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ARTICLE

Depth-Coupled Functional Readiness of Urban Soil Health Evidence

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Abstract

The analysis of urban soil health should facilitate decision-making concerning park management, de-sealing, urban forestry, stormwater management, carbon sequestration, and restoration of disturbed soil. Therefore, any analysis of urban soil health requires measurements that reflect chemical, physical, biological aspects, sampling depth, and ecological services associated with urban soils. In this regard, we performed the analysis of urban soil health based on a calculation of a Depth–Function Coupling Portfolio of selected 63 out of 217 papers. The dataset used in this work included data about 61 geographical samples, 59 samples characterized by land use and 51 samples described in terms of their sampling depths. Chemical aspects were reported in 76% of the publications, physical – in 60%, biological – in 44%, soil health indexes – in 37%, and ecosystem services – in 33%. Among land use categories, the greatest number of cases refers to open space (32), park (26), and residential land use (23). Among vegetation types, grass has the largest frequency (48), followed by trees (23) and shrubs (15). Moreover, vertical sampling is limited in more than 70% of samples, where sampling was made not deeper than 20 cm. Only two studies considered soil samples obtained deeper than 120 cm. Soil function coverage index equals 0.507, depth awareness index equals 0.457, the score reflecting the disjunction between soil functions and depth equals 0.469, while the portfolio stress equals 0.500. Ecosystem service proxies have the highest contribution into total measurement deficit (26.8%), followed by soil health indexes (25.2%) and biological measurements (22.4%). Raising the proportion of biological and ecological services covered by urban soil research to 0.60 would increase the soil function coverage index to 0.637. Combined with the depth adequacy value of 0.50, this value will increase depth-awareness index to 0.607 and portfolio stress to 0.284.

Keywords: urban soil health; sampling depth; soil indicators; ecosystem-service proxies; green infrastructure; soil function; urban monitoring

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1. Introduction

Urban soils are now regarded as environmentally useful elements since they impact vegetation growth, water storage, contaminant trapping, carbon cycling, nutrient recycling, heat management, and the performance of green infrastructure. The significance of their role grows in densely developed cities, where limited volumes of soil should support trees, accept stormwater runoff, mitigate pollutants, store carbon, and ensure human safety. Such demands can hardly be answered based on chemical analyses. Even if the soil sample tests positive in terms of pH or metal content, it can still be highly compacted, poorly aerated, biologically degraded, too shallow for root systems, and impermeable to rainfall.

Research on soil quality proved the need for soil evaluation according to its functional potential within specific ecosystem and land-use frameworks [4, 7]. Further development of soil health science enhanced the living system approach by considering mineral particles, organic matter, water, air, roots, microbiota, and fauna interactions in soils [3, 8]. The integrative approach is essential for urban settings because the soil body can be shifted, filled, capped, compacted, irrigated, contaminated, or engineered. Anthropic urban soils can contain buried horizons, construction waste, sharp changes in texture, foreign substrates, and organic amendments within a limited vertical section [6, 9, 15].

The effects of urbanization on soil functions include sealing, change in vegetation cover, alterations in hydrology, and intensive management of the surface environment. Sealing impacts water inflow and gas exchange in the soil, while compaction limits porosity and rootability [18]. Carbon and nitrogen cycling is affected by urban atmosphere, irrigation practices, turf management, tree planting, and substrate mixtures [10, 21]. The findings about turfgrass, residential soils, and urban parks revealed that soils store large amounts of carbon, which, however, depends on land-use history, vegetation, sampling depth, and degree of management [5, 16]. These factors made profile analyses as important as surface chemistry.

The service role of urban soils was well-documented too. Urban, industrial, transportation, mining, and military soils are capable of providing regulating, supporting, cultural, and provisioning services provided that they were kept from contamination and structural challenges [13]. Such soils help to store carbon, regulate water balance, grow food, preserve biodiversity, serve recreational purposes, and ensure efficient functioning of green infrastructures [12, 14, 19]. However, the provision of such services requires establishing the relationship between measured variables and ecosystemic functions. For instance, soil pH, content of organic matter, and metal concentration are useful for diagnostics, but not for measuring infiltration capacity, rooting volume, microbial activity, and services' delivery.

Unequal coverage of measurement indicators has been noted multiple times as one of the problems of soil assessment. It was demonstrated in literature reviews dedicated to soil quality assessment and soil health evaluation, which found less consistent use of biological indicators, soil function measurements, and proxies for ecosystems services than chemical variables [1–3]. In urban soils, another problem emerges related to the change in depth. High organic matter in the topsoil may not reflect an appropriate rooting volume if the soil body under this layer contains compacted or waste materials. Therefore, a soil profile can support grass on the surface and fail to grow trees or absorb rainwater beneath.

This work will address the question of whether the urban soil health literature set with 63 studies has sufficient representation in terms of measurement indicators and soil sampling depths for functional interpretation. The current Depth-Function Coupling Portfolio (DFCP) calculation will be performed in order to quantify five parameters related to measurement deficits: domain deficit contribution, soil function coverage, depth-based adequacy, service-depth

disjunction, and portfolio stress. The objective is to pinpoint the particular measurement domains and sampling depths that restrain the readiness of soils to perform the required services with the aid of the same calculation formula and recorded data.

