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RESEARCH PAPER

Stormwater Drainage Impact of Impervious Structures on Surrounding Soil

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Abstract

Data collection and data processing play a crucial role on storm water management. Meanwhile, pluvial floods have an increasing trend in the Mediterranean Region. Although climate change has altered flood events and their magnitude, anthropogenic impacts on flood recurrency and the associated damage cannot be ignored. Appropriate design of storm water infrastructure mostly depends on the existing hydrological data. In this study, the designing stage of a prototype storm water infrastructure together with the required data collection were explained. As a case study, the surrounding area of the indoor sports hall of Antalya Bilim University Turkey, has been investigated due to historical water accumulations in this area during the intense precipitation events. To this end, field infiltration tests and surveying studies were conducted across the target area. A 25-year design storm having the duration of 10 minutes has been used to estimate design runoff using the Storm Water Management Model (SWMM). The design criteria of the structure has been determined according to code of storm water design from the Environment and Urban Ministry of Turkey. The experimental results showed the recession coefficient of 0.647 for the surrounding soil profile. Maximum velocities and flow depths of the model output have shown that the existing drainage infrastructure isn't sufficient to handle design storm water events.

Keywords: Drainage; SWMM; Flood; Antalya

1. Introduction

Sustainability has become one of the tabloid subjects among engineering practices in recent years [20]. Conservation of water and water management is an important part of the concept of a sustainable city [7], [15] Historically, first drainage infrastructures lead back to third millennium B.C. in Indus civilization [13]. Ever since drainage infrastructures have been used to avoid seasonal floods, floods due to coastal storms, and those due to excessive rainfall events. Stormwater drainage systems also combined with the sewer systems in many regions [21, 4]. None the less this type of applications induce volatility on the infrastructure in the regions which intense precipitation events occur [18].

Usually, stormwater management is presented in the form of the water that is transport from different sources such as transportation system, domestic, building, and others in the way of rapidly and efficiently. This is established using the conveyance network of storm sewers, lined channel, roof drain, that all lead to consecrated water flow. This phenomena has substantial negative impact on reshaping streams, habitat damage and ecosystem disruption, introduction to new pollutant sources, and others [9]. On drainage infrastructure design precipitation intensity plays an important role. High intensity of precipitation can lead to serious issue in the drainage design and especially for a regions where the phenomena of precipitation is highly changes owing to the climate change [1, 16]. This is also acknowledged by the recent studies have indicated significant increase on precipitation intensity in many regions around the world [22, 17, 6, 11]. Hence precipitation intensity becomes more important rather than precipitation volume in some regions. On the other hand, unplanned urbanization creates volatility against high intensity precipitation events [14, 3]. Therefore, design stage of drainage infrastructure should take delicately on unplanned urban areas. Our investigations showed that in small scale construction projects in Turkey, such as the construction of university campuses, storm water risk might not be carefully considered in the design of storm water drainage systems. Therefore, in this study, source of the surface flow accumulation during high intensity precipitation event over Antalya Bilim University (ABU), Turkey, has been investigated and a solution has been suggested.

ABU campus located 18 km outside of the Antalya city center to the northern inland, Turkey. As a newly established university ABU campus being developed without a drainage infrastructure plan. Due to this reason medium to high intensity precipitation events results in surface water accumulations on impervious area as well as on uncultivated land. Experiences from the visual observations pointed out that uncultivated land accumulations more likely to be seen around impervious fields. As case study location, ABU sport center facility, has been chosen to perform this study. Sport center is surrounded by barren soil which creates better environment for taking soil samples and infiltration test. Roof of the facility is covered by polymer-based geomembrane which creates significant impermeable surface for the study area (See Figure 1).

