

Nature-based Solutions for Urban Systems

By Prof Ir Rudy C Tarumingkeng, PhD

www.ruduct.com/cv.pdf

Institut Bisnis dan Multimedia (IBM ASMI)

Academic Article

Abstract

Nature-based Solutions (NbS) have emerged as a central approach for addressing the complex environmental, infrastructural, climatic, and social challenges of contemporary cities. Rather than relying exclusively on conventional engineered systems, NbS use ecological processes, living systems, and landscape functions to deliver services such as flood attenuation, stormwater management, urban cooling, erosion control, water purification, biodiversity support, carbon storage, recreation, and public-health improvement. In urban areas, these solutions include urban forests, wetlands, restored rivers, green roofs, green walls, bioswales, rain gardens, permeable landscapes, coastal mangroves, dunes, constructed wetlands, ecological corridors, and multifunctional parks.

This article develops a comprehensive systems perspective on Nature-based Solutions for Urban Systems. It explains the conceptual foundations of NbS, their relationship with ecosystem services, green and blue infrastructure, ecological engineering, climate adaptation, and urban resilience. It examines their design, performance, governance, financing, monitoring, maintenance, and integration with gray infrastructure. Special attention is given to urban flooding, extreme heat, water security, biodiversity, public health, coastal resilience, circularity, social equity, climate justice, digital monitoring, artificial intelligence, and urban digital twins.

The article argues that NbS should not be understood as decorative urban greening or as a universal substitute for conventional infrastructure. Their effectiveness depends on context, scale, ecological function, engineering design, maintenance, land availability, institutional capacity, and social legitimacy. Hybrid systems that combine ecological and engineered infrastructure often provide the most robust results. For Indonesia and other rapidly urbanizing tropical countries, NbS offer particularly significant opportunities because intense rainfall, urban flooding, heat, coastal exposure, biodiversity pressures, and infrastructure deficits occur simultaneously. Successful implementation requires locally adapted design, lifecycle

management, participatory governance, credible performance metrics, long-term finance, and integration into mainstream urban planning. NbS should therefore be seen as a strategic form of urban infrastructure that contributes to resilience, sustainability, human well-being, and the ecological regeneration of cities.

Keywords

Nature-based Solutions; urban systems; ecosystem services; green infrastructure; blue-green infrastructure; urban resilience; climate adaptation; urban flooding; heat mitigation; biodiversity; ecological engineering; urban planning; Indonesia

1. Introduction: Reconnecting Urban Systems with Nature

Modern cities are often designed as if nature were external to the urban system. Rivers are channelized, wetlands are drained, soils are sealed, vegetation is fragmented, and stormwater is rapidly transferred into pipes. This approach supported urban growth and sanitation, but it also reduced the ecological functions that once helped regulate water, temperature, biodiversity, and environmental quality.

Nature-based Solutions offer a different perspective. They recognize that ecological processes can be intentionally designed, restored, or managed to provide urban services. A wetland can store floodwater while supporting biodiversity. A tree canopy can reduce heat exposure while improving air quality and creating public space. A green roof can retain rainfall while lowering surface temperature and providing habitat. A restored river corridor can provide flood conveyance, recreation, and ecological connectivity simultaneously.

The concept does not imply a return to a pre-urban natural condition. Cities are hybrid socio-ecological systems. Roads, buildings, utilities, institutions, and ecosystems interact. The purpose of NbS is therefore not to remove engineering but to expand the engineering toolkit by including living systems and ecological processes.

This shift is significant because many urban challenges are interconnected. Flood control, heat reduction, public health, biodiversity, recreation, and climate adaptation are frequently managed by different departments. NbS can create multifunctional infrastructure that addresses several objectives at once.

However, multifunctionality also creates complexity. Benefits occur at different scales and times. A park may provide immediate recreation but require years for tree canopy to mature. Wetlands may reduce flood peaks but require maintenance and land. Green roofs may reduce runoff but cannot replace major drainage infrastructure during extreme storms.

A mature NbS strategy must therefore combine ecological ambition with engineering realism. It should identify where nature can provide reliable functions, where hybrid systems are preferable, and where conventional infrastructure remains essential.

2. Defining Nature-based Solutions

Nature-based Solutions are commonly understood as actions that protect, sustainably manage, restore, or create ecosystems in order to address societal challenges while providing benefits for human well-being and biodiversity. This definition is broader than traditional conservation because NbS are explicitly connected to societal objectives such as climate adaptation, water management, health, food security, or disaster-risk reduction.

In urban contexts, the term includes interventions that range from conserving existing ecosystems to constructing new ecological features. Protecting a floodplain is an NbS because it preserves natural water-

storage capacity. Restoring a degraded river is an NbS because ecological processes are re-established. Building a rain garden is an NbS because vegetation and soil are intentionally designed to manage runoff.

Nature-based Solutions overlap with related concepts. Green infrastructure refers to networks of green spaces that provide ecosystem services. Blue-green infrastructure integrates vegetation and water systems. Ecosystem-based adaptation focuses on using ecosystems to adapt to climate change. Ecological engineering applies ecological principles in engineered systems. Water-sensitive urban design integrates water cycles with planning. Sponge-city approaches emphasize infiltration, storage, and reuse of rainfall.

The conceptual overlap is useful but can also create ambiguity. A practical distinction is that NbS are defined by their reliance on ecological processes and their intention to address societal challenges while producing environmental co-benefits.

Not every green project is automatically an NbS. A decorative lawn with high irrigation demand may provide limited ecological function and could even increase resource consumption. A poorly designed tree-planting project may damage sidewalks or fail under drought. Performance and context matter.

The term should therefore be tied to measurable function. A project should clearly identify the challenge it addresses, the ecological processes involved, expected services, potential trade-offs, and the method by which performance will be monitored.

3. From Ecosystem Services to Urban Infrastructure

The ecosystem-services framework helps explain why nature has economic and social value. Ecosystems provide regulating services such as flood attenuation, temperature regulation, water purification, erosion control, and carbon storage. They also provide cultural services such as recreation, aesthetic value, and sense of place.

Treating these functions as infrastructure changes urban management. Infrastructure is expected to have defined objectives, budgets, maintenance, performance indicators, and responsible institutions. The same discipline should apply to NbS.

A mature urban forest, for example, is not simply a collection of trees. It is a distributed cooling, shading, stormwater, biodiversity, and public-space system. Its performance depends on species, canopy size, soil volume, water availability, maintenance, and spatial distribution.

Wetlands can be viewed as treatment and storage infrastructure. Their hydraulic residence time, vegetation, sediment processes, and pollutant removal can be measured.

This infrastructure framing is important because it helps NbS compete for capital budgets. Traditional budgeting often treats parks as amenities and drainage as infrastructure. Yet a flood-storage park may perform both functions.

At the same time, living infrastructure differs from concrete infrastructure. It grows, changes, reproduces, and responds to climate. Performance may improve as vegetation matures, but systems can also degrade through drought, pests, invasive species, neglect, or excessive use.

Lifecycle management must therefore combine engineering and ecology.

4. Systems Thinking and Urban Multifunctionality

Nature-based Solutions are particularly valuable because they can perform multiple functions simultaneously. A conventional stormwater pipe mainly conveys water. A vegetated swale can convey water, filter pollutants, reduce temperature, support habitat, and improve streetscape quality.

Multifunctionality can improve the social return on land and investment. This is important in dense cities where space is limited.

However, multifunctionality also requires integrated planning. The drainage department may value storage capacity, the parks department may prioritize recreation, the ecology department may prioritize habitat, and communities may prioritize safety and access. Design must balance these objectives.