2. Materials and Methods

2.1. Study material and recorded variables

The study material consisted of 63 urban soil health studies chosen from the initial pool of 217 records reported by Vuono et al. [22]. These recorded values describe the geographic origin, land-use category, vegetation type, sampling depth range, thematic orientation, and soil health indicator domains of each study. The measurement structure of literature data will be analyzed, not the health status of urban soils at a particular place.

The distribution across continents was known for 61 articles: 38% in the Americas, 33% in Asia, 23% in Europe, and 5% in Oceania, one record in Africa. Information about land use was available in 59 articles: 32 open spaces, 26 parks, and 23 residential areas. The dominant vegetation was grass in 48 studies, trees in 23, and shrubs in 15. The sampling depth of more than 70% of 51 soil profiles was limited to the top 20 cm, and only two profiles exceeded 120 cm.

The calculation process is visualized in Figure 1. The figure shows the selection of initial data, formation of the 63 urban soil health subset, partitioning the latter into three subsets for geographic, land-use, and depth-oriented analyses, and the five indicator domains utilized in calculations. It is necessary to emphasize the importance of different denominators in each category.

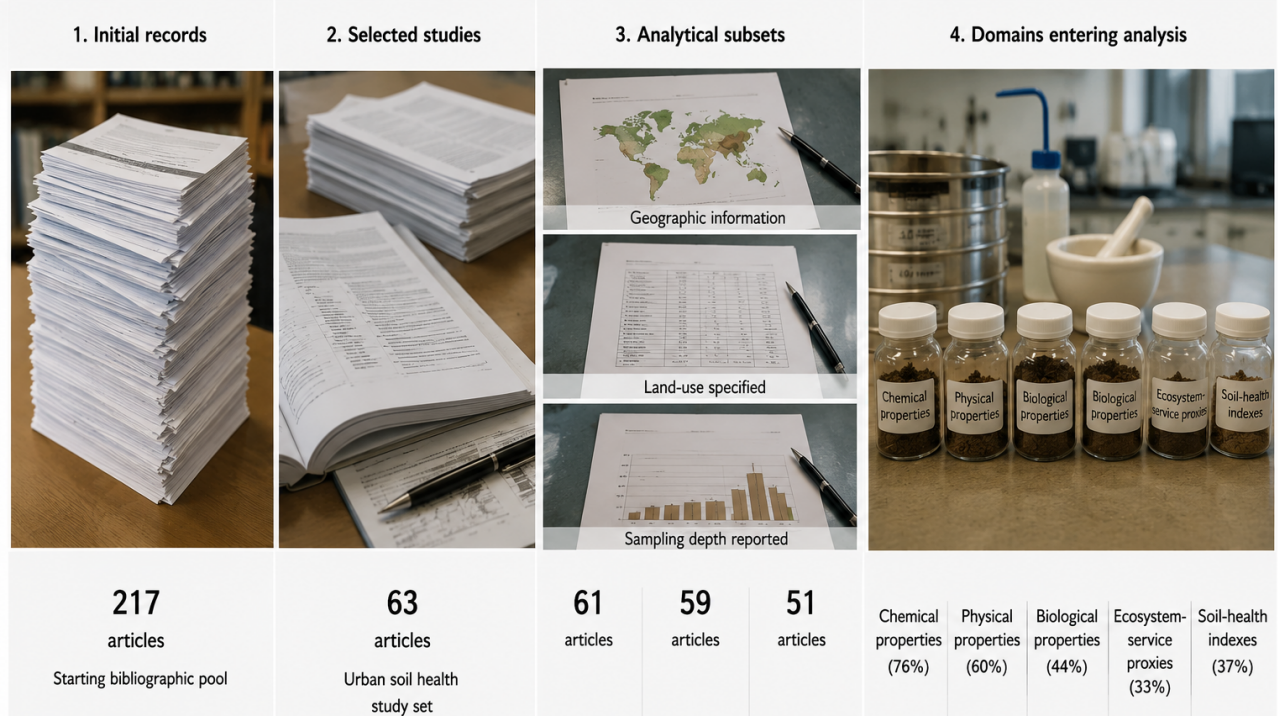

Figure 1. Study material.

The visual summary in Figure 1 clarifies the numerical basis of the paper before any score is calculated. It shows that the final analytical set is much smaller than the initial 217-record pool and that the most detailed calculations depend on subsets of 61, 59, and 51 studies. This prevents the later values from being read as if every retained

study reported every variable.

2.2. Depth–Function Coupling Portfolio calculation

The soil-health measurement vector was defined as

$$\mathbf{x} = (x_C, x_P, x_B, x_E, x_I),$$

where x_C is chemical-property coverage, x_P is physical-property coverage, x_B is biological-property coverage, x_E is ecosystem-service proxy coverage, and x_I is soil-health index coverage. The recorded vector was

$$\mathbf{x} = (0.76, 0.60, 0.44, 0.33, 0.37).$$

The five values represent different evidence domains and are not interchangeable. Chemical coverage cannot replace missing biological activity, and a soil-health index cannot compensate for shallow sampling when the function under discussion depends on profile conditions.

