Land Use and Urban Drain Water Quality: An Insight into Alternative Nature-Based Method

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Abstract

The provision of effective urban drainage and stormwater management is challenging for the Urban Local Bodies in towns and cities. The present study seeks to investigate the variation of drainage water quality with respect to the land use of different catchments of the municipal area of Sundargarh town and evaluate the potentiality of nature-based technologies for wastewater treatment and stormwater management. Geographical Information System GIS) is used for the assessment of the existing drainage characteristics and drain water quality is lab tested. It is found that the quality of drain water discharge from different areas varies with their land use. The comparison of hydrological maps shows that the natural drainage channels have undergone alteration and water bodies have shrunk due to changing land cover. Potential solutions using green infrastructure and nature-based technologies can benefit handling altered hydrological conditions, improve the urban stormwater quality discharged to the surface water course, and help maintain the river ecology.

Keywords: Drain water, water quality, nature-based, environmental sustainability

Introduction

Water stands at the core of every aspect of development and it links with nearly every Sustainable Development Goal (SDG). To achieve climate and development goals, water must be at the core of adaptation strategies. Freshwater resources drive economic growth, development, support healthy ecosystems, and influences and human settlement patterns. Whereas, water resource particularly surface water is susceptible to the threat of depletion and degradation of their quality due to the processes of urbanization. Climate change manifests itself through water-related issues, which transcend through food, energy, urban and environmental systems. Increased urbanization, frequent cyclones, and events of high intensity of rainfall due to climate changes have a direct impact on the local hydrologic cycle. Due to climate change and urbanization stormwater volumes and pollution are getting more and more important (Sims, 2015). If the effects of urbanization and climate change are not appropriately managed, channel geomorphology and aquatic ecology will degrade, stream base flow will decrease, water quality will diminish, and flooding frequency will increase. Urbanization impacts not only the physical but also the chemical and biological conditions of the waterways. The degradation of surface water quality is mostly due to anthropogenic factors, such as urbanization, and industrial and agricultural activities. The provision of effective urban drainage is challenging for the Urban Local Bodies (ULB) in towns and cities. Potential solutions can benefit to improve the stormwater quality discharged to the natural surface water course and help to maintain the river ecology. Appropriate urban drainage systems and stormwater management need to be designed to prevent urban flooding along with the controlling rate of flow and runoff.

The conventional approaches adopted for planning policies with respect to the provision of urban infrastructure lack the integration of ecological concepts and green techniques for environmental protection. Urban areas are witnessing the loss of biodiversity, which has become a major environmental challenge as a result of highly fragmented landscapes by roads, commodified constructed landscapes, resource-intensive urban infrastructure, and development. In this context, nature-based approaches and concepts of green infrastructure are being researched and modalities of effective integration in mainstream planning policies are discussed in recent literatures. Professionals, researchers, and policymakers are collaborating to apply scientific approaches related to green infrastructure and ecosystem services at different levels of planning and policy formulation (Saarikoski, 2018) (Marino, 2018). Integration of green infrastructure concepts in land use planning is studied to understand their effectiveness in terms of enabling ecosystem services for the provision of different sociocultural, economic, and ecological benefits (Bezák, 2017) (Hansen, 2015). This paper has attempted to understand the urban ecology together with the built, grey and green infrastructure that is characterized by the natural and social processes and the abiotic factors that contribute to and alter the functioning of the urban ecosystem and discuss the applications of the nature-based approaches gathered from past studies for the sustainable stormwater drainage system.

Literature Review

Designing an effective urban drainage system is challenging as it involves a complex dynamic environment of man-made, abiotic, and biotic elements that alters the urban landscape. An appropriate system is required to mitigate the effects of urban development on natural ecosystems and solve urban water-related problems at the same time. Critical understanding of the evolving urban wastewater management, and in particular the concept of nature-based solution and its objective in terms of urbanization and climate; examining the difficulties and uncertainties in the implementation of nature-based techniques; designing feasible solutions for specific urban areas and sustainability of this alternative green infrastructure is important.

Urban rainwater management earlier primarily targeted flood mitigation and small-scale collection for private use. From the 19th century onwards the objective of stormwater management has broadened to integrate biodiversity, eco-restoration, water recharge, water urbanism, and community purposes. The impact of massive industrialization and unprecedented urbanization in the 20th century necessitated western countries to devise policies and strategies to address water-related issues specifically. Problems of urban water flooding and pollution have been investigated in developed countries since the 1970s (Fletcher, 2014). Altered hydrological conditions that arise from the changes in ecological processes due to interventions can be restored by the long-term processes that define an environmental threshold to blue-green infrastructure and nature-based implementations. Examples of long-term processes are through energy input, different patterns of matter circulation, and managing energy fixation ratio (Wright, 1983) (Turner, 1987). This can be combined with short-term methods that enhance ecosystems' adaptive capacity, such as with various restorative efforts of nature-based implementations, that is combining the stormwater system with on-site substrate infiltrations and growth of vegetation for pollution trapping by water bodies (Krauze, 2019). As a mitigation measure for these hydrological issues, nature-based solutions have been explored to revive and maintain watersheds and their flow regimes by applying nature practices that replicate natural processes (Fletcher, 2013). The nature-based solution is found to benefit urban areas by enabling eco-regeneration, climate change adaptation, promoting human well-being and economic value of resource use, and stimulating a circular economy (WWAP, 2018).

