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The Effects of Soil Conditions on Bio-pore Infiltration Hole Needs and Potential Runoff Reduction as an Alternative Sustainable Urban Drainage

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ABSTRACT

This study aims to analyze the effect of type, compaction, and the cover of vegetation on the soil to the hydraulic conductivity to determine the need for bio-pore infiltration holes (BIH) of different soil types. The methods used in this study are the measurement of infiltration rate on the ground surface which will be used as a reference for determining the runoff coefficient and the analysis of calculating hydraulic conductivity in the BIH using the Porchet method to determine the optimum capacity of holes in delivering water. The result shows that with the same soil conditions, for example, vegetated and compacted soil, on the silty soil tends to have lower BIH land use ratio to inundation area than clayey soil in order to achieve the same amount of reduced runoff water ratio.
KEYWORDS: *bio-pore infiltration hole, compaction, hydraulic conductivity, inundation, soil, vegetation cover*

INTRODUCTION

Nowadays, along with the development of population, urban expansion continues, where it can threaten natural dynamics, resource availability and environmental quality [1], including human intervention through both greenhouse gas emissions and land cover changes which cause global climate change and can affect the hydrological cycle [2, 3]. According to Apollonio et al., expansion of development in urban areas causes a reduction in water catchment areas, resulting in an increase in runoff and causing flooding and inundation [4], which still occurs in a number of large cities in Indonesia such as Jakarta and Surabaya.

Zhou explained that a sustainable urban drainage system (SUDS) was promoted as an alternative to the conventional drainage concept [5], which in Indonesia is better known as environmental drainage. This system installed based on natural hydrological cycle process which use some portion of urban landscape like vegetated land surfaces with purposes to reduce flood impacts by encouraging infiltration of stormwater to the ground, filtering the pollutants from source, and also temporarily storing water [6, 7, 8]. One of the potential sustainable drainage concepts is bio-pore infiltration hole (BIH). BIH is one of the SUDS technologies that can be used as an alternative effort to improve environmental hydrological functions to overcome flooding and inundation by increasing water absorption in the soil so that it can potentially be a conservation of water in the soil [9].

Water absorption by land is one of the important factors in designing and determining the needs of the amount of BIH so that in the context of BIH application, it must be known in advance how the soil conditions from the flood area and inundation that want to be reduced by BIH. This is because an area does not necessarily have the same type and characteristics of the land as other regions, even though it is in a city [10]. This study aims to analyze the effect of type, compaction and cover of vegetation on the soil on the infiltration rate and hydraulic conductivity to determine the need for bio-pore infiltration holes (BIH) of different soil types.

METHODS

Initial Data Collection & Field Surveys

The preliminary data needed in the study were the soil type map, inundation survey data, rainfall height and intensity of Surabaya city from their respective city departments. Those data are used as the basis for surveying and determining some locations at Surabaya that will be used as field tests, especially BIH tests. The chosen locations for this study are Kenjeran Beach Amusement Park and Lempung Urban Forest, Surabaya, that can be seen on Figure 1. Some soil were sampled from those locations to be tested in laboratorium to determine the texture soil class. Each of the locations will be divided into 4 test plots, where the conditioning on each plot described in Table 1.