For each domain, the measurement deficit was calculated as

$$s_k = 1 - x_k,$$

and the share of total deficit was calculated as

$$g_k = \frac{s_k}{\sum_{j=1}^{5} s_j}.$$

The resulting shares identify the domains that contribute most to undermeasurement across the literature set.

The soil-function coverage index was calculated from the four primary functional domains:

$$\mathrm{SFCI} = (x_C x_P x_B x_E)^{1/4}.$$

The geometric mean was used because low coverage in one functional domain should reduce the total score. This is appropriate for soil health because chemical, physical, biological, and service-related measurements describe complementary parts of the same soil system.

The depth adequacy factor was set at

$$d = 0.30,$$

because more than 70% of depth-specified studies remained within 20 cm. The depth-aware adequacy score was calculated as

$$\mathrm{DAS} = (x_C x_P x_B x_E d)^{1/5}.$$

This score adds vertical representation to the indicator calculation. The service–depth disjunction score was calculated as

$$\mathrm{SDD} = (1 - x_E)(1 - d),$$

so the value increases when ecosystem-service proxies are scarce and deeper sampling is limited.

The domain balance ratio was calculated as

$$\mathrm{DBR} = \frac{\min(x_C, x_P, x_B, x_E)}{\max(x_C, x_P, x_B, x_E)}.$$

The portfolio stress index was calculated as

$$\mathrm{PSI} = 0.5(1 - \mathrm{SFCI}) + 0.3(\mathrm{SDD}) + 0.2(1 - \mathrm{DBR}).$$

The three terms represent functional incompleteness, service-depth separation, and imbalance among the four primary domains.

The calculation plate in Figure 2 shows the values entering SFCI, DAS, and DBR. The arrangement is deliberately compact because the method is a direct computation from recorded proportions rather than a multi-stage modelling procedure.

The setup in Figure 2 highlights the effect of the limiting aspect of biological and service coverage. The chemical and physical values are 0.76 and 0.60, while biological and service values are 0.44 and 0.33. The depth coverage value of 0.30 reduces the adequacy score because surface-level sampling does not fully reflect the volume of soil necessary for many urban processes.

Figure 2. Portfolio values.

2.3. Score response evaluation

Two scenarios with respect to the score-response function were determined using the same formulae. For the first scenario, the values of biological property coverage and ecosystem services proxy coverage were increased to 0.60, corresponding to the values of physical property coverage. Chemical coverage was 0.76, physical coverage was 0.60, and depth adequacy was 0.30. For the second scenario, the aforementioned values were kept, while depth adequacy increased from 0.30 to 0.50. It is evident from this calculation how the current values would respond if the least developed aspects became as common as physical properties and deeper soil investigations.

3. Results

3.1. Study composition and urban settings

The dataset comprised 63 scientific articles, and it was spatially unbalanced and biased toward the areas convenient for urban research. Out of the 61 studies containing geographical information, 71% came from the Americas and Asia combined, 23% from Europe, 5% from Oceania, and there was one study from Africa. It is obvious that the available literature is more abundant for more easily accessible regions and scarce for a few others facing rapid urbanization.

Table 1. Recorded study values.

Component	Value	Meaning
Initial records	217 articles	Bibliographic pool before screening
Retained studies	63 articles	Urban soil health set used for calculation
Studies with geographic information	61 articles	Regional distribution denominator
Studies with land-use information	59 articles	Urban land-use denominator
Studies with sampling-depth information	51 articles	Vertical sampling denominator
Open-space instances	32	Most frequent land-use category
Park instances	26	Managed public green-space representation
Residential instances	23	Neighbourhood-scale soil representation
Grass instances	48	Dominant vegetation category
Tree instances	23	Moderate woody-vegetation representation
Shrub instances	15	Lower multi-layer vegetation representation
Studies not exceeding 20 cm	More than 70%	Strong surface-layer concentration
Studies beyond 120 cm	2 studies	Rare profile-scale sampling

As seen in Table 1, it is clear that the best representation is achieved in common green space environments. The presence of open spaces, parks, and residential lands can be seen to be more prominent compared to other forms of disturbed or restricted urban soils. Such a combination would allow the characterization of soils found in public or residential green spaces, although it would not adequately represent roadside soils, tree pits, brownfields, paved surfaces, and demolition sites due to their limitations.

The photograph classification in Figure 3 follows the same trend. In the top row, we find open spaces, parks, and residential lands, while in the bottom row, there are grass, trees, and shrubs. The use of actual urban and vegetation environments allows the numerical values to correspond to actual soil environments. The setting distribution in Figure 3 helps explain why shallow sampling is common. Grass-dominated sites are easy to access and are often assessed through surface soil properties. Tree- and shrub-associated soils are less frequent in the recorded material, even though their functions depend more strongly on rooting depth, soil volume, aeration, and profile continuity. The land-use and vegetation composition therefore influences the functional scope of the literature.