Systems thinking helps identify interactions. Increasing vegetation can reduce heat but may increase water demand. Retaining water can improve flood management but may create mosquito habitat if poorly designed. Coastal vegetation can reduce waves but may conflict with port access.

Trade-offs should be explicit rather than hidden. The strongest NbS projects are those in which multiple benefits are achieved without undermining the primary service objective.

Systems thinking also extends to spatial scale. A single green roof provides local benefit, while a network of roofs, parks, wetlands, and restored waterways can influence district-scale hydrology and temperature.

Urban NbS therefore work best as networks rather than isolated objects.

5. Urban Forests as Climate and Health Infrastructure

Urban forests include street trees, parks, institutional landscapes, riparian vegetation, community forests, and remnant natural areas. Their most visible contribution is shade, which reduces radiant heat exposure and improves outdoor comfort.

Trees also cool air through evapotranspiration. The magnitude depends on species, canopy density, soil moisture, and climate.

Urban forests contribute to stormwater management by intercepting rainfall, improving infiltration, and increasing soil permeability.

They also provide habitat and ecological connectivity, although biodiversity value depends on species diversity and structural complexity.

Health benefits can arise through improved thermal comfort, recreation, stress reduction, and opportunities for physical activity.

Urban forestry requires engineering attention to root space, utilities, pavements, drainage, and wind. Trees planted in insufficient soil volume often fail to mature.

Species diversity improves resilience to pests and climate change. Native species can support local biodiversity, but species selection should also consider tolerance to urban stress.

Maintenance is a long-term obligation. Pruning, watering, soil care, replacement, and risk inspection require stable budgets.

6. Green Roofs and Green Walls

Green roofs place vegetation and growing media on building roofs. They can retain rainfall, delay runoff, reduce roof temperatures, improve insulation, and provide habitat.

Their performance depends on substrate depth, vegetation, drainage layers, climate, roof slope, and maintenance.

Extensive green roofs use shallow substrates and relatively low-maintenance vegetation. Intensive roofs support deeper soils and larger plants but require stronger structures and more maintenance.

Green roofs can reduce peak runoff for frequent storms, but their storage can be exhausted during prolonged rainfall. They should therefore complement, not replace, broader drainage systems.

Thermal benefits are particularly relevant in hot cities because green roofs reduce surface temperature and can lower cooling loads.

Green walls can provide shading, aesthetics, and limited microclimate benefits. Their water and maintenance requirements should be considered carefully.

Retrofitting existing buildings requires structural assessment because saturated substrates add load.

Performance monitoring should include runoff, vegetation health, irrigation, and thermal effects.

7. Rain Gardens, Bioswales, and Bioretention

Rain gardens and bioswales capture and treat stormwater close to where it falls. They typically use engineered soil, vegetation, and drainage layers to slow, infiltrate, and filter runoff.

These systems are particularly effective for streets, parking areas, residential areas, and public spaces.

Bioretention can remove sediments, nutrients, metals, and other pollutants through filtration, adsorption, plant uptake, and microbial processes.

Design must consider soil infiltration, groundwater level, overflow pathways, maintenance access, and local rainfall.

In tropical cities, intense storms require reliable overflow design. The NbS should manage frequent rainfall but remain safely connected to conventional drainage during extreme events.

Maintenance includes sediment removal, vegetation care, litter removal, and ensuring inlets remain clear.

Bioswales can be integrated into street design, creating green corridors that also improve pedestrian environments.

Their cumulative effect becomes significant when deployed across a catchment.

8. Constructed Wetlands and Urban Water Treatment

Constructed wetlands use vegetation, soils, microbial communities, and controlled hydrology to treat water. They can be applied to stormwater, wastewater polishing, industrial effluent, or landscape water.

Wetlands reduce suspended solids, nutrients, and some contaminants through sedimentation, filtration, biological transformation, and uptake.

They also create habitat and public landscape.

Hydraulic design is essential. Water depth, residence time, flow distribution, vegetation, and loading rates influence treatment performance.

Wetlands require land, which can be difficult in dense urban areas. However, they can be incorporated into parks, peri-urban areas, river corridors, or treatment facilities.

Public access should be designed safely where water quality may vary.

Maintenance includes sediment management, vegetation control, inlet and outlet inspection, and invasive-species management.

Constructed wetlands illustrate how ecological processes can perform infrastructure functions when designed with measurable criteria.

9. Restored Rivers and Floodplain Reconnection

Urban rivers have frequently been straightened, concreted, narrowed, or buried. Restoration seeks to recover ecological and hydraulic functions.

Floodplain reconnection gives rivers more space during high flows. This can reduce downstream flood peaks and create habitat.

River restoration can also improve water quality, recreation, and urban identity.

In dense cities, full restoration may be impossible. Partial naturalization, setback levees, widened channels, vegetated banks, and floodable parks can still provide benefits.

Hydraulic modeling is necessary because changes in channel form affect water levels and velocities.

Restoration should consider sediment transport, erosion, bridges, utilities, and adjacent development.

Social dimensions are important because river corridors may contain informal settlements or economically vulnerable communities. Adaptation should avoid displacement without fair alternatives.

Successful river restoration combines hydrology, ecology, planning, and community engagement.

10. Floodable Parks and Multifunctional Public Space

Floodable parks are designed to function as public space during normal conditions and temporary water-storage areas during storms. This is a powerful example of multifunctionality.

Sports fields, plazas, playgrounds, and open landscapes can be shaped to accept controlled inundation.

Design must ensure that water enters and leaves safely, critical equipment is protected, and surfaces recover after flooding.

Public communication is important so residents understand temporary closures and risk.

Floodable parks are particularly useful where land is expensive because adaptation infrastructure also provides everyday social value.

They can be connected to drainage systems, rivers, or detention networks.

Maintenance after flood events includes sediment, debris, vegetation, and surface repair.

Such spaces represent a shift from trying to exclude all water to creating urban landscapes that can coexist with temporary flooding.

11. Permeable Surfaces and Urban Soils

Impervious surfaces prevent infiltration and accelerate runoff. Permeable pavements, porous asphalt, permeable concrete, and reinforced grass surfaces allow water to enter underlying layers.

These systems can reduce peak runoff and support groundwater recharge where conditions are suitable.

Performance depends on subsoil infiltration, clogging, traffic load, groundwater, and maintenance.

Vacuum sweeping and sediment control may be necessary to maintain permeability.

Urban soils themselves are critical infrastructure. Compacted or contaminated soils limit infiltration and tree growth.

Soil restoration can improve water storage, vegetation performance, and ecological function.

NbS planning should therefore include soil as a designed resource rather than treating it as leftover space around buildings.

12. Urban Heat Mitigation through Nature

Urban heat is influenced by surface materials, building geometry, vegetation, moisture, anthropogenic heat, and regional climate.

Vegetation reduces heat primarily through shade and evapotranspiration. Trees are especially effective because shade directly reduces radiant exposure.

Parks can create localized cooling, although effects depend on size, vegetation, irrigation, and surrounding urban form.

Green roofs reduce roof temperature and building heat gain. Green walls provide shading.

Water bodies can influence microclimate, but evaporation and humidity effects vary.

Heat mitigation should be targeted toward places where people are exposed: sidewalks, transit stops, schools, markets, hospitals, and low-income housing.

Equity matters because tree canopy is often unevenly distributed.

Urban cooling strategies should integrate NbS with cool materials, building design, and efficient mechanical cooling.

13. Biodiversity and Ecological Connectivity

Cities can support meaningful biodiversity if habitats are connected and managed appropriately.