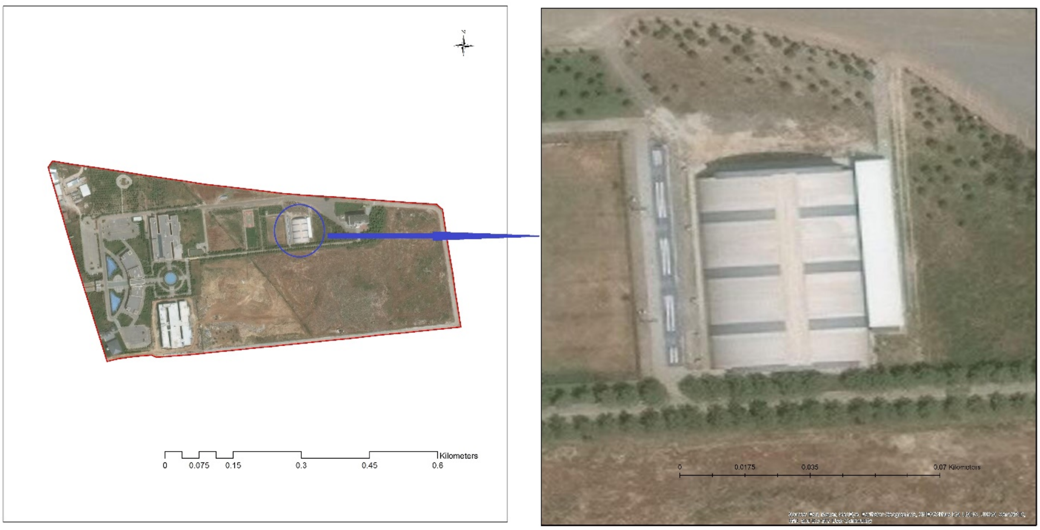

Figure 1: *Study area: Antalya Bilim University (left) and indoor sports hall (right).*

Antalya located in the Mediterranean region and high volume and intensity precipitations are well known fact for the region. Because of the extreme precipitations seasonal flood events deemed to be common in the City of Antalya. Under these circumstances planned urbanization and sufficient drainage infrastructure plays key role in the region from aspect of flood hazards. Table 1 shows the position of Antalya province among the largest volumes of precipitation events in Turkey.

Table 1: *Highest precipitation volumes that observed in Turkey. (From Turkish Meteorology Organization (MGM)).*

Duration	Precipitation (mm)	Location	Date
5 min	50.5	Hopa	07.07.1988
10 min	60.6	Hopa	07.07.1988
15 min	70.7	Hopa	07.07.1988
30 min	90.9	Hopa	07.07.1988
1 hour	131.0	Antalya	03.11.1995
2 hour	180.5	Antalya	03.11.1995
3 hour	230.9	Marmaris	11.12.1992
4 hour	332.3	Antalya	04.11.1995
5 hour	374.3	Antalya	04.11.1995
6 hour	390.3	Antalya	04.11.1995
8 hour	410.4	Antalya	04.11.1995
12 hour	428.1	Antalya	04.11.1995
18 hour	464.8	Marmaris	10-11.12.1992
24 hour	466.3	Marmaris	10-11.12.1992

2. Methodology

Soil texture and infiltration capacity relation has been reviewed in many studies [12, 19, 8]. On the field studies an observation pit with a depth of 2 m has been established and two set of soil samples has been collected from first 1.5 m and 1.5 to 1.7 m from the surface. Collected samples are subjected to sieve analysis and soil texture has been determined. Results validated in-site infiltration test results which conducted in the same region and with together leveling study example drainage line design for the structure established.

2.1 Soil Texture

Infiltration test and sieve analysis experiments were carried out to determine the soil structure and hydraulic properties within the study site. Within the framework of the data and observations obtained from these experiments, the necessary parameters for the drainage model were determined. As shown in Figure 2, an observation pit excavated on the south-west of the study location. In the observations made, the fill layer consisting of sandy and natural ground was found in the first 1.5 m section of the floor elevation; and clay units with a dark red color of 20 cm were found below 1.5 m. to 1.7 m below the ground. Also, after 1.7 m. limestone formations are observed, which is often seen in the center of Antalya.

In Figure 2 filler layer can be seen as light-colored with sandy texture. Two set of soil samples has been collected from first 1.5 m. and 1.5 m. to 1.7 m. Soil samples are subjected to sieve analyses and results are presented in Figure 3 and Figure 4.

Sieve analyses test have been conducted in Antalya Bilim University material laboratory according to ASTM standards. As can be seen from the gradation curves, the first 1.5 m layer has been determined as GW – GP (gravelly, sandy unit) and consists of a coarse-grained filling of sandy-gravelly and natural limestone formations. The 20 cm layer located 1.5 meters below ground level was determined as SM – SC (silty, sandy, clay unit). SM - SC units are units with high porosity and water holding capacity which is specific to Terra Rossa native to Mediterranean Region.

