

The Permeability of Different Materials: Testing the Infiltration of Gravel, Sand, Rubber Paver, Concrete, and Compressed Dirt

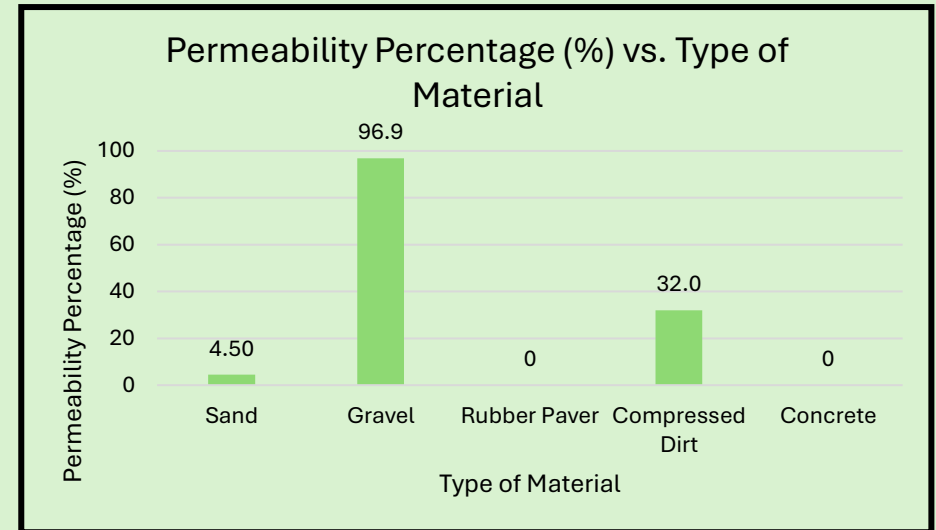
Research Question:

Observing the differences in permeability between sand, gravel, rubber paver, concrete, and compressed soil.



Photo Credit: Jiayi Zhang

Data Analysis:



Procedure:

1. A testing box was built.
 - a. Four wooden planks were glued as sides.
 - b. Mesh was glued as a bottom.
 - c. Box was put on a slope using diagonally cut wooden beams.
2. The box was filled with testing material (concrete was the only material didn't use the testing box).
3. Water was poured over the testing material.
4. The water collected was measured in infiltration, runoff, and excess.
5. The testing material was discarded, and steps 2-4 were repeated for the other materials.

Conclusions:

- Gravel has the greatest permeability and one of the lowest runoff amounts out of all tested materials, with a 96.9% permeability percentage and 0 mL of runoff.
- Concrete has the lowest permeability and highest runoff of all materials, with an 83.5% runoff percentage, 0 mL of infiltration, and only 15.7 mL of excess (out of 95.7 mL total poured).
- Sand has the highest absorption amount out of all the tested materials, due to its high excess amount of 209 mL out of 219 mL total.

Rapid Urbanization Leads to an Increase in Impermeable Surfaces

What is it?

- The conversion of non-urban land (e.g., agricultural areas, forests, and grasslands) into urban areas.¹
 - Urban areas are concentrated human settlements that change their landscapes through various anthropogenic activities – such as cities or towns.¹
- The world is currently going through rapid urbanization.
- Urban infrastructure includes paved surfaces like roofs, asphalt roads, etc.³
 - Roads in this context are defined as lanes of transport for motor vehicles
 - Often, urban infrastructure are impermeable surfaces.

Why is it a problem?

- Impermeable surfaces don't allow for infiltration due to little pore space (air pockets).
 - They decrease ground water recharge and disrupts the hydrologic cycle.⁶
 - They deteriorate topsoil.⁴
 - They increase runoff which can carry pollutants into nearby freshwater.⁴
 - Flooding risk increases.⁶
- Urban heat island effect happens because artificial, paved surfaces (often darker colored with lower albedo) absorb and conduct heat much easier than vegetation or soil.⁴



Permeable vs. Impermeable Pavements

What is it made of?

➤ Impermeable Pavements -

- Aggregate (gravel, crushed stone, etc.) held together by bitumen or cement.²
 - Bitumen (petroleum residue) is used to make asphalt.²
 - Cement is used to make concrete.²

➤ Permeable Pavements -

- Since the technology is still largely under development, the materials and structure vary widely.³
- Full depth permeable pavement (FDPP) refers to a structure with multiple permeable layers and subsurface layers made of high particle size aggregates to increase porosity.³
- Interlocking pavers.³

Why is the integration of permeable pavements such a challenge?

