学 位 論 文 内 容 の 要 旨

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Role of treated wastewater in mitigating urbanization impacts and maintaining regulatory ecosystem services
（都市化の影響を緩和し調整生態系サービスを維持する上での処理水の役割）

Urbanization is a continuously happening phenomenon worldwide. With rapid and often unplanned urban growth, several environmental settings in the landscape are impaired in the city premises. The perceived benefits of urban facilities entice rural populations to move into urban areas. This is resulting in overcrowding and unplanned occupation of urban areas, including urban green spaces (UGS). The other drawbacks include strain on resources and energy, along with environmental vulnerability to air and water pollution, elevated land surface temperature (LST), urban heat island (UHI) effect and summer heatwaves and severe storm-water runoff adversities.

The creation and sustenance of urban green spaces (UGS) can effectively reduce these impacts. Indeed, urban trees (or the urban forest) can be managed to effectively deal with adverse impacts on urban water, heat, carbon, and pollution. In this regard, use of treated wastewater available year-round in the cities can be advantageous from climate change mitigation, urban sustainability, carbon storage and sequestration perspectives as well as from improving the regulatory ecosystem services which harmonize microclimate features. Thus, the relationship between urban landscape patterns and microclimate needs to be sufficiently understood to make urban living ecologically, economically, and ergonomically acceptable. “Urban green infrastructure” is a cost-effective and energy-saving means for ensuring sustainable development. The vegetation of any kind in urban areas such as parks, gardens, vertical gardens, trees, hedge plants, and roadside plants is this green infrastructure. In this regard, information on diverse patterns of land use intensity or spatial growth is essential to delineate both beneficial and adverse impacts on the urban environment.

With this background, the present study aimed to address the adverse effects of UHI and elevated LST resulting from land use land cover (LULC) alterations along with the role of UGS in regulating microclimate. The other objective was to estimate water requirements of UGS during the non-rainy months, its carbon biomass and sequestration potential. This study also aimed to evaluate whether treated wastewater is a dependable alternative for maintaining UGS as a measure to mitigate the adverse impacts of urbanization as well as to reduce groundwater extraction. Two traditional cities in India, experiencing different climatic features, were chosen for this study. Panaji city (Koppen classification: Am) situated on the west coast of India receives over 2750 mm rainfall and Tumkur city (Koppen classification: BSh/Aw) located in the interior region receives around 600 mm rainfall. Both cities are proposed to be developed as smart cities.

The methods followed included the analyses of satellite imageries for delineating 1990-2019 land use land cover changes and characterization of the 2019 spectral indices of both cities for understanding the LST difference among other microclimate features. Primary (satellite imageries, field survey-based data, and inputs from key-informant survey questionnaires) and secondary (websites, reports in public domain) data were used to address the above-stated objectives. By following the standard methods, the monthly evapotranspiration rates were also derived for both these cities for calculating the UGS water requirement. The calculation of water requirements and carbon stocks and sequestration rates of trees, hedge-plans as well as grass-cover was carried out by following standard methods.

While the LST varied within 38-42◦C range in Panaji with a substantial water spread area, it remained quite high in the 42-48 ◦C range in Tumkur (a much larger but highly water-scarce city). The average daily water requirements of 34 different tree species, hedge-plants m-2 and grass-cover m-2 were calculated following standard methods. The larger the canopy/crown area, higher the volume of water required. With the canopy area ranging from 4.491 m2 to 593.66 m2, the daily water requirement ranged respectively from 3.05 Ld-1 to 369.43 Ld-1 averaging 23.87 Ld-1tree-1. Similarly, for hedge plants the daily requirement was 6.77 Lm-2, and for grass-cover(=lawns) 4.57 Lm-2. Using this information, the water requirements for the entire UGS in Panaji and Tumkur were estimated. The UGS of 1.86 km2 in Panaji city requires 6.96 million litres daily. This volume is under 50% of the total treated wastewater of 14 MLD produced in Panaji (over 99% of this treated wastewater is currently drained into a polluted creek). Notwithstanding the wide variance between 34 different tree species (covering 4012 individual trees), the weighted mean of CO2 sequestered per tree averaged 55 kg y-1. The CSR estimated in this study are first reports for 23 tree species. These rates are well within the ranges reported for some tropical species.

With a view of showcasing the possibility of improved regulatory ecosystem services, an option to use the treated wastewater for watering the entire UGS in Panaji was examined. From this exercise, it is reasoned that less than half of over 14 MLD treated wastewater (=recycled water which is environmentally safe) available year-round is sufficient for meeting the demand of entire UGS in Panaji. From the UGS regulatory ecosystem services viewpoint, numerous ecological and economic advantages with the use of treated wastewater are highlighted. Ample reduction in groundwater extraction, compensation of evapotranspiration losses, enhanced thermal comforts, greater elimination of water-stress and additional employment opportunities are some of the ecosystem services that can be improved by using treated wastewater for sustainable urban green spaces in Panaji or any other cities.