Urban NbS can create stepping stones and corridors for birds, insects, plants, and other species.

Biodiversity value depends on habitat quality, not merely green area. Native vegetation, structural diversity, water, dead wood, and reduced pesticide use can improve ecological function.

Connectivity helps species move through fragmented landscapes and may become more important under climate change.

Urban biodiversity also supports ecosystem services such as pollination and pest regulation.

However, conflicts may arise with public safety, maintenance, or invasive species.

Biodiversity objectives should therefore be integrated into NbS design from the beginning.

14. Coastal Nature-based Solutions

Coastal cities can use mangroves, dunes, salt marshes, reefs, and vegetated shorelines to reduce erosion and wave energy.

These systems can complement seawalls and levees in hybrid protection strategies.

Mangroves are particularly relevant in tropical regions because their root structures trap sediment, reduce waves, and provide nursery habitat.

Performance depends on water depth, wave climate, sediment supply, species, and shoreline geometry.

Nature-based coastal protection is not suitable for every location. Very high-energy coasts or dense urban waterfronts may require substantial engineered structures.

Landward migration space is important as sea level rises. Coastal ecosystems trapped between development and rising water can be lost.

Restoration should therefore be integrated with long-term coastal planning.

15. NbS for Urban Water Quality

Stormwater carries sediments, nutrients, metals, hydrocarbons, plastics, and pathogens into waterways.

Vegetated systems can reduce pollutant loads through filtration, sedimentation, biological uptake, and microbial processes.

Treatment trains are often effective. Runoff may pass through gross-pollutant traps, swales, bioretention, wetlands, and receiving ecosystems.

Performance varies by pollutant and environmental conditions.

Maintenance is essential because accumulated sediments can eventually reduce capacity or become contamination sources.

Water-quality objectives should be defined explicitly and monitored.

NbS can complement treatment plants by reducing pollutant loads before water enters major systems.

16. NbS and Urban Water Security

Nature-based Solutions can contribute to water security by improving infiltration, protecting watersheds, capturing stormwater, and supporting groundwater recharge.

Upstream forest conservation can protect water quality and regulate flows.

Urban wetlands and infiltration systems can retain rainfall that would otherwise become rapid runoff.

Stormwater harvesting can combine ecological treatment with storage for non-potable use.

Water-sensitive landscapes can reduce irrigation demand through appropriate planting and soil design.

However, infiltration may be inappropriate in contaminated areas or where groundwater levels are high.

NbS should be integrated into the full urban water cycle rather than treated only as drainage features.

17. Public Health and Well-being

Green and blue spaces can contribute to public health through cooling, recreation, stress reduction, improved environmental quality, and social interaction.

Access matters as much as total green area. A large park may not benefit residents who cannot reach it safely.

Tree shade can reduce heat exposure for pedestrians and outdoor workers.

Nature contact can support mental well-being, although outcomes depend on quality, safety, and cultural context.

NbS can also create health risks if poorly designed. Standing water may encourage vectors, dense vegetation may create perceived insecurity, and allergenic species may affect sensitive populations.

Health outcomes should therefore be included in design and monitoring.

18. Social Equity and Green Justice

Urban environmental benefits are often unevenly distributed. Wealthier neighborhoods may have more trees, parks, and higher-quality public space.

Nature-based Solutions can reduce inequality if investments prioritize vulnerable communities.

However, successful greening can increase property values and contribute to displacement, a phenomenon sometimes called green gentrification.

Equitable NbS therefore require affordable housing, community participation, and anti-displacement measures where necessary.

Distributional analysis should examine who receives cooling, flood protection, recreation, and health benefits.

Procedural justice concerns who participates in planning and whose knowledge is respected.

Urban nature should be treated as essential public infrastructure rather than a luxury.

19. Climate Adaptation and Urban Resilience

Nature-based Solutions are increasingly used for climate adaptation because they can respond to flood, heat, drought, erosion, and coastal hazards.

Their adaptive value often comes from flexibility. Vegetation can grow, ecosystems can self-repair to some extent, and landscapes can provide storage over large areas.

NbS can also reduce exposure by creating buffers around rivers and coasts.

However, ecosystems themselves are vulnerable to climate change. Drought, heat, pests, sea-level rise, and extreme storms can damage them.

Resilience planning should therefore consider the resilience of the NbS, not only the resilience provided by the NbS.

Species diversity, redundancy, ecological connectivity, and adequate maintenance improve robustness.

20. Hybrid Gray-Green Infrastructure

The most practical urban strategies often combine conventional and nature-based infrastructure.

A drainage system may use pipes for conveyance and wetlands for storage and treatment.

A coastal system may combine mangroves with levees.

A building may use green roofs together with conventional stormwater tanks.

Hybrid systems can provide high reliability while generating ecological co-benefits.

Design should define the role of each component. NbS should not be expected to perform beyond their realistic capacity.

Hydraulic, structural, ecological, and operational models can be combined to evaluate system performance.

Hybrid infrastructure represents integration rather than competition between engineering and ecology.

21. Performance Measurement and Evidence

Nature-based Solutions need measurable performance if they are to become mainstream infrastructure.

Hydrological metrics can include runoff volume, peak flow, infiltration, and storage.

Thermal metrics can include surface temperature, air temperature, radiant temperature, and human thermal comfort.

Ecological metrics can include species richness, habitat quality, and connectivity.

Social metrics can include accessibility, use, safety, satisfaction, and health indicators.

Economic metrics can include avoided damage, maintenance cost, energy savings, and property impacts.

Monitoring should distinguish short-term and long-term outcomes because vegetation matures over time.

Evidence should also document failure and underperformance. Learning from unsuccessful projects is essential.

22. Lifecycle Management and Maintenance

Living infrastructure requires continuous care. The assumption that nature maintains itself is one of the major causes of NbS failure.

Maintenance begins with clear ownership. Someone must be responsible for pruning, sediment removal, irrigation, litter, invasive species, drainage inspection, and replacement.

Budgets should be secured for the entire lifecycle.

Maintenance needs can change as systems mature.

Inspection after major storms is particularly important.

Digital asset-management systems can track condition, work orders, and performance.

Lifecycle plans should also include renewal. Plants die, soils clog, structures deteriorate, and land use changes.

NbS should therefore be managed with the same professional seriousness as conventional infrastructure.

23. Digital Monitoring, IoT, and Urban Digital Twins

Digital technologies can improve NbS management. Soil-moisture sensors can guide irrigation. Water-level sensors can monitor wetlands and detention areas. Weather stations can link performance to climate conditions.

Remote sensing can measure vegetation health, canopy cover, land-surface temperature, and landscape change.

Drones can support inspection of large wetlands or coastal ecosystems.

Urban digital twins can integrate NbS with drainage, buildings, transportation, and environmental data.

A flood twin can estimate how parks, wetlands, and permeable surfaces influence runoff.

A heat twin can estimate the cooling contribution of trees and green roofs.

Digital monitoring should support decisions rather than become a technology project disconnected from maintenance.

24. Artificial Intelligence for NbS Planning and Management

Artificial intelligence can help analyze spatial patterns, classify vegetation, predict maintenance needs, and optimize placement of NbS.

Machine learning can identify neighborhoods where heat exposure, low canopy, social vulnerability, and flood risk overlap.

Computer vision can estimate tree canopy or detect vegetation stress from imagery.

Optimization models can identify portfolios of green infrastructure under land and budget constraints.

AI can also help predict irrigation demand or wetland performance.

However, AI models depend on data quality and may reproduce spatial bias.

