Nature Based Solutions to Ecosystem Management

Companion Volume to

Handbook on
‘Structured Approach to Urban Ecosystem Health Assessment’

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1 What are Nature Based Solutions?

Nature Based Solutions (NBS) are strategies designed to help to address a range of environmental, social, and economic issues in a sustainable manner. The solutions essentially resonate with nature and mimic the nature's healing or curing mechanisms. In certain cases, the solutions emerge from indigenous knowledge and expertise while in some cases they are built based on the new interventions. These solutions are often cost effective requiring low capital and operating expenditures and easy to implement/operate compared to resource intensive and mechanized conventional solutions.

NBS could be used for the following objectives:

1. Preserving the integrity of ecosystems.
2. Improving sustainable management of ecosystems to meet human and livestock needs.
3. Restoring degraded ecosystems and building their resilience .

NBS are intended to address major societal challenges, such as food security, climate change, water security, human health, disaster risk, social and economic development.

Typically, NBS consists of following critical elements, where:

- Nature - relates to biodiversity in aggregate, individual elements of biodiversity (individual species, habitats, ecosystems), and/or ecosystem services.
- Nature-based – refers to ecosystem-based approaches, biomimicry, or direct utilisation of elements of biodiversity.
- Solutions – refers to design, implementation and upkeep or maintenance to ensure sustained outcomes

NBS should be developed along with following principles

1. Maintain biological and cultural diversity and the ability of ecosystems to evolve over time
2. Have applicability on a wide range of spatial scales
3. Achieve trade-offs between immediate economic benefits due to proposed development, and future returns due to availability of ecosystems services
4. May not substitute but in some cases complement the conventional solutions
5. Will have ability to mainstream in the overall design of policies, and measures or actions, allowing ownership and participation of the stakeholders

NBS will have to be context specific. Further a number of NBS measures may have to be considered together. A comparative analyses with the conventional approaches may also be required. Sometimes, a combination may be considered as prudent considering strength and weaknesses of each approach. See Box 1 as an illustration.

Box 1 – Illustration of combined use of NBS with conventional infrastructure based solution[1]

This hypothetical case relates to a protected area in a coastal landscape. The protected area, originally created to provide an intact habitat for a particular rare species, is located near a watershed that is bordered by human settlements. In the past, flooding had not been a frequent problem as the forest and wetland had been able to absorb a large part of any storm surges. Over time however, deforestation and degradation of the forest and wetland ecosystems have left the expanding settlements more susceptible to flooding. The remaining forest in the protected area now plays a critical role in absorbing flood flows. In order to strengthen the ability of the protected area to perform this 'new' function and reduce flooding risk, it needs to be reconnected to the wider landscape to improve the entire watershed's functionality.

The main NBS intervention – namely restoration of the watershed, including the protected area – is therefore undertaken in combination with other NBS interventions. Figure 1 shows a hypothetical scenario of NBS being used in conjunction with infrastructure development and protected area conservation (such as mangrove replanting and wetland restoration) and conventional measures (such as construction of a concrete flood barrier). Together these solutions not only mitigate flooding, but also support biodiversity and local livelihoods.

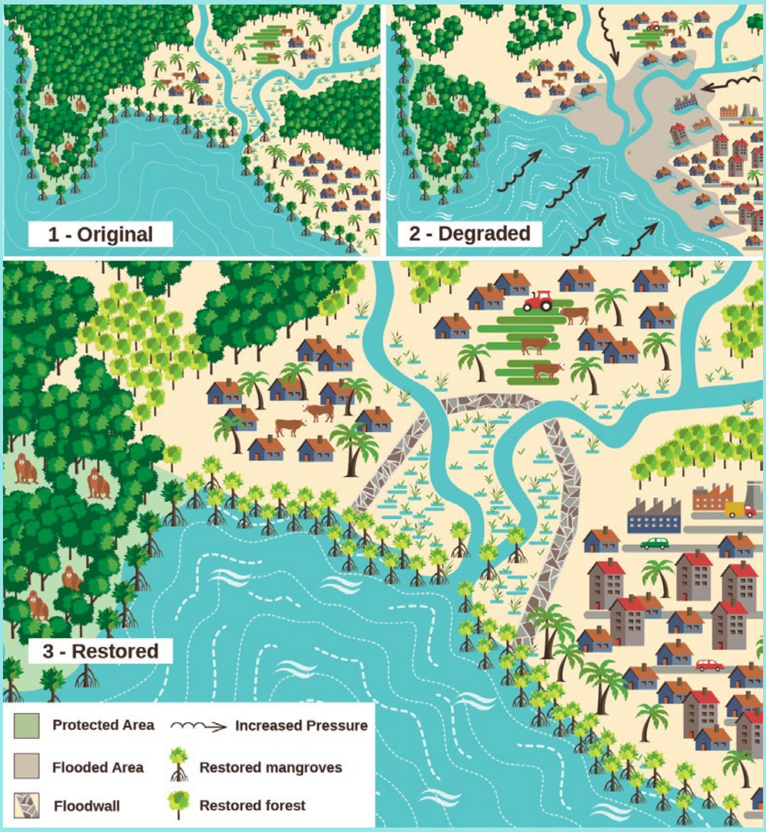

Figure 1 Hypothetical scenario of Nature-based Solutions being used in conjunction with infrastructure development and protected area conservation

[1] *Source: Cohen-Shacham, E., Walters, G., Janzen, C. and Maginnis, S. (eds.) (2016). Nature-based Solutions to address global societal challenges. Gland,Switzerland: IUCN.*

2 A Compendium of Nature Based Solutions

A compendium of possible NBS is presented in this section. For each NBS, an overview is provided with expected key outcomes and a case study. This information may be used by the urban practitioners to identify NBS to address the hot spots identified after the assessment of the urban ecosystems.

The NBS covered are summarized below. Each of the NBS may have impacts on more than one theme (refer Table 1).

1. Wetlands
2. Protecting & Restoring Mangroves
3. Providing infiltration and Bioretention
4. Tapping rainwater using Blue Roofs
5. Forest landscape Restoration
6. Green Roofs
7. Green Walls
8. Creation of Urban Greens
9. Sustainable Land Management
10. Constructed Wetlands
11. Rain Garden
12. Permeable Pavement Systems
13. Rainwater Harvesting
14. Stormwater Tree Pits
15. Slope Stabilization
16. Re-Meandering of River
17. Lake Restoration
18. Microclimate Regulation and Air Quality Improvement
19. Urban Ventilation Corridor Planning
20. Building Urban Ecological Infrastructure
21. Biocatalysts
22. Bioremediation of Rivers
23. Growing algae to absorb vehicular pollution.