Green infrastructure in cities serves as a planning approach to develop a network of green spaces and adopt water bodies as an instrument for the implementation of nature-based solutions, with the aim to enhance ecosystem services and work as a structural framework for the functioning of nature-based solutions (Krauze, 2019). Water is considered the main limiting and driving factor to blue-green infrastructure and nature-based solutions in the city (Zalewski, 2003). In cities, NBS is dependent on human intervention within the degraded natural environment, due to the dependency on the availability and accessibility to water, and on the functioning of the biodiversity and biotic processes and modified abiotic environment: climate and soil, and available space (Morgenroth, 2013). Krauze and Wagner (2019) have highlighted the critical role of urban nature-based solutions from preserving to enabling urban ecosystems while avoiding their misuse and meeting the expectations of policymakers and society by being resilient to change and functioning with diversified management styles and setting different targets for different zones of the city. Herein, three different management styles have been identified: self-regulatory, bandwidth, and high-reliability, which would be applicable to different zones of the city having different environmental characteristics, and types of natural areas, reflecting different disturbance regimes.

As discussed in the literature (Nguyen, 2019) (Zölch, 2017) to obtain different ecosystem services, nature-based approaches are to be implemented at the watershed scale and be flexible to adapt to different catchment characteristics and at multiple scales. The existing drainage system, water-bodies, natural streams, rivers, and topography are required to be considered along with the built and unbuilt landscape of the urban area to suggest appropriate strategies for drainage system and stormwater management with the objective of climate change resilience, delivery of ecosystem services and sustainable urban development. This will ensure the optimal management of wastewater and stormwater, appropriate water treatment, and limit flooding during high-intensity rainfall events. With this objective, the study seeks to explore the applicability of nature-based approaches for preserving the river ecology, restoring depleting water bodies, and enabling sustainable environmental management of urban areas. A scenario framework is adopted to assess the effect of the built environment on the quality of wastewater discharged to the river and the potential of existing blue-green infrastructure to improve wastewater quality discharged to the river and reduce stormwater runoff.

Methods

The case study of the urban area of Sundargarh town is undertaken, which is favourably positioned with natural inland waterbodies and flowing river course, whereas, it is a land stressed with haphazard urbanization, degraded green areas, and burden on the river to receive the wastewater generated in the town. The establishment of different large-scale and small-scale industries nearby has drawn a large mixed population and brought about changes in the land cover and land use of the town. With a population density of 1890 persons per sq. km, the total geographical area of Sundargarh municipality is 24 sq. km. Patches of the town are characterized by higher built-up and population densities, and consequential increase in the impermeable surface, and a lowering of green share and pressure on the water bodies.

Sundargarh experiences a sub-tropical climate characterized by hot and dry summer, cold winter, and erratic rainfall in monsoon. The normal rainfall of the district is approximately 1230 mm/year with maximum hourly rainfall of 50 mm/hr. But there is a deviation in receipt of rainfall pattern, which is likely to influence the quality and quantity of surface drain water to be discharged into the IB river. Quality of surface drain water discharged to the adjoining IB river during dry periods is a point of concern.

Geospatial inputs are gathered from high-resolution satellite images for identifying land use and landcover and Google Earth Pro satellite image-based coordinates and GPS Visualizer Website for digital elevation model (DEM) and Contours generation. Multi-temporal high-resolution satellite images have been interpreted using a hybrid approach of Digital Image Processing and on-screen interpretation. Land Use/ Land Cover both at Level-1 and Level-4, natural drainage system and artificial drainage system have been interpreted, mapped, and corresponding Geodatabase have been developed both for the Sundargarh Municipality area and the Surrounding natural drainage catchment. The study undertaken for storm and sewage management of Sundargarh Municipality area is based upon the basic geospatial inputs matching individual plots of the municipality and its surrounding natural drainage catchment.

To analyze the quality of different chemical and organic components present in the drain water, stormwater samples were collected during summer in the month of April and monsoon time in the month of August. Municipal wastewater was collected by grab sampling techniques during the month of April 2021 from 4 sampling sites and August 2021 from 8 sampling sites of the four major drains of Sundergarh town i.e., Drain-A (PHED), Drain-B (Mahadev Temple), Drain-C (Samaleswari Temple) and Drain-D (Regent Market). The collection, transportation, preservation, and analysis of the collected water samples were carried out in accordance with the procedures mentioned in the Standard Methods (APHA, 2005). The wastewater samples were analyzed in duplicate using methods suggested by APHA and BIS for different Physical, Chemical, and Microbial Parameters.

