National Urban Research & Extension Center

Physical, Chemical, and Microbial Properties of Soils in Three Peri-Urban Farms: South Puget Sound, WA

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Collecting soil samples on Farm 3

Introduction

Urbanization is rapidly transforming landscapes worldwide, with 68% of the global population projected to live in urban areas by 2050 (United Nations, 2018). North America is the most urbanized region, with 82% of its inhabitants residing in urban centers (Bolay, 2020; Kohlhase, 2013). This shift has dramatically altered land use and land cover (LULC), leading to significant farmland loss. For example, nearly 11 million acres of farm and ranchland in the US were converted to commercial and residential uses during 2001–2016 alone (Freedgood et al., 2020). In the US Puget Sound region, 58% of farmland has been lost due to development since 1950 (Canty et al., 2012). Such land transitions have disrupted hydrologic systems, increasing runoff and flooding, degrading soil, and contributing to diffuse pollution (Suttles et al., 2018; Fu et al., 2023).

Peri-urban agricultural areas, which lie at the edges of cities and play a vital role in food production and ecosystem services, are increasingly threatened by urban sprawl. These zones are under pressure from development and resource competition, while simultaneously offering green space preservation, economic opportunities, and ecological benefits (Heimlich, 1989; Ebissa & Desta, 2022). However, increased stormwater runoff and pollution from adjacent urban areas impact the physical, chemical, and microbial properties of soil, affecting its health and productivity (Feng et al., 2021; Gómez-Brandón et al., 2022).