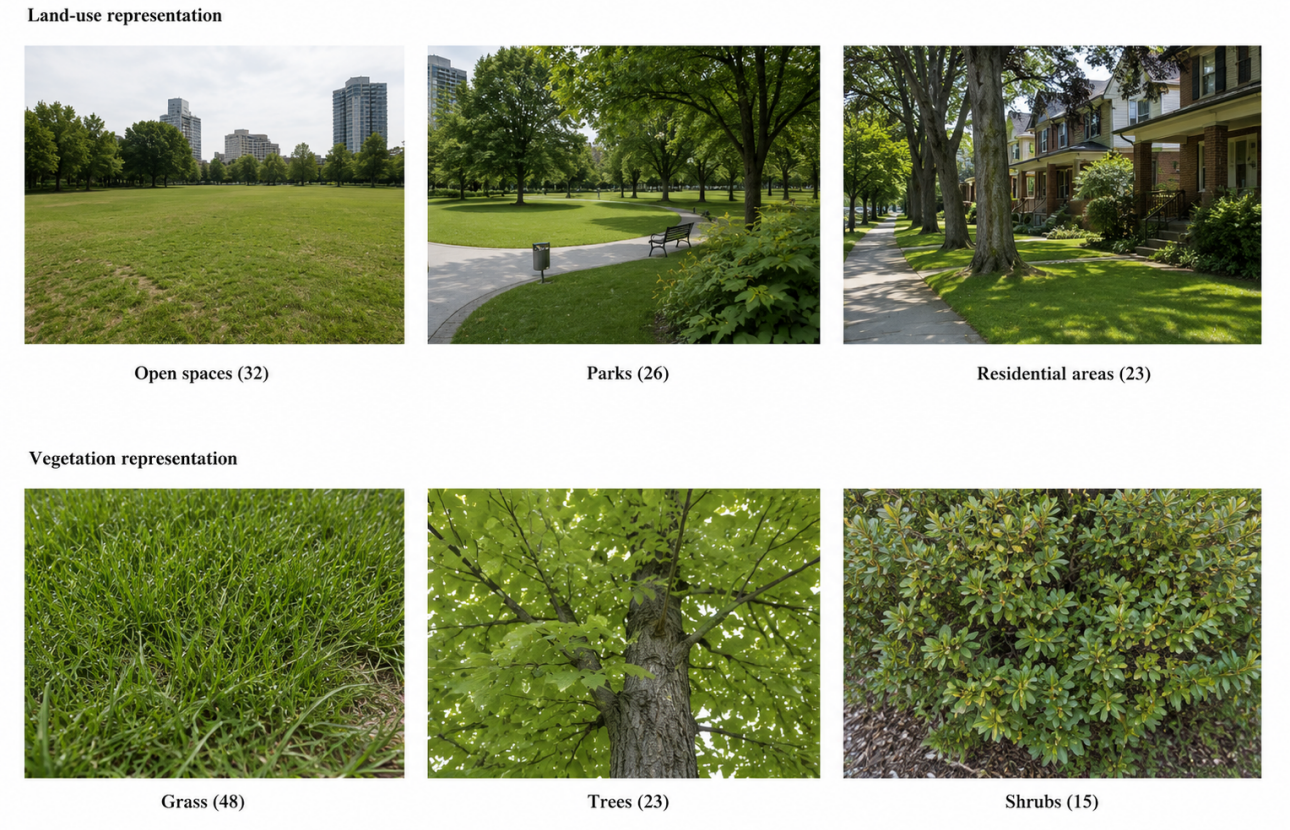

Figure 3. Urban settings.

3.2. Topic distribution

The thematic distribution is led by soil pollution and remediation, which accounts for 37% of studies. Soil health assessment accounts for 30%, ecosystem services for 14%, water management and green infrastructure for 11%, and stakeholder or policy themes for 8%. Pollution and general assessment together therefore form the centre of the literature, while service delivery, hydrology, design use, and governance receive lower attention.

The distribution in Table 2 indicates that urban soil health research is still strongly shaped by contamination and general assessment concerns. These topics are necessary because urban soils often contain legacy pollutants and need diagnostic evaluation before reuse. However, the smaller shares for ecosystem services and water management show that fewer studies directly connect soil indicators to the urban functions often used to justify soil protection.

Table 2. Topic distribution.

Topic	Share	Primary emphasis
Soil pollution and remediation	37%	Contaminants, risk, and treatment
Soil health assessment	30%	Indicator use and soil condition
Ecosystem services	14%	Service interpretation and urban benefits
Water management and green infrastructure	11%	Hydrology and design application
Stakeholder surveys and policy	8%	Governance and planning uptake

3.3. Indicator-domain imbalance

Chemical properties are the most frequently recorded indicator domain, appearing in 76% of studies. Physical properties appear in 60%, biological properties in 44%, soil-health indexes in 37%, and ecosystem-service proxies in 33%. This order shows a clear decline from routine soil testing toward living-system, integrative, and service-linked interpretation.

The values in Table 3 identify the exact source of imbalance. Chemical properties contribute only 9.6% of the total deficit because their coverage is high. Ecosystem-service proxies contribute 26.8%, soil-health indexes 25.2%, and biological properties 22.4%. The literature is therefore not simply incomplete; it is uneven in a direction that limits the interpretation of soil life, service delivery, and integrated soil condition.

