Effect of the Pervious Concrete and Scoria Rock Permeability to Micro-Hydropower Generation from Stormwater

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Abstract. Micro-hydropower is a most sustainable source of energy that may generate 2kW to 100kW of electricity. The production of electrical power of micro-hydropower is from kinetic energy converted into electrical energy by the flow of water through a drain or channel and distribute to the desire location. In urban areas, micro-hydropower is generated through the flow of water from surface runoff. The source of flow is surface runoff on the impermeable layer that contain particles and suspended solids. These particles and suspended solid are unfavourable for the turbines used in micro-hydropower as they may slow the rotation, thus decreasing the generation of electricity. Filter media is a significant component in micro-hydropower. Stormwater will permeate through the filter media and the flow will rotate the turbines to generate electricity. In this study, stormwater is treated through filter media of pervious concrete and scoria rocks. It is expected to improve the efficiency of the turbine rotation. This is important in maintaining the production of electricity through micro-hydropower.

1. Introduction
Renewable energy is a form of energy known to have a lesser impact on the environment. Hydropower is considered a vital source of renewable energy. Based on Erinofardi [1] electricity from hydropower is the most economical and reliable. Its role has been well established and utilized specifically in the energy sector. This kind of renewable energy plays a crucial role in developing countries. In some countries, hydropower is the only energy that has the potential to be expanded to large populations [2].

According to Bairwa [3], there are several sizes of hydropower, namely large hydropower, medium hydropower, small hydropower, mini-hydropower, micro-hydropower and pico-hydropower. This study is focussing on the development of micro-hydropower generation from stormwater sources. The technique involves the physical treatment of stormwater sources and could generate at least 5kW to 100kW of electricity. Basically, the generation of power by micro-hydropower are from kinetic energy that is form by the flow of water thus rotates the turbine which is then produced electrical power from the generator [4]. The installation of micro-hydropower can provide electricity for an isolated home, or small community. The installation takes place usually depending on the desire capacity or usage. It has been installed all around the world along streams, nearby waterfalls or even in a drainage system.

Micro-hydropower runs from a source of kinetic energy, namely flowing water that moves the turbine. In urban areas, stormwater runoff is a source of kinetic energy that produces electricity through moving turbines. Every year precipitation in Malaysia is 3000 mm, equivalent to 990 billion m³ for the whole nation. This abundant rainfall turns into stormwater runoff, especially in urban areas, which have more impervious surfaces as compared to pervious surfaces. The stormwater runoff contains
contaminants which will either end up in groundwater or transferred through the pavement along the drainage system.

Stormwater runoff has various types of pollutants and particles including sediments, litter, organic matter, nutrients, heavy metal, oils and pesticides [5]. For micro-hydropower, these particles present will affect the efficiency of turbines, resulting in diminished electricity production. To minimize this problem, installation of filter media is a good initiative in minimizing the effect. Pervious concrete is a good match as a filter media, because it would help to filter particles from surface runoff. Pervious concrete is a type of concrete that is good in permeability and is often used as pavement.

2. Description of study area
The samples of surface runoff were taken in Shah Alam at three locations shown in figure 1 below. Point 1 is in Seksyen 7 at Sekolah Kebangsaan Seksyen 7 (figure 2 and figure 3), Point 2 is in Seksyen 14 at Masjid Sultan Salahuddin Abdul Aziz (figure 4 and figure 5), and Point 3 is in Seksyen 22 in a residential area (figure 6 and figure 7). These three locations are chosen because of their surroundings were expected to complement the installation of micro-hydropower.

![Figure 1](image1.jpg)

**Figure 1.** The samples of stormwater were taken at Seksyen 7 (Point 1), Seksyen 14 (Point 2) and Seksyen 22 (Point 3).
Figure 2. Point 1 located in front of Sekolah Kebangsaan Seksyen 7, Shah Alam (Side View).

Figure 3. Point 1 located in front of Sekolah Kebangsaan Seksyen 7, Shah Alam (Front View).