Many of the NBS may seem overlap however each NBS has its own characteristics, advantages as well as limitation. The case studies described for each NBS may be followed through references to select the most appropriate NBS for addressing the issues.

Finally, it should be remembered that in practice, while NBS should be the first preference, support of conventional solutions is also required, especially to address emergent issues e.g., for addressing problems such as industrial pollution through effluent treatment plants or taking on remediation through mechanical and chemical means to prevent aquifer pollution.

Table 1: Suggested Nature based Solutions and their expected impact on Themes

No.	Solutions	Water	Air	Land	Flora Fauna	Quality of Life	Natural Hazards	Climate Change
1	Wetlands							
2	Protecting & Restoring Mangroves							
3	Bioswales and Bioretention Planter							
4	Tapping Rainwater using Blue Roofs							
5	Forest Landscape Restoration							
6	Green Roofs							
7	Green Walls							
8	Creation of Urban Greens							
9	Sustainable Land Management							
10	Constructed Wetlands							
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23	Bioremediation of Rivers							
24	Growing algae to absorb vehicular pollution							

2.1 Wetlands

Overview

Wetlands shelter a diversity of species, serve as a sponge to excessive floodwaters and help in carbon sequestration.

Another, often-overlooked benefit of wetlands is water purification. Outside the Indian city of Kolkata, a conservation project functions as a natural filtration system for the assimilation of sprawling city's wastewater. Untreated sewage is channelized into this water body that serves as a source of nutrients to the wetland's plants and removing thereby undesirable microbes in the process.

The partially treated wastewater is then used to farm fish in nearby ponds, and to irrigate fruit and vegetables in the paddy fields. The wetland treats a large portion of the city's waste and provides a livelihood for over 50,000 people and food to millions.[4]

Key Outcomes

- a pollutant removal area composed of a grid, a sedimentation tank and four vertical sub-surface flow constructed wetlands.
- a multipurpose area with a surface flow constructed wetland or pond with multiple roles
- a recreational park with restored riparian trees, green open space, walking and cycling paths.

Case Study

Figure 2 Picture Showing Gorla Maggiore Water Park[2]

Location: Milano, Italy
City population: 3,063,361
Project duration: 2008 - 2013
Project cost: 500,000 – 2,000,000 EUR
Financing source(s): Public regional budget, Private Foundation

The Gorla Maggiore water park, inaugurated in March 2013, is situated within the municipality of Gorla Maggiore, in the Italian region Lombardy, located about 30 kilometres northwest of Milan. The water park is a constructed wetland built on the banks of the Olona river.[3] It has resulted in building adequacy of food via aquaculture and horticulture.

[2] Image Source: Photographer: Fabio Masi (IRIDRA), retrieved 09/11/2018
[3] https://www.naturvation.eu/NBS/milano/gorla-maggiore-water-park
[4] https://chinadialogue.net/en/nature/what-are-nature-based-solutions/

2.2 Protecting & Restoring Mangroves

Overview

Mangroves are considered as one of the most specialized ecological assemblages of halophytic plants acting as a transient zone between land and ocean. They comprise of taxonomically diverse shrubs and trees, distributed along tropical and sub-tropical environments having specific habitats such as shores, estuaries, tidal creeks, backwaters, lagoons, marshes, mudflats and even at upstream points where water remains saline[7].

Mangrove forests are extremely productive ecosystems that provide numerous good and services both to the marine environment and people.

Key outcomes

- They help in land stabilisation and Reduction, Prevention of shoreline erosion
- The mangrove ecosystem plays a vital role in natural cycles and nutrient recycling thereby maintaining the environmental balance.
- Mangroves moderate extreme events like flash floods and storms, by acting as a natural sponge
- They help treat wastewater by breaking complex pollutants into nutrients with their biological systems and organisms
- Mangrove forests also contribute greatly to carbon sequestration.
- Strengthening of connected marine ecosystem and supporting local urban biodiversity.
- It plays a vital role as nursery for many estuarine and marine fish in addition to supporting some unique floral and faunal diversity.

Costing

- Mangroves provide valuable ecosystem services estimated to be worth about US$33,000-57,000 per hectare

Case Study

Figure 3 Image showing Mangroves in Vietnam.

In Vietnam, planting and protecting 12,000 hectares of mangroves has resulted in an increase in carbon storage, enhanced biodiversity, and improved coastal protection, saving dike maintenance costs which amounted to 7 million dollars each year.

Figure 4 Image showing Godreg Mangroves in Mumbai

Godrej Mangroves in Vikhroli (Mumbai)

- ISO 14001:2004 Certified forest
- Marine Aquarium
- Protection from Encroachment
- Thematic Gardens
- Mangrove Nursery

Godrej mangroves on West coast of Thane creek are diverse and dense than East coast for its conservation[5]. About 60,000 equivalent tonnes of carbon dioxide is sequestered annually[6].

[5] Godrej Mangroves Management. Available at https://mangroves.godrej.com/management-mangroves.html as accessed on 9th Jan 2021

[6] Godrej Presentation. Available at https://mangroves.godrej.com/Resources/others/Mangroves-presentation.pdf as accessed on 9th Jan 2021

[7] Qasim, S. Z. 1998. Mangroves, In: Glimpses of the Indian Ocean, University Press, Hyderabad, 123-129.

2.3 Bioswales and Bioretention Planter

Overview

Bioswales are planned green spaces that collect runoff and remove harmful pollutants from the stormwater before it is discharged into surface water sources[8]. They are shallow drainage courses that are filled with vegetation, compost, and/or riprap. As a part of the surface runoff flow path, they are designed to maximize the time water spends in the swale, that aids in the trapping and breakdown of certain pollutants.

A bioretention planter is an impervious ponding reservoir containing a minimum of 45 cm of bioretention soil, a layer of uniformly graded washed gravel, an underdrain, and an overflow.[9]

Key Outcomes

- It promotes infiltration and filtration through the largely-sand media and underdrain while maintaining stormwater conveyance on the surface during large rainfall events.
- Reduced runoff: In a typical road, a 4-meter swale can reduce approximately 25 percent of total rainfall runoff.
- Instead of releasing stormwater into the drainage system, stormwater can be filtered and may provide some groundwater recharge.
- Sustainable, decentralized stormwater management systems may be more cost effective than centralized stormwater systems. At the minimum, these nature based technologies reduce pressure on existing systems and the maintenance costs associated with centralized stormwater management systems[10].
- Bioswales are more suitable for storm-water control on a large scale. They can be made along the roadsides so that rainwater from the road flows towards them and percolates into the ground[11].