Figure 2: *The observation pit used in the study.*

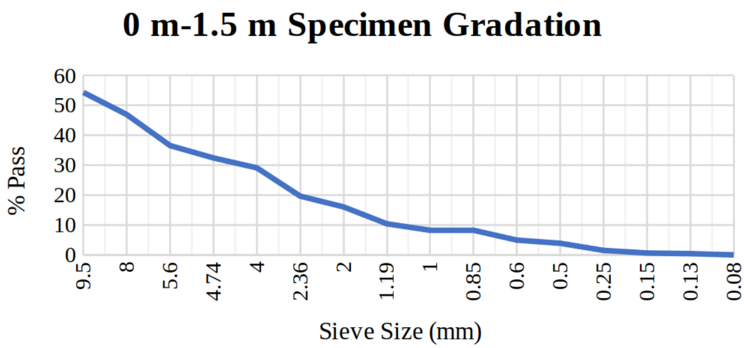

Figure 3: *Gradation curve for the soil 1.5 m depth from the ground level.*

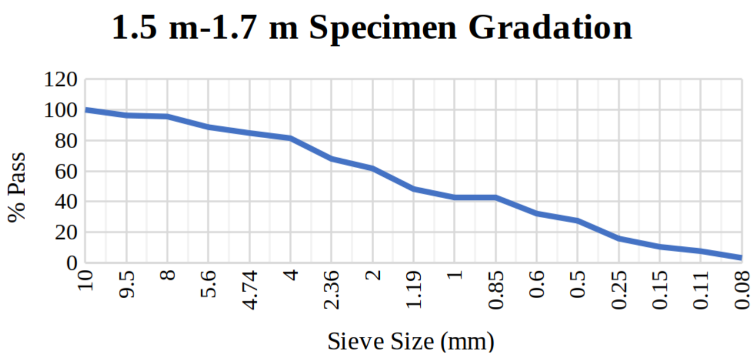

Figure 4: *Gradation curve for the soil 1.5 m to 1.7 m depth from the ground level.*

2.2 Infiltration Test

Infiltration test is an experiment that was used to determine the time-dependent infiltration volume of water into the soil. The experimental equipment is called infiltrometers. Infiltrometers are divided into two types: double ring and single ring infiltrometers [5]. The double cylinder infiltrometer is used for the site experiment which manufactured according to American Society for Testing and Materials (ASTM) standards with an inner ring diameter of 30 cm and an outer ring diameter of 60 cm (Figure 5).

Figure 5: *Double ring infiltrometer setup at the study area.*

The experiment in question is often used in the design of drainage systems and irrigation systems. Compared to the pressurized and unpressurized permeability experiments conducted in drilling wells, it is required to apply to the organic layer. In constant head and falling head permeability experiments, disturbance of the sample or insufficient representation of soil layers are the two well know issues. However, infiltration test can present closest infiltration values in site conditions. The test period is dependent on soil texture and often takes 5 to 7 hours. Principally test continues until infiltration rate converges with the horizontal axis (Figure 6).

Aim of the test is to determine saturated, unsaturated infiltration rates and "k" Horton recession constant which will be used as an input for the model in SWMM. Equation 1 expresses Horton formula f that states soil infiltration capacity during a storm event.

$$i - i_c = (i_0 - i_c)e^{-kt}, \tag{1}$$

where i is the momentery infiltration rate (cm/hour), i_0 is the innitial infiltration rate (cm/hour), i_c is the saturated infiltration rate (cm/hour), t is the passing time (hour), and k is the recession parameter.

The values of i_0 and i_c in Equation (1) has been determined as 70 cm/h and 30 cm/h, which are the points where the curve converges, respectively, in Figure 6. "k" recession constant has been calculated from the Equation (1), Table 2 and presented in Figure 7.