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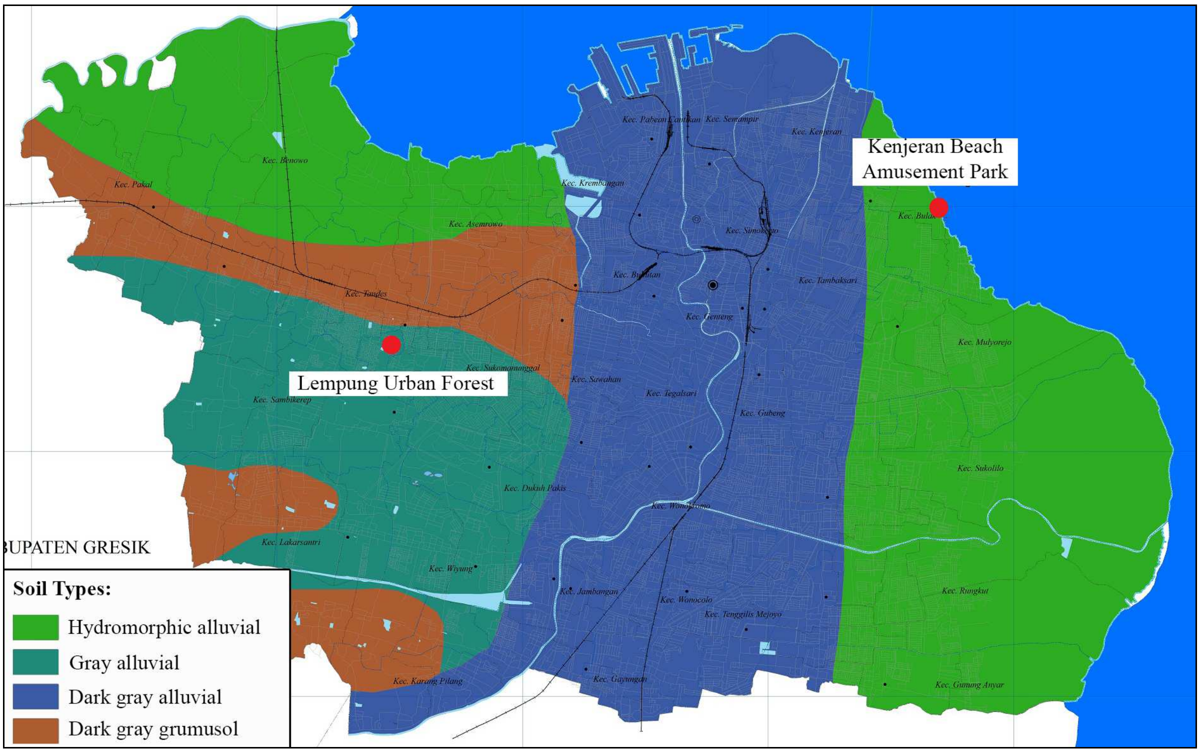

Fig. 1: Test field locations on map of soil types at Surabaya City

Table 1. Conditioning on each test plots

Numb.	Location	Vegetation cover	
		With	**Without**
1	Kenjeran Beach Amusement Park	No compaction (K1)	No compaction (K3)
		With compaction (K2)	With compaction (K4)
2	Lempung Urban Forest	No compaction (L1)	No compaction (L3)
		With compaction (L2)	With compaction (L4)

Test Fields Preparations

These preparations include compacting soils, measuring the infiltration rate, and creating BIH. Four out of eight areas will be compacted by stamper with durations around 30 seconds based on Gregory et al. [11]. After that, infiltration rate measurement will be conducted at every test plots using single-ring infiltrometer. Then, BIH will be constructed in every test plots by boring it using auger hand bore with the sizes of the hole about 10 cm of diameter and 100 cm of depth. After that, that hole will be covered using a pored casing pipe with the same size as the hole.

Hydraulic Conductivity Measurements

Hydraulic conductivity will be measured using inverse auger hole method [12],[13], with some small modification, which single-ring infiltrometer and ruler will be used to measure surface water level changes instead of using measurement tape. Water will be added to the system and maintained in the same water level after it changes in several minutes. Measurement will be stopped if changes in the surface water level of the system remain the same after the last three tries.

Initial Data Analyses

Hydraulic conductivity analysis will be conducted using Porchet method from all gathered data measurements in the field. Comparisons between control plots (K3 for Kenjeran Beach Amusement Park and L3 for Lempung Urban Forest) with other test plots also will be analyzed to know the influence of soil conditioning (vegetation cover and compaction) on hydraulic conductivity. The equation for calculating hydraulic conductivity is as follows:

$$K = \frac{D}{4} \times \frac{\ln\left(h_0 + \frac{D}{4}\right) - \ln\left(h_t + \frac{D}{4}\right)}{t} \quad (2)$$

Equation (2) can be modified to determining the water absorption rate into the hole as follows:

$$\begin{aligned} \Delta Q &= K.\Delta A \\ &= K.\ (A_0 - A_t) \\ &= K.\pi.D\ [(h_0 - h_t) + D/4] \end{aligned} \quad (3)$$

information:
K = Hydraulic conductivity (cm/hr)
h_0 = Initial surface water level (cm)
h_t = Constant surface water level (cm)
t = time (hr)
D = Diameter of hole (cm)