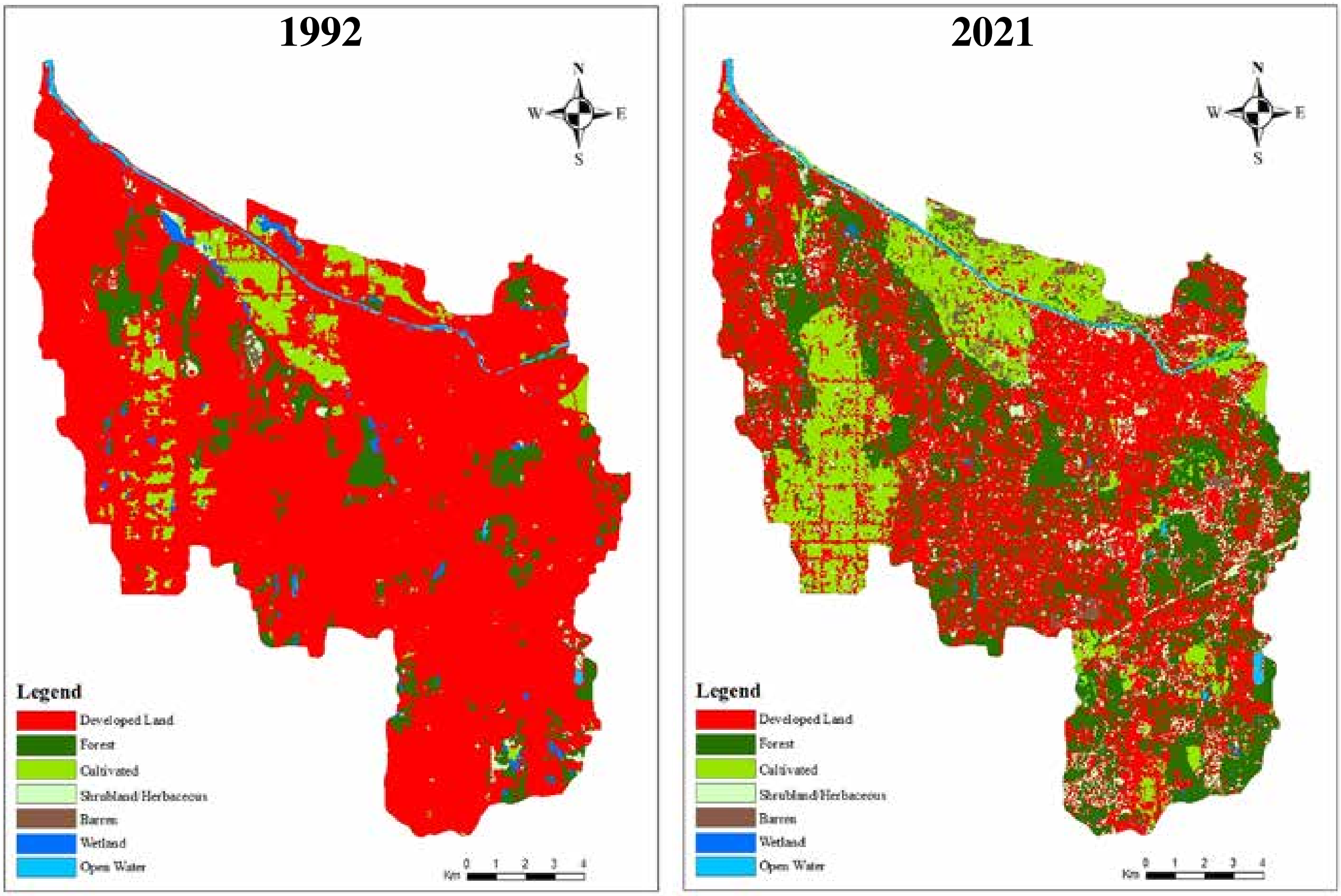


Figure 1a and 1b. Land use and land cover change of the lower Puyallup River watershed 1992-2021 illustrating an increase in developed land.

Soil physical properties such as texture, porosity, and water-holding capacity influence water retention, nutrient availability, and microbial activity (Brady et al., 2008; Xia et al., 2020). Soil chemical properties, e.g., soil pH, organic matter, nutrient levels, and trace metals, are more variable and influenced by land management practices and environmental conditions. Nutrients, including nitrogen and phosphorus, are essential for plant growth but can contribute to environmental degradation if imbalanced (Barrow et al., 2023). Heavy metals such as copper and zinc can negatively affect microbial communities and plant health (Karimi et al., 2021).

Soil microbial communities are fundamental to nutrient cycling, organic matter decomposition, and pollutant detoxification (Aislabie et al., 2013; Wang et al., 2022c). They serve as indicators of environmental change (Santorufo et al., 2021). Changes in LULC and hydrologic regime due to urbanization can disrupt microbial populations (Santorufo et al., 2021). The interplay among soil's physical, chemical, and microbial properties is complex and dynamic, with research showing that specific conditions, such as pH, organic matter, and metal concentrations, strongly shape microbial communities (Yu et al., 2024; Abbaszade et al., 2023).

In the US Puget Sound region, analysis of land use in the lower Puyallup River watershed during 1992–2021 reveals a 70% decrease in agricultural land and an 85% increase in developed land (Figure 1a and 1b) while in the lower Green River watershed agricultural land has decreased by 68% and developed land has increased by 37% (Figure 2a and 2b). These changes highlight the urgency to understand soil responses. This study aims to (i) measure and characterize the soil physicochemical and microbial properties in three urban farms located in Pierce and King Counties, Washington, and (ii) evaluate the interrelationships among these properties.