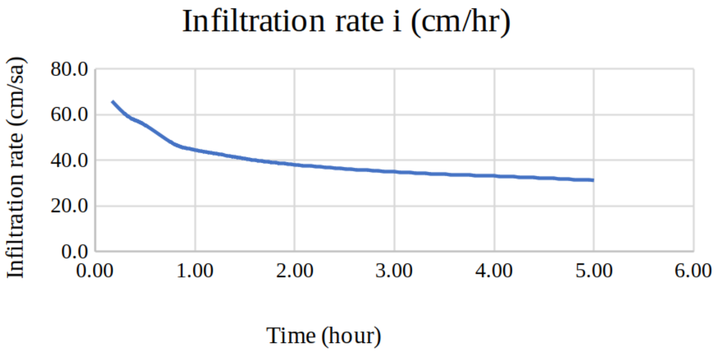

Figure 6: *Infiltration test results for total test duration 5 hours.*

Table 2: *Horton recession constant calculation from infiltration test results.*

Time (hour)	Cumulative Infiltration (cm)	Infiltration rate i (cm/hr)	$i - i_c$ (A)	$i_0 - i_c$ (B)	(A/B)	ln (A/B)
0.17	11	66.0	36.0	40	0.90	-0.11
0.33	19.7	59.1	29.1	40	0.73	-0.32
0.50	27.7	55.4	25.4	40	0.64	-0.45
0.75	36.1	48.1	18.1	40	0.45	-0.79
1.00	44.5	44.5	14.5	40	0.36	-1.01
1.50	61.1	40.7	10.7	40	0.27	-1.32
2.00	76.1	38.1	8.1	40	0.20	-1.60
3.00	104.6	34.9	4.9	40	0.12	-2.11
4.00	132.3	33.1	3.1	40	0.08	-2.57
5.00	156	31.2	1.2	40	0.03	-3.51

Considering the decrease on the infiltration rate drop; collected data found to be sufficient and experiment has been terminated on fifth hour. "ln (A/B)" vs "$-kt$" is plotted against time as in Figure 7. The slope of the resulting curve gives the parameter "k" and is determined to be 0.6468. The k parameter is used as an input to the model together with the infiltration capacity and the saturated infiltration rate.

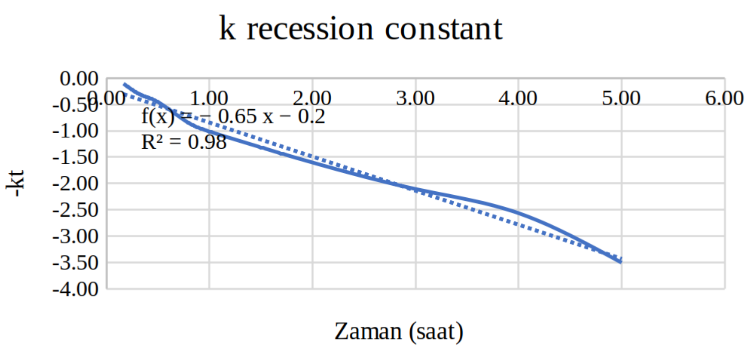

Figure 7: *"k" recession constant presented as the slope of the trend line.*

2.3 Leveling Study

To achieve topographical data that requires for SWMM model leveling study has been conducted (Figure 8). As a result of the leveling, surface shapes were obtained around the structure (Figure 8). As can be seen from modeling study, the A-B profile is on the agricultural embankment and has a different appearance to the natural structure of the land. Considering the natural slope of the land in the South-South-East direction, line outlet was established in the South-East corner of the structure in the model studies.

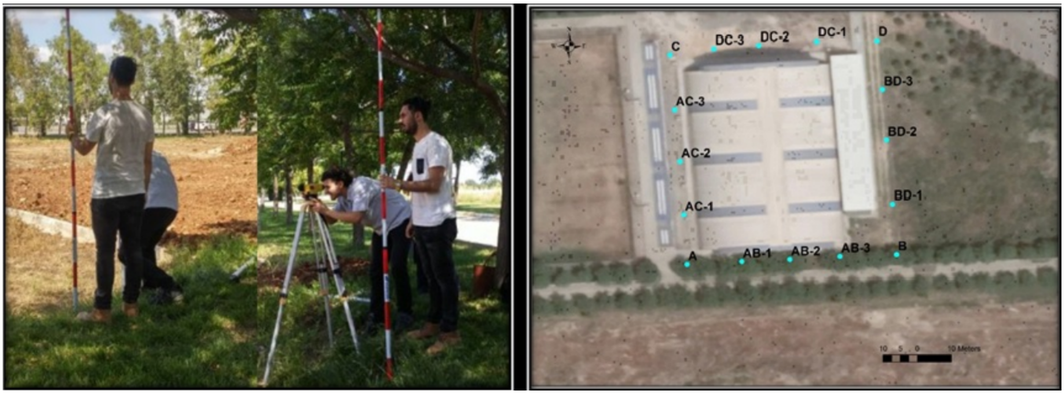

Figure 8: *Leveling study (left) around the target area and its drainage line plan (right).*

3. Results

To observe different scenarios more easily according to changing inputs and to evaluate precipitation - flow relations more easily, a mathematical model of the study area has been established. SWMM (Storm Water Management Model) software was used as the simulation environment in which the model was prepared. SWMM has been developed by the EPA (United States Environmental Protection Agency) in 1971 and gone through various of updates until today. Models utilize kinematical wave equation to simulate velocities and loads in the drainage infrastructure.