Meteorological data such as rainfall height in last 10 years and rainfall intensity in last 13 months gathered from nearest weather station will be used to determine the average value of each data and to calculate runoff coefficient from each test plot along with infiltration rate measurement on the field of study and depression loss values from UDFCD (Urban Drainage Flood Control District, USA). Based on Guo and Urbonas, the calculation of runoff coefficient is done by using some equations [14] which can be reviewed below:

- The equation for calculating the rainfall volume is as follows:

$$V_P = PA \quad (3)$$

- The equation for calculating the runoff volume is as follows:

$$V_R = (P - D_L - F)\ A \quad (4)$$

- The equation for calculating the runoff coefficient is as follows:

$$C = \frac{V_R}{V_P} \quad (5)$$

information:
V_P = rainfall volume (m^3)
V_R = runoff volume (m^3)
P = rainfall height (m)
A = watershed (m^2)
C = runoff coefficient
D_L = depression losses (m)
F = infiltration height (m)

Analysis of Bio-pore Infiltration Hole Needs and Runoff Reduction

In this analysis, the need for bio-pore infiltration holes (BIH) will be determined by adjusting Regulation of Environmental Ministry Numb. 12/2009 concerning the provisions of the distance between bio-pores, so it is assumed that every 1 m^2 area will be installed with 1 BIH, and how much runoff volume can be reduced, and the assumption that the land used has undergone compaction. The analysis was carried out at 3 locations as representatives referring to the inundation data survey obtained from the Public Works Departement of Highways and Drainage on Surabaya City as well as a map of soil types. Then, determining the broad portion of the location that can be used BIH installations such as green lanes, schoolyards, offices and so on, is done using Google Earth software. The calculation of BIH land use ratio to inundation area is done by using the equation below:

$$\%\ A_{BIH} = A_{BIH} / A_{in} \quad (6)$$

information:
$\%A_{BIH}$ = BIH land use ratio to inundation area
A_{BIH} = bio-pore infiltration hole land use (m^2)
A_{in} = inundation area (m^2)

For the calculation of runoff reduction is done by using the equation which can be reviewed below:

$$\% \text{ Reduction} = (V_{BIH} \times \text{number of BIH needed}) / V_{R\ in} \qquad (7)$$

information:
V_{BIH} = bio-pore infiltration hole volume (m^3)
$V_{R\ in}$ = initial runoff volume before BIH applied (m^3)

RESULTS AND DISCUSSION

Soil Texture of Test Fields

Based on the results of laboratory analysis, the soil sampled from the study site was dominated by fine-sized particles, where the soil in Kenjeran Beach Amusement Park was dominated by silt particles, while Lempung Urban Forest was dominated by clay particles. For the particle composition of the soil sampled can be seen in Table 2.

Table 2. Soil texture of test fields

Plot	Soil Texture	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
K1	Silty clay loam (0-25 cm)	0.011	0.120	63.652	36.217
	Landfill (26-100 cm)				
K2	Silt loam (0-25 cm)	0.167	4.707	74.428	20.698
	Landfill (26-100 cm)				
K3	Silt loam (0-30 cm)	5.387	13.960	64.026	16.627
	Landfill (31-100 cm)				
K4	Silt loam (0-30 cm)	0.423	1.843	81.456	16.278
	Landfill (31-100 cm)				
L1	Clay (0-100 cm)	0.284	20.308	19.376	60.031
L2	Clay (0-100 cm)	0.980	31.285	11.092	56.643
L3	Clay (0-100 cm)	0.713	14.759	23.166	61.362
L4	Clay (0-100 cm)	0.709	27.051	11.276	60.964

Hydraulic Conductivity Analysis

This analysis was carried out to determine the ability of the soil surface to drain water into the soil, and examine the effect of soil conditions namely soil type, land density and vegetation cover on hydraulic conductivity. The constant hydraulic conductivity from each test plot can be seen at Table 3.

Table 3. The constant hydraulic conductivity from each test plot

Test plot	K(cm/hr)	Q (cm^3/hr)
K1	20.89	24,616.54
K2	10.91	11,572.43
K3	16.88	16,914.78
K4	8.88	8,019.52
L1	12.39	9,736.42
L2	5.40	3,286.12
L3	10.85	7,674.78
L4	4.75	2,610.69

From Table 3 data above, it can be seen that test plot with the highest hydraulic conductivity value and water absorption rate is plot K1 with silty, vegetated and uncompacted soil. Meanwhile the smallest one is plot L4 with clayey, non-vegetated and compacted soil. For the comparison of hydraulic conductivity from conditioned test plots with control plots can be seen at Table 4.