Costing

- The average cost of installation of Bioswale is about USD 10-20 per sq. m.

Case Study

Figure 5 Image showing bioswales in Museum of Science Portland

Figure 6 Image showing bioswale in Jellicoe Street, Auckland, New Zealand

Figure 7 Image showing Bioretention in Derbyshire Street, London

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[8] Lee, J.(2019), Green Infrastructure as a Solution to Hydrological Problems: Bioswales and Created Wetlands, University of Florida College of Design, Construction, and Planning,

[9] http://www.seattle.gov/util/cs/groups/public/@spu/@usm/documents/webcontent/spu01_006397.pdf as accessed on 21/01/20

[10] https://www.asla.org/bioswales.aspx as accessed on 21/01/20

[11] Kamal ,A.(2014).Groundwater Pollution: Rain Gardens And Bioswales To The Rescue

2.4 Tapping Rainwater using Blue Roofs

Overview

Blue roof are non-vegetated roofs that use to detain and retain the stormwater. Dikes used at drain inlets allow temporary water storage and gradual release of rainwater.

The potential of blue roofs is mostly untapped in india owing to various reasons such as erratic rainfall patterns and extreme temperatures.

Key Outcomes

- The pivotal focus of blue roofs is to harvest rainwater in a catchment
- Light coloured roofing material is used to maintain low temperature on rooftop
- They are cost effective as compared with green roofs and can substantially reduce the runoff in an area.
- It reduces the chances of flash floods in urban areas.

Costing

- The average cost of Blue Roofs (50 years of life cycle) is about USD 10-25 per sq. m.

Case Study

Figure 8 Image showing blue roofs in Walter Bos Complex, Apeldoorn

Figure 9 Image showing blue roofs in Walter Bos Complex, Apeldoorn

2.5 Forest Landscape Restoration

Overview	Forest landscape restoration (FLR) is the ongoing process of regaining ecological functionality and enhancing human well-being across deforested or degraded forest landscapes. FLR is more than just planting trees – it is restoring a whole landscape to meet present and future needs and to offer multiple benefits and land uses over time. FLR integrates a number of guiding principles, including: focus on landscapes, restore functionality, involve stakeholders, tailor to local conditions and Avoid further reduction of natural forest cover.[12]
Key outcomes	• FLR is an on-going process of regaining ecological functionality and enhancing human well-being across deforested or degraded forest landscapes. • FLR is more than just planting trees – it is restoring a whole landscape to meet present and future needs. • It is long-term process because it requires a multi-year vision of the ecological functions. • The majority of restoration opportunities are found on or adjacent to agricultural or pastoral land. In these situations, restoration must complement and not displace existing land uses. • This result in a mosaic of different land uses including agriculture, agroforestry systems and improved ecological corridors.
Costing	• The cost of Forest landscape restoration is about USD 500-10000 per ha.

Case Study

Figure 10 Image showing Edible forest in Alcalá de Henares, Spain

Creation of an edible forest increased the biodiversity in an peri-urban area in Alcalá de Henares, Spain. The main objective of the project was to increase the biodiversity of a peri-urban area, re-naturalizing it through the creation of an urban edible forest

Figure 11 Image showing Alpilles Regional Natural Park

The Alpilles Regional Natural Park, that hosts unique biodiversity and man-made landscapes, has decided to adjust Mediterranean forest management to minimize fire hazards. In the 1950s, there has been an increasing dominance of softwoods, accompanied by a severe agricultural decline.

[12] https://www.insightsonindia.com/2019/06/18/forest-landscape-restoration-flr-and-bonn-challenge/
https://www.iucn.org/theme/forests/our-work/forest-landscape-restoration

2.6 Green Roofs

Overview

A green roof is a layer of vegetation planted over a waterproofing system that is installed on top of a flat or slightly sloped roof. Green roofs are also known as vegetative or eco–roofs[13].

It can also include supplementary layers such as a root barrier, drainage and irrigation systems.

Key Outcomes

- National Research Council of Canada found that an extensive green roof reduced the daily energy demand for air conditioning in the summer by over 75% (Liu 2003)[14].
- Green roof can increase the life of a 10-20-year water proofing layer to 50 years.
- Green roofs have the potential to remove NOx, SO_2 and particulate matter.
- Green roofs can provide energy savings, especially in poorly insulated buildings. Green roof vegetation uses about 60% the incoming solar radiation for photosynthesis[15].
- In summer, green roofs can retain 70-90% of the precipitation that falls on them.
- Green roofs can also help reduce the distribution of dust and particulate matter, as well as the production of smog. This can play a role in reducing greenhouse gas emissions and adapting to a future climate with warmer summers.

Although Green roofs are not a popular phenomenon in India due to its absence from National Building Code and other built regulations, but it is widely considered as an excellent approach towards saving the environment.

Costing

- The cost of Green roof (assuming 50 years life cycle) is USD 200 per sq. m. or INR 2000 per sq. m.

Case Study

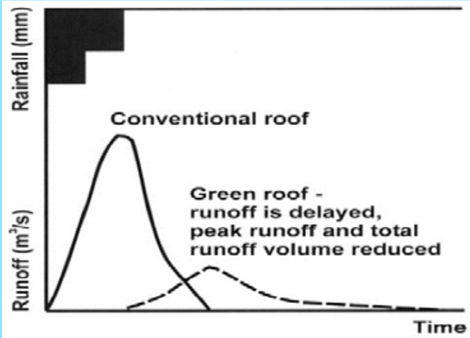


Figure 12 Image showing Rainfall runoff response of the green roof and conventional roof

The potential of Green roofs is mostly unexplored in India but is widely prevalent aspect of built design in Western developed nations. Over the last 30 years, green roofs have become more popular, particularly in most of the developed countries such as: Germany, Australia, Switzerland, Austria, USA, Japan, Kina, Singapore, and South Korea.

For example, a law in Tokyo requires the installation of green roofs in private buildings with built areas larger than 1000 m^2 and in public buildings with built areas larger than 250 m^2, while integrated green roofs must encompass not less than 20% of the whole roof-top area.

Figure 13 Image showing Fukuoka Prefectural International Hall, Tokyo

[13] nps.gov as accessed on 21/01/20

[14] Liu, K. 2003. Engineering performance of rooftop gardens through field evaluation. Proc. of the 18th International Convention of the Roof Consultants Institute. 93–103.

[15] Suvada Jusić., et al. "Stormwater Management by Green Roof". Acta Scientific Agriculture 3.7 (2019): 57-62.