Figure 4. Point 2 located inside Masjid Sultan Salahuddin Abdul Aziz, Seksyen 14 (Side View)

Figure 5. Point 2 located inside Masjid Sultan Salahuddin Abdul Aziz, Seksyen 14 (Plan View)

Figure 6. Point 3 located at residential area, Alam Sanjung, Seksyen 22 (Side View).

Figure 7. Point 3 located at residential area, Alam Sanjung, Seksyen 22 (Front View).
3. Methodology
This study was conducted in five stages. The first stage was the preparation of materials for both pervious concrete and scoria rocks. The materials used were cement, water, aggregate (10mm – 20mm), scoria rocks and surface runoff. Pervious concrete filter media materials were adopted from Huang [6].

In second stage, the specimen for filter media, including concrete and scoria rock, were fabricated and cast into 100 mm Ø X 200 mm height of cylinder for the mixing and curing of the pervious concrete. The ratio of cement, aggregate, water (1:4.5:0.5) was adopted from Huang [6]. After 24 hours, the moulded pervious concrete was demoulded and cured in a tank.

In the third stage, the fabricated filter media were tested for permeability. A scoria rocks filter media was placed in a cylinder mould with a permeated cover. Third stage were testing on the permeability parameter. Pervious concrete and scoria rocks were both tested on permeability test. The stormwater samples were tested for turbidity and suspended solids before and after going through the media. The permeability test was measured according to EN 12697–40: 2011. The testing was repeated with three different samples in Shah Alam. From the results, the range of energy generation based on the rate of water flow after the treatment has been estimated.

Last but not least the data collection will be analysed. In order to get a good analysis and result in this study, the procedure in the making of it must be reliable, specific and precise. In this chapter, the procedure of the fabrication of filter media and testing of turbidity and suspended solid were explained. Generally, it is divided into five stages.

3.1 Material and Samples of Specimens
Pervious concrete is based on the standard from pervious research and British Standard. Table 1 shows the mix proportion for pervious concrete that is adopted from Huang [6].

| Aggregate Size (mm) | Cement (kg/m³) | Coarse Aggregate (kg/m³) | Water (kg/m³) |
|--------------------|----------------|--------------------------|---------------|
| 10 – 12            | 10.15          | 22.04                    | 1.13          |

The scoria rock filter media were prepared using the same size and shape of the pervious concrete media. Scoria rock at around 8 mm to 10 mm was installed in a mould of 100 mm diameter, with a height of 200 mm.

3.2 Testing of Permeability by Outflow Meter
The flow rate in this study was determined by the volume of water passing through the filter media and entering the turbine per unit time [7]. Pervious concrete and scoria rock have very good permeability characteristics. The standard test method for measuring texture drainage is EN 12697-40: 2011. Permeability was tested by using outflow meter device as shown in Figure 8 below.

![Figure 8. Outflow meter that are setting up for permeability test.](image)

An outflow meter is a device that measures the time (in second) needed for a quantity of water to flow through the voids of the specimen under the gravitational pull. The samples of stormwater taken from three different locations were filled in the Outflow Meter device as shown in the Figure 8. The filter media were placed right below the device, where the outflow is discharged pass through the media. Figure 8 above shows the position of the filter media and outflow meter device. The valve was opened...
and the time taken for the water to flow through the media was measured. From this test, the surface drainage of the pavement or specimen can be evaluated.

3.3 Turbidity Test
Turbidity is the presence of cloudiness in the water sample. Generally, it is the result of silt, sand or mud. In this study, turbidity has been measured in terms of Nephelometric Turbidity Units (NTU) and tested using a turbidity meter as shown in Figure 9. Each sample was tested before and after going through the pervious concrete and scoria rocks filter media. The table below shows the samples tested for this study. The average of each point location is taken. The filtered water indicates the quality of the water.

![Figure 9. Turbidity meter that measure in NTU.](image)

3.4 Suspended Solid Test
Total suspended solids were measured using a Spectrophotometer in the Environmental Laboratory, as shown in Figure 10. There were three locations at which the samples were which in Shah Alam. Each location had nine samples tested for suspended solids, as shown in the table below. The results are then recorded and analysed in the next section.