From the Table 4 data, it can be seen that there are significant differences related to the effect of research variables or conditioning on soil with the hydraulic conductivity on each plot. If those data reviewed by the effect of compaction, the compacted plots have a lower constant hydraulic conductivity than the control plots which are not compacted. The previous study by Zhang et al. confirms this with some laboratory experiments [15]. Also, this confirmed with some explanation from Gregory et al. before, that compaction affects the physical properties of the soil while reducing the porosity and pore distribution in the soil [11].

Table 4. Comparison of hydraulic conductivity with control plot

Test plot	K (cm/hr)	Soil Conditioning	Control plot	K of control plot (cm/hr)	Difference (%)
K1	20.89	Vegetated	K3	16.88	+ 23.76
K2	10.91	Vegetated & Compacted	K3	16.88	- 35.37
K4	8.88	Compacted	K3	16.88	- 47.39
L1	12.39	Vegetated	L3	10.85	+ 14.19
L2	5.40	Vegetated & Compacted	L3	10.85	- 50.23
L4	4.75	Compacted	L3	10.85	- 56.22

At Kenjeran Beach Amusement Park, the constant hydraulic conductivity at plot K2 is 35.37% lower than the plot K3 and that on the plot K4 is 47.39% lower than the plot K3. Meanwhile at Lempung Urban Forest, the constant hydraulic conductivity at plot L2 is 50.23% lower than the plot L3 and that on the plot L4 is 56.22% lower than the plot L3.

From the vegetation cover existence, the vegetated plots have a higher constant hydraulic conductivity than the other plots which are not vegetated. This was confirmed by Gadi et al. that higher vegetation density in the soil results in higher hydraulic conductivity value [16]. Exception occurs on the soil conditioning that coupling both vegetation cover and compaction. Vegetation presences on the compacted soils cannot uplift the hydraulic conductivity value and that value is smaller compared to the control plots. But, it still higher compared to the test plots that only compacted and not vegetated.

At Kenjeran Beach Amusement Park, the constant hydraulic conductivity at plot K1 is 23.76% higher than the plot K3 and that on the plot K2 is 35.37% lower than the plot K3. Meanwhile at Lempung Urban Forest, the constant hydraulic conductivity at plot L1 is 14.19% higher than the plot L3 and that on the plot L2 is 50.23% lower than the plot L3.

Runoff Coefficient of Test plots

The average of rainfall height in the last 10 years and rainfall duration in the last 13 month calculated by data from nearest weather stations at Surabaya City are 99.61 mm and 2.28 hours, respectively. Based on test plot conditions, using UDFCD guideline book, the depression losses value for every vegetated soil are 0.35 in or 8.89 mm and 0.4 in or 10.16 mm for bare soils. The runoff coefficient of each test plot can be calculated together with all those data above and infiltration rate measurement.

Infiltration rate measurement is conducted to determine the constant infiltration rate from each test plot. After that, those data will be multiplied with average rainfall duration at Surabaya City to find the constant infiltration height. The result of measurements and infiltration height calculations can be seen at Table 5.

Table 5. The constant infiltration height from each test plot

Test plot	f (mm/hr)	F (mm)
K1	8.000	18.24
K2	1.999	4.5372
K3	1.999	4.5372
K4	1.333	3.03997
L1	1.500	3.42
L2	0.125	0.285
L3	1.000	2.28
L4	0.0625	0.1425

From Table 5 above, it can be seen that test plot with the highest constant infiltration rate and infiltration height in 2,28 hr is plot K1 with silty, vegetated and uncompacted soil. Meanwhile the smallest one is plot L4 with clayey, non-vegetated and compacted soil. For the result of runoff coefficient calculation can be seen in Table 6.

Based on Table 6 data, the plot that generates the highest runoff is the L4 plot with clay-textured, bare and compacted soil at 0.089308 m^3, while the plot with the lowest runoff volume is on K1 plots with silt-textured, with vegetation cover and uncompacted soil by 0.07248 m^3. The trends also happened with the runoff coefficient. The plot that has the biggest runoff coefficient value is the L4 plot with 0,896572, while the plot with the lowest runoff coefficient value is on K1 plot with 0,727638.

