River Stream Order and Tree Branches or Roots: An Analogy Related to Water Retention Capacities

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Abstract: *Order concept for hydrological basin is presented and a comparison is made with shapes presented by both the branches and roots of trees and plant species, indicating that said order can be seen as an indicator of intersection or water retention capacities, level of water stress and species adaptation to climate change.*

Keywords: *Rainwater interception, water harvesting, tree hydrology, adaptation to climate change*

1. Introduction

The concept of river flow order can be effectively analogized to the branching patterns of tree limbs or roots, highlighting their similarities in water retention capacities. Both systems demonstrate how hierarchical structures contribute to their overall functionality and efficiency.
The order of a river's stream is determined by its position within the basin's drainage network. Smaller streams (first-order) combine to form larger streams (second-order), which in turn merge to create even larger streams (third-order), and so on. The complexity of the river system's order affects its ability to manage and retain water, influencing flood control, groundwater recharge, and ecosystem support.
Similar to river flow order, tree branches and roots exhibit a hierarchical structure. Primary branches and roots give rise to secondary and tertiary branches and roots, creating a complex network. Branching hierarchy plays a crucial role in the tree's water absorption and retention capabilities. Leaves and smaller branches intercept rainfall, while roots absorb and distribute water throughout the tree, maintaining overall hydration and health.
The main river channel can be compared to a tree's trunk, serving as the primary conduit for water flow and support. Smaller streams (tributaries) are analogous to secondary branches and roots, distributing water and nutrients throughout the system moreover, floodplains and wetlands in a river system are akin to the soil and root zones around a tree, acting as storage areas that help maintain water balance and prevent overflow or drought stress. By understanding this analogy, we can gain insights into how both natural systems optimize water management through their hierarchical structures. This knowledge can inform strategies for urban planning, forestry, and conservation, enhancing the resilience and sustainability of our environments.
Trees play a crucial role in water conservation, acting as natural sponges that capture and store water in their vegetation and root structure. This process helps minimize runoff and increase water infiltration into the soil. Trees intercept rainwater on their leaves and branches, reducing the speed and volume of water reaching the ground, which prevents soil erosion, improves water retention, and facilitates the recharge of underground aquifers. Through transpiration, trees release water into the air, contributing to cloud formation and precipitation. Tree roots act as filters, absorbing pollutants and preventing them from contaminating water sources. Trees like willow, ash, and poplar are especially effective at conserving water due to their ability to thrive in wet areas and their deep root systems that help filter and clean water [1].
Studies have shown that tree canopies can intercept up to 30% of precipitation, with canopy flow (through leaves and branches) being greater than stem flow (through the trunk) [2]. Trees absorb water and nutrients from their roots, and through evapotranspiration, they generate upward thrusts

of water, distributing it against gravity to higher areas [3]. Research by Huber and Ramírez (1978) [4] proposed a method to estimate water consumption through transpiration, finding that transpiration rates vary with air temperature.
The concept of order can also be applied to tree roots. The variation in root order over time can indicate a tree's adaptation to climate change, as some species modify their root networks to cope with water stress, which occurs when water demand exceeds supply or when water quality is too low for use [5-8]. David et al. (2016) [5] compiled studies and found that Mediterranean trees have developed structural and physiological attributes to cope with drought. These adaptations aim to maintain a favorable balance between water lost through leaves and water absorbed by roots. Adaptations include:

- Regulating stomatal and hydraulic conductivity.
- Adjusting the photosynthetic and nitrogen capacity of leaves.
- Reducing leaf size and/or increasing leaf thickness.
- Limiting the leaf area index.
- Establishing a canopy with low tree density.
- Maximizing water absorption by exploiting deep water sources.

These strategies enable Mediterranean trees to thrive in arid conditions by efficiently managing water resources. Recent advancements have improved the mapping of tree roots using minimally invasive procedures. For example, More and Ryder (2017) [9] found that at 200 mm depth, the vertical location of tree roots in Australia was more accurately depicted by Ground Penetration Radar (GPR) scans than the horizontal location, with two out of three scans showing accurate root locations. Urban trees are often studied for their role in sustainable cities, providing environmental services like oxygen generation and water retention to reduce urban flooding, despite facing challenges like pollution, water stress, and drought [10-11].

2. Methodology

2.1 Order applied to rivers and trees

River stream order a is determined by its hierarchical position within a river basin. In exoreic basins, stream order provides insights into drainage capacity and river system flow dynamics. The method for determining stream order is as follows [12].
Order 1: The smallest streams with no tributaries.
Order 2: Formed by two first-order streams confluence.
Order 3: Formed by two second-order streams confluence of, and so on.
For example, in Figure 1, order 4 basin is shown, illustrating a more complex and interconnected system as order increases.