2.7 Green Walls

Overview

Green wall corresponds to all forms of vegetated vertical surfaces. The green wall systems can have a reduced environmental burden by contributing to the thermal resistance of the wall, leading to a reduction in energy demand for heating and cooling[16] and would significantly reduce noise.

Key Outcomes

- At a building scale, green wall systems can be used as a passive design solution contributing to buildings sustainability performance.
- Vegetation has the potential to improve the microclimate both in winter and summers
- It functions as a complementary insulation layer during winters
- In summer, it provides shade and an evaporative cooling effect[17] absorbs large amounts of solar radiation
- Evapotranspiration of plants further reduces the impact of solar radiation, showing increased humidity levels and surface temperatures lower than hard surfaces[18].

Costing

- The average cost of installation of Green walls is about INR 500-2000 per sq. m.

Case Study

Figure 14 Image showing Vertical Gardens in Bengaluru

An initiative of SayTrees, the organic garden has been constructed in Hosur Road Electronics City (Bengaluru) Flyover where over 3,500 saplings of 10 different species have been planted.

Figure 15 Image showing Vertical gardens in Caixa Forum plaza, Madrid

Situated in the heart of the Madrid's cultural district, the Caixa Forum Museum vertical garden was designed and created by Patrick Blanc using his Le Mur Végétal system. The adjacent square is accessible to the public who can walk up, touch, and explore over 15,000 plantings on the hydroponic living.

[16] Ottelé M, Perini K, Fraaij A, Haas E, Raiteri R. Comparative life cycle analysis for green façades and living wall systems. Energy Build 2011; 43:3419–29.

[17] M. Manso, J. Castro-Gomes, Green wall systems: A review of their characteristics, Renewable and Sustainable Energy Reviews 41 (2015) 863–871

[18] Bass B. Green roofs and green walls: potential energy savings in winter, Report on Phase 1. Adaptation and impacts research division environment Canada at University of Toronto Centre for Environment; 2007.

2.8 Creation of Urban Greens

Overview

Urban greens in the city can be created in the following two ways:

- **Park-based:** Involve change to the physical environment only, or use a dual approach combining a change to the physical environment with programming or marketing events to promote use of parks. For. Eg . Freshness areas in Orleans City.

- **Greenways/trails:** Development of new greenways (typically continuous linear corridor of green space facilitating walking, cycling and other activities) or the modification of existing greenways or walking/cycling trails (e.g. addition of signage)[19].

Key Outcomes

- Combat air and noise pollution
- Soaks up rainwater that may otherwise create flooding
- Creates a corridor for animal movement
- Improve morale in the people.
- improve the microclimate

Case Study

Figure 16 Image showing Urban Green in New Orleans City, USA

New Orleans City Council, USA has chosen to innovate in the field of climate and biodiversity through the establishment of "freshness areas". It has launched several sustainable development initiatives (Agenda 21 in 2006, "Biodiversity Plan" in 2009, Territorial Energy and Climate Plan in 2012, Land use planning scheme in 2013) where Orleans is defined as a "garden city".

Figure 17 Image showing Railway Platforms on Parkland Walk, North London, England

Figure 18 Image showing Community garden in Bogotá and urban garden in London

[19] https://link.springer.com/chapter/10.1007/978-3-030-02318-8_17 as accessed on 7th Jan 2021

2.9 Sustainable Land Management

Overview

The United Nations defines sustainable land management (SLM) as "the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions".

Key outcomes

SLM combines technologies, policies, and activities aimed at integrating socioeconomic principles with environmental concerns, to simultaneously:

- maintain and enhance production (productivity)
- reduce the level of production risk, and enhance soil capacity to buffer against degradation processes (stability/resilience)
- protect the potential of natural resources and prevent degradation of soil and water quality (protection)
- be economically viable (viability)
- be socially acceptable, and assure access to the benefits from improved land management (acceptability/equity)

Case Study

Figure 19 Image showing activities of Sustainable Land Management in Augustenborg, Denmark

The neighbourhood of Augustenborg, during the 1980s and 1990s was frequently flooded by an overflowing drainage system. Between 1998 and 2002 it was regenerated. The physical changes in infrastructure included the creation of sustainable urban drainage systems (SUDS), including 6km of water channels and ten retention ponds.

The rainwater from roofs, roads and car parks is channelled through trenches, ditches, ponds and wetlands, with only the surplus being directed into a conventional sewer system. Green roofs have been installed on all developments built after 1998 and retro fitted on 10,000 square meters on an existing building. As a result, problems with flooding have ceased.

2.10 Constructed Wetlands

Overview

A constructed wetland is an artificial wetland created as a new or restored habitat for native and migratory wildlife, for discharge such as wastewater, stormwater runoff, or sewage treatment and for land reclamation in natural areas impacted by development.

They are generally built on seriously degraded wetlands or new areas where there are problems with drainage and water quality. They can substitute for conventional stormwater and greywater treatment plants.

Wetlands are frequently constructed by excavating, backfilling, grading, diking, and installing water control structures to establish desired hydraulic flow patterns. They consist of shallow (usually less than 1-meterdeep) ponds or channels which have been planted with aquatic plants.

Key outcomes

- Wetlands act as a biofilter, removing sediments and pollutants such as heavy metals from the water, and constructed wetlands can be designed to emulate these features.
- Wetlands trap suspended solids while other pollutants are transformed and taken up by plants or rendered inactive.
- Provides food and habitat for wildlife.
- Improves water quality.
- Provides flood protection, drought relief, and
- opportunities for recreation.

For more information refer, Manual on Constructed Wetland as an alternative technology for sewage management in India (2019)

Costing

- The average cost of Constructed Wetland is USD 4000-40000 per acre.

Case Study

Figure 20 Image showing Constructed Wetland in city of Tianjin, China

In the Chinese city of Tianjin, the strategy of “adaptive palettes” was used to create a series of biologically diverse ecosystems that could repair contaminated soils and treat urban stormwater by relying on nature’s processes. Today, Qiaoyuan Park has reclaimed a brownfield by integrating regenerative ecological functions, using native plants in a landscape that is allowed to adapt and evolve, and educates visitors in a relaxing recreational space designed for the dense community surrounding the park.[20]

Figure 21 Image showing Kanjli Wetland, Punjab

Kanjli Wetland, a man made Wetland, which subsumes the Kanjli Lake, located in the Kapurthala district of Punjab state in India, was created in 1870 by constructing the headworks across the perennial Bien River, a tributary of the Beas River to provide irrigation facilities to the hinterland.

[20] http://www.youthla.org/2010/08/qiaoyuan-park/

2.11 Rain Garden

Overview

A rain garden detains rainfall and stormwater runoff to slow flow, reduce pollution, and increase infiltration. Usually, it is a small garden designed to withstand the extremes of moisture and concentrations of nutrients, particularly nitrogen and phosphorus, that are found in stormwater runoff.