Analysis

Understanding the urban mosaic is primarily important for any intervention in the regime of blue-green infrastructure. The ecological perspective views the city as a coevolution between man and nature, where local-level built-up and other infrastructural interventions cause modification of greater-scale ecological and geological processes (Holling. 2001).

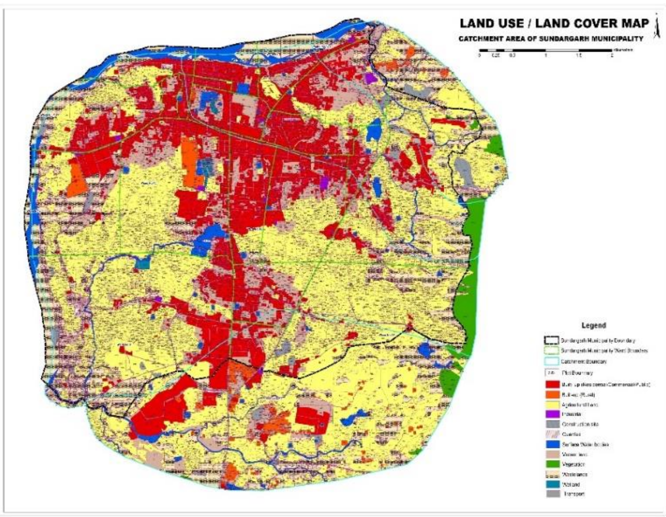
Characteristics of Urban Structure and Hydrology

In the present study, the spatial data characterizing the topography and catchment hydrology is correlated with the existing land use and land cover of the urban area to assess the load on the drainage system and identify the potentiality of nature-based solution implementation.

Urban Structure

The Municipality is divided into 19 Wards. However, for stormwater and sewage study, the extended area of the natural drainage catchment surrounding the municipality, with a spatial extent of 35.15 sq. km. has been delineated for the analysis (Figure 1.). Coordinates of places having major activities have been georeferenced to identify load on the drainage system. It is also revealed from the GIS map of the city that there are 4 streams that pass through the geographical area of the city. These streams carry the runoff of the city and fall into the nearby Ib River. The spatial data of LULC of these 4 streams flowing in the municipality extent are shown in Table 1. These streams are demarcated in the Catchment Map as A, B, C, and D in Figure 2.

The growth and development of Sundargarh town is influenced by large-scale industrial activities. Rapid development is taking place in the area with respect to setting up industries and commercial centers, educational institutions, and trading activities. A lot of demand has been generated for residential land use in the area and degraded waste agricultural land near the roadsides is being converted to residential areas. The Land Use/ Land Cover (LULC) map (Figure 1) shows the highest density of built-up area towards the Northern side and along the major central road that runs through the center of the urban area.



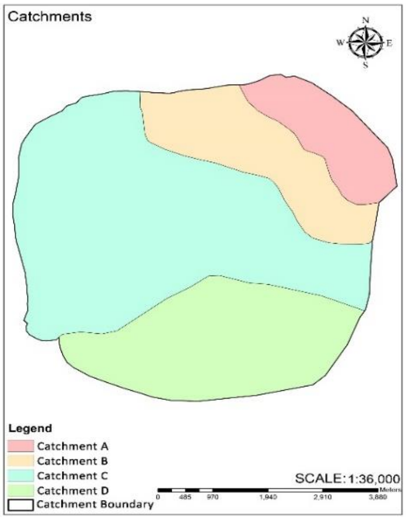


Figure 1. Land use/Landcover Map of Catchment

Figure 2. Four Catchments Zones

Table I. shows that major land use in all the catchments except catchment B is agricultural land of 40% to 50%. Considerable tracts of the wasteland of 27% are present in catchment A. Built-up area is highest in Catchment B with 34.75% of the total catchment area, which contributes to the greater quantity of stormwater to the drains. There are quite a few surface water bodies present in all the catchments, which can prove to be useful as blue-green infrastructure to provide nature-based alternatives for storm and wastewater management. The third highest share of land use is vacant land, which shows the town is likely to be urbanised more with larger requirements of utility infrastructure.