Engineering and ecological judgment remain necessary, especially where data are sparse or future climate differs from historical experience.

25. Economic Valuation and Cost-Benefit Analysis

NbS often produce benefits that fall across different budgets. A tree may reduce heat, manage stormwater, improve health, support biodiversity, and increase property value.

Traditional project appraisal can undervalue these multifunctional benefits.

Lifecycle cost-benefit analysis should include construction, land, maintenance, avoided damages, energy savings, health, recreation, and ecosystem services where credible.

Double counting should be avoided when benefits overlap.

Distribution matters because aggregate benefits can hide unequal outcomes.

Economic valuation is useful but should not imply that all ecological or cultural values can be fully monetized.

Multi-criteria analysis can complement monetary appraisal.

26. Financing Nature-based Solutions

Funding NbS can be difficult because benefits are diffuse and revenue streams are uncertain.

Municipal budgets, climate funds, green bonds, stormwater fees, development charges, philanthropic funding, and public-private partnerships can contribute.

Developers may be required or incentivized to provide green infrastructure.

Water utilities can finance NbS when they reduce drainage or treatment costs.

Insurance and resilience finance may support projects that reduce risk.

Bundling projects into portfolios can attract larger investors.

Long-term maintenance finance is as important as initial capital.

27. Governance and Institutional Coordination

NbS frequently cross administrative boundaries. Parks, drainage, roads, water, environment, and planning agencies may all be involved.

Without coordination, responsibilities become unclear.

A citywide NbS strategy should establish standards, priority areas, ownership, maintenance, and data requirements.

Cross-department budgeting can help because benefits occur across sectors.

Metropolitan and watershed governance is important where rivers, forests, and coastlines cross municipal boundaries.

Community organizations and private landowners may also be key partners.

Governance should therefore combine technical standards with collaborative institutions.

28. Planning, Zoning, and Land Policy

Land is often the limiting resource for NbS.

Planning can protect floodplains, river corridors, wetlands, coastal buffers, and ecological networks before development makes restoration difficult.

Zoning can require minimum green space, permeable surfaces, or tree retention.

Development rights can be transferred away from high-risk areas.

Public land can be used strategically for multifunctional green infrastructure.

Land acquisition may be necessary for major flood or ecological corridors.

Planning should consider future climate and ecosystem migration, not only present conditions.

29. Procurement and Standards

Nature-based Solutions require procurement methods that reflect living systems.

Specifications should define performance objectives, plant quality, soil, hydrology, establishment periods, monitoring, and maintenance.

Lowest-cost procurement can produce poor outcomes if contractors reduce soil volume or plant quality.

Performance-based contracts can link payment to establishment success or hydraulic function.

Standards are developing but should remain flexible enough to accommodate local ecosystems.

Professional competence is essential. Landscape architects, ecologists, hydrologists, engineers, planners, and maintenance specialists should collaborate.

30. Community Participation and Co-design

Local communities often possess detailed knowledge of flooding, heat, informal drainage, public-space use, and ecological change.

Co-design can improve location, safety, cultural relevance, and long-term stewardship.

Participation should occur before final design decisions.

Community gardens, neighborhood rain gardens, and local tree programs can strengthen social ownership.

However, public participation does not eliminate the need for professional technical responsibility.

Maintenance arrangements should avoid shifting excessive burden onto communities.

Trust grows when authorities show how local input affected final decisions.

31. Risks, Trade-offs, and Maladaptation

Nature-based Solutions can create unintended consequences.

Poorly designed wetlands may create nuisance or vector concerns.

Trees can damage pavements or utilities if species and root space are poorly planned.

Green roofs can increase structural load.

Urban greening can increase irrigation demand.

Coastal restoration may fail if sediment conditions are unsuitable.

Green gentrification can displace vulnerable residents.

A rigorous NbS assessment should identify such risks in advance and include mitigation measures.

The existence of co-benefits should never be assumed automatically.

32. Scaling from Projects to Networks

Many cities have successful demonstration projects but struggle to scale NbS.

Scaling requires standard design guidance, financing, maintenance capability, and integration into capital planning.

Networks are more powerful than isolated sites. Connected green corridors improve biodiversity and pedestrian comfort. Distributed stormwater systems reduce catchment runoff.

Spatial planning can identify priority networks based on flood pathways, heat, biodiversity, and social vulnerability.

Scaling also requires supply chains for plants, soils, design expertise, and maintenance.

Pilot projects should therefore be designed for replication.

33. Tropical Cities and NbS Design

Tropical cities have distinct conditions: intense rainfall, high humidity, rapid vegetation growth, year-round biological activity, and often strong development pressure.

Stormwater systems must handle high-intensity rainfall.

Plant species should tolerate heat, humidity, and local pests.

Maintenance can be more frequent because vegetation grows rapidly.

Mosquito management requires good hydraulic design that avoids stagnant water.

Coastal NbS such as mangroves may be especially relevant.

Tropical design should use local ecological knowledge rather than import temperate-city templates.

34. Indonesia: Strategic Opportunities for Nature-based Solutions

Indonesia has exceptional potential for urban NbS because it combines high biodiversity, tropical rainfall, extensive coastlines, rapid urbanization, flood risk, heat exposure, and diverse urban forms.

Flood-prone cities can use retention parks, restored river corridors, wetlands, permeable landscapes, and neighborhood bioretention to complement drainage and pumping.

Coastal cities can integrate mangrove restoration with engineered defenses where geomorphological conditions permit.

Urban forests can reduce heat exposure in dense metropolitan areas.

Watershed protection is critical because upstream land-use change influences downstream flooding and water quality.

Secondary cities have an opportunity to protect ecological assets before development pressure becomes irreversible.

Indonesia's kampung environments also offer opportunities for community-scale green and blue infrastructure, although land and tenure constraints must be respected.

NbS should be integrated with national and local spatial planning, disaster-risk reduction, water management, and climate policy.

Universities can contribute to monitoring, design standards, species selection, hydrological modeling, and evaluation.

The strategic opportunity is not simply to make Indonesian cities greener, but to make natural processes functional components of urban resilience and service delivery.

35. Mangroves, Coastal Settlements, and Indonesian Cities

Mangroves are among the most important coastal NbS in Indonesia.

They can reduce wave energy, trap sediment, support fisheries, and store carbon.

Their effectiveness depends on shoreline conditions, sediment supply, tidal range, and ecosystem health.

Planting alone is often insufficient if hydrological conditions are unsuitable. Restoration should focus on recovering appropriate tidal and sediment processes.

Mangroves should be integrated with spatial planning so that future inland migration is possible where sea level rises.

In dense urban waterfronts, hybrid systems may combine mangroves with levees, seawalls, or elevated infrastructure.

Community participation is important where livelihoods depend on coastal ecosystems.

Monitoring should assess both coastal-protection performance and ecological condition.

36. NbS for Indonesian Urban Flood Management

Urban flooding in Indonesia often results from intense rainfall, river overflow, inadequate drainage, sediment, waste blockage, land subsidence, and development in flood-prone areas.

Nature-based Solutions can address several of these mechanisms.

Upstream forests and retention areas can slow runoff.

Urban wetlands and floodable parks can store water.

Bioswales and permeable surfaces can manage frequent rainfall close to source.

River restoration can increase conveyance and storage where space exists.

However, NbS cannot solve severe flood risk alone in all metropolitan settings. Pumping, tunnels, channels, barriers, and building adaptation may remain necessary.

The strongest strategy is therefore catchment-based hybrid infrastructure.

Maintenance, especially waste control and sediment management, is essential.