Table 6. The runoff coefficients of test plots

Plot	F (mm)	D_L (mm)	$(P-D_L-F)$ (mm)	V_R (m^3)	C
K1	18.24	8.89	72.48	0.07248	0.727638
K2	4.5372	8.89	86.1828	0.086183	0.865202
K3	4.5372	10.16	84.9128	0.084913	0.852453
K4	3.03997	10.16	86.41003	0.08641	0.867483
L1	3.42	8.89	87.3	0.0873	0.876418
L2	0.285	8.89	90.435	0.090435	0.907891
L3	2.28	10.16	87.17	0.08717	0.875113
L4	0.1425	10.16	89.3075	0.089308	0.896572

Analysis of Bio-pore Infiltration Hole Needs and Runoff Reduction

There are 3 locations that are used as representatives or samples for analysis of reduction based on inundation data and map of soil types, namely Arif Rahman Hakim St. with hydromorphic alluvial soil types, Satelit Selatan St. with gray alluvial soil types, and Imam Bonjol St. with dark gray alluvial soil. All these locations can be seen on Figure 2.

Fig. 2: Sample of inundation area at Surabaya City

The selection of these three locations is due to the existence of a green lane on the left, right, and or median of the road in the form of land overgrown by vegetation, where the place can be used for bio-pore expansion, so on Arif Rahman Hakim St., the characteristics of the land are represented by plot K2 (silty, vegetated and compacted soil) and for Satelit Selatan St. and Imam Bonjol St.'s characteristic soil is represented by plot L2 (clayey, vegetated and compacted soil). The results of the analysis can be seen in Table 7.

Based on Table 7, in terms of the amount of land use for BIH and the BIH needs, for silty soils, the percentage of land (% A_{BIH}) that can be used on Arif Rahman Hakim St. for the installation of BIH is 8.73% or 17 m^2 out of inundation areas in there, so the BIH needed that can be installed are 17 pieces. For clay soil, the percentage of land that can be used on Satelit Selatan St. for BIH installation of 25.97% or 177 m^2 out of 681.60 m^2 with BIH needed about 177 pieces and on Imam Bonjol St. the percentage of land that can be used is 4.09% or 420 m^2 out of 10,275.24 m^2 with BIH needed about 420 pieces.

Table 7. Bio-pore infiltration hole needs and runoff reduction from representative locations at Surabaya City

Location	A_{in} (m^2)	A_{BIH} (m^2)	BIH needs	% A_{BIH}	$V_{R\ in}$ (m^3)	Σ V_{BIH} (m^3)	% Runoff Red.
Arif Rahman Hakim St.	194.74	17	17	8.73%	16.78	0.449	2.67%
Satelit Selatan St.	681.60	177	177	25.97%	61.64	1.326	2.15%
Imam Bonjol St.	10,275.24	420	420	4.09%	929.24	3.147	0.34%

In regards to the reduction of runoff volume, for silty soils, the percentage of runoff reduction at Arif Rahman Hakim St. after the installation of BIH is 2.67%. For clay soil, the percentage of runoff reduction at Satelit Selatan St. after the installation of BIH is 2.15% and on Imam Bonjol St. the percentage of runoff reduction after the installation of BIH is 0.34%. Based on these calculations, to achieve the same amount of reduced runoff percentage, 2% or more for example, BIH land use ratio to inundation area on the silty soil tends to be lower than clayey soil when those type of soils are handled in same conditions (vegetated and compacted soils).

Because the compaction was only based on the duration and only have 2 variations between compacted and non-compacted soils, potentially the soils are not compacted enough or have a low degree of compaction, thus area needed for BIH installation and the amount of BIH may be higher on the land or soil with higher degree of compaction for reducing a small percentage of runoff water, especially in big cities with high land uses and in the tropical climate like Surabaya City.

CONCLUSION

The results of the study show that all three research variables have a significant influence on hydraulic conductivity and BIH requirements. Compaction can reduce the hydraulic conductivity in the range of 35.37 - 47.39% on silty soil and 50.23 - 56.22 on clayey soil. The presence of vegetation cover can increase the hydraulic conductivity around 23.76% on silty soil and 14.19% on clayey soil. With the same soil conditions, for example, vegetated and compacted soil, on the silty soil tends to have lower BIH land use ratio to inundation area and less BIH requirements than clayey soil in order to achieve the same amount of reduced runoff water ratio. However, this may be only applicable to the land or area that not have a high degree of compaction because the compaction variables were not on the wide range. And, that possibility requires further research.