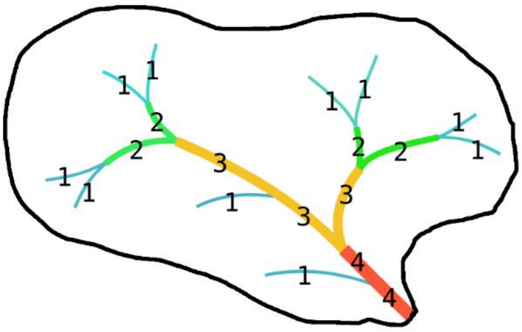

Fig. 1. Order 4 basin (Source: own design)

An analogy was made between order concept in a basin and branches or roots order for tree or bush, seeking to find correlations between this order and factors such as rainfall interception, evapotranspiration, and he adaptive certain species capacity to climate change or water stress in urban areas. This methodology aims to understand how the hierarchical natural systems structure can influence their functionality and resilience.

3. Application and Results

Consider hypothetical tree in Figure 2. By applying the definition of order to the branches of this tree, and assuming all branches have similar bifurcations, we approximate the tree's order to be 4. The complexity of this order increases if the tree is leafy rather than deciduous. This fourth-order can be interpreted as an index of the tree's potential to intercept rainwater. By analysing area of its leaves and branches, we can estimate the canopy flow, which contributes to rainfall interception.

Fig. 2. Hypothetical tree branches Order (Source: Google images © [13])

In Figure 3, tree roots are shown to have a 5 order, considering trunk as output. This higher order indicates a greater adaptive capacity for groundwater capture, suggesting that tree can efficiently manage water resources in its environment.

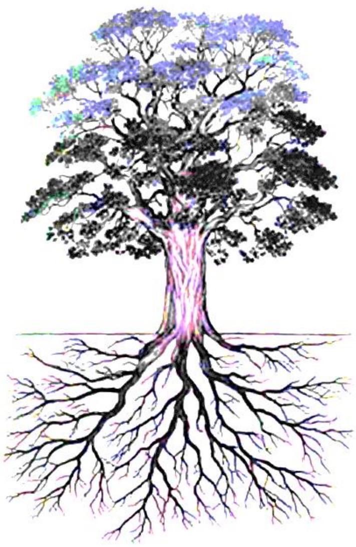

Fig. 3. Tree roots order (Source: Google images © [13])

4. Conclusions

This study draws an analogy between order concept in a river basin and the branches order or roots in a tree or bush. The correlation between these orders and various ecological functions such as rainfall interception, evapotranspiration, and adaptive capacity to climate change or water stress was explored. Understanding these relationships can provide insights into how natural systems maintain stability and resilience, especially in urban areas where trees face significant environmental challenges.
Trees intercept rainwater on their leaves and branches, reducing the amount and speed of water reaching the ground. This helps to prevent soil erosion, increase soil moisture, and recharge groundwater supplies. The order of the branches can indicate the tree's efficiency in intercepting rainfall.
Trees absorb water through their roots and release it into the atmosphere as vapor by means of evapotranspiration. This helps to regulate temperature and humidity levels, contributing to local climate stability. Higher-order root systems can enhance a tree's ability to access water and sustain evapotranspiration rates during dry periods.
Trees with more complex root and branch structures (higher order) are better equipped to adapt to environmental stressors such as drought and heat. These trees can efficiently manage water uptake and retention, making them more resilient to climate change.
In urban areas, trees face environmental challenges such as limited space for root growth, soil compaction, pollution, and heat stress. Understanding the order of tree branches and roots can help in selecting species and designing urban landscapes that maximize ecological benefits, such as improved water management and climate regulation.
By studying these analogies, urban planners and environmental scientists can develop innovative strategies to enhance the ecological functions of trees in urban environments. This research can lead to more effective urban forestry practices, such as selecting tree species that are better adapted to local conditions and designing green spaces that maximize environmental benefits. For instance, understanding how different tree orders affect water retention and evapotranspiration can inform the placement and maintenance of trees to reduce urban heat islands, manage stormwater runoff, and improve air quality. Moreover, integrating these insights into urban planning can promote biodiversity, create more resilient urban ecosystems, and provide residents with numerous health and well-being benefits. Trees contribute to cleaner air, reduced noise pollution, and cooler temperatures, which can enhance the overall quality of life in cities. Additionally, well-designed urban green spaces can foster social cohesion, provide recreational opportunities, and support mental health.
By leveraging the knowledge gained from these analogies, cities can implement more sustainable development practices, ensuring that urban areas remain liveable and resilient at climate change face and other environmental challenges. This holistic approach to urban forestry and green space management not only improves the immediate urban environment but also contributes to long-term sustainability and resilience, benefiting both current and future generations.

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