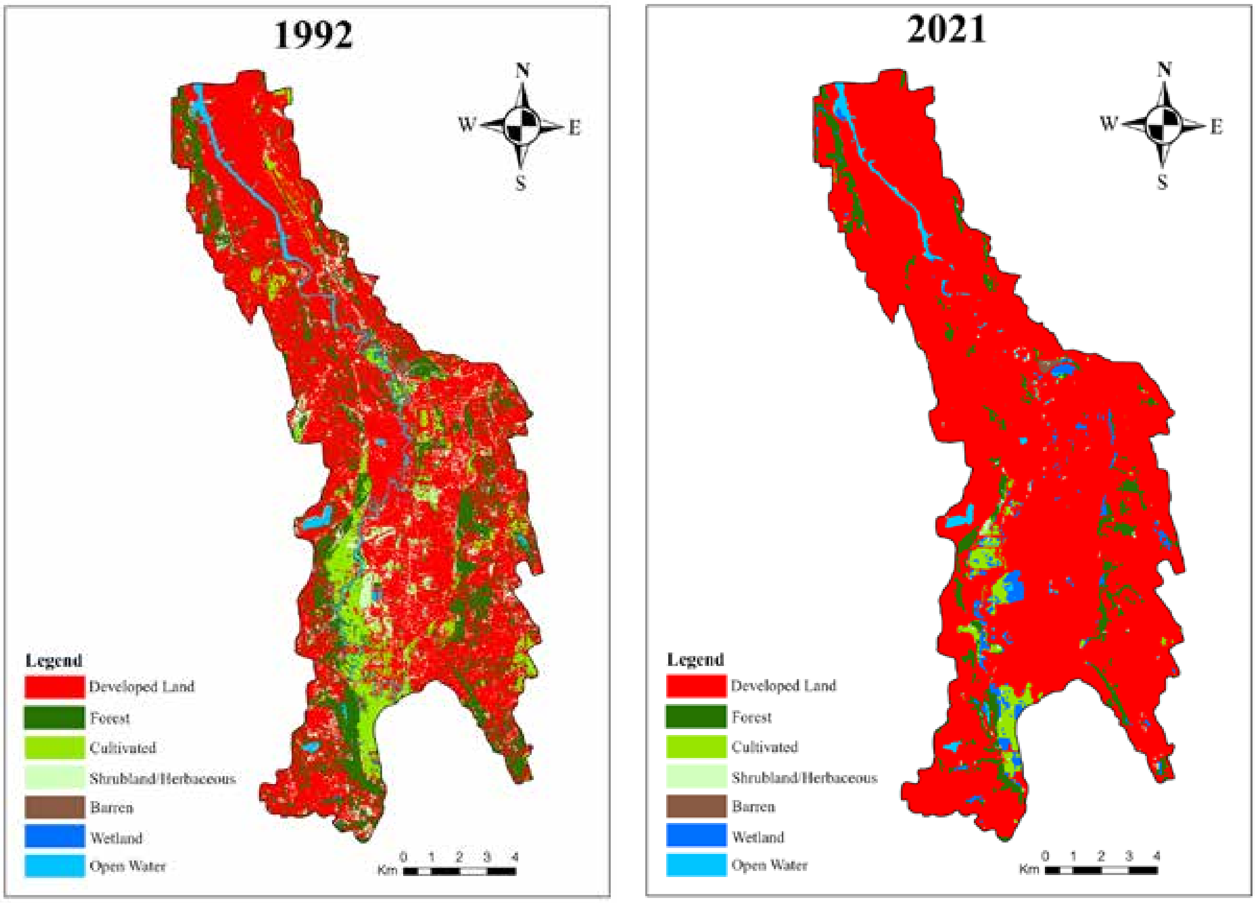
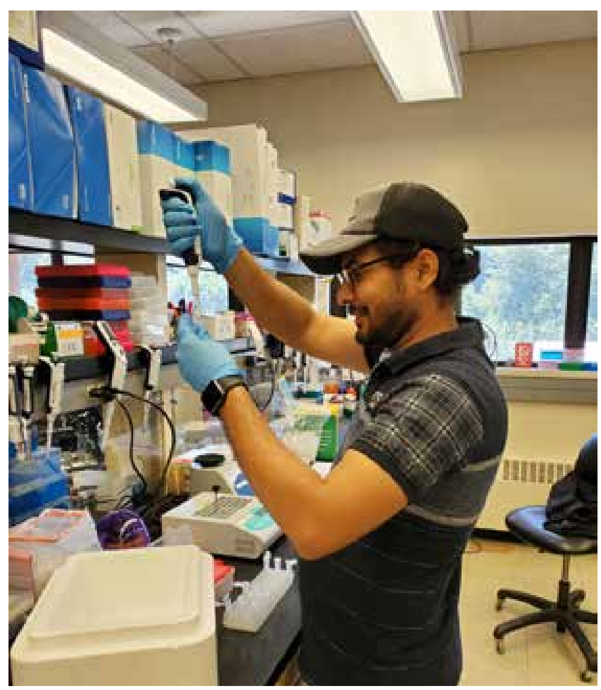


Figure 2a and 2b. Land use and land cover change of the lower Green River watershed 1992-2021 illustrating an increase in developed land.