![Figure 10. Spectrophotometer.](image)

3.5 Data Collection and Analysis
All the data were tabulated and analyse appropriately and accordingly. The results for the study include the infiltration rate from the permeability test, turbidity from the turbidity test and suspended solids from the spectrophotometer. The turbidity and suspended solids are represented in terms of the actual value and after treatment value. The parameters that will be used in future are the permeability of pervious concrete and scoria rocks, the turbidity index and total suspended solid before and after flowing through the media. These results are plotted for a comparison of performance of pervious concrete structures and scoria rocks filter media.

4. Results and Discussion
4.1 The Permeability of Pervious Concrete and Scoria Rock
Pervious concrete is well known for its high infiltration rate. The composition structure of pervious concrete has a porosity which allows water to pass through. It also has been utilised in many industries for years because of its ability to infiltrate water. All the three points were taken in Shah Alam, Selangor.
Point 1 had the highest flow rate. The maximum recorded discharge was 0.068 L/s. Point 3 recorded the lowest discharge at 0.0425 L/s. Point 1 (in front of a school) had the lowest particles and sediment present. Point 3 (near a residential area) had the most particles and sediment present.

| Location       | Pervious Concrete | Scoria Rocks |
|----------------|-------------------|--------------|
| Point 1 (Seksyen 7) | 0.0585            | 0.0680       |
| Point 2 (Seksyen 14) | 0.0562            | 0.0610       |
| Point 3 (Seksyen 22) | 0.0425            | 0.0530       |

Scoria rocks also have good permeability and produced a higher discharge rate than pervious concrete for all three location of studies. On average, the discharge passing through scoria rock was 0.0607 L/s while that of pervious concrete was 0.0524 L/s. As shown in Table 2, the highest filtration rate was at Point 1 (Section 7), while the lowest filtration rate was at point 3 (Section 22). The trend appears to be the same as for pervious concrete, as Section 7 recorded the highest discharge at 0.0585 L/s and Section 22 had the lowest with at.0425 L/s. Point 2 located in Section 14 was in the middle for both treatments.

Figure 11. Permeability of Pervious Concrete and Scoria Rock.

Figure 11 shows the permeability of pervious concrete and scoria rock. It is clear that samples taken at Point 1 had the highest discharge. Scoria rocks outperformed pervious concrete in terms of permeability for all three locations. This is because of the void between the rocks and the void between scoria itself helps the stormwater permeate more rapidly. The composition of scoria rock also helps in infiltrating the stormwater well [8]. Therefore, this filter media would help in mitigating pollution with acceptable discharge. In addition, the infiltration process is a technique that has been recognised to effectively manage the volume of urban runoff and mitigate the pollution of water [9].
4.2 Turbidity of Surface Runoff (NTU)

Turbidity is the amount of cloudiness present in a stormwater sample [10]. It is also known as the reduction of clarity in water due to the presence of suspended or colloidal particles. Turbidity is measured by the amount of light which is reflected by the particles.

This study used a turbidity meter to measure the cloudiness or haziness of the stormwater samples. Sample testing involved pre- and post-treatment. The test compared the performance of both filter media. Table 3 shows turbidity level before and after the stormwater flowed through the media.

Table 3. Turbidity before and after treatment (NTU).

| Location          | Before Treatment | After Treatment |
|-------------------|-----------------|----------------|
|                   | Pervious Concrete | Scoria Rocks   |
| Point 1           | 6.26            | 4.73           | 4.46           |
| (Seksyen 7)       |                 |                |                |
| Point 2           | 8.94            | 6.93           | 4.78           |
| (Seksyen 14)      |                 |                |                |
| Point 3           | 11.6            | 11.2           | 7.98           |
| (Seksyen 22)      |                 |                |                |

Point 3 has the highest turbidity for all three locations. Pervious concrete does not do well as scoria rock in removing turbidity in the surface runoff sample in this study. While Point 1 has the lowest turbidity index before and after treated by pervious concrete and scoria rocks that is 4.73 NTU and 4.46 NTU. Figure 12 indicate the performance in removing turbidity for both pervious concrete and scoria rock. In overall scoria rocks does surpass the performance of pervious concrete in treated turbidity.