Rain gardens are ideally sited close to the source of the runoff and serve to slow the stormwater as it travels downhill, giving it more time to infiltrate and less opportunity to gain momentum and erosive power.

Key Outcomes

- Clean and break down pollutants like oil, fertilizer, pesticides, pet waste, transportation chemicals, and sediment, and prevent them from re-entering the water system
- Reduce localized flooding and strain on stormwater systems
- Provide wildlife habitat
- Contribute to groundwater recharge

Costing

- The average cost of set up of a Rain garden is about USD 10-15 sq. m.

Case Study

Figure 22 Image showing Raingarden in Middlebury Vermount.

Rain garden is located at Riverfront Park, adjacent to Otter Creek Falls in Middlebury, Vermont[21].

The rain garden at Riverfront Park captures and treats stormwater runoff from surrounding impervious surfaces that would otherwise flow to the Otter Creek. It also serves as an attractive educational feature that enhances a highly popular outdoor space.

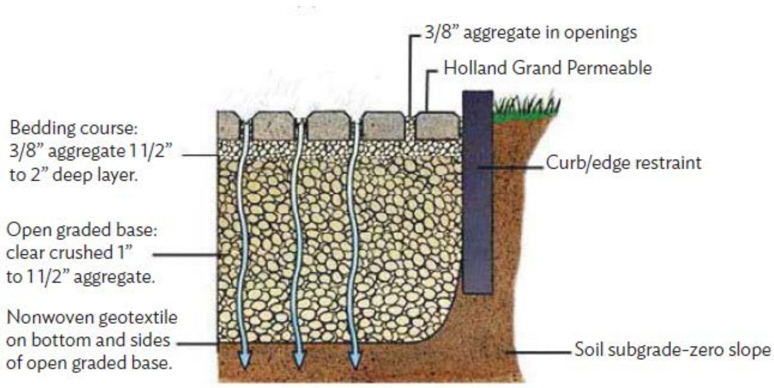
[21] "Middlebury Riverfront Park." LandWorks VT, 2014. Web. . "Rain Garden Design Templates - What is a rain garden?." Low Impact Development Center, 2007..

2.12 Permeable Pavement Systems

Overview

Permeable pavements are paved surfaces that infiltrate, treat, and/or store rainwater where it falls. They may be constructed from pervious concrete, porous asphalt, permeable interlocking pavers, and several other materials.

They function similarly to sand filters. They filter the water by forcing it to pass through different aggregate sizes and filter fabric



Key outcomes

- Reduces flooding during storm events
- Stormwater pollutants are broken down in the soil instead of being carried to surface waters
- Allows water seepage to groundwater recharge
- Helps prevent stream erosion problems
- Takes pressure off existing drainage and stormwater management systems.
-

Costing

- The average cost of construction of Permeable pavement is INR 500-1000 per sq .m.

Case Study:

Figure 23 Image showing Permeable Pavements along Jackshon stree, St. Paul

The City of St. Paul constructed two off street bike trails along portions of Jackson Street, Kellogg Boulevard, St. Peter Street, 9th Street and 10th Street using porous asphalt.

2.13 Reimagining Public Spaces

		Case Study
Overview	Reviving public spaces (such as parks, community gardens, schoolyards, public plazas, vacant lots, playgrounds, public seating areas, traffic islands etc.) with creation of green spaces, on-site composting, efficient irrigation, lighting systems, urban farming, community gardening etc.	 *Figure 24 Image showing Miyawaki Forests in Delhi* A sewage ridden patch of land near Barapullah drain, Delhi was converted into an Urban Forest. The land of 750-meter square was planted with 2278 trees that includes 44 native species of trees.
Key outcomes	• Lowering temperature • Supporting local wildlife • Sequestration of carbon • higher survival rate of native tree species • rebuilding the ecosystem • improving the soil health	

In the past one year, the garden department of the Brihanmumbai Municipal Corporation (BMC) has planted 1.62 lakh trees of 45 species in as many as 24 Miyawaki forests in Mumbai. In December 2019, then Municipal Commissioner Praveen Pardeshi had appointed contractors for planting saplings, using the Miyawaki concept of gardening and plantation. On 26 January 2020, Maharashtra Chief Minister, Uddhav Thackeray and State Minister of Environment Aaditya Thackeray had inaugurated the 'Miyawaki project Mumbai'. Total 64 open spaces of the municipal area were selected for Miyawaki plantation. Of the total number of places, forests in 24 places are now well established.

Figure 25 Image showing The then and now images of Miyawaki Forest at Malad (W).

Figure 26 Image showing A barren stretch in Malad has turned lush green after the rains.

2.14 Rainwater Harvesting

Overview

Rainwater harvesting (RWH) is a technology used for collecting and storing rainwater from rooftops, the land surface, or rock catchments using simple techniques such as jars and pots as well as more complex techniques such as underground check dams. The harvested water can be used as drinking water, for domestic needs, and for irrigation.

The following methods are used for RWH:

- Roof top Rain Water Harvesting (RRWH)
- Campus RWH (RWH other than Roof area)
- Storm water harvesting & Defunct Bore well Recharge
- Defunct Quarry/Mines water usage
- Restoration and rejuvenation of water bodies
- Grey water recycling, Reduce & Reuse

Key outcomes

- Reduces domestic and municipal water demand and expenses.
- Is an accessible replacement for groundwater.
- Reduces pollutants and flow into surrounding surface waters.
- Serves as a backup water supply during emergencies and natural disasters.
- Reduces size of traditional stormwater management practices.
- Lowers strain on municipal water supply system.
-

Costing

- The cost of RWH systems is about 10 -20 USD per sq. m. or INR 10-100 per sq.m.