Photo by Prabesh Khanal

Farm 2 in spring 2023



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Analyzing soil samples

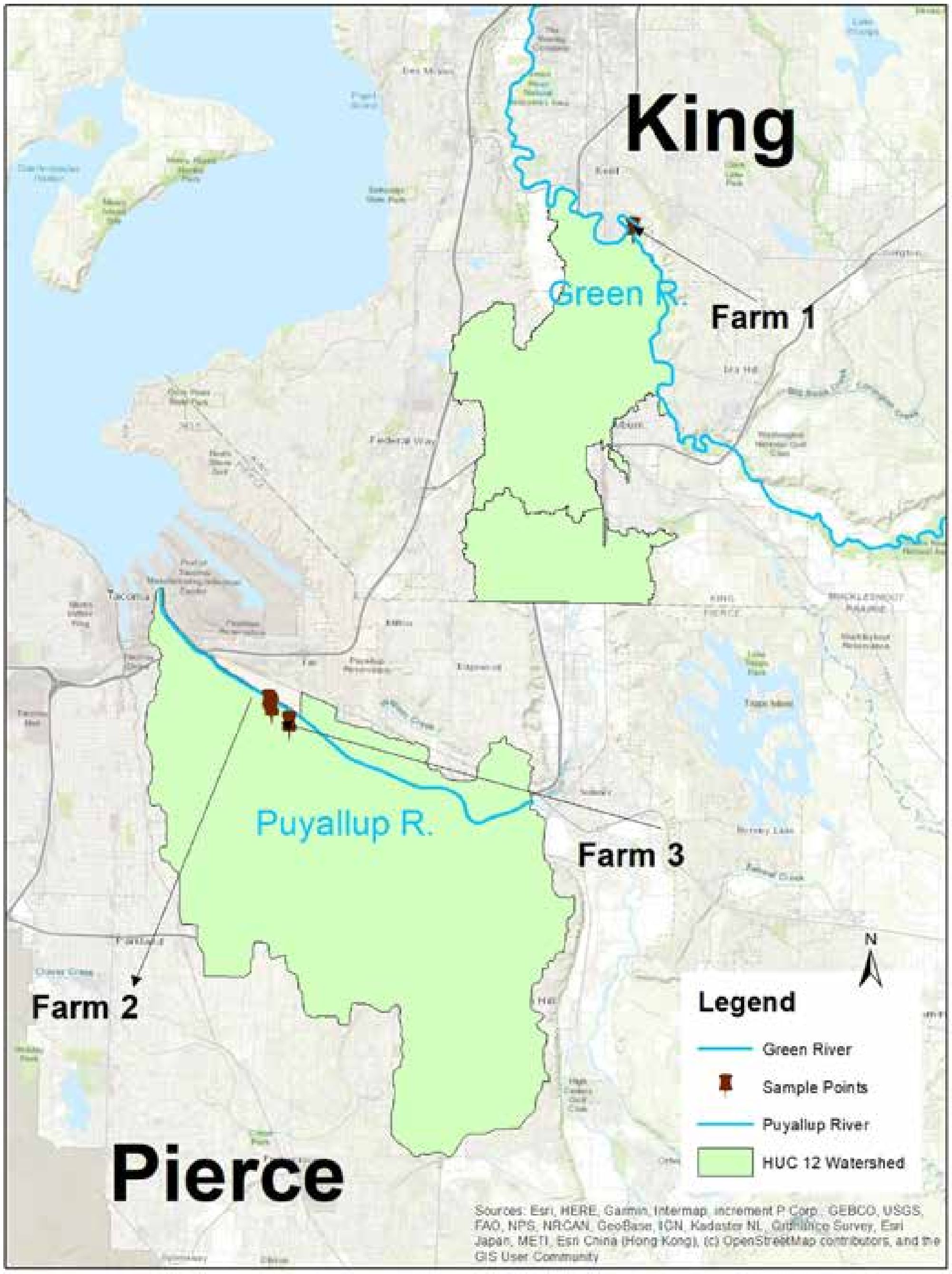

Figure 3. Study area and field sampling locations at three farms in the Puyallup and Green River watersheds.

Methodology

Field Soil and Water Sampling

Soil and water samples were collected at three farms, one community farm in King County and two small, organic farms in Pierce County (Figure 3). Both counties face increased urbanization, and all farms are located on floodplains subject to the impact of urban stormwater. Soil and groundwater samples were collected twice at each location, first in the fall of 2022, before the onset of the rainy season and the so-called first flush, and then in the spring of 2023 during the rainy season, potentially reflecting the reduced concentrations of pollutants carried in the runoff from dilution. Surface water was sampled from the Green River, and not from the Puyallup River (due to lack of safe access during the sampling period).