![Figure 12. Turbidity Measurement before and after treatment in NTU](image)

Pervious concrete and scoria rocks were displaying its capability in improving the turbidity of the stormwater samples for all three locations. Scoria rock has an average of 35.5% turbidity removal of the stormwater sample. Percentage removal of turbidity for pervious concrete is 16.79%. At Point 3, the performance in removing turbidity between pervious concrete and scoria rock shows a significant difference. Turbidity removal efficiency of pervious concrete were 3.45%, while, scoria rocks turbidity removal was 31.21%. The total gap difference at Point 3 were 27.76%. Based on the removal efficiency, it is clear that scoria rocks excel in treating turbidity of stormwater sample with 46.53% of removal at Point 2 (Masjid Sultan Salahuddin Abdul Aziz). In the contrary, pervious concrete were not as good as scoria rocks especially at Point 3 where in only has 3.45% of removal as shown in Table 4.
4.3 Total Suspended Solid (TSS)

Total suspended solid was tested for the stormwater sample before and after treatment. The test is run by using Spectrophotometer. Based on Table 5, total suspended solid were highest at Point 3 (residential area) while the lowest at Point 1 (parking lot area). Total suspended solid after treatment are the lowest at Point 1 after treatment for both pervious concrete and scoria rocks. Sharing the value at Point 2 for scoria rocks after filtered also 9 mg/L of TSS.

Table 5. Total suspended solids before and after treatment (mg/L).

| Location | Before Treatment | After Treatment |
|----------|------------------|----------------|
|          | Pervious Concrete | Scoria Rocks   |
| Point 1  |                  |                |
| Seksyen 7| 15               | 9              |
| Point 2  |                  |                |
| Seksyen 14| 18              | 11             |
| Point 3  |                  |                |
| Seksyen 22| 29              | 15             |

Figure 13 shows the result of total suspended solid before and after the stormwater sample passing through the media. Both filter media were good in removing suspended solid because of significant removal of suspended solid. However, scoria rocks are slightly performed better in removing suspended solid.

Table 6 shows the removal efficiency of suspended solid after passing through pervious concrete and scoria rock. The highest removal efficiency at Point 3 for scoria rocks media with 55.17%. While...
the lowest were at Point 2 for pervious concrete media which is 38.89% of removal. The average removal efficiency of suspended solid for both pervious concrete and scoria rocks are 42.39% and 48.39% respectively.

### Table 6. Removal efficiency of suspended solid (%).

| Location   | Pervious Concrete | Scoria Rocks |
|------------|-------------------|--------------|
| Point 1    | 40.00             | 40.00        |
| Seksyen 7  |                   |              |
| Point 2    | 38.89             | 50.00        |
| Seksyen 14 |                   |              |
| Point 3    | 48.28             | 55.17        |
| Seksyen 22 |                   |              |

It is crucial to remove the existence of suspended solid or silt as it may result in reducing the operational life of a micro-hydropower [7]. It was also stated that hydropower was abandoned in Malawi because of the suspended solids present in the flow [11]. Pervious concrete and scoria rock are a suitable option in preventing such an incident.

### 4.4 Power Generation from Discharge Passing through Scoria Rock Media

Table 7 tabulates the range of energy generation based on the rate of water flow after the treatment. The power generation is calculated by using equation, \( P = N \rho gQH \).

### Table 7. Power generation based on head discharge after treatment.

| Scoria Rocks | Power = N\(\rho\)gQH (kW) |
|--------------|----------------------------|
|              | Head (m)                   |
|              | 0.5 | 1  | 2  | 3  |
| Point 1      |     |    |    |    |
| Section 7    | 0.234| 0.467| 0.934| 1.401|
| Point 2      |     |    |    |    |
| Section 14   | 0.210| 0.419| 0.838| 1.257|
| Point 3      |     |    |    |    |
| Section 22   | 0.182| 0.364| 0.728| 1.092|

Figure 14 shows the power generation against head based on location at Point 1, Point 2 and Point 3 were all located in Shah Alam, Selangor. The graph in Figure 14 shows that power generation, \( P \) is directly proportional to the head, \( H \), for all three locations. Point 1 would produce the most energy out of these three locations. This may be because the suspended solids contained in the sample form Point 1 were the least, thus promoting higher flow rate and power production.