37. Urban Agriculture and Productive Landscapes

Urban agriculture can be considered an NbS when it contributes to ecosystem services as well as food production.

Community gardens can improve infiltration, social cohesion, local food access, and biodiversity.

Rooftop agriculture can use underutilized surfaces.

Agroforestry approaches can combine food, shade, and habitat.

Water quality and soil contamination must be assessed carefully.

Urban agriculture should be integrated with circular systems such as composting and safe water reuse.

Its primary value may be social and educational rather than large-scale food supply.

38. NbS and the Circular Urban Economy

Nature-based Solutions can support circularity by transforming waste streams into resources.

Compost can improve urban soils.

Treated organic residues can support landscape systems where safe.

Constructed wetlands can recover nutrients and improve water reuse.

Stormwater capture reduces demand for potable water.

Urban biomass can be managed through composting or other recovery pathways.

Circularity should be governed by health and environmental standards.

The broader principle is to close urban water, nutrient, and material loops where feasible.

39. A Nature-based Solutions Maturity Model

Cities can assess NbS maturity across several stages.

Level 1 consists mainly of isolated landscaping projects.

Level 2 introduces project-level green infrastructure for drainage or cooling.

Level 3 integrates NbS into planning standards and capital projects.

Level 4 develops citywide networks, monitoring, lifecycle budgets, and hybrid infrastructure.

Level 5 treats ecosystems as strategic urban infrastructure integrated with climate, health, water, biodiversity, and social policy.

Maturity depends on maintenance and governance as much as project quantity.

A city with many poorly maintained green projects may be less mature than a city with a smaller but well-managed network.

40. Key Performance Indicators

Key indicators should connect ecological interventions to urban outcomes.

Flood indicators include storage, runoff reduction, peak-flow reduction, and affected population.

Heat indicators include canopy, shade, surface temperature, and thermal comfort.

Biodiversity indicators include habitat quality, species diversity, and connectivity.

Water indicators include pollutant removal, infiltration, and reuse.

Social indicators include accessibility, use, safety, and equity.

Economic indicators include lifecycle cost, avoided damage, and energy savings.

Maintenance indicators include survival rates, condition, sediment accumulation, and inspection completion.

Indicators should be used for learning, not merely reporting.

41. Implementation Roadmap

Implementation begins with defining priority urban challenges.

The second step is spatial assessment of heat, flood, biodiversity, social vulnerability, land availability, and existing green infrastructure.

The third step is development of an NbS portfolio with clear functions.

The fourth step is engineering and ecological design, including overflow and failure pathways.

The fifth step is economic, social, and environmental evaluation.

The sixth step is finance and procurement.

The seventh step is construction or restoration with establishment monitoring.

The eighth step is long-term maintenance, monitoring, and adaptive management.

The roadmap should be integrated into normal urban investment processes.

42. Research and Education Agenda

Nature-based Solutions require interdisciplinary research across ecology, engineering, planning, architecture, health, economics, and management.

More evidence is needed on long-term performance under tropical conditions.

Hydrological research should examine catchment-scale effects of distributed NbS.

Heat research should connect vegetation with human thermal exposure.

Social research should examine equity, participation, and displacement.

Management research can address governance, financing, procurement, and organizational coordination.

Digital twins and remote sensing provide new opportunities for monitoring.

Universities can use campuses as living laboratories.

Students should learn that nature-based infrastructure requires both ecological literacy and engineering discipline.

43. Future Directions

Future urban NbS will likely become more measurable, networked, digitally monitored, and integrated with infrastructure planning.

Climate change will increase demand for cooling, flood management, coastal resilience, and water security.

Digital twins may allow cities to test NbS portfolios before implementation.

AI can support spatial prioritization and maintenance.

Biodiversity objectives will become more important as cities recognize ecological decline.

Hybrid gray-green systems will become mainstream.

Finance may increasingly recognize resilience and ecosystem services.

The central challenge will be moving from pilot projects to durable institutional systems.

44. Conclusion

Nature-based Solutions represent a major evolution in urban infrastructure thinking. They reconnect engineering with ecological processes and allow cities to address multiple challenges through multifunctional landscapes.

Their value lies in functions: cooling, water storage, filtration, habitat, erosion control, recreation, health, and resilience.

However, NbS are not automatically sustainable or effective. They require appropriate site selection, engineering design, ecological knowledge, maintenance, governance, and monitoring.

Hybrid systems are often the most realistic approach because living infrastructure and conventional infrastructure have different strengths.

Social equity must be central. Urban nature should reduce vulnerability rather than become another source of exclusion.

For Indonesia, NbS offer powerful opportunities in flood management, coastal resilience, urban cooling, watershed protection, biodiversity, and community development.

The strategic objective is not simply to increase green area. It is to design urban systems in which ecological processes are intentionally integrated into infrastructure, planning, and public-service delivery.

A nature-positive city is therefore not a city that merely contains nature. It is a city that allows nature to perform meaningful work for resilience, sustainability, biodiversity, and human well-being.

45. Urban Ecological Networks: From Isolated Projects to System Connectivity

The long-term performance of Nature-based Solutions depends not only on the quality of individual projects but also on the connectivity among them. A single park can provide shade and recreation, but a connected system of parks, river corridors, street trees, wetlands, green roofs, and peri-urban forests can influence hydrology, biodiversity, mobility, and microclimate at a much larger scale. This network perspective is essential because ecological processes operate across space. Water flows through catchments, species move between habitats, heat is transported by air, and residents move through public-space networks.

Urban ecological networks can be planned using hubs, corridors, stepping stones, and buffers. Hubs are larger ecological areas such as major parks, wetlands, forests, or river systems. Corridors connect these hubs through green streets, riparian zones, rail corridors, or linear parks. Smaller green roofs, pocket parks,

and vegetated institutional sites can function as stepping stones. Buffers reduce disturbance around sensitive habitats or water bodies.

Connectivity creates resilience. If one habitat is damaged, species may survive in other locations and recolonize. Distributed stormwater features reduce reliance on one detention structure. A continuous shaded walking network provides greater heat protection than isolated shaded sites.

Network planning requires spatial analysis. GIS can combine land ownership, hydrology, canopy, biodiversity, heat, transportation, and social vulnerability. Planners can identify where one intervention closes several gaps simultaneously. For example, restoring a river corridor may connect habitats, create a cycling route, provide flood storage, and improve access to green space in underserved neighborhoods.

The network approach also highlights fragmentation caused by infrastructure. Highways, walls, and large developments can interrupt ecological movement. Wildlife crossings, vegetated bridges, restored waterways, and street-tree networks can reduce fragmentation where appropriate.

Institutional coordination is necessary because ecological networks cross departmental and property boundaries. A city may control roads and parks, utilities may control easements, private owners control gardens and roofs, and regional governments control rivers. Incentives, regulations, and partnerships are therefore part of ecological infrastructure design.

The strategic lesson is that NbS should be planned as a connected urban system. Isolated projects may produce local benefits, but networks can create cumulative performance and ecological resilience that no single intervention can achieve.

46. Watershed-scale Nature-based Solutions and Upstream-Downstream Relationships

Urban flooding and water quality are fundamentally watershed processes. Rainfall occurring far upstream can determine flood conditions in a downstream city. Urbanization in one municipality may increase runoff in another. This means that effective Nature-based Solutions often need to extend beyond administrative urban boundaries into peri-urban and upstream landscapes.

Watershed-scale NbS include forest protection, reforestation, wetland conservation, floodplain restoration, agricultural soil management, riparian buffers, and distributed retention. These measures can reduce runoff velocity, sediment, nutrients, and erosion before water reaches dense urban areas.