REFERENCES

[1] McGrane, S.J. (2016). Impacts of Urbanisation on Hydrological and Water Quality Dynamics, and Urban Water Management: A Review. *Hydrological Sciences Journal*, 61(13): 2295-2311.

[2] Bosmans, J.H.C., van Beek, L.P.H., Sutanudjaja, E.H. and Bierkens, M.F.P. (2017). Hydrological Impacts of Global Land Cover Change and Human Water Use. *Hydrology and Earth System Sciences*, 21: 5603-5626.

[3] Sucahyanto, S., Setiawan, C. and Septiani, R. (2018). Land Cover Changes and Its Effect to Sediment Growth in Cacaban Reservoir, Tegal District, Central Java Province, Indonesia. *IOP Conference Series: Earth and Environment Science*, 145: 1-12.

[4] Apollonio, C., Balacco, G., Novelli, A., Tarantino, E. and Piccinni, A.F. (2016). Land Use Change Impact on Flooding Areas: The Case Study of Cervaro Basin (Italy). *Sustainability*, 8(996): 1-18.

[5] Zhou, Q. (2014). A Review of Sustainable Urban Drainage Systems Considering the Climate Change and Urbanization Impacts. *Water*, 6: 976-992.

[6] Hoang, L and Fenner, R.A. (2016). System Interactions of Stormwater Management using Sustainable Urban Drainage Systems and Green Infrastructure. *Urban Water Journal*, 13(7): 739-758.

[7] Li, L. and Bergen, J.M. (2018). Green Infrastructure for Sustainable Water Management: Practices of Five Forerunner Cities. *Cities*, 74: 126-133.

[8] Mguni, P. Herslund, L. and Jensen, M.B. (2016). Sustainable Urban Drainage Systems: Examining The Potential for Green Infrastructure-based Stormwater Management for Sub-Saharan Cities. *National Hazards*, 82: 241-257.

[9] Anggraeni, M., Prayitno, G., Hariyanti, S. and Wahyuningtyas, A. (2013). The Effectiveness of Bio-pore as an Alternative Eco drainage Technology to Control Flooding in Malang City (Case Study: Metro Sub-Watershed). *Journal of Applied Environmental and Biological Sciences*, 3(2): 23-28.

[10] Phillips, T.H., Baker, M.E., Lautar, K., Yesilonis, I, and Pavao-Zuckerman, M.A. (2019). The Capacity of Urban Forest Patches to Infiltrate Stormwater is Influenced by Soil Physical Properties and Soil Moisture. *Journal of Environmental Management*, 246: 11-18.

[11] Gregory, J.H., Dukes, M.D., Jones, P.H. and Miller, G.L. (2006). Effect of Urban Soil Compaction on Infiltration Rate. *Journal of Soil and Water Conservation*, 61(3): 117-124.

[12] van Hoorn, J.W. (1979). Determining Hydraulic Conductivity With The Inversed Auger Hole and Infiltrometer Methods. *Proc. Int. Drainage Workshop,* Rubi. 25, ILRI, Wageningen, the Netherlands.

[13] Noshadi, M., Parvizi, H. and Sepaskhah, A.R. (2012). Evaluation of Different Methods for Measuring Field Saturated Hydraulic Conductivity under High and Low Water Tables. *Vadose Zone Journal*, 11: 1-9.

[14] Guo, J.C.Y. and Urbonas, B. (2014). Volume-based Runoff Coefficients for Urban Catches. *Journal of Irrigation and Drainage Engineering*, 140(2): 1-5.

[15] Zhang, S., Grip, H. and Lovdahl, L. (2006). Effect of Soil Compaction on Hydraulic Properties of Two Loess Soils in China. *Soil & Tillage Research*, 90: 117-125.

[16] Gadi, V.K., Tang, Y., Das, A., Monga, C., Garg, A., Berretta, C. and Sahoo, L. (2017). Spatial and Temporal Variation of Hydraulic Conductivity and Vegetation Growth in Green Infrastructures using Infiltrometer and Visual Technique. *Catena*, 155: 20-29.