Bioretention Systems Optimization and Design Characterization Model

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Urban stormwater has become a persistent concern on a global scale due to its adverse environmental implications. It is the prime vector of aquatic contaminants worldwide that causes pollutants when water bodies drain. Bioretention systems are increasingly used to alleviate setbacks associated with stormwater run-off in urban locales. It has played a substantial role in the implementation of low impact development (LID), a concept that addresses urban stormwater problems caused by land changes and development. The use of LID technologies is an innovative approach.

bioretention | EMC parameters | rainfall analysis | Weibull distribution | rule induction | fuzzy rough set algorithm | rough set theory | Preece test

1. The Growing Concern about Urban Stormwater Run-Off

The sprawl of population in urban centers has brought forth massive development in infrastructures, with the conversion of natural areas into impervious surfaces as one of the main upshots [1]. Concomitant with the expansion of impervious cover is the increase in quantity and rate of stormwater run-off. The increase in the extent of impervious surfaces renders the precipitate incapable of infiltrating into the ground, making urban run-off a prime contributor to non-point source pollution [2]. With the shifting context of urbanization and policies on climate and management, pollution associated with stormwater discharge varies from area to area, based on volume and quality. In a naturally functioning environment, only a trivial proportion of precipitation contributes to surface run-off, but as urbanization amplifies, this percentage considerably increases. This run-off typically drains to the nearest river or stream, which in turn, causes the following adverse impacts to the receiving water bodies: altered streamflow [3], disruption of normal hydrologic processes [4], changes in the natural drainage path, increased flood volumes and stormwater run-off, amplified amount of wash-off pollutants affecting water quality [1], water body alteration and biodiversity problems [5]. Other aftereffects of urban run-off have been documented, including stream bank erosion, contamination of drinking water sources, exposure of humans to pathogenic bacteria, and adverse impact on the economy due to beach closures [4]. In view of the mayhem associated with urban run-off, attention has been focused on developing stormwater management strategies, such as bioretention systems.

2. Bioretention: Its Concept and Underpinnings

Bioretention, also recognized as bioinfiltration or biofilters, is defined as land-based water quality and water quantity management practice that uses physical, chemical, and biological properties of soils, plants, and microbes for the elimination of pollutants from stormwater run-off [6]. It was first developed in the early 1990s by Prince George's County, Department of Environmental Resources as a component of the low impact development (LID) concept [7][8]. To compensate for the environmental consequences of land development on hydrological processes and water quality, the LID approach integrates a hydrologically functional site design with pollution deterrence measures. This concept administers stormwater run-off in small, economical landscape features situated on each lot incorporating natural processes, such as infiltration, filtration, sedimentation, adsorption, volatilization, ion exchange, decomposition, phytoremediation, and storage facility [6][8][9]. Examples of LID techniques are rain gardens, bioswales, green roofs, permeable pavements, and bioretention cells [10].

Among the LID practices, bioretention has gained much impetus as more areas grapple with the ecological impacts of urbanization [11]. Bioretention systems draw inspiration from the natural system's ability to treat waste as a resource. It maximizes the existing physical, chemical, and biological pollutant removal processes found in the soil and flora component of a terrestrial vegetated community [7].

3. Bioretention Systems: Design and Function

Bioretention uses soil media and woody and herbaceous plants to reduce pollutant loads from stormwater run-off coming from urban areas [7]. This system is engineered to receive the first-surge run-off from any rainfall event, with an adept capacity to take hold of a sizeable volume of run-off from rainfall episodes persisting over several hours [7][12]. The water that passes through the facility enters either of these routes: (1) infiltrates deeper for groundwater recharge, and (2) collected in subsurface perforated pipes and passed to conventional storm drains [12].