The benefits are often cumulative rather than dramatic at one site. A restored upstream wetland may not prevent an extreme urban flood by itself, but a portfolio of retention areas, permeable landscapes, and river restoration can reduce peak flows and improve water quality.

Watershed interventions create governance challenges because the locations providing ecological services may be different from the locations receiving the benefits. An upstream municipality may bear the opportunity cost of conserving land while a downstream city receives flood reduction. Payment for ecosystem services, intergovernmental transfers, watershed funds, or development-compensation mechanisms can help align incentives.

Hydrological modeling is important for estimating effects. Simplistic assumptions can overstate NbS performance. Forests and wetlands influence runoff differently depending on soil, slope, saturation, rainfall intensity, and land management. Models should be calibrated with local data where possible.

Watershed-scale planning also improves water-security strategy. Protecting source catchments can reduce treatment costs and preserve base flows. Riparian restoration can reduce sediment and improve habitat. Agricultural nutrient management can reduce downstream eutrophication.

For Indonesian metropolitan regions, watershed coordination is particularly important because rapid urban expansion often crosses municipal boundaries. Upstream development, quarrying, deforestation, or conversion of agricultural land can change downstream flood risk. Urban NbS policy should therefore connect city planning with wider watershed management.

47. Restoration Ecology and the Difference between Planting and Restoring

Nature-based Solutions increasingly include ecological restoration, but restoration is more demanding than planting vegetation. Planting creates biological material; restoration seeks to recover ecological structure, processes, and function. A mangrove plantation may fail if tidal hydrology is wrong. A river planted with vegetation may remain ecologically degraded if flow, sediment, and connectivity are not restored. A wetland may look green while providing limited water-treatment function.

Restoration begins with diagnosis. Practitioners need to understand the historical ecosystem, current pressures, hydrology, soil, species composition, invasive species, and surrounding land use. The objective is not necessarily to recreate a historical condition exactly, especially under climate change, but to restore functional ecological processes.

Reference ecosystems can help define targets. These may be nearby healthy ecosystems or reconstructed descriptions of appropriate structure and function. However, urban environments are highly modified, so targets should remain realistic.

Hydrology is often the critical driver. Wetlands, riparian zones, and mangroves depend on water depth, timing, salinity, sediment, and connectivity. Correcting hydrology may be more important than large-scale planting.

Restoration also requires time. Ecological systems mature over years or decades. Early performance indicators should therefore distinguish establishment from mature function. Survival of planted trees after one year is not equivalent to formation of a resilient urban forest after twenty years.

Adaptive management is essential. Monitoring may reveal that species are failing, erosion is occurring, or invasive plants are dominating. Management should allow corrective action rather than treating construction completion as the end of the project.

This distinction has major implications for procurement and budgeting. Restoration contracts should include establishment periods, ecological monitoring, and performance-based milestones. The goal is functional ecosystem recovery, not merely completion of landscape construction.

48. Designing NbS for Extreme Events, Not Only Average Conditions

Many Nature-based Solutions perform well under frequent, moderate events. The more difficult engineering question is what happens during rare extremes. Climate change increases the importance of this question because rainfall intensity, heatwaves, drought, and coastal events may exceed historical experience.

A rain garden may capture ordinary storms but overflow during extreme rainfall. This is acceptable if the overflow is safely routed. A wetland may store water up to a threshold but become submerged during a major flood. A park may be intentionally designed for temporary inundation. The key principle is safe exceedance.

Safe exceedance requires predefined pathways. Water should move toward areas where temporary flooding causes limited damage and away from hospitals, substations, schools, and homes. Surface grading, curbs, overflow structures, and emergency storage must be coordinated with the NbS.

Extreme drought creates a different challenge. Trees and wetlands that provide cooling and ecological services during normal years may become stressed when water is scarce. Species selection, soil design, recycled-water irrigation, and drought-management plans improve resilience.

Coastal vegetation can reduce wave energy, but extreme storms may damage the ecosystem. Hybrid defenses can provide a second layer of protection. Similarly, urban forests can lose branches during strong winds, so inspection and species selection are part of risk management.

The design objective should therefore not be to claim that NbS eliminates hazard. It should define performance under normal, design, and exceedance conditions. This makes ecological infrastructure comparable with conventional engineering practice.

Performance curves can be useful. Instead of reporting one number such as storage capacity, engineers can describe how the system performs across increasing rainfall or heat. This improves transparency and allows realistic integration into urban risk models.

49. Nature-positive Urban Regeneration

Urban regeneration creates opportunities to embed Nature-based Solutions at a scale that is difficult to achieve through small retrofits. Former industrial areas, aging housing estates, waterfronts, transport corridors, and underused land can be redesigned to create connected ecological and social infrastructure.

A nature-positive regeneration strategy starts by mapping ecological assets and deficits. Existing trees, waterways, soils, biodiversity, flood pathways, heat hotspots, and social needs become part of the master-planning baseline. Development density can then be arranged around ecological corridors and multifunctional public spaces.

Regeneration offers opportunities to unseal land. Former parking or industrial surfaces can be converted into permeable landscapes, wetlands, and tree systems. Rivers can be daylighted or widened. Buildings can include green roofs and courtyards. Streets can incorporate bioretention and shade.

The concept of nature-positive development goes beyond minimizing ecological damage. It seeks a measurable improvement in ecosystem condition and function compared with the pre-project baseline. This requires indicators and long-term management.

Urban regeneration can also integrate circularity. Demolition materials can be reused, excavated soils can be managed carefully, organic materials can support soil improvement, and captured stormwater can irrigate landscapes.

Social outcomes require attention. Ecological regeneration can improve neighborhood quality but may also increase land values. Affordable housing, local employment, public access, and community participation should be incorporated so benefits remain inclusive.

Nature-positive regeneration demonstrates how NbS can influence the fundamental structure of urban development rather than being added after buildings and roads are already designed.

50. Institutional Capability: Building Organizations that Can Manage Living Infrastructure

The transition from conventional infrastructure to integrated gray-green systems requires new institutional capability. Cities accustomed to managing pipes, roads, and concrete assets may not have sufficient ecological expertise, while parks departments may not be organized around hydraulic or resilience performance. NbS therefore challenge traditional departmental boundaries.

Organizations need interdisciplinary teams. Hydrologists, civil engineers, landscape architects, ecologists, arborists, soil scientists, planners, public-health specialists, economists, and community-engagement professionals may all contribute to one project. Coordination mechanisms should clarify decision authority and technical responsibility.

Asset ownership must be explicit. A bioswale in a road corridor may serve drainage, streetscape, and ecology. Which department maintains it? Who removes sediment? Who replaces vegetation? Who pays after storm damage? Unclear responsibility leads to deterioration.

Training is important for field staff. Maintenance crews need to understand that vegetation and soil are functional components. Conventional practices such as excessive mowing, compacting soil, or removing wetland plants can destroy performance.

Procurement capability must also evolve. Tender documents need ecological specifications, establishment requirements, monitoring, and lifecycle maintenance. Contract managers must be able to evaluate whether these requirements are being met.

Organizational learning should be formalized. Cities can maintain databases of project performance, maintenance cost, plant survival, hydraulic function, and community feedback. Future designs should incorporate these lessons.

The mature organization treats NbS neither as experimental landscaping nor as a special environmental program. It incorporates living infrastructure into ordinary asset-management systems while preserving the ecological expertise needed to manage dynamic systems.