- An inverse relationship between porosity/infiltration and strength limits its applicability in high stress situations.²
 - Compaction decreases permeability.⁶

Different versions of permeable full depth permeable pavements.

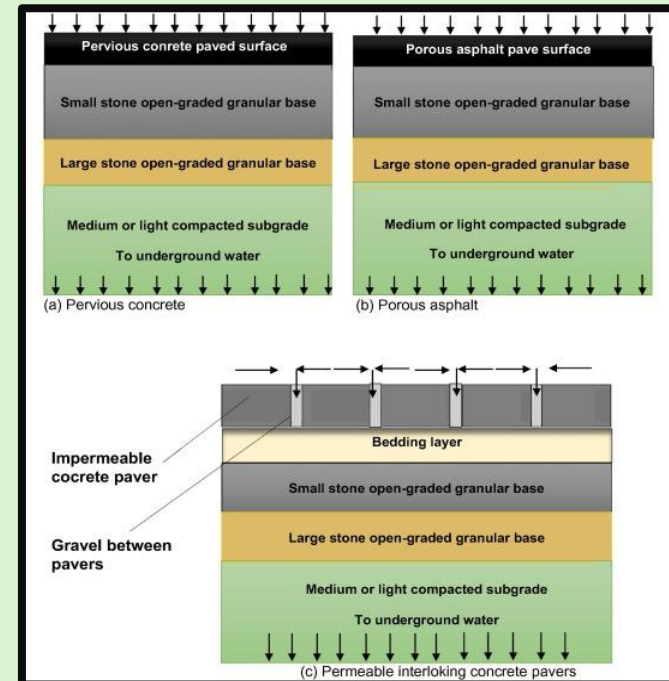


Photo Credit: <https://doi.org/10.1016/j.ijst.2019.01.001>

The construction of interlocking pavers.



Photo Credit: <https://designsbystonescapes.com/how-to-install-interlocking-pavers-for-your-home/>

Research Question, Hypotheses, and Variables

Research Question

Observing the differences in permeability between sand, gravel, rubber paver, concrete, and compressed soil.

Hypotheses

Gravel will have the greatest permeability percentage due to its large particle size and therefore its high porosity.

Concrete will have the lowest permeability percentage because its lack of larger/coarser aggregate.

The largest portion of the water usage will go to the excess, because the much of the water will be absorbed by any given testing material.

Variables

Independent Variable

The material being tested.

Dependent Variables

The amount (in milliliters) of runoff, excess, and infiltrated water.

Controlled Variables

The time and liquid amount ratios per square area of material and the source of the water.

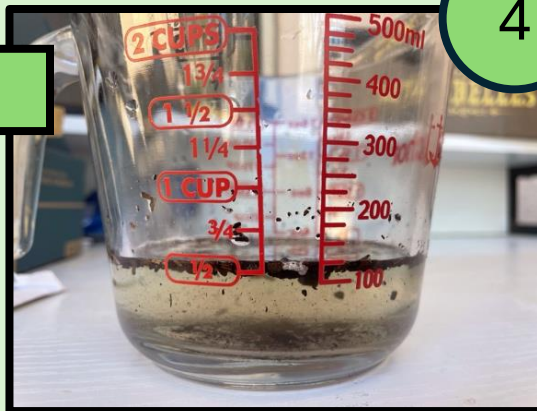
Procedure for Testing the Permeability of Materials



1
The box used to test each material (excluding concrete) consisted of a wood frame and mesh flooring that allowed for liquid but not solids to pass through. Two water collection containers were set.



2
The material being tested was prepared.



4
Both water collection containers were measured separately in a measuring cup and recorded.



3
A designated amount of water was poured over a designated amount of time – calculated beforehand based on standard ratios.