The filtration of particles and suspended solids also give a significant impact. It is followed by point 2 which located at Section 14 with a range of 0.21 kW to 1.257 kW. Point 3 (located in Section 22) had the lowest range of power from 0.5 m to 3m at 0.182 kW to 1.092 kW. The overall range of power after the stormwater was treated by scoria rock was 0.182 kW to 1.257 kW, which according to Bairwa [3]; Erinofiaradi [1] is enough to produce electricity for a few houses.
Furthermore, the graph in the figure 14 also indicate that point 1 has the most potential to be installed micro-hydropower since it may generate up to 2kw. It is followed by point 2 and point 3 which also in acceptable range of power. Therefore, based on the stormwater taken from all three location, Shah Alam (Section 7, Section 14 and Section 22) is possible to have a micro-hydropower since it may generate from 0.182 kW to 1.257 kW which believe were enough to provide electricity to number of houses [1].

4.5 Power Generation from Discharge Passing Through Pervious Concrete Media

Power that may be generated from the discharge that flow through pervious concrete are presented in table 8 and the graph in figure 15. Table 8 indicates that power generated based on the discharge of stormwater from Point 1, Point 2 and Point 3. This discharge was filtered by pervious concrete media. The table also includes head differences to illustrate the trends with increasing head sizes. The head differences used are from 0.5 m to 3 m, and were chosen based on Shah Alam terrain.

**Table 8.** Power generation based on head and discharge passing through pervious concrete media.

| Pervious Concrete | Head (m) | Power = NpgOH (kW) |
|-------------------|----------|---------------------|
|                   | 0.5      | 1                   | 2           | 3           |
| Point 1 Seksyen 7 | 0.201    | 0.402               | 0.804       | 1.206       |
| Point 2 Seksyen 14| 0.193    | 0.386               | 0.772       | 1.158       |
| Point 3 Seksyen 22| 0.146    | 0.292               | 0.584       | 0.876       |

Power generated from stormwater flow treated by pervious concrete is the highest at point 1 for all the heads. The range is from 0.201 kW to 1.206 kW. It is followed by Point 2 at 0.193 kW to 1.158 kW and Point 3 at 0.146 kW to 0.876 kW, which is the lowest among these three locations. This range is affected by the composition of pervious concrete which allow the stormwater to permeate in a range of flow rates [6,12].
Figure 15 illustrates the possible generation of power outcomes from discharge of stormwater through the pervious concrete media. Point 1 and Point 2 have nearly the same power generation rate, while point 3 has a significant decrement. This is due to the stormwater at Point 3 being a bit murky compared to Point 1 and Point 3. This affects the flow rate and power that can be generated. Pervious concrete also has slightly poorer performance than scoria rocks.

4.6 Relationship Between Power Generation, Turbidity and Total Suspended Solid

Scoria rock and pervious concrete media showed good performance for micro-hydropower generation. Both media may generate power for a few houses which is good in urban area since it has limited of land use. The generation of power that is possible to be produced is affected by the quality and characteristics of the stormwater. Different places have different amounts and types of particles in stormwater. Shah Alam is an urban area that were chosen for this study which the sample were taken. Table 9 shows the results of power over hydraulic conductivity, K, suspended solid and turbidity for both pervious concrete and scoria rock. This table indicates the final analysis in finding the relationship of the objectives of this study.

Table 9. Power generation/hydraulic conductivity, total suspended solid and turbidity from pervious concrete and scoria rock.

| Location | Power / Hydraulic Conductivity, K | Removal of Total Suspended Solid (%) | Removal of Turbidity (%) |
|----------|----------------------------------|--------------------------------------|--------------------------|
|          | Head (m)                         |                                      |                          |
|          | 0.5 | 1 | 2 | 3 | PC | SR | PC | SR | PC | SR | PC | SR | PC | SR | PC | SR |
| Point 1  | Seksyen 7 | 9.3 | 2.9 | 18.6 | 5.8 | 37.3 | 11.6 | 56.0 | 17.5 | 40.00 | 28.75 |
| Point 2  | Seksyen 14 | 8.3 | 2.6 | 16.7 | 5.2 | 33.5 | 10.4 | 50.2 | 15.7 | 50.00 | 46.53 |
| Point 3  | Seksyen 22 | 7.2 | 2.2 | 14.5 | 4.5 | 29.1 | 9.1 | 43.6 | 13.6 | 55.17 | 31.21 |