51. Monitoring Frameworks, Baselines, and Long-term Evaluation

Reliable monitoring is essential because NbS performance is context-dependent and changes over time. Without a baseline, cities cannot determine whether an intervention improved conditions. Without long-term monitoring, they may know whether plants survived but not whether the system delivered expected flood, heat, or biodiversity outcomes.

Monitoring design should begin before implementation. Baseline data may include pre-project runoff, water quality, surface temperature, biodiversity, canopy, public-space use, and social perceptions. Post-project monitoring can then compare changes.

Indicators should match objectives. If the primary goal is flood mitigation, hydraulic performance should be monitored. If cooling is the goal, measurements should capture thermal exposure where people are present. If biodiversity is the goal, ecological indicators should be appropriate to target species or habitats.

Control or comparison sites improve evaluation where feasible. They help distinguish project effects from wider climate or urban change.

Remote sensing can provide citywide information on canopy, vegetation health, and temperature. Field sensors provide higher temporal detail. Citizen science can contribute observations but should be quality-controlled.

Monitoring frequency should reflect system dynamics. Water-level sensors may record every few minutes, while tree-canopy surveys may be annual. Biodiversity surveys may follow seasonal cycles.

Results should be linked to management. Monitoring is not useful if data remain in reports. Thresholds can trigger irrigation, sediment removal, replanting, or redesign. Long-term evaluation turns NbS from one-time projects into adaptive infrastructure systems.

52. Strategic Portfolio Management for Nature-based Solutions

Cities usually face more potential NbS projects than they can fund. Portfolio management helps select combinations of interventions that collectively address strategic objectives. The task is not simply to rank individual projects but to build a balanced system across neighborhoods, hazards, ecosystem types, and time horizons.

Portfolio design can begin with citywide objectives such as reducing flood exposure, increasing canopy, connecting habitats, improving access to green space, and restoring waterways. Spatial analysis identifies where interventions produce the highest marginal benefit.

Projects can then be grouped by function. Some provide immediate risk reduction, such as detention basins. Others build long-term ecological capacity, such as urban forest expansion. Some are low-cost distributed interventions, while others are major land and restoration projects.

Diversification is valuable. Relying on one NbS type creates vulnerability. A portfolio combining trees, wetlands, river restoration, green roofs, and permeable streets provides different functions and risk profiles.

Sequencing matters. Protecting land for a future river corridor may need to occur before development, even if construction happens later. Young urban forests require early planting because canopy benefits take years to mature.

Portfolio evaluation should include equity. Investment should not cluster only in high-profile central districts. Heat, flood, health, and green-space deficits should guide distribution.

Strategic portfolio management makes NbS a long-term urban investment program rather than a collection of disconnected environmental projects.

53. Public Value, Cultural Meaning, and Sense of Place

Nature-based Solutions create values that are difficult to capture through engineering metrics alone. Rivers, trees, wetlands, and coastal landscapes can carry cultural meaning, collective memory, identity, and spiritual significance. Urban nature can connect residents with local history and ecology.

This cultural dimension affects acceptance. A technically efficient design may be rejected if it erases valued landscape features or conflicts with community use. Conversely, restoration can strengthen civic identity when it reconnects a city with a river, coastline, or native landscape.

Design should therefore include social and cultural analysis. Which places are valued? How are public spaces used? Which species or landscapes have cultural importance? How do different groups experience safety, access, and belonging?

Interpretation and education can strengthen public value. Signs, digital applications, school programs, and community monitoring can explain how wetlands treat water or how trees reduce heat. Understanding can increase stewardship.

Public value also includes dignity. High-quality green infrastructure should be available in low-income neighborhoods, not only flagship commercial districts. Maintenance quality sends a message about whose environment is valued.

Cultural ecosystem services should not be treated as vague extras. They influence social legitimacy, public use, political support, and long-term protection of NbS assets.

The most successful projects combine measurable infrastructure performance with landscapes that people recognize as meaningful parts of urban life.

54. Strategic Leadership and the Future of Nature-based Urbanism

Nature-based urbanism requires strategic leadership because it challenges conventional patterns of investment, land use, and professional responsibility. Leaders must be willing to protect space for ecological function even when short-term development pressures favor construction. They must also ensure that NbS are held to credible performance standards rather than promoted through vague sustainability language.

The first leadership task is to frame nature as infrastructure. This shifts discussion from whether a city can afford green investment to how ecological and conventional systems should be combined to deliver services most effectively.

The second task is institutional alignment. Planning, public works, water, parks, environment, housing, transport, and finance agencies need common objectives and data. Leadership can resolve conflicts and create shared accountability.

The third task is long-term stewardship. Trees, wetlands, rivers, and coastal ecosystems require decades of management. Political cycles are much shorter. Stable policies, budgets, standards, and professional capacity are necessary to protect continuity.

The fourth task is public legitimacy. Leaders should communicate both benefits and limitations. Nature-based Solutions are not magical substitutes for engineering, but neither are they ornamental luxuries. Transparent explanation builds trust.

The fifth task is learning. Cities should compare predicted and actual performance and adjust. Successful innovations should be standardized and scaled; failures should be documented rather than hidden.

For management education, NbS provide an important case of strategic integration. They require investment under uncertainty, cross-sector coordination, lifecycle thinking, stakeholder engagement, and balancing measurable performance with social and ecological values.

The future of nature-based urbanism will depend less on the novelty of individual projects than on whether cities build institutions capable of managing nature as a permanent component of urban systems.

The strategic objective is a city in which ecological processes, engineered infrastructure, and human institutions reinforce each other rather than compete.

55. Final Integrative Framework: Toward Regenerative and Resilient Urban Systems

The broader significance of Nature-based Solutions is that they invite cities to reconsider the relationship between infrastructure and ecology. Conventional urban development often treats ecological systems as constraints to be controlled or amenities to be added after engineering decisions are complete. A regenerative urban approach reverses this logic. It asks how urban development can restore ecological capacity while still providing housing, mobility, water, energy, safety, and economic opportunity. Nature-based Solutions become one of the principal mechanisms through which this integration can occur.

A regenerative framework begins with protection. Existing wetlands, mature trees, floodplains, mangroves, healthy soils, and river corridors often provide greater ecological value than newly constructed substitutes. Avoiding unnecessary degradation is therefore usually more effective than compensating after damage. The second principle is restoration: where ecological function has been lost, hydrology, soil, vegetation, and connectivity should be repaired where feasible. The third principle is creation: in highly modified urban areas, engineered ecological systems such as green roofs, bioswales, constructed wetlands, and floodable landscapes can introduce new functions. The fourth principle is connection: projects should form networks across catchments, neighborhoods, and metropolitan regions. The fifth principle is stewardship: ecological infrastructure must be maintained and monitored throughout its lifecycle.

This framework also changes how success is defined. A project is not successful merely because construction is completed or vegetation appears green. Success means that measurable urban functions improve: runoff is reduced, heat exposure declines, habitat quality increases, water becomes cleaner, vulnerable communities gain access to safer public space, and ecosystems remain functional under changing climatic conditions. Such outcomes may take years to mature, which requires long-term institutional commitment.

Nature-based Solutions also provide a bridge between climate adaptation and mitigation. Urban forests and soils can store carbon while reducing heat. Wetlands can reduce flood risk while supporting biodiversity. Compact green corridors can make walking and cycling more attractive. Yet trade-offs must remain visible. Water-intensive landscapes can be problematic during drought; poorly managed biomass can create hazards; green development can increase property pressure. Sustainable outcomes therefore depend on context-specific design rather than generic labels.