5
All the data was recorded in Excel. Excess amount and the permeability percentage was also calculated on Excel.

Data Tables for Ratios Used to Determine Trials

	Con- crete	Rubber Paver	Compre- ssed Dirt	Sand	Gravel
Cubic Centimeters(cm³)	957	1250	2188	2188	2188
Total Water (mL)	95.7	125	219	219	219
100 cm³/1 mL water					
Pouring Time (sec)	9.57	12.5	21.9	21.9	21.9
10 mL water/1 sec					

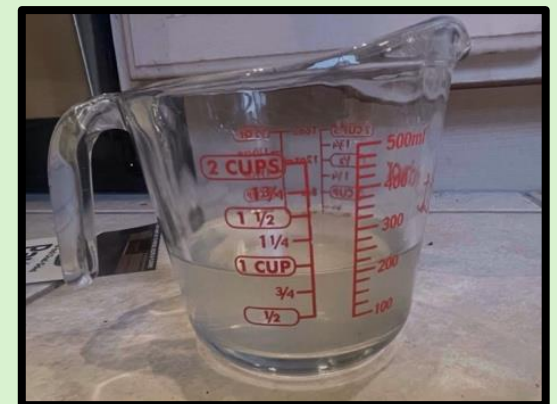
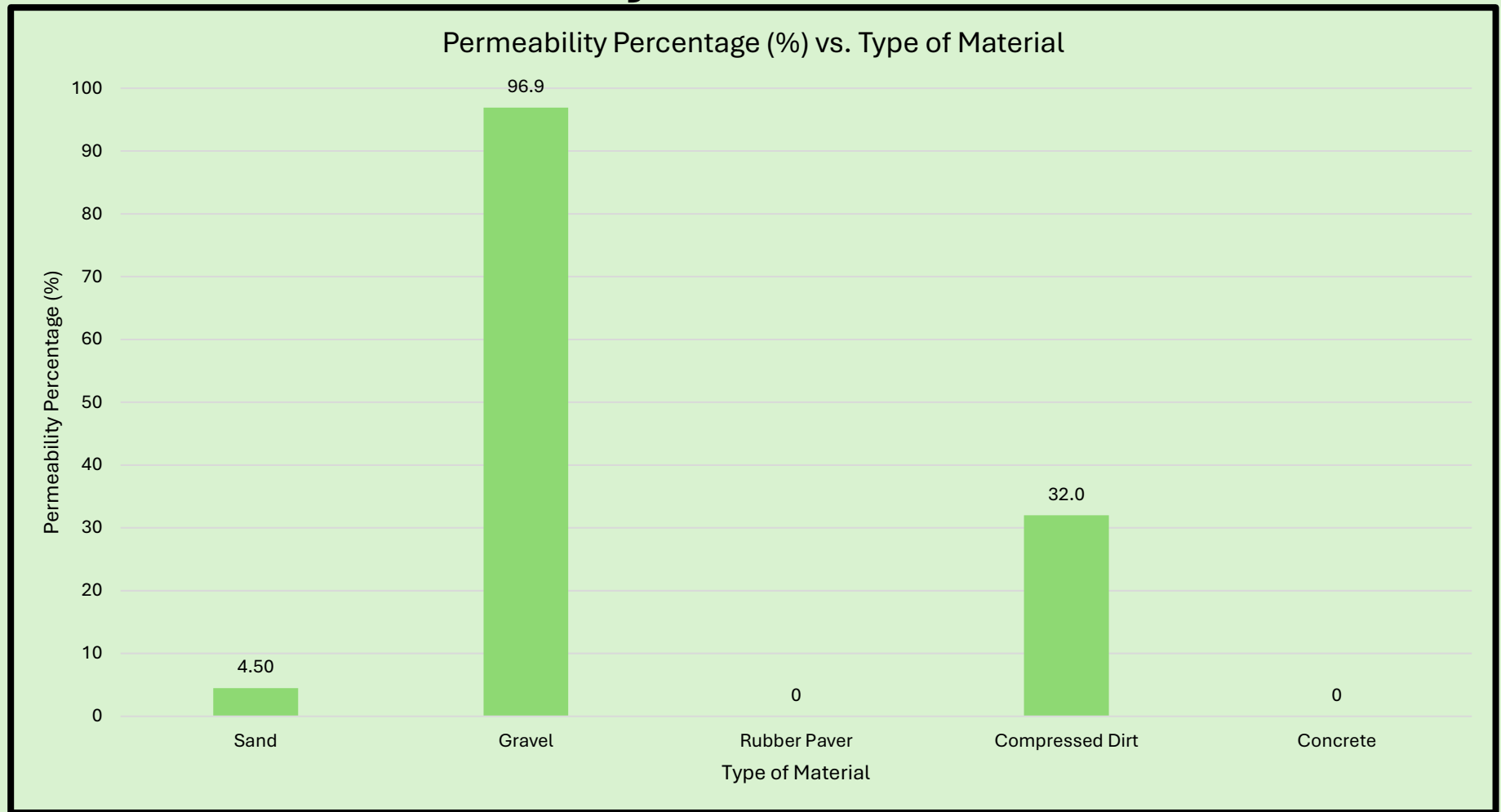


