input parameters, which are the slope and the water absorption of the waste material used as drainage layer, based on the developed mathematical equations from the analysis of variance (ANOVA) for each green roof hydrological performance. The amount of error for model analysis between actual experimental data and expected response of the output variables from the generated equations range between -15% to 15% is consider acceptable and within tolerance. As a result, the mathematical equations are valid. The R – squared values from the regression analysis for each hydrological parameter are greater than

0.900, which is closer to 1.0. The models created in this study are acceptable because the model is relevant when the value for R – squared is approaching to 1.0. Based on observation and analysis, 2D contour and 3D surface plots, peak runoff values showing reduction as the slope and water absorption values reducing. Peak attenuation and water absorption increases as the slope decreases. Water retention and water absorption also showing increment as the slope decreases. RSM model's optimization data also showing the corelation between slope, water absorption and peak runoff. Peak runoff achieved its maximum value when slope and water absorption at 4.4242% and 8.8700%, respectively. Meanwhile, peak attenuation reached its maximum value when slope and water absorption at 0% and 4.3248%, respectively.

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