Table 3. Indicator deficits.

Indicator domain	Coverage	Deficit	Deficit share
Chemical properties	0.76	0.24	9.6%
Physical properties	0.60	0.40	16.0%
Biological properties	0.44	0.56	22.4%
Ecosystem-service proxies	0.33	0.67	26.8%
Soil-health indexes	0.37	0.63	25.2%

The coverage pattern in Figure 4 makes the chemical dominance visually clear. Chemical and physical measurements occupy the upper part of the range, whereas biological, ecosystem-service, and index-based domains remain lower. This distribution explains why the calculated soil-function coverage index does not rise above 0.507 despite the high chemical value.

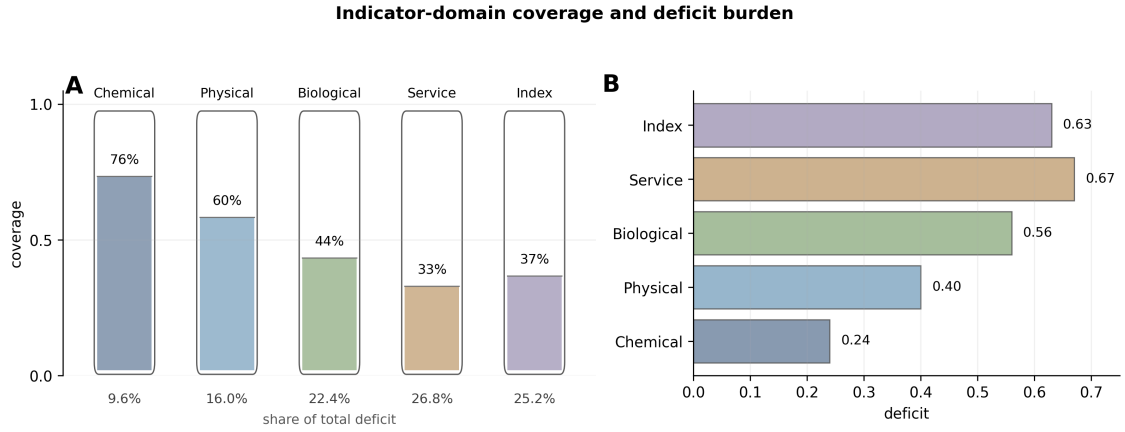

Figure 4. Indicator coverage.

The soil-function coverage index was

$$\mathrm{SFCI} = (0.76 \times 0.60 \times 0.44 \times 0.33)^{1/4} = 0.507.$$

The domain balance ratio was

$$\mathrm{DBR} = \frac{0.33}{0.76} = 0.434.$$

A DBR of 0.434 means that the least represented primary domain, ecosystem-service proxies, has less than half the coverage of chemical properties. This imbalance matters because many urban soil claims involve services rather

than chemistry alone.

3.4. Vertical sampling adequacy

Sampling depth adds a second constraint. More than 70% of the 51 studies with depth information do not exceed 20 cm, and only two studies sampled beyond 120 cm. The depth adequacy factor of 0.30 therefore reflects the limited proportion of studies moving beyond the shallow surface layer.

The profile in Figure 5 shows why the 20 cm threshold is important for interpretation. Surface sampling can describe turf-related properties, immediate organic matter inputs, and near-surface contamination. It does not reliably describe deeper compaction, buried fill, subsurface storage, tree rooting volume, or restrictive layers that affect stormwater infiltration and vegetation performance.

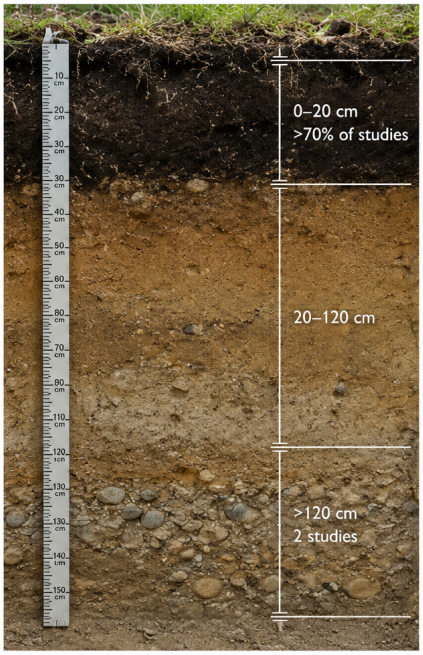

Figure 5. Sampling depth.

The depth-aware adequacy score was

$$\mathrm{DAS} = (0.76 \times 0.60 \times 0.44 \times 0.33 \times 0.30)^{1/5} = 0.457.$$

The service–depth disjunction score was

$$\mathrm{SDD} = (1 - 0.33)(1 - 0.30) = 0.469.$$

These values show that service interpretation is weakened by two simultaneous limitations: ecosystem-service proxies occur in only 33% of studies, and deeper sampling is uncommon. This combination is especially important for carbon retention, stormwater regulation, and urban forestry because each depends on properties extending beyond the immediate surface.