Pervious concrete and scoria rock media had a significant impact on the generation of micro-hydropower. These media would decrease the flow of stormwater. Figure 16 shows the relationship between the generation of power affected by pervious concrete and scoria rock media from the
stormwater. The two main parameters influencing stormwater flow are turbidity and total suspended solids.

Total suspended solid is one of the most visible indicators of water quality because of its physical characteristics. These suspended particles can come from various sources such as soil erosion, runoff, discharges and land used.

![Graph](image)

**Figure 16.** Power generation from scoria rock and pervious concrete with its turbidity and total suspended solid removal.

Figure 16 shows that the highest percentage removal of total suspended solid is at Point 3 with scoria rock media. The high amount of total suspended solid contributed to the higher percentage of removal. This is because Point 3 was located nearby an unfinished site project. This slowed down the flow rate of stormwater infiltrating through the media. Eventually, this will decrease the power generated by micro-hydropower. This was supported by Shaw & Schmidt [13], as filter media will slow down the flow of surface runoff or stormwater.

Based on these three locations, scoria rock media performed better in removing total suspended solid and turbidity as compared to pervious concrete media. This relates to its generation of power, as scoria rock is estimated to produce higher power generation, while pervious concrete was slightly lower. However, both filter media were able to filter the stormwater with a range that can produce electricity up to two houses [3]. The utilization of scoria rocks and pervious concrete may promote the ‘Low Impact Development’ program. Pervious concrete is also a suitable material for road pavement, especially for low volume traffic and parking lot areas [14].

In conclusion, point 1 located at Section 7 in a sidewalk parking area is the most suitable location for micro-hydropower. This is because of particles and suspended solids being the lowest, leading to increased effectiveness of both filter media. This would provide a better amount of power at up to 2 kW.
According to Bairwa [3] and Erinofardi [1], it is enough to provide for few houses which will benefit urban areas. It will give an acceptable amount of renewable energy that would have a significant impact for the sustainable use of power. Point 2 and Point 3 are also possible locations for micro-hydropower, since they would produce range of energy just a slightly lower but in an acceptable range.

5. Conclusions
This study is initiated to analyse the permeability of pervious concrete and scoria rock and how it gave impact towards the generation of power by micro-hydropower. The infiltration rate for both pervious concrete and scoria rock are observed and compared. The effect of pervious concrete and scoria rock as a filter media for micro-hydropower were concluded.

The infiltration rates of stormwater passing through pervious concrete for Point 1, Point 2 and Point 3 were 0.0585 L/s, 0.0562 L/s and 0.0425 L/s, respectively. Scoria rock media had better performance in permeability as compared to pervious concrete at 0.068 L/s, 0.061 L/s and 0.053 L/s for Point 1, Point 2 and Point 3, respectively.

The turbidity removal efficiency for pervious concrete and scoria rocks are 16.70% and 35.50%, respectively, while the suspended solid removal efficiency for pervious concrete and scoria rocks reached 42.39% and 48.39%. This shows that scoria rock has better removal efficiency for both turbidity and suspended solid.

The range of power generation based on the flow rate of stormwater sample for pervious concrete was from 0.146 kW to 2.01 kW, with heads of 0.5 m and 3 m respectively. The range of power generation for scoria rocks was from 0.182 kW to 2.335 kW for a head of 0.5 m to 3 m, respectively. This indicates that scoria rocks filter media would produce more electricity as compared to pervious concrete, but both have an acceptable potential rate of power generation.

Acknowledgement
The authors would like to thank the Universiti Teknologi MARA in providing the grants; 600-RMC/LESTARI SDG-T 5/3 (121/2019) as the financial support for this research.

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