Photo Credit: Jiayi Zhang

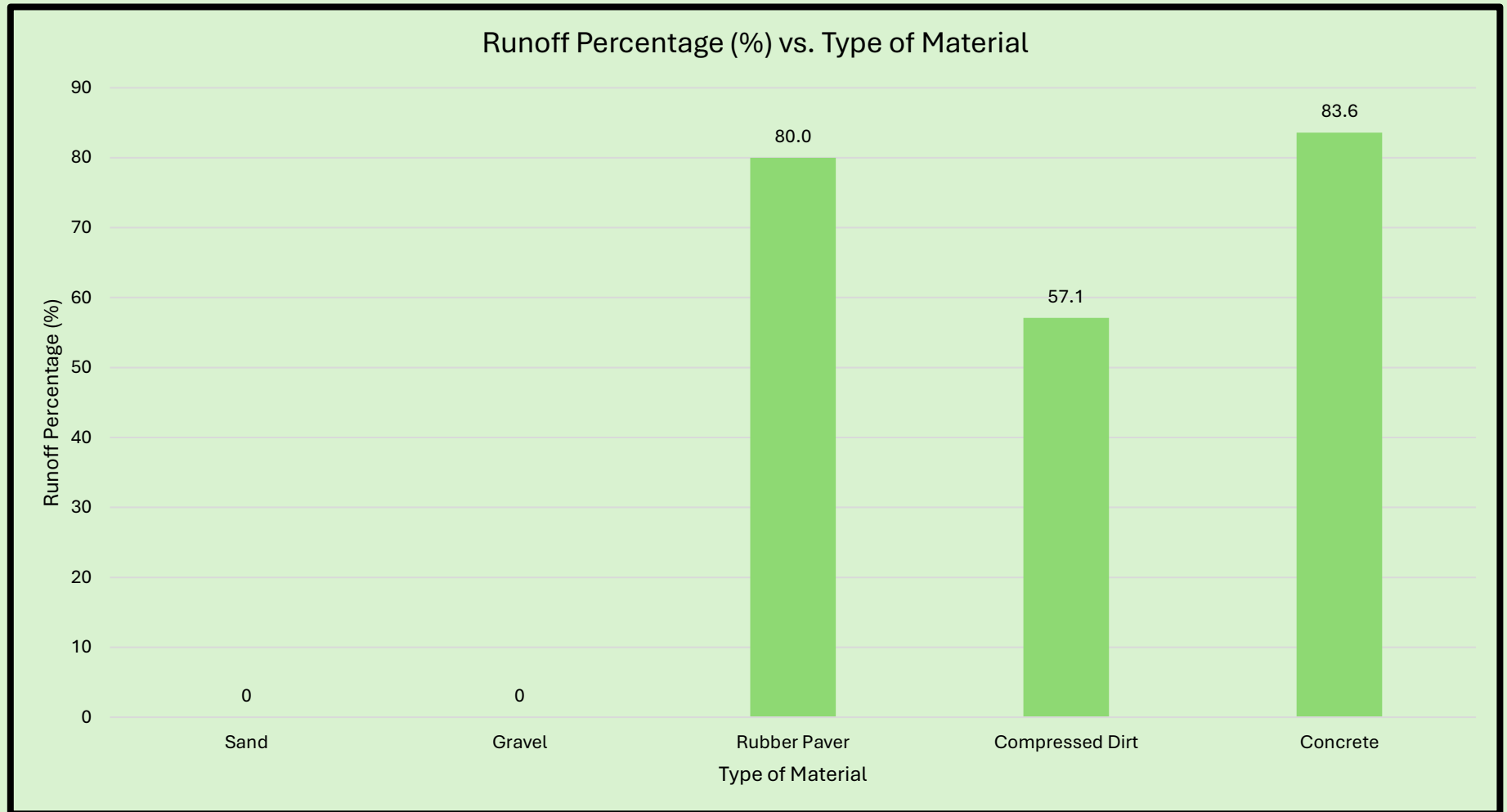
Permeability of Tested Materials



Permeability was calculated by taking the measure of water (in mL) collected from the infiltration collection container and dividing it by the total water used.