Analysis of Soil Physicochemical and Microbial Properties

Soil samples were shipped to, and analyzed in, commercial labs (Analytical Resources, LLC, Tukwila, WA, for nitrate-nitrite, total Kjeldahl nitrogen, total phosphorous, copper, and zinc; and Soil Test Farm Consultants, Inc., Moses Lake, WA, for soil texture, cation exchange capacity, and organic matter). Soil pH was measured at the Low-Impact Development Lab, WSU Puyallup. Soil DNA extraction and bacterial 16S rRNA gene amplicon sequencing were performed at the Resilient Environmental Bioprocess Engineering Lab, WSU. The pooled samples were then sent to the Northwest Genomics Center, University of Washington, Seattle, USA, for Illumina MiSeq sequencing.

Statistical Analysis

All statistical tests were conducted at a significance level $\alpha=0.05$. Analysis of variance and Spearman's rank-order correlation were conducted to elucidate within- and across-farm characters of soil physicochemical and microbial properties. Additionally, soil microbial species richness and composition were evaluated via diversity analyses.

Interactions with Farmers

The cooperative farm owners (in Pierce County) and farm manager (in King County) provided valuable support to this project. They granted access to their farms and answered questions during field sampling. Additionally, we carried out a survey focused primarily on cropping systems and fertilizer use by mailing a questionnaire and conducting in-person interviews.

Results

i. Four soil textures—sandy loam, loamy sand, silty loam, and loam—were identified at the three study farms. Sand, silt, and clay contents significantly differed between Farms 1 and 2 as well as between Farms 1 and 3, exhibiting spatial variation between watersheds. The spatial variability may be due to different geological settings and land management practices at individual watersheds.

ii. All analyzed soil properties, except pH, did not differ significantly (significance level $\alpha=0.05$) between the two sampling events. The soil pH level at Farm 3 varied significantly from Farms 1 and 2, with low pH levels (acidic conditions) detected at certain sampling locations. The spatial variability in soil pH may be due to site-specific management practices, such as crop variety and rotation, fertilizer application, liming, and irrigation.

iii. All three study farms had high TP (total phosphorus) concentrations (>800 mg/kg). Two likely contributing factors are: (i) the farms' locations on floodplains, which are buffer regions for nutrient (especially phosphorus) retention, and (ii) prolonged use of phosphorus fertilizers.

iv. Total phosphorus in surface water during the spring sampling event exceeded the US EPA's eutrophication limit (0.1 mg/l) for flowing water. The high TP levels in the adjacent farm soils may be the cause of the high TP in the surface water of the Green River.

v. Proteobacteria, Actinobacteria, Firmicutes, Verrucomicrobia, and Planctomycetes were the most dominant bacterial phyla at all three farms. The alpha diversity index followed the order Farm 1 > Farm 2 > Farm 3. The bacterial richness and diversity at Farm 3 were significantly lower than at Farms 1 and 2. The low soil pH levels, among other factors, might have contributed to the low microbial richness and diversity at Farm 3.

vi. The beta diversity at Farm 1 significantly differed from that at Farms 2 and 3, suggesting a greater similarity of microbial communities between Farms 2 and 3 than between Farms 1 and 2 or Farms 1 and 3. This result may be due to the fact that Farms 2 and 3 are closely situated in the same Puyallup River watershed, whereas Farm 1 is located in a different (Green River) watershed.

vii. Bacterial communities were mainly correlated with NO_3^--NO_2^- and pH at Farm 1, with sand and clay at Farm 2, and with clay and CEC (cation exchange capacity) at Farm 3. Farm-specific correlations between bacterial communities and soil physicochemical properties reflect the unique geological conditions and management practices at each farm, calling for farm-specific nutrient management to protect and restore soil health.

Photo by Carly Thompson

Sampling groundwater at Farm 2

Conclusion

Findings from this study suggest that soil physical, chemical, and microbial properties are influenced by local geological settings and land use management practices. High soil phosphorus levels were detected at all three study farms, raising the concern of their potential contribution to nutrient loading in adjacent surface waters. Other concerns include soil acidity and low microbial diversity (found at one farm) that may have resulted from long-term application of fertilizers. Soil acidity can limit nutrient availability, increase toxic metal solubility, and lead to less favorable growth environments for microorganisms. Our findings suggest the need for strategic interventions, including regular soil tests, tailored nutrient management to reduce the use of fertilizers and potential nutrient loading to surface waters, and adopting farm-specific practices such as liming acidic soils and incorporating organic amendments, to improve soil quality.

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