Hydrology

The rainfall data of the city is taken from the sources of SRC. The rainfall spread during monsoon is considered for the analysis from the year 2000-2020. In order to find the impact of rainfall, the daily maximum rainfalls are collected from the monthly data over the same period of time. It is found that average annual rainfall is around 1315 mm and the monsoon share is 1209 mm, which is around 91.9% of the annual rainfall. During the years 2001and 2020 the annual rainfall crosses 1600 mm mark. The general percentage of monsoon rainfall is above 90%, except the year 2018 and 2020, when it was below 80% of annual rainfall. The runoff depth for various land cover is different, as different LULC within a catchment area receiving same amount of precipitation will give different runoff. The increase of residential area has resulted in increase of more impervious area resulting in more runoff. Soil conservation service- curve number (SCS-CN) method is used as it is one of the most accurate and easy calculation method for rainfall-runoff modelling. The scope of the present study is limited to correlation of spatial characteristics of LULC with the status of existing drain discharge and the role of existing water bodies.

Although, the rainfall pattern has not changed significantly, there is a decline in number and size of waterbodies due to increase in built up areas, which has led to elimination of the natural streams that feed these water bodies. Waterbodies within the municipal area of Sundargarh have underdone significant changes with reduction in size, quality of water and amount of water stored. The total size of these water bodies has reduced from 64.8 Ha in 1972 to 39.38 Ha in the present time of 2021 (Figure 3.) The water body marked No.2 is shown in Figure 4. The waste water drains at few locations also flow to these water bodies before discharging to the river Ib.

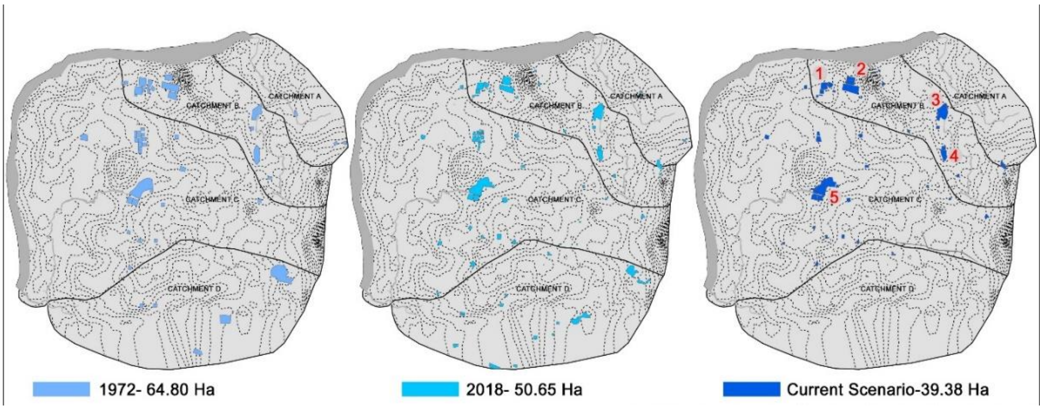


Figure 3. Surface Water Bodies in the Catchment Area of Sundargarh Municipality

Figure 4. Waterbody acting as an intermediate sink for the drain

Correlation between Urban Structure and Drain Discharge.

Sundargarh has a combined drainage system wherein, the domestic grey sewage water and stormwater are discharged to the Ib river through a single combined constructed open drain. Due to the growth of Sundargarh town during the last decades, the generation of domestic sewage has increased. To make an assessment of the quality of drain water discharged to the river and establish its relationship with land use, laboratory testing of the drain water samples collected from the drain discharge points and from different locations of the town as indicated in Figure 5. was conducted. Land use and major activities impacting wastewater disposal were mapped with respect to the constructed drains in the town as enumerated in Table 2.

Table 2. Surface Drainage and Land-use

	Discharge Point A		Discharge Point B		Discharge Point C		Discharge Point D	
Sl. No.	**A1**	**A2**	**B1**	**B2**	**C1**	**C2**	**D1**	**D2**
Ward No.	1,18	16,17, 19	12,13,14	15,18	11	2,4,5,10	9,10	10,11,6,7,3 ,8
Land-use	I	R, C & I	R & C	R & C	R, C & HC	R, C & HC	R, C & HC	R, C & HC
Major activities impacting water quality	Auto-mobil e garage s	Auto-mobile garages	Hotels and Eateries	Hotels and Eateries	Pesticides of Agricultural farm, Hospital, Hotels and Restaurants	Pesticides of Agricultura l farm, Hospitals, Hotels	Hospita l and Agricul tural farm	Hospital and Pesticides of Agricultur al farm

Point A receives waste water from the north-east part of the town. The main drain is present in Ward no. 1 and receives the waste water from Ward no.1,18 and 19, which receives sewage water from residential areas of Ward No. 19 and from commercial plots and repair shops, garages and vehicle wash areas (Figure 5.). The catchment area of the main drain that comprises the eastern part of the town discharges to the river at point B. The bus stand area which comes under Ward no. 18 also contributes to the wastewater flowing to point B. Point C is to downstream of point B and joins the river near the Samlai Temple. The main drain flows in Ward No. 2, which receives sewage water from densely built residential areas, educational institutions, and the weekly market. This area has the highest growth rate as compared to other areas in the city in terms of growing investment in real estate, and this may lead to even further increased wastewater discharge in the future. Point D towards the downstream of point C is the point where the last drain flows into the IB river. The District Headquarters Hospital (DHH) located in the southern part exists in this catchment area which discharges at point D. The quality of drain water discharging at point D is bad due to the poor environmental quality of the area that disposes wastewater to this drain.