3.5. Integrated score behaviour

The portfolio stress index combines incomplete functional coverage, service-depth separation, and domain imbalance:

$$\text{PSI} = 0.5(1 - 0.507) + 0.3(0.469) + 0.2(1 - 0.434) = 0.500.$$

A value of 0.500 indicates moderate-to-high stress in the measurement structure. The largest portion comes from the incomplete soil-function term, followed by service-depth separation and domain imbalance.

The decomposition in Figure 6 shows that portfolio stress is not driven by one isolated weakness. Functional incompleteness contributes 0.247, service-depth separation contributes 0.141, and domain imbalance contributes 0.113. The combined value of 0.500 is therefore a product of multiple measurement limitations rather than a single missing indicator.

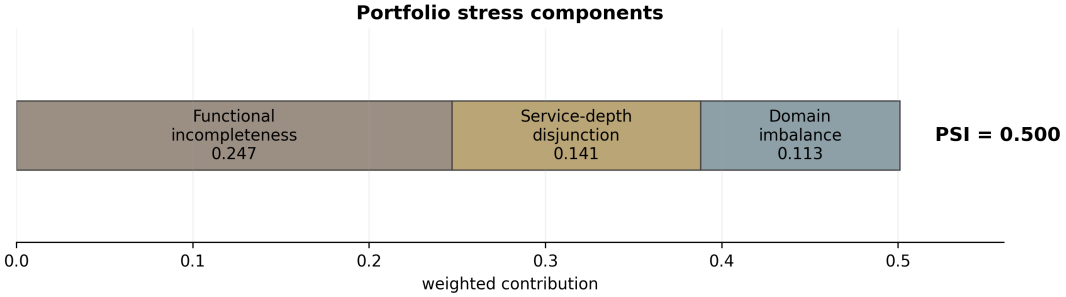

Figure 6. Stress components.

The two score-response conditions show how the same calculation reacts when the weakest domains are strengthened. Raising biological and ecosystem-service coverage to 0.60 increases SFCI from 0.507 to 0.637 and decreases PSI from 0.500 to 0.308. Adding depth adequacy of 0.50 raises DAS to 0.607 and lowers PSI to 0.284.

The values in Table 4 show that indicator balance and depth adequacy affect different parts of interpretation. Increasing biological and service coverage has the strongest effect on SFCI and PSI. Increasing depth adequacy has the strongest additional effect on DAS and SDD. The calculation therefore separates the benefit of measuring more functional domains from the benefit of sampling a deeper and more relevant soil volume.

Table 4. Score response.

Condition	SFCI	DAS	SDD	PSI
Current measurement structure	0.507	0.457	0.469	0.500
Biological and service coverage at 0.60	0.637	0.548	0.280	0.308
Coverage at 0.60 with depth adequacy at 0.50	0.637	0.607	0.200	0.284

The service-depth plane in Figure 7 places the current condition at ecosystem-service coverage of 0.33 and depth adequacy of 0.30. The strengthened condition moves to 0.60 and 0.50, where SDD falls from 0.469 to 0.200. This change means that service interpretation becomes more credible when service proxies are measured more often and sampling better represents the profile.

The trajectories in Figure 8 demonstrate that not all scores respond in the same direction. SFCI increases when biological and service coverage are raised; DAS increases further when depth adequacy improves; SDD and PSI decline as measurement structure becomes less constrained. This behaviour confirms that the current calculation is sensitive to the two weaknesses most visible in the recorded values.

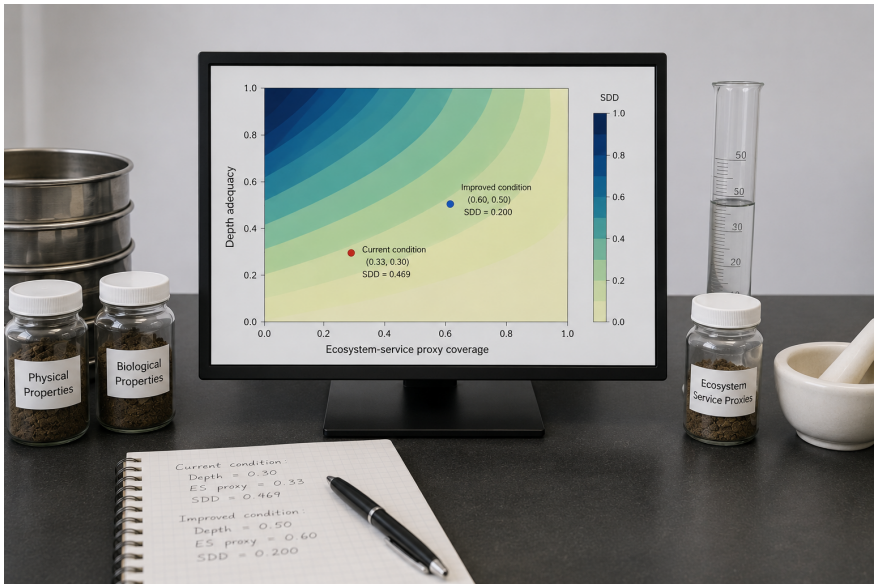

Figure 7. Service-depth score.