Case Study

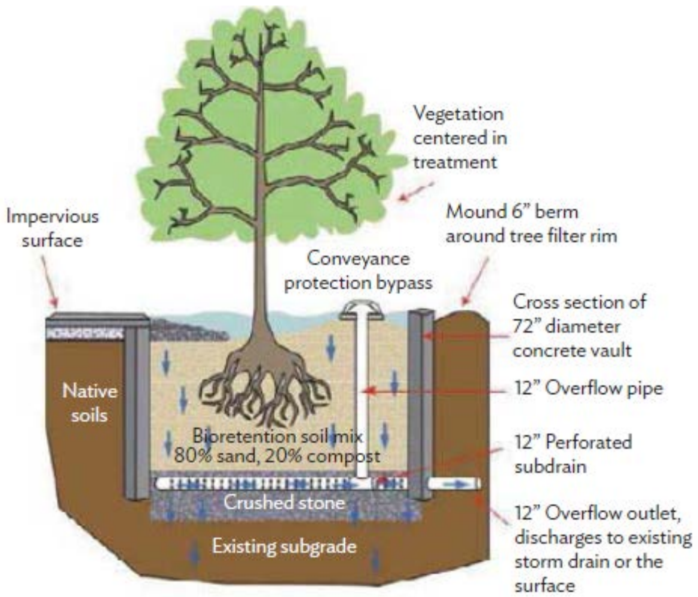
The RWH movement was launched in Tamil Nadu in 2001. It has had a tremendous impact in recharging the groundwater table all over Tamil Nadu. The State made it mandatory to provide RWH structures in all new buildings by. To consolidate the gains, various measures have been taken up for rejuvenation of RWH structures created already in both public and private buildings, besides creating new ones[22].

[22] https://www.tn.gov.in/dtp/rainwater.htm

2.15 Stormwater Tree Pits

Overview

Stormwater tree pits consist of an underground structure and aboveground plantings which collect and treat stormwater using bioretention. Treated stormwater is then infiltrated into the ground or, if infiltration is not appropriate, discharged into a traditional stormwater drainage system.



Key outcomes

- Reduce stormwater runoff volume, flow rate and temperature
- Increase groundwater infiltration and recharge
- Treat stormwater runoff
- Improve quality of local surface waterways
- Improve aesthetic appeal of streets and neighbourhoods
- Provide wildlife habitat
- Require limited space
- They are simple to install

Case Study

Figure 27 Image showing Stormwater Tree Pits in Minnesota, USA.

Tree trenches to collect stormwater were installed in parking area of Maplewood Mall in Minnesota, USA.[23]

Figure 28 Image showing Traffic Island in Pennsylvania, USA

The Bio-Infiltration Traffic Island (BTI) retrofitted off a traffic island situated in the West Campus of Villanova University in Pennsylvania, USA.

[23] https://stormwater.pca.state.mn.us/index.php/Case_studies_for_tree_trenches_and_tree_boxes as accessed on 7 th Jan 2021

2.16 Slope Stabilization

Overview

One of the method used for slope stabilization is vegetated riprap. It is a method which uses a combination of rock and dormant cuttings to stabilize a stream bank. It comprises a combination of rock and native vegetation in the form of live cuttings. Biological and technical bank protection techniques are combined to give excellent waterside erosion protection together with natural scenic beauty.

Key Outcomes

- Resists hydraulic forces.
- Increases geotechnical stability, and prevents soil loss
- Creates habitat for both aquatic and terrestrial wildlife
- Improves aesthetic and recreation
- Roots, stems, and shoots help anchor the rocks and resist "plucking" and gouging by debris.

Costing

- The estimated cost of slope stabilization is about INR 65 lakh per km.

Case Study

Figure 29 Image showing slope stabilization in French Broad river bank in Tennessee, USA

A section of French Broad rive bank in Tennessee, USA was severely damaged due to flooding conditions during the construction of a new bridge. The bank erosion threatened both the recently installed bridge infrastructure and adjacent railroad line. A vegetative rip rap was placed at the toe of the slope for stabilization.

2.17 Re-Meandering of River

Overview

River re-meandering consists of creating a new meandering course or reconnecting cut-off meanders, therefore slowing down the river flow. The new form of the river channel creates new flow conditions and can have a positive impact on sedimentation and biodiversity.

The newly created or reconnected meanders also provide habitats for a wide range of aquatic, Provides excellent silt deposition that are nutrient rich and fertile for plants or agriculture/horticulture and land species of plants and animals.

Key Outcomes

- Improving status of biology quality elements
- Improving status of physico-chemical quality elements
- Improving status of hydromorphology quality elements
- Take adequate and co-ordinated measures to reduce flood risks
- Protection of important habitats
- Better protection for ecosystems and more use of Green Infrastructure
- More sustainable agriculture and forest
- Better management of fish stocks
- Prevention of biodiversity loss
- Natural biomass production
- Biodiversity preservation
- Groundwater/aquifer recharge
- Flood risk reduction[24].

Case Study

Figure 30 Image showing Before and after state of river Re-meandering.

[24] http://wiki.reformrivers.eu/index.php/Remeander_water_courses

2.18 Lake Restoration

Overview

Lake restoration is a broad term used for different techniques aiming to bring a lake back to or closer to anthropogenically undisturbed conditions. Usually, lake restoration refers to methods used inside the lake, but sometimes it also refers to measures taken outside the lake system such as reduction of the external nutrient loading by improved wastewater treatment.

Various guidelines are available in India for lake restoration. They are:

- "Approach to Waterbody Rejuvenation – A Perspective" https://www.borda-sa.org/nature-based-solutions-for-waterbody-rejuvenation-in-india/ as accessed on 9th Jan 2021
- National plan fore conservation of Aquatic Ecosystems (NPCA)[25]. http://moef.gov.in/wp-content/uploads/2019/09/NPCA-MOEFCC-guidelines-April-2019-Low-resolution.pdf as accessed on 9th Jan 2021

Key outcomes

- Collect storm runoff
- Store river water
- Reduce erosion and/or sediment delivery
- Create aquatic habitat
- Create riparian habitat
- Water storage
- Natural biomass production
- Fish stocks and recruiting
- Biodiversity preservation
- Erosion/sediment control
- Recreational opportunities
- Aesthetic/cultural value High
- Improving status of biology quality elements
- Protection of important habitats
- Better protection for ecosystems and more use of Green Infrastructure
- Prevention of biodiversity loss
- Better management of fish stocks

Costing

- The average cost of Lake Restoration is INR 5-10 lakh per acre.

Case Study

Figure 31 Image showing Mahadevapura Lake in Bangalore, India

Mahadevapura Lake in Bangalore, India: One of the first lakes rejuvenated through CDD Society's Nature Based Solutions approach

Figure 32 Image showing Neknampur Lake in Hyderabad

Neknampur Lake in Hyderabad was previously a weed-choked mixture of chemical pollutants and domestic sewage. Floating 'island' were created to clean up Neknampur Lake. The island is in fact a floating treatment wetland (FTW). Several plants on this FTW play the part of cleaning the lake by absorbing nutrients dissolved in the water, such as excess nitrates and oxygen, thereby reducing the content of these chemicals.

25

2.19 Microclimate Regulation and Air Quality Improvement

Overview

Urban Ecosystems of the current era face three major challenges: Urban Heat Islands (UHIs), degrading Air Quality and physical and mental health issues of its residents.