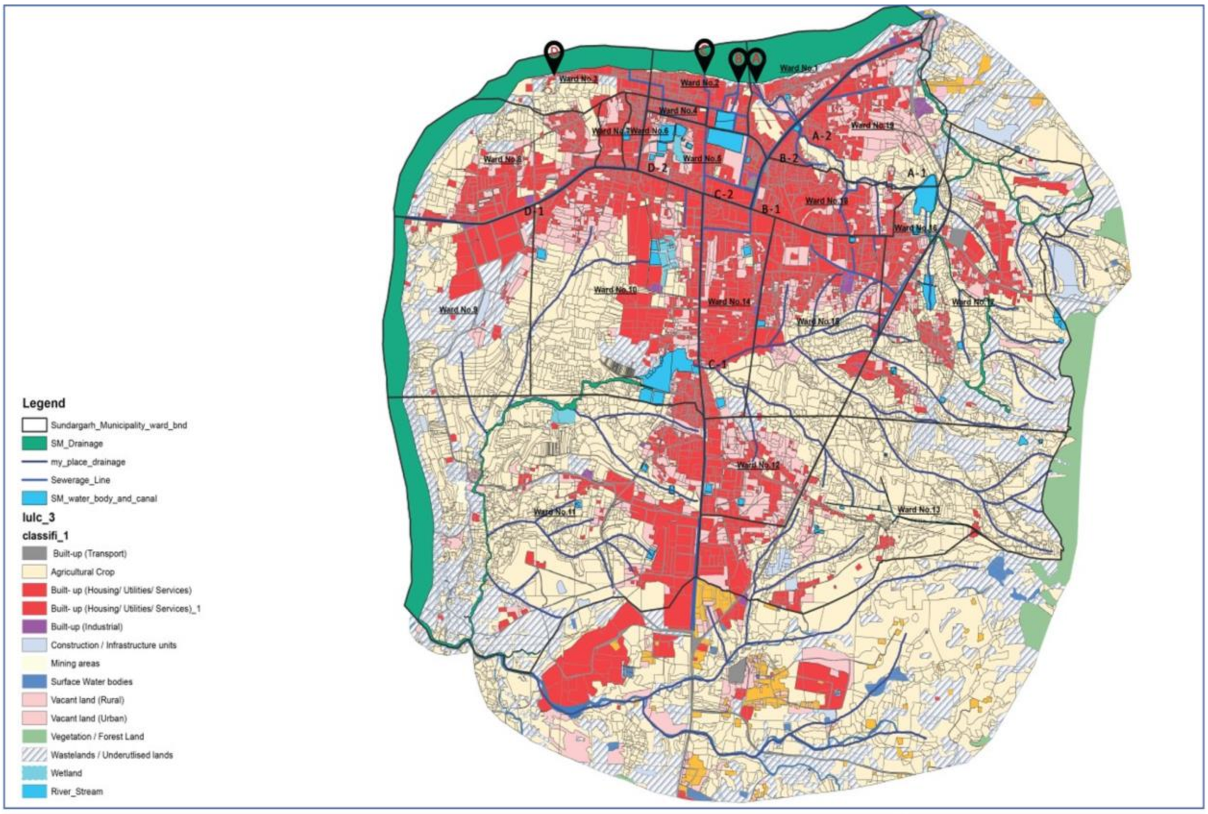


Figure 5. LULC map indicating drain water sample collection points

The combined drains that serve both as domestic sewer lines and stormwater drainage channels pass through water bodies at a few locations as shown in Figure 7. before discharging to the river. There are large waterbodies of size 42,514 sq mt. The land use adjoining the water bodies and drains that pass through them are shown in Table 3. Drain discharging at points B and C are connected to water bodies WB1, WB2, and WB3. This will help to suggest appropriate strategies for disposal and treatment. Most of the land use adjoining the drain is residential and commercial.