Gravel had, by far, the greatest permeability percentage out of all tested materials – with almost all the water permeating through. Rubber paver and concrete both had no water permeation, making them the least permeable materials out of all tested. Sand also had very little permeability, and compressed dirt had about a third of its total water infiltrate.

Runoff of Tested Materials

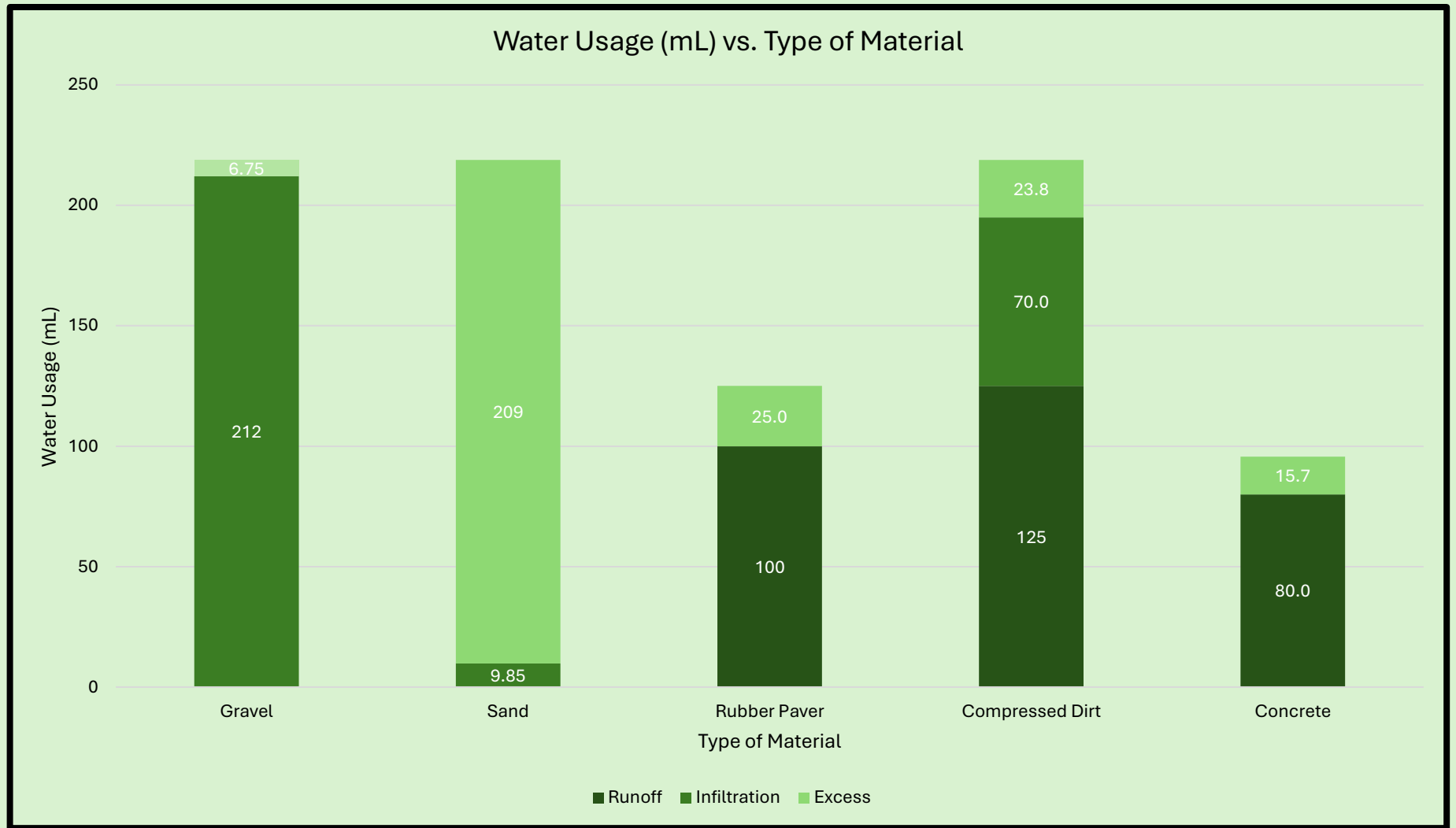