Rapid urbanization leads to an increase of temperatures and air pollutants in city centres that can reach different degrees in some cases as compared to rural areas, due mainly to the hard surfaces, heating systems, traffic, and decreased turbulence in cities. Along with poor thermal comfort, this can lead to extreme temperatures which might induce heat shocks, dangerous especially for children and elderly people. This also has serious implications or urban vegetation and productivity. Poor air quality and lack of thermal comfort are also linked to stress, cardiovascular and respiratory diseases in human beings.

Increase in green and blue spaces in the city with concepts like Park Cool Islands and green roofs and walls are known to reduce the temperature gradient in city centres. Use of herbaceous vegetation on roofs and walls are known to absorb pollutants such as particulate matter, ozone, sulphur and nitrogen oxides as well as carcinogenic VOCs along with sequestration of atmospheric CO_2. Exposure to outdoor green and blue spaces improve mental health and physical activity[27].

Key Outcomes

- Improvement in thermal comfort amongst residents
- Removal of pollutants from ambient air and indoor environment
- Improvement in physical and mental well-being of residents
- Improvement in vegetation cover of the urban ecosystem
- In colder climates, dense tree canopy helps reduce wind chills

Case Study
Natural Outdoor environments and mental and physical health[26]

Location: Catalonia, Spain
Sample size of population: 9000
Project duration: 2010-2012

Health data for adults in the region were collected and analysed. Indicators used were sociodemographic data, general and mental health, physical activity and social support.

Green and Blue spaces were found to improve overall health, cognitive abilities in children, reduction in cardiovascular and respiratory diseases in urban adults and children. The effects of green and blue spaces on human health indicators in Catalonia are given below:

Psycho-Physiological Indicators	Green Spaces	Blue Spaces
Total Mood Disturbance	-	-
Attention Capacity - backwards digit-span task (BDSP)	(-)	=
Salivary cortisol	(-)	-
BP (Systolic)	-/+	(-)
BP (Diastolic)	+	-/+
Heart Rate	-/+	-/+

Notes: *Signs + and – represent significant positive or negative effects, signs in parenthesis represent a tendency but not a significant effect, = represents no effect, -/+ represents a great variability of responses from the different case studies.*

[26] Phenotype project and Triguero-Mas et al., 2017
[27] Nature-based Solutions for microclimate regulation and air quality

2.20 Urban Ventilation Corridor Planning

Overview

Urban ventilation corridor is the use of wind characteristics, from the ventilation system, under the effect of wind pressure, the city suburb of fresh air into the city, urban carbon oxygen balance, adjust the microclimate.

The following principles form the basis of designing urban ventilation corridors:[28]

- Vegetation should be placed to surround developments and larger, connected green spaces should be created or maintained throughout developed areas to facilitate air exchange
- Valleys serve as air delivery corridors and should not be developed
- Hillsides should remain undeveloped, especially when development exists in valleys, since intensive cold- and fresh-air transport occurs here
- Saddle-like topographies serve as air induction corridors and should not be developed

Key Outcomes

- Preserve and channel cool air throughout the city
- Connecting rural areas with the city centre
- Prevent urban heat island effect and poor air quality
- Enhance biodiversity
- Support health and wellbeing of citizens providing more recreational spaces

Case Study

Location: Stuttgart, Germany
Project duration: 2008-2014

Stuttgart's location in a valley basin, its mild climate, low wind speeds, industrial activity and high volume of traffic made it susceptible to poor air quality. Development on the valley slopes had prevented air from moving through the city, which worsened the air quality and contributed to the urban heat island effect. A Climate Atlas was developed for the Stuttgart region, presenting the distribution of temperature and cold air flows according to the city's topography and land use. Based on this information, a number of planning and zoning regulations were recommended aimed at preserving and increasing open space in densely built-up areas. As a result of the implementation of the recommendations included in the Climate Atlas and Climate Booklet, over 39% of Stuttgart's surface area has been put under the protection of nature conservation orders. Stuttgart contains 5,000 hectares of forests and woodland, 65,000 trees in parks and open spaces and 35,000 street trees. 300,000 square meters of rooftops have been greened and 40 out of 250 kilometres of tram tracks have been grassed (as of 2007). Targeted interventions such as a building ban in the hills around the town, and prevention of building projects that might obstruct the ventilation effect of nocturnal cold-air flows have resulted in preservation and enhancement of air exchange and cool air flows in the city.

[28] Climate Adapt Europe

2.21 Building Urban Ecological Infrastructure

Overview

Ecological infrastructure refers to the natural or semi-natural structural elements of ecosystems and landscapes that are important in delivering ecosystem services. It is similar to 'green infrastructure', a term sometimes applied in a more urban context. The ecological infrastructure needed to support pollinators and improve pollination services includes patches of semi-natural habitats, including hedgerows, grassland and forest, distributed throughout productive agricultural landscapes, providing nesting and floral resources.

Urban Environmental Infrastructure encompasses all parts of a city that include ecological structures and functions.

Key outcomes

Ecological structure is the physical components that make up ecosystems (e.g. species, soils, waterways) while ecological function is the processes that result from interactions among the structural components (e.g. primary production, nutrient cycling, decomposition).

UEI forms a critical bridge between nature in cities and the people that live in cities via its purveyance of urban ecosystem services.

Case Study

Figure 33 Image showing Port of Antwerp, Belgium

Location: Antwerp, Belgium
City population: 499,254
Project duration: 2015 - ongoing
Project cost: 500 000 - 2 000 000 EUR
Financing source(s): Corporate investment

The area of the Port of Antwerp is one of the most important habitats for threatened species, even at the European level. Therefore, a species protection programme was launched in 2014 for the conservation of 90 protected species by means of creating an ecological infrastructure of green areas, green corridors and small green spaces that include spawning grounds, ecological river banks, and road verges.

2.22 Biocatalysts or Bioenzymes

Overview

Catalysts can be produced following natural processes that help in enhanced production of active oxygen to accelerate biological processes that clean polluted surface water, ground water and wastewater. The biocatalyst can be sprayed to sanitize soil, garbage heaps, medical waste, and animal carcasses. The spraying also controls odor, pathogens, and pests such as mosquitoes, flies, cockroaches, and rats[29].