Table 3. Natural Water Bodies and Drainage Sinks

Water Body	WB1 (Wet land behind SP Residence)	WB2 (Bijli Bandh)	WB3 (Rani bandh)	WB4 (Brahmani bandh)
Area	13,664 sq mt.	37,327 sq mt.	18,453 sq mt.	42,514 sq mt.
Connected Discharge Point	B & C	B & C	B & C	C & D
Land-use	Residential, Commercial, Public/Semi-public	Residential, Commercial, Public/Semi-public	Residential, Commercial, Public/Semi-public	Residential, Commercial, Public/Semi-public, Public Utilities

Drain water quality, was tested for different Physical, Chemical, and Microbial Parameters, adopting analytical procedures like physical characterization, Gravimetric method, Winkler Method of Measuring Dissolved Oxygen (Titrimatic method), Closed reflux method, and other respective methods for each of the parameters. The hydrogen ion activity is measured as pH, which is a measure of acidity and alkalinity in aquatic bodies. The hydrogen ion concentration expressed as pH is a valuable parameter in the operation of biological units, caused by a great variety of suspended solids. Fresher or more concentrated sewage generally has greater turbidity. The values of turbidity ranged from 39 to 87 NTU. Though sewage contains only about 0.1 percent solids, the rest being water, still the nuisance caused by the solids cannot be overlooked, as these solids are highly putrescible and therefore need proper disposal.

The sewage solids are classified into dissolved solids, suspended solids, and volatile suspended or dissolved solids. The values of suspended solids, dissolved solids, and volatile suspended solids ranged from 83 to 175 mg/L, 219 to 375 mg/L, and 63 to 119 mg/L (Table 4). Organic compounds present in sewage are of particular interest for evaluating the environmental impact on the disposal sink. Two standard tests based on the oxidation of organic material 1) the Biochemical Oxygen Demand (BOD) and 2) the Chemical Oxygen Demand (COD) tests are conducted. The general range of BOD observed for raw sewage is 100 to 400 mg/L. The COD of raw sewage at various places is reported to be in the range of 200 to 700 mg/L. The samples tested showed the values of BOD (at 20°C) and COD in the range of 88 to 150 mg/L and 179 to 288 mg/L (Table 4). The lowest values of the parameters highlighted in Table 4 show less presence of pollutants in the drain water.

Table 4. Results of Drain Water Quality Parameters

Parameter	**Drain-A**	**Drain-A (A1)**	**Drain-A (A2)**	**Drain-B**	**Drain-B (B1)**	**Drain-B (B2)**	**Drain-C**	**Drain-C (C1)**	**Drain-C (C2)**	**Drain-D**	**Drain-D (D1)**	**Drain-D (D2)**
pH	7.7	7.6	7.6	7.7	7.4	7.4	7.4	7.2	7.2	7.5	7.2	6.8

Electrical Conductivity (μs/cm)	442	534	528	367	462	463	365*	387	387	560	610	467
Turbidity (NTU)	52	61	62	48	54	56	39*	51	53	79	87	58
Dissolved Solids (mg/L)	259	319	314	223	272	272	219*	233	233	344	375	274
Total Soilds (mg/L)	370	442	437	317	382	384	302*	334	332	495	550	389
Suspended Solids (mg/L)	111	123	123	94	110	112	83*	101	99	151	175	115
Volatile Suspended Solids (mg/L)	74	82	83	71	79	80	63*	78	76	105	119	80
Biological Oxygen Demand (mg/L)	98	112	112	88*	98	102	108	128	124	134	150	106
*Chemical oxygen demand (*mg/L)	198	226	220	179*	201	206	218	268	258	256	288	194
Alkalinity (mg/L as $CaCO_3$)	56	70	68	56	68	70	52*	55	55	84	94	66
Chloride as Cl^- (mg/L)	49.7	120	120	42.6	66	70	35.5*	56	68	71	130	72
Sulphate as SO_2^{-3} (mg/L)	129	160	158	115	142	144	98*	108	106	158	172	126
Nitrate as NO_3^{-2} (mg/L)	23.4*	32.4	32.6	34.1	44.2	46.4	48.6	52.6	52.8	37.5	40.2	27.6
Phosphate as PO_4^{-2} (mg/L)	2.7	2.6	2.2	3.8	2.9	2.6	3.9	1.9	2.4	2.2	2.6	2.9
Oil and Grease (mg/L)	7.4	8.5	8.6	4.3	3.2	2.1	3.9	1.5	2.2	1.9	1.5	2.1

* Lowest value

Discussion

Findings

The catchment level analysis for slope and flow accumulation and the rainfall data for the town shows that though the stormwater can be discharged to the river by gravity flow, there are areas with less gradient and higher order stream and flow accumulation, which is vulnerable to urban flooding.

The existing municipal sewer is a combined drain for stormwater drainage also. The quality of drain water was tested and analyzed with respect to the LULC of the town. Although, the physical, chemical, and microbial parameters are within the permissible limit, with the growing population and urbanization the drain water quality is likely to deteriorate and will degrade the river ecology and environmental quality of the town if not treated appropriately before discharging to the river. Discharge point D has the lowest water quality as the land use along this drain has pollutant-generating activities. The correlation of land use impacts and quality test results shows that municipal sewer water quality is related to land use. Hence, an appropriate decision for urban stormwater and sewer water management has to be taken keeping in view the spatial and functional structure of the city.