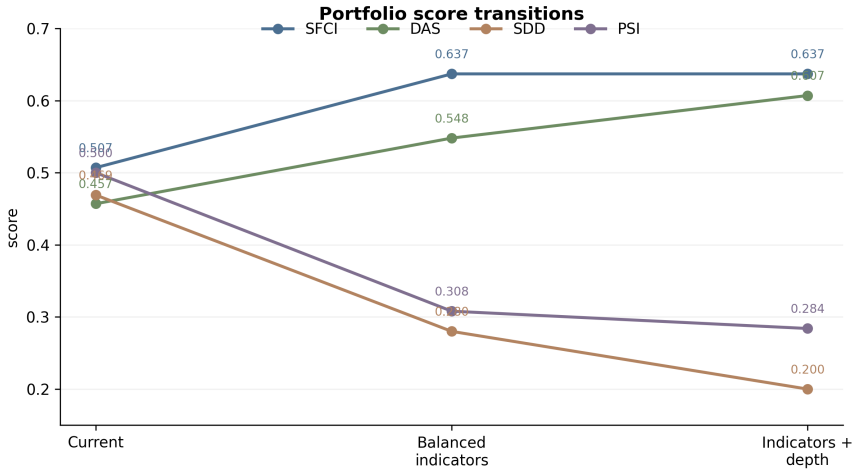

Figure 8. Score transitions.

3.6. Function-matched monitoring specification

The results support a practical measurement specification for urban soil monitoring. The strongest gains would come from keeping chemical diagnosis while adding biological activity, physical structure, ecosystem-service proxies, and profile-aware sampling where the urban function requires it.

The monitoring design presented in Figure 9 reflects how score values can be turned into field parameters. In the case of urban forestry, rooting volume, aeration, compaction, water availability, biological activity, and profile depth need to be taken into account. For stormwater regulation, infiltration, water-holding capacity, soil physical structure, and restrictive-layer information will be necessary. Contamination and remediation will benefit from chemical safety indicators informed by depth variations in pollutant transport or exposure. De-sealing and green infrastructure will need profile description, compaction assessment, biological activity, and service response indicators.

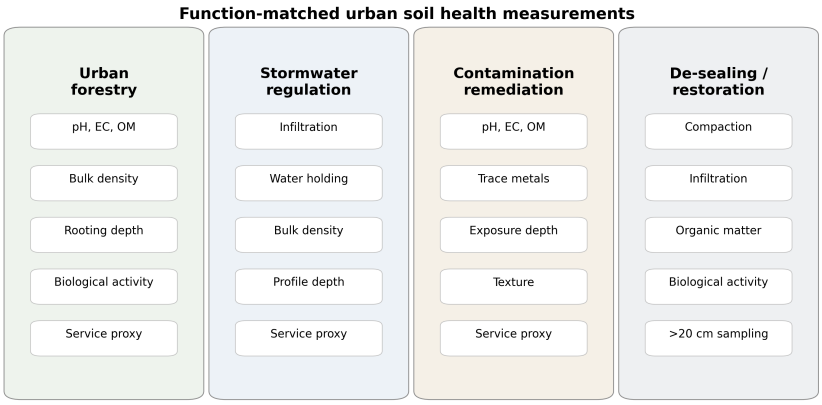

Figure 9. Monitoring specification.

4. Discussion

4.1. Chemical diagnosis and functional interpretation

The results of the study suggest that the evaluated urban soil health literature is best in its chemical measurement. Such a conclusion is justified by the reality that urban soils may contain contaminants, salts, changed pH, construction leftovers, and nutrient imbalance. Chemical information is required for public safety considerations, vegetation establishment, remediation options, and soil constraint identification.

At the same time, chemical measurement cannot be considered equivalent to functional readiness by itself. Soil health implies physical structure, biological activity, organic matter, water relations, root development, and service delivery. As evidenced by the recorded coverage rates, biological properties, soil-health indices, and ecosystem-service proxies are less common than chemical properties by far. This creates limitations in interpreting soil as an active and productive medium. Such limitation is reflected by the SFCI score of 0.507.

These biological properties are particularly important due to their roles in nutrient recycling, structural regeneration, microbial respiration, enzymatic activity, soil fauna, organic matter decomposition, and root interaction. The soil may still remain biologically inactive even after chemical recovery or remediation. Biologically active soil is an essential element of soil health that should not be left out in any case.

Ecosystem-service proxies are another key element lacking in the urban soil literature. These are important due to the relevance of soil health in the context of ecosystem services. Some of these services include stormwater regulation, carbon retention, plant growth, temperature moderation, food production, and pollutant buffering. The lack of ecosystem-service proxies in 67% of papers makes their demonstration difficult.

4.2. Profile depth and service interpretation

Sampling depth impacts soil interpretation significantly. Surface sampling may suffice for certain purposes, such as fertility for grass, surface organic matter, or surface contamination. However, when assessing rooting, stormwater capacity, or carbon storage, for instance, a deeper sample may be required.

A recorded depth pattern shows a tendency to emphasize surface sampling: more than 70% of depth-specified samples did not exceed 20 cm, and only two studies sampled up to 120 cm. DAS is thus lower than SFCI, and the SDD score suggests that ecosystem services are interpreted inefficiently in light of the sampling depth requirement.