For rapidly developing cities, the timing of decisions is critical. Once floodplains are urbanized, rivers constrained, soils sealed, and ecological corridors fragmented, restoration becomes difficult and expensive. Protecting ecological space before development is therefore a form of strategic infrastructure investment. Indonesian cities, in particular, have an opportunity to integrate forests, rivers, mangroves, wetlands, urban agriculture, neighborhood green spaces, and engineered blue-green systems into development before remaining ecological assets are irreversibly lost.

The ultimate strategic lesson is that cities should not choose between nature and engineering. They should choose the most appropriate combination of ecological and engineered processes for each urban challenge. Concrete, pumps, pipes, sensors, trees, wetlands, soils, and communities all have roles. The strongest urban systems are hybrid systems in which each component performs the tasks for which it is best

suited. Nature-based Solutions are therefore not a rejection of modern engineering; they represent an expansion of engineering toward a more complete understanding of how cities function as living socio-ecological systems.

Glossary

Bioswale: A vegetated linear feature designed to convey, slow, infiltrate, and treat stormwater.

Blue-green infrastructure: An interconnected network of water and vegetated systems delivering hydrological, ecological, climatic, and social functions.

Constructed wetland: A designed wetland system that uses physical, chemical, and biological processes to treat water or manage runoff.

Ecological connectivity: The degree to which landscapes allow movement of species, ecological flows, and genetic exchange.

Ecological engineering: The design of sustainable systems that integrate human needs with ecological processes.

Ecosystem services: Benefits people obtain from ecosystems, including regulating, provisioning, cultural, and supporting functions.

Green gentrification: Displacement or exclusion associated with rising land values following environmental or green-space improvements.

Green infrastructure: Networks of natural and semi-natural areas designed or managed to provide ecosystem services.

Green roof: A roof system supporting vegetation and engineered growing media for environmental and building-performance benefits.

Hybrid infrastructure: Infrastructure combining conventional engineered components with ecological or nature-based components.

Nature-based Solutions (NbS): Actions that use, restore, protect, or emulate ecological processes to address societal challenges while generating biodiversity and human well-being benefits.

Permeable pavement: A pavement system designed to allow water to infiltrate through its surface into underlying layers.

Rain garden: A shallow vegetated depression designed to capture, infiltrate, and treat stormwater runoff.

Riparian corridor: Vegetated land adjacent to rivers or streams that supports ecological and hydrological functions.

Sponge city: An urban water-management approach emphasizing infiltration, storage, detention, purification, reuse, and controlled drainage.

Urban forest: The total network of trees and woody vegetation across streets, parks, private land, institutions, and remnant ecosystems in a city.

Urban heat island: The tendency of built-up urban areas to be warmer than surrounding areas because of surfaces, geometry, reduced vegetation, and anthropogenic heat.

Water-sensitive urban design: An approach integrating urban planning and design with sustainable management of stormwater, water supply, and wastewater.

References

- Raymond, C. M., Frantzeskaki, N., Kabisch, N., Berry, P., Breil, M., Nita, M. R., Geneletti, D., & Calfapietra, C. (2017). A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas. *Environmental Science & Policy*, 77, 15-24. <https://doi.org/10.1016/j.envsci.2017.07.008>
- Frantzeskaki, N., McPhearson, T., Collier, M. J., Kendal, D., Bulkeley, H., Dumitru, A., Walsh, C., Noble, K., van Wyk, E., Ordóñez, C., Oke, C., & Pintér, L. (2019). Nature-based solutions for urban climate change adaptation: Linking science, policy, and practice communities for evidence-based decision-making. *BioScience*, 69(6), 455-466. <https://doi.org/10.1093/biosci/biz042>
- Eggermont, H., Balian, E., Azevedo, J. M. N., Beumer, V., Brodin, T., Claudet, J., Fady, B., Grube, M., Keune, H., Lamarque, P., Reuter, K., Smith, M., van Ham, C., Weisser, W. W., & Le Roux, X. (2015). Nature-based solutions: New influence for environmental management and research in Europe. *GAIA*, 24(4), 243-248. <https://doi.org/10.14512/gaia.24.4.9>
- Kabisch, N., Korn, H., Stadler, J., & Bonn, A. (2017). Nature-Based Solutions to Climate Change Adaptation in Urban Areas - Linkages Between Science, Policy and Practice. In *Nature-Based Solutions to Climate Change Adaptation in Urban Areas*. Springer. https://doi.org/10.1007/978-3-319-56091-5_1
- Kabisch, N., Stadler, J., Korn, H., & Bonn, A. (2017). Nature-Based Solutions for Societal Goals Under Climate Change in Urban Areas - Synthesis and Ways Forward. In *Nature-Based Solutions to Climate Change Adaptation in Urban Areas*. Springer. https://doi.org/10.1007/978-3-319-56091-5_19
- Meerow, S., & Newell, J. P. (2017). Spatial planning for multifunctional green infrastructure: Growing resilience in Detroit. *Landscape and Urban Planning*, 159, 62-75. <https://doi.org/10.1016/j.landurbplan.2016.10.005>
- Gill, S. E., Handley, J. F., Ennos, A. R., & Pauleit, S. (2007). Adapting cities for climate change: The role of the green infrastructure. *Built Environment*, 33(1), 115-133. <https://doi.org/10.2148/benv.33.1.115>
- Bowler, D. E., Buyung-Ali, L., Knight, T. M., & Pullin, A. S. (2010). Urban greening to cool towns and cities: A systematic review of the empirical evidence. *Landscape and Urban Planning*, 97(3), 147-155. <https://doi.org/10.1016/j.landurbplan.2010.05.006>
- Fletcher, T. D., Shuster, W., Hunt, W. F., Ashley, R., Butler, D., Arthur, S., Trowsdale, S., Barraud, S., Semadeni-Davies, A., Bertrand-Krajewski, J.-L., Mikkelsen, P. S., Rivard, G., Uhl, M., Dagenais, D., & Viklander, M. (2015). SUDS, LID, BMPs, WSUD and more - The evolution and application of terminology surrounding urban drainage. *Urban Water Journal*, 12(7), 525-542. <https://doi.org/10.1080/1573062X.2014.916314>
- Berland, A., Shiflett, S. A., Shuster, W. D., Garmestani, A. S., Goddard, H. C., Herrmann, D. L., & Hopton, M. E. (2017). The role of trees in urban stormwater management. *Landscape and Urban Planning*, 162, 167-177. <https://doi.org/10.1016/j.landurbplan.2017.02.017>
- Depietri, Y., & McPhearson, T. (2017). Integrating the grey, green, and blue in cities: Nature-based solutions for climate change adaptation and risk reduction. In N. Kabisch et al. (Eds.), *Nature-Based Solutions to Climate Change Adaptation in Urban Areas*. Springer. https://doi.org/10.1007/978-3-319-56091-5_6

- Ahern, J. (2011). From fail-safe to safe-to-fail: Sustainability and resilience in the new urban world. *Landscape and Urban Planning*, 100(4), 341-343. <https://doi.org/10.1016/j.landurbplan.2011.02.021>
- Demuzere, M., Orru, K., Heidrich, O., Olazabal, E., Geneletti, D., Orru, H., Bhawe, A. G., Mittal, N., Feliu, E., & Faehnle, M. (2014). Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure. *Journal of Environmental Management*, 146, 107-115. <https://doi.org/10.1016/j.jenvman.2014.07.025>
- European Commission. (2015). Towards an EU Research and Innovation policy agenda for Nature-Based Solutions & Re-Naturing Cities. European Union. <https://doi.org/10.2777/765301>