It is observed from the quality test result that the chemical and microbial parameters of drain water at discharge points B and C are the lowest, which is less polluted (Table 4). These drains flow through large tracts of existing water bodies in the town before discharging into the river (Table 4).

Purification and Run-off Regulation Potential of Green Infrastructure.

The study provides direction for reinforcing the natural ecosystem within urban areas to maintain their adaptive capacities and provide ecosystem services to the town by restoring existing natural waterbodies. River restoration and stormwater retention ponds in urban areas will play an important role in the conservation of biodiversity and prevent landscape degradation. The application of the water body (WB2) is shown in Figure 6. Here the aim of ecohydrology is not only to conserve river habitat structure but also to reach a balance between spatial and economic development and introducing nature. As Sundargarh is a moderately urbanized area, the biotic regulation of ecohydrological processes is stronger than in bigger cities. This has practical feasibility for nature-based solution implementation. Suitable environmental conditions for water and vegetation entail greater investment in the alternative nature-based solution. As pointed out by K. Krauze and I. Wagner (2019) urban ecological systems with stronger biotic control have greater potential for nature-based approaches and they mostly are supportive of nature. Therefore, it is suggested to adopt alternative nature-based techniques involving the blue-green infrastructure.

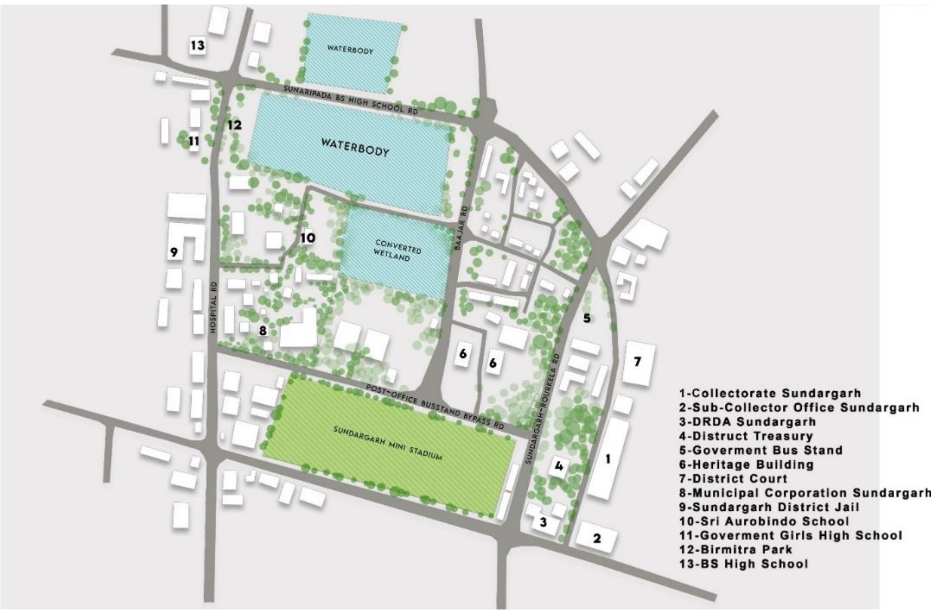


Figure 6. Nature-based proposal with the Available Blue Green Infrastructure

The urban drainage system is to aim at both flood control and pollution control. This alternative urban stormwater management approach provides methods that allow control at the source and handle the quality and quantity of the runoff at the local level or nearby the source (decentralized technologies) and enables social and amenity perspectives to be incorporated into stormwater management approaches. Figure 8. shows the application of the proposed nature-based strategy by using the existing water body near discharge point C. Wastewater will flow to the first pond which is considered a converted wetland, through the filter material usually sand or gravel, and planted with vegetation tolerant of saturated conditions. The treatment can be carried out by chemical, physical, and biological processes. It will mimic natural hydrological processes and will use natural elements such as soil and plants to turn rainfall into a resource instead of a waste.

Conclusion

Current conventional urban drainage systems which is a combined sanitary sewer system were built to manage stormwater to prevent urban flooding and dispose of municipal sewage to the Ib river flowing along Sundergarh city. The main idea of drainage design has been that stormwater is a waste product and must be removed as quickly as possible
away from the source and into the adjacent river. As this conventional approach focuses primarily on managing the disposal of stormwater and sewer water it will do very little to achieve sustainable development goals.

Close-to-nature practices can help to address hydrological issues in urban areas by implementing nature-based solutions. The decision has to be taken based on the extent of urbanization and the LULC characteristics of the urban area. Constructed wetlands have been implemented successfully for treating different types of wastewater for decades and have been identified as a sustainable wastewater management option. Stormwater infiltration systems can help to reduce peak flows to water treatment plants and rivers, regulate microclimate, and increase groundwater level (17) The positive outcomes are improved biodiversity, delayed downstream water transfer, stabilized erosion and sedimentation, reduced nutrient transfer, a number of ecosystem services (13) and improved aesthetics and recreation in the city.