With the linking goal to reduce the quantity and improve the quality of run-off in urban areas, bioretention systems use shallow storage, landscaping, and soil media to collect stormwater before draining to the watershed and adjacent water bodies [7]. The basic design consists of three distinctive layers—filtration, transition, and drainage layers—which mimic the function of the natural environment [9][13]. The initial bioretention system design is much like a depression backfilled with planting soil lined by a thin layer of sand underneath and planted with native grass, shrubs, and various kinds of trees as treatment media [12]. The soil characteristically has a high sand content to facilitate rapid infiltration, with low proportions of silt and clay to render faster attenuation of pollutant loads during infiltration. A thin layer of wood mulch overlays the soil, intended to prevent erosion and excessive desiccation of the soil layer. The system is also installed with grasses, shrubs, and other plant species for water removal through evapotranspiration, effectual infiltration, and pollutant conversion [12]. Plant species utilized in bioretention are chosen based on the following attributes: (1) well-suited to the existing soil and climatic conditions of the area; (2) tolerant to urban disturbance, such as water and air pollutants, fluctuating soil moisture, ponding variations; (3) nutrient removal efficiency [12][14]. Bioretention systems are useful in commercial, industrial, and residential settings. They can also be applied in other functions, such as roadway and institutional developments, community redevelopment, streetscape projects, trailways and parks, which can be designed in accordance with individual areas and site-specific conditions [8]. The expansion of impermeable surfaces in urban locales has led to increased flood volumes, stormwater peak surges and intensified pollutant wash-off, which could drastically degrade the water quality of run-off [15]. Stormwater run-off serves as a vector of pollutants transporting contaminants, such as organic matter, suspended solids, nitrogen, phosphorus, heavy metals, hydrocarbons, sediments, pesticides, and fertilizer effluents, to the receiving watersheds. Bioretention systems have been found to cleanse pollutants of various sorts from infiltrating run-off. Several studies have demonstrated its ability to remove nutrients such as Kjeldahl nitrogen, total nitrogen, phosphorus [12][15], and ammonium [11]. Heavy metals such as copper, lead, zinc, and other contaminants such as oil and grease, suspended solids, hydrocarbons, motor oil, and pathogenic bacteria were also found to be efficiently removed by bioretention facilities [8][9][11]. Despite its proven efficacy, the full potential of bioretention systems is limited by setbacks in data management, such as insufficient and/or imprecise data [6]. This challenge can be addressed by adapting statistical methods to simulate various scenarios in a locale.

4. Rough Set Theory: Concept and Uses

The origin of rough set theory dates back to 1982 when Zdzislaw Palwak introduced it as a contemporary mathematical approach to deal with imprecise knowledge [16][17]. It offers efficient methods, tools, and algorithms for establishing covert patterns in data. The concept of a rough set is grounded on the supposition that, contrary to the classical set theory, additional information, knowledge, and data about elements of a set exist [18]. Since its inception, rough set theory has demonstrated the ability to develop computationally efficient and mathematically sound systems to deal with issues of finding patterns from databases, creation of decision rules, data reduction, principal component analysis, and interpretation of inference on the basis of existing data [16]. The first part of the rough set theory is to establish concepts and rules through the categorization of the relational database. The second component is to discover knowledge through sorting the equivalence relation and classification for the target approximation [19].

The advantages of the rough set approach to data analysis have been established, which include: (1) provision of efficient algorithms to find hidden patterns in data; (2) identifying of relationships that would not be established using statistical procedures; (3) finding of minimal sets of data reduction; (4) allowing for the use of both qualitative and quantitative data; (5) assessing data significance; (6) generation of decision rules from available data; (7) easy to understand; (8) offers a forthright interpretation of gathered results [17].

5. Rough Set Data Explorer

Rough Set Data Explorer is a software system based on rough set theory and other methods for rule discovery [16] which was developed by the Laboratory of Intelligent Decision Support Systems of the Institute of Computing Science in Poznan [20]. This system is a descendant of RoughDAS and RoughClass systems, which are considered one of the first successful implementations of the rough set theory. The software allows for the application of the variable prediction rough set and the classical model designed by Pawlak to construct approximations. Rough Set Data Explorer is basically comprised of a graphical user interface and a collection of separate computational modules. It is devised to be a user-friendly tool that can be implemented in data exploration and analysis. It is equally useful for beginners and experts, as well as for occasional users who want to perform data analysis [21].

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