Such a conclusion is made possible by the SDD score of 0.469.

Many urban soils have vertical discontinuities that do not reveal themselves on the surface. Shallow soils may be composed of organic-rich surface soil, sealed compact fill, rubble, clay soil, or poorly-draining material. The layer below the surface influences infiltration, root growth, aeration, and pollutant transportation. Therefore, it is essential that sampling depth matches soil function for proper interpretation.

4.3. Land use, vegetation, and transferability

The current material is focused predominantly on open spaces, parks, residential zones, and grass-dominated vegetation. Such focus is justified by accessibility of these sites, as well as direct municipal or private management and soil health visibility. At the same time, transferability suffers due to poor coverage of highly disturbed soils, such as roadside strips, brownfields, affected by construction, compacted tree pits, and recent de-sealing sites.

Vegetation coverage is another aspect of the problem. There are grass samples in 48 cases, trees in 23, and shrubs in 15. Grasses can be evaluated via surface characteristics, whereas the tree- and shrub-rooting systems require deeper sampling and better attention to soil volume, water availability, and subsurface constraints. Thus, urban forestry and multi-tier plantings require measurement methods beyond those used most frequently in the current research.

4.4. Interpretation of score response

Score response analysis has shown that the highest possible increase in structural efficiency of urban soil interpretation is achieved by increasing biological and ecosystem service coverage up to 0.60. It has thus increased SFCI by approximately 25.5%. This means that the best structural gains come from making living system assessments more similar to physical assessments.

An increase in depth adequacy from 0.30 to 0.50 increases DAS from 0.548 to 0.607 and reduces SDD from 0.280 to 0.200. As seen, these are two separate, yet mutually complementary, ways to enhance the structural integrity of soil interpretation. Indicators improve domain balance, whereas sampling depth ensures adequate soil interpretation for each domain.

Decline in the PSI score from 0.500 to 0.284 shows that significant enhancement in measurement structure is possible without compromising chemical coverage. This does not mean that chemical measurement can be done away with, but rather suggests that it should be complemented with physical, biological, service-based, and depth-matched measurements.

4.5. Implications for urban soil assessment

Urban soil assessment should consider measurement structure depending on soil function. A chemical assessment should retain chemical safety indicators as the main ones. A tree planting soil assessment should additionally include rooting depth, compaction, aeration, water availability, and biological activity indicators. A stormwater soil assessment should include infiltration capacity, water holding, physical structure, and restrictive layer information. A de-sealing assessment should take into consideration profile description, compaction correction, biological activity restoration, and service response.

The proposed monitoring method should maintain pH, electrical conductivity, organic carbon/organic matter, nutrients, and relevant contaminants. The addition should consist of bulk density or penetrometer, infiltration or water-holding capacity, biological activity measurement, and service proxy related to the objective at hand.

Sampling should be conducted for a minimum of 20 cm in all relevant cases. This will provide comprehensive soil measurement.

5. Limitations

The present analysis uses the recorded number of publications per category and the corresponding proportions. A few categories can coincide in a single paper since different themes, land uses, or vegetation may be covered by one publication. Consequently, all scores refer to the structure of the measurement rather than probability distributions.

Depth adequacy is an approximate metric, which states that over 70% of depth-specified samples do not exceed 20 cm, so 0.30 is used to express it. Future applications may benefit from more precise information in terms of sampling intervals, horizon description, layer thickness, and depth requirements based on specific soil functions.

The portfolio stress index uses fixed weights for domain coverage, depth/service separation, and domain balance, making the structure of the index transparent and easy to understand. Nonetheless, this index is neither a probability distribution nor a universal standard. Future applications may find other weights more convenient for soil assessment.

The figures included in the manuscript help readers understand recorded values and how they are calculated. They do not introduce new metrics or field observations. The role of figures is to facilitate understanding of the literature composition, measurement imbalance, depth inadequacy, behavior of various score indicators, and implications for monitoring design.

6. Conclusion

The question of this research was whether the evaluated literature on urban soil health provides balanced and depth-adequate data for functional interpretation. The answer is that it provides chemical diagnosis well and moderately characterizes soil physically, but not so well regarding biological activity, ecosystem services, health indices, and sampling depth.

Chemical coverage is 0.76, biological properties coverage is 0.44, soil-health index coverage is 0.37, and ecosystem-service proxy coverage is 0.33. The largest contribution to the deficiency share comes from ecosystem-service proxies at 26.8% and soil-health indices at 25.2%. Biological properties are deficient next with a share of 22.4%. Depth is also a limiting factor in that over 70% of studies do not sample below 20 cm, and there are only two papers exceeding 120 cm in sampling depth.

These limitations translate to the following score values: SFCI = 0.507, DAS = 0.457, SDD = 0.469, and PSI = 0.500. Biological property and ecosystem service coverage of 0.60 increases SFCI to 0.637, whereas DAS of 0.50 increases DAS to 0.607 and reduces PSI to 0.284.

Thus, the urban soil health literature reviewed in this article may benefit from retaining chemical measurement but abandoning functional interpretation through it alone.

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