Despite the recognised benefits and functions, the use of nature-based solutions remains marginal and grey infrastructure and technology-driven solutions continue to dominate urban development. In order to shift this dominance, new planning approaches with Urban Green Infrastructure are needed for the development, implementation, and mainstreaming of nature-based solutions.

References

[1] Bezák, P. Mederly, Z. Izakovičová, J. Špulerová and C. Schleyer, Divergence and conflicts in landscape planning across spatial scales in Slovakia: An opportunity for an ecosystem services-based approach? *International Journal of Biodiversity Science, Ecosystem Services & Management*, **13(2),** p. 119–135, 2017.

[2] Fletcher, T.D., W. Shuster, W. F. Hunt, R. Ashley, D. Butler, S. Arthur, S. Trowsdale, S. Barraud, A. Semadeni-Davies, J. L. Bertrand-Krajewski, P. S. Mikkelsen, G. Rivard, M. Uhl, D. Dagenais, M. Viklander, SUDS, LID, BMPs, WSUD and more –The evolution and application of terminology surrounding urban drainage. *Urban Water J.,* **12 (7),** p. 525–542, 2014.

[3] Fletcher, T. D., H. Andrieu, P. Hamel, Understanding, management and modelling of urban hydrology and its consequences for receiving waters: a state of the art, *Adv Water*

*Resour***. 51 (0),** p. 261‑279, 2013.

[4] Hansen, R., N. Frantzeskaki, T. McPhearson, E. Rall, N. Kabisch, A. Kaczorowska, J.H. Kain, M. Artmann and S. Pauleit, The uptake of the ecosystem services concept in planning discourses. *Ecosystem Services*, **12,** p. 228–246, 2015.

[5] Holling, C. S., Understanding the complexity of economic, ecological, and social systems. *Ecosystems*, **4**, p. 390–405, 2001.

[6] Krauze, K. and I. Wagner, From classical water-ecosystem theories to nature-based solutions - Contextualizing nature-based solutions for a sustainable city, *Science of the Total Environment*, **655,** p. 697–706, 2019.

[7] Marino, M. Di, J. Niemela, K. Lapintie, Urban nature for land use planning. *Urbanistica* **159**, p.94–102. 2018.

[8] Morgenroth, J., G. Buchan, B. C. Scharenbroch, Below ground effects of porous pavements—soil moisture and chemical properties, *Ecol. Eng*. **51**, 221–228, 2013.

[9] Nguyen, T., T. H. H. Ngo, W. Guo, X. C. Wang, N. Ren, Guibai Li, J. Ding and Heng Liang, Implementation of a specific urban water management - Sponge City, *Science of the Total Environment*, **652,** p. 147–162, 2019.

[10] Sims, A. W., *Stormwater Management Performance of Green Roofs*, p.121, Thesis and Dissertation Repository, The University of Western Ontario, 2015.

[11] Saarikoski, H., E. Primmer, C. Schleyer, R. Aszalós, Baró, F., Berry, P., Garcia Blanco, G., Goméz-Baggethun, E., Carvalho, L., Dick, J., Dunford, R., Hanzu, M., Izakovicova, Z., Kertész, M., Kopperoinen, L., Köhler, B., Langemeyer, J. Lapola, D., Liquete, C., Luque, S., Mederly, P., Niemelä, J., Palomo, I., Martinez Pastur, G., Peri, P., Preda, E., Priess, J.A., Saarela, S-R., Turkelboom, F., Vadineanu, A., Verheyden, W., Vikström, S. and Young, J., Institutional challenges in putting ecosystem service knowledge in practice. *Ecosystem Services*, 2018.

[12] Turner, J. R. G., C. M. Gatehouse, C. A. Corey, Does solar energy control organic diversity? Butterflies, moths and the British climate. *Oikos*, **48**, p. 195–205, 1987.

[13] Wright, D. H., Species-energy theory: an extension of species–area theory, *Oikos* **41**, p. 496–506, 1983.

[14] WWAP (United Nations World Water Assessment Programme)/UN-Water, *The United Nations World Water Development Report 2018: Nature-based Solutions for Water.* UNESCO, Paris, 2018.

[15] Zalewski, M., V. Santiago-Fandino, J. Neate, Energy, water, plant interactions: 'green feedback' as a mechanism for environmental management and control through the application of phytotechnology and ecohydrology, *Hydrol. Process.* 17, 2753–2767, 2003.

[16] Zölch, T., L. Henze, P. Keilholz, S. Pauleit, Regulating urban surface runoff through nature-based solutions ‑ An assessment at the micro-scale, *Environmental Research*, **157**, p. 135‑144, 2017.