The design precipitation data were taken from the model output of the study conducted in the Antalya region [10]. Due to the small size of the study area design precipitation duration was taken as 10 minutes. Model suggests for 25 years repetition, 10 minutes duration rainfall event precipitation intensity of 2.851 mm/min. Subject area divided into sub-catchment areas and parameters for each sub-catchment determined (Figure 9). Slope for catchment number 9, 10, 11, 12, 13 and 14 have been taken as 30% regarding structures dimensions.

The relationship between precipitation and runoff in drainage areas has been established by the Horton infiltration curve. If the intensity of the precipitation is less than the momentary infiltration capacity, the precipitation infiltrates underground; In cases where the precipitation rate is greater than the momentary infiltration capacity, excessive precipitation built upon the surface. After surface storage filled model runs kinematic wave equation to simulate surface flow.

Surface storage amounts vary according to surface slopes and permeability and indicate the amount of precipitation that must be stored on the surface before it flows. The surface storage table, which is the output of Bennett's work in 2000, was used to determine the amount of surface storage (Table 3).

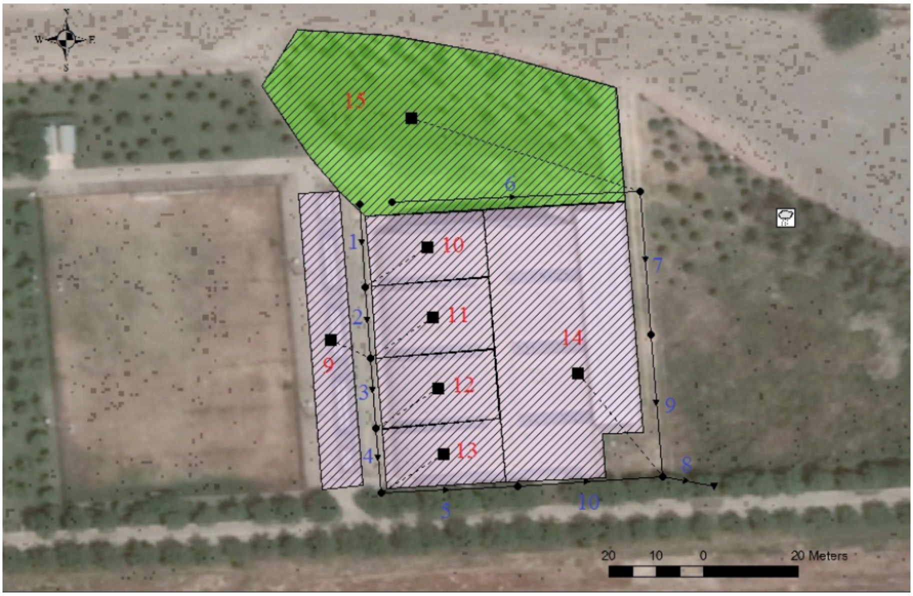

Figure 9: *Model Sub-catchments and drainage lines.*

Table 3: *Surface storage parameter estimation [2].*

Description	Slope %	Surface Storage (mm)		
		Min.	Ave.	Max.
Impervious area	-	3.2	4.8	6.4
Steep slope	> 30		1	
Moderate slope	5-30	6.4	9.55	12.7
Flat	0-5		50.8	

Due to grading that held during the construction and landscaping; permeable area surface storages taken as 50.8 mm which corresponds to flat surface. Impervious area surface storages have been taken as 3.2 mm (Table 3). The manning roughness coefficients in the drainage areas were taken as 0.010 due to the polyethylene-derived material on the top cover of the gymnasium and concrete structures taken as 0.016.