The runoff percentage was calculated by taking the measure of water (in mL) collected from the runoff collection container and dividing it by the total water used.

Concrete had the highest runoff percentage, with rubber paver having almost as much. Both sand and gravel had absolutely no runoff, and compressed dirt had around half of its water as runoff.

Compared to the permeability percentage graph, there is a clear inverse relationship between runoff and infiltration.

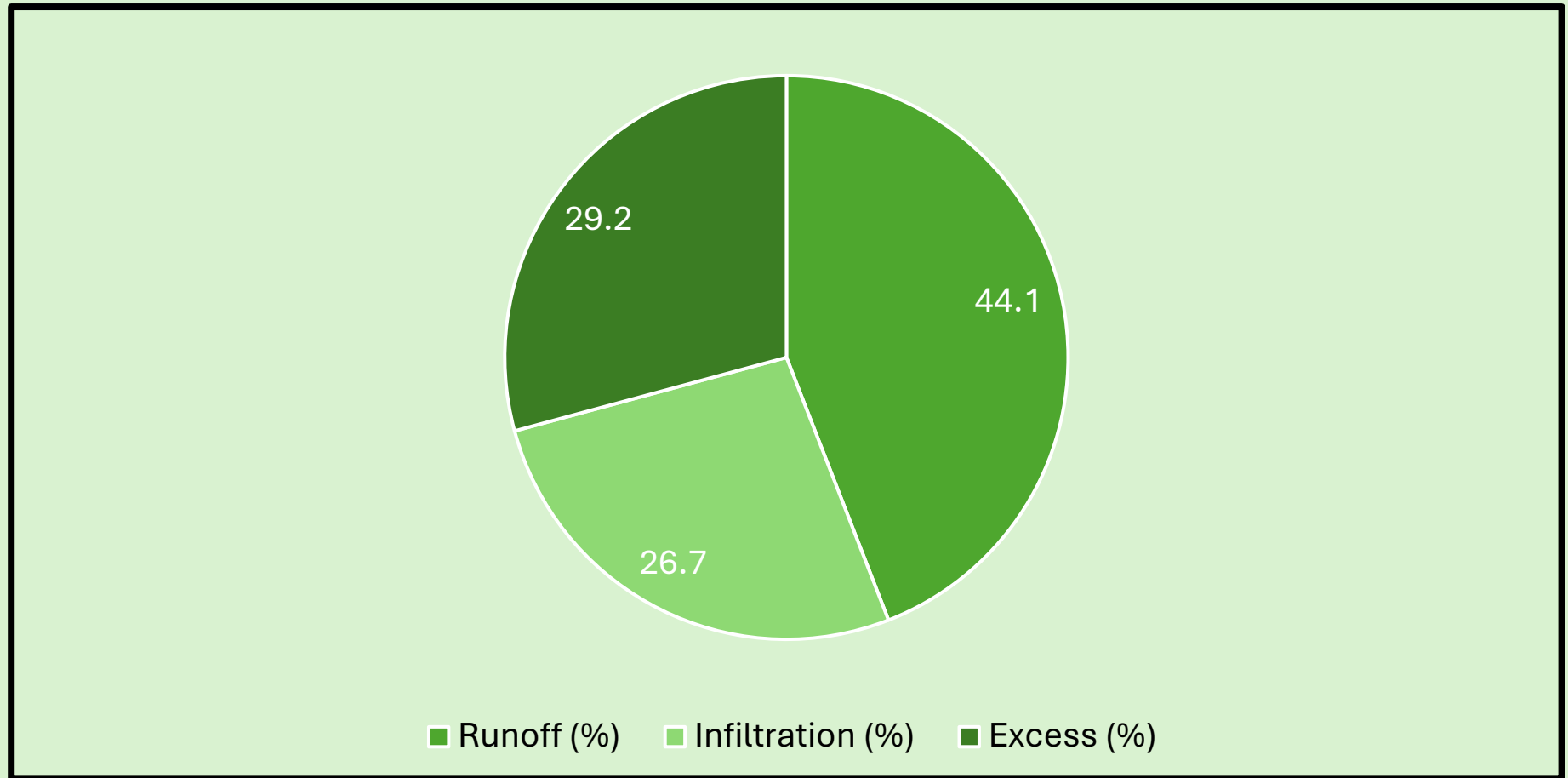
Distribution of Water Used for Tested Materials