Key outcomes

- Sewage Treatment
- Lake Clean-up
- Eco- sanitation of Sewers
- Eco- sanitation of Sewage Streams (Nallas)
- Decentralized Sewage Treatment
- Decentralized Garbage Composting Units
- Treatment of Saline and Brackish Groundwater

Case Study

Figure 34 Image showing Taj Hotel at Madurai, India

Taj Hotel at Madurai, India had set up a conventional sewage treatment plant wherein a compressor was to be used to inject air into diffuser pipes submerged in the aeration tank. This plant was retrofitted with BIOSANITIZER, in 1997, and aeration system was turned off. BIOSANITIZER was able to produce tertiary treated sewage without any recurring charges, also without producing any sludge and greenhouse gases. The treated water is used for gardening. It has reduced inputs on fertilizers because the treated oxygen-rich water acts as a bio-stimulant to the plant life.

Figure 35 Image showing Powai Lake in Mumbai City.

Powai Lake In Mumbai and Pashan Lake in Pune were successfully treated with BIOSANITIZER. Both the lakes were getting sewage streams into them, rainwater coming only for about 60 days of the year. Water hyacinth and mosquito breeding were controlled in both the lakes. Useful vegetation such as lotus plants and fodder grass has started growing on the shallow edge. Any useful plant matter gets harvested and this helps the ecology.

[29] Bhawalkar, U.S.(1997)Vermiculture Bioconversion of Organic Residues, PhD thesis, Chemical Engineering Department, IIT Bombay, Mumbai.

2.23 Bioremediation of Rivers

Overview

Bioremediation is defined as the process whereby wastes can be biologically degraded or encapsulated under controlled conditions to an innocuous state, or to levels below the respective concentration limits, as set by the controlling authorities. In other words, bioremediation employs the living organisms, most notably microorganisms, to degrade the pollutants and convert them into less toxic or nontoxic form. The suitable organisms can be bacteria, fungi, or plants, which have the physiological abilities to degrade, detoxify, or render the contaminants harmless. In some occasions, the microorganisms can be already present on the site (indigenous microorganisms), or can be isolated from elsewhere and added to the treated material, using bioreactors as an example[31].

The concept of bioremediation was first used on a large scale in 1972 for the cleaning of Sun Oil pipeline spill at Ambler, Pennsylvania.

Critical conditions for bioremediation include:

- Host microbial contaminants that provide fuel and energy to parasitical microbes
- Parasitical microbes that feed off their harmful hosts and destroy them.
- Oxygen in sufficient amounts to support aerobic biodegradation.
- Water, either in liquid form or in soil moisture content
- Carbon is the foundation of microbial life and its energy source.
- Temperature, not too cold or hot for microbial life to flourish.
- Nutrients like nitrogen, phosphorous, potassium and sulphur to support microbe growth.
- Acid and alkaline proportions or pH ratio in the range of 6.5 to 7.5

Case Study

Figure 36 Image shows Bio remediation of River Ganga

Microbes used to treat Ganga water at 54 new sites[30]

Bioremediation technology has been successfully demonstrated in pilot projects by the Central Pollution Control Board. The technology is now used for cleaning up some parts of the river under the National Mission for Clean Ganga.

[30] http://timesofindia.indiatimes.com/articleshow/61336579.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppst as accessed on 5th Jan 2021

[31] Anastasios I. Zouboulis, ... Savvina G. Psaltou, in Encyclopedia of Environmental Health (Second Edition), 2019

Classification

Bioremediation Classes

There are two main classifications of bioremediation. This refers to where remediation is carried out. Bioremediation is done either:

In situ, where all bioremediation work is done right at the contamination site. This can be polluted soil that's treated without unnecessary and expensive removal, or it can be contaminated groundwater that's remediated at its point of origin. In situ is the preferred bioremediation method, as it requires far less physical work and eliminates spreading contaminants through trucking or pumping away to other treatment locations.

Ex situ means removing contaminated material to a remote treatment location. This classification is less desirable. It involves the big job of excavating polluted soil and trucking it offsite. In the case of contaminated water, ex situ is rare, except for pumping groundwater to the surface and biologically treating it in an enclosed reservoir. Ex situ bioremediation poses a hazard to spreading contamination or risking an accidental spill during transport.

Key Outcomes

- Under bioremediation technique, activated microbes eat up contaminants such as oil and organic matter.
- The bacteria play a vital role in treatment of sewage without causing any release of foul odour.
- Pollutants like heavy metals and toxic chemicals are reduced.

Case Study

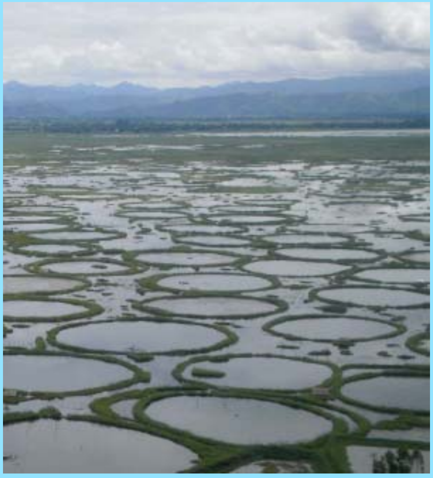


Figure 37 Image showing Loktak Lake in Manipur, India

Loktak lake (Ramsar site) in Manipur showing characteristic Phumdis (floating islands). This water body is serving as receptacle for sewage and agrochemicals. The various aquatic plants are playing a major role in phytosanitation and bioremediation[32].

[32] https://www.indiawaterportal.org/articles/bioremediation-its-applications-contaminated-sites-india-state-art-report-ministry as accessed on 5th Jan 2021

2.24 Growing algae to absorb vehicular pollution

Overview

Road transportation is the greatest contributor of global warming according to NASA, accounting for more than half of the carbon monoxide and nitrogen oxide levels emitted into the air.

To reduce the pollution from road transportation, an algae farm is set on an overpass over the highway and consists of a closed system of transparent, algae-filled tubes. The tubes are hooked up to secondary equipment such as filters, pumps and solar panels.

Careful species selection for landscaping and road side vegetation to retain the aim or beautification, barrier, sound control but increase the ability to absorb pollutants.

Key outcomes

- Algae is ten times more efficient in producing oxygen than that of trees and grass and can cut CO_2 emissions by up to 68 % when converted into biofuel[33].

Case Study

Figure 38 Image showing Garden Festival in Geneva

As part of a recent garden festival in Geneva, the team at Cloud Collective aimed to create an algae garden that uses the highway's excess of carbon dioxide coupled with sunlight to transform the polluted landscape into a smart space for urban farming. The system is quite simple, the algae are cultivated inside tubes, and a series of pumps, filters and solar panels aid the process. Once the algae mature, they can be used into a number of different products, including biodiesel, nutrients, medication and cosmetics.

[33] https://theplaidzebra.com/urban-algae-farm-eats-highway-pollution-and-turns-it-into-organic-fuel/ as accessed on 7th Jan 2021