The data obtained from the topographic measurements has been used to design manhole depths, pipe inlet and outlet elevations. The western side of the roof of the gym is divided into four equal drainage areas, and the collected rainwater is planned to discharge to the manholes. Since the material from which the corrugated pipes are manufactured is polyethylene, the manning roughness coefficient for all pipes is taken as 0.010. Manhole inlet and outlet elevations of all pipes are designed to be 10 cm above the manhole floor elevation.

As can be seen from Table 4 simulation estimates the total precipitation to be infiltrated due to the high infiltration values in the drainage area number 15. In impermeable drainage areas, the difference between precipitation and flow heights is due to the amount of surface storage.

In Figure 10, the simulated flow rate (10a) and pipe capacity (10b) can during the designed storm event be seen.

Table 4: *Drainage area simulation results.*

Drainage Area	Total Precipitation (mm)	Total inflow to the area (mm)	Total Infiltration (mm)	Total Flow Height (mm)	Peak Flow Rate (m^3/s)	Flow Coefficient
9	28.51	0	0	23.95	0.02	0.84
10	28.51	0	0	25.29	0.02	0.887
11	28.51	0	0	25.29	0.02	0.887
12	28.51	0	0	25.29	0.02	0.887
13	28.51	0	0	25.3	0.01	0.887
14	28.51	0	0	25.25	0.08	0.886
15	28.51	0	28.51	0	0	0

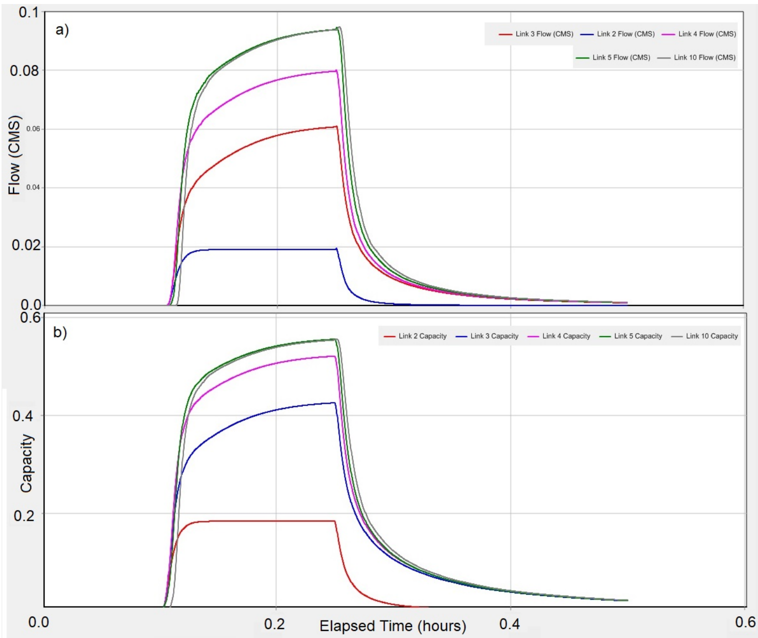

Figure 10: *Conduit runoff hydrograph (a) and Capacity (b) during the storm.*

In design, the conduits sizes surrounding the structure and discharge conduit have been taken as ∅300 mm and ∅400 mm respectively for infrastructure to handle the design storm discharge. For all the conduits maximum permissible velocity and maximum capacity has been used respectively 5 m/s and %80 according to the regulations of Environment and Urban Ministry of Turkey. According to the model output, example design is capable of draining storm water due to the design precipitation event.

4. Conclusion

According to the infiltration test and laboratory results from soil specimens points out that topsoil layer has high infiltration capacity and requires excessive intense precipitation events to build up water accumulations. Also sieve analyses results further supports the argument presented in section 2.1. Consequently, only compelling reason for the water accumulations around the structure seem the temporal water accumulations due to surface water flow from the impervious area of the structure.

Our results showed that the existing drainage infrastructure design with Ø100 mm corrugated conduits are not sufficient to handle intense precipitation events. Future more lacking or improperly placed connections between barbicans and manholes forces existing infrastructure to drain mostly from soil while in saturation condition. From the results it is easy to articulate on the importance of the drainage infrastructure planning before structure construction begins, especially for the structures have high surface areas. Increasing precipitation intensities due to global climate change further increase the importance of flood safe urban design.

Conflicts of Interest: **The authors have no conflict of interest to any part.**

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