The excess water was calculated by subtracting the sum of both water collection container amounts from the total amount of water poured.

The graph shows that gravel was almost entirely runoff, sand was almost entirely absorbed (excess), and the water usage for compressed dirt was split between runoff and absorption/infiltration. Both concrete and rubber paver was mostly runoff with some absorption.

Average Distribution of Water Across Tested Materials



First, the percentage of total water that was collected in the form of runoff, infiltration, and excess in each individual trial was calculated. Then, those numbers were averaged across all tested materials to determine the averages of each category.

The data shows that runoff accounted for the largest proportion of average water usage across all tested materials, representing nearly half of the total water used. The remaining water usage is relatively evenly distributed between infiltration and excess water. These findings suggest a general lack of permeability in the materials tested.

Discussion of Results

Claim:	➤ Gravel has the greatest ability to let liquid pass through it and decrease runoff out of all five tested materials.	➤ Rubber paver and concrete have the least ability to let liquid pass through and increase runoff greatly.	➤ Sand has the greatest ability to absorb liquid – however, it retains it rather than allowing it to pass through.
Evidence:	➤ Gravel had a permeability percentage of 96.9% and 0 mL of runoff.	➤ Both rubber paver and concrete had a 0% permeability percentage and 0 mL of infiltration.	➤ 209 mL of water was excess out of the total 219 mL poured over the sand.
Reasoning:	➤ Gravel's high permeability and low runoff indicates a high porosity – meaning that there is relatively more pore space that doesn't allow for retention of liquid within the material.	➤ Rubber paver and concrete's distribution of water was almost entirely runoff and had no infiltration, indicating complete impermeability and no pore space for liquid to pass through.	➤ The sand trial's low infiltration and runoff indicate high absorption. Of course, other factors could lead to excess (e.g., evaporation) but given visual cues, the testing material absorbed the liquid.

Errors within Experiment

Possible Errors:

- Only a single trial was run of each material.
- The location of the experiment was moved about halfway through due to weather factors.
- The testing box structural stability started to deteriorate by the end of the experiment.
- The amount of material tested differed between trials.

Possible Effects:

- It may have exposed the experiment to "chance" external factors.
- Previously controlled variables (e.g., temperature, air moisture) were changed.
- A change in slope may have occurred, possibly changing the water distribution.
- It could affect the amount of time required for the liquid to infiltrate and therefore the water distribution.

Future Experiments

Testing the Strength of Tested Materials:	➤ Testing the inverse relationship between the permeability of a surface and its compressive strength.	➤ Method would probably involve compressive equipment (e.g., hydraulic press or evenly distributed weights).	➤ Could be used to better determine the practical applicability of tested materials.
Testing Biological Synergism:	➤ Testing the root structures of some plants, as they may increase permeability.	➤ Method would most likely consist of soil trials involving plants, possibly different species with different root structures.	➤ Could be used to expand the possible reduction methods for increased impermeability within urban areas.
Testing More Materials:	➤ Testing other possible aggregates, especially more synthetic ones that require more preparation to obtain.	➤ Method would probably involve materials like porous asphalt/pervious concrete (specifically designed for higher porosity).	➤ Could be used to gain a wider perspective/range of potential solutions for the best possible one.



Real World Application

- Materials could be used as components (especially as aggregates) in creating more permeable, sustainable road pavements.
- By learning about the impermeability of some materials, more focus could be on shifting them out of infrastructure.
- On a more individual scale, the use of permeable materials in private landscaping can be better chosen.

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