HOKKAIDO UNIVERSITY

Title	Role of treated wastewater in mitigating urbanization impacts and maintaining regulatory ecosystem services [an abstract of dissertation and a summary of dissertation review]
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Degree Grantor	北海道大学
Degree Name	博士(環境科学)
Dissertation Number	甲第14331号
Issue Date	2021-03-25
Doc URL	https://hdl.handle.net/2115/81818
Rights(URL)	https://creativecommons.org/licenses/by/4.0/
Type	doctoral thesis
File Information	Manish_Ramaiah_review.pdf, 審査の要旨

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学 位 論 文 審 査 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 an inevitable modern phenomenon worldwide, and more rapidly in developing countries. The perceived ‘comforts’ and benefits of urban facilities entice the rural population to move into towns and cities, which often get overcrowded. Education and employment opportunities, healthcare facilities, and access to advanced infrastructure are notable advantages in an urban setting. However, the drawbacks of rapidly expanding urbanization -often haphazardly- include strain on resources and energy, along with environmental vulnerability to pollution, elevated land surface temperature (LST), and urban heat island (UHI) effect etc. From the urban sustainability perspective, the steps essential for regulating/balancing the microclimate features, creation and upkeeping of urban green spaces (UGS) are vital. Smart Cities Mission of the Government of India (GoI) is one of mega project to improve quality of urban centers. Therefore, this research is focusing on the role of UGS in maintaining regulatory ecosystem services. There are only a few studies related to the Smart Cities Mission of GoI. Hence, this research aimed to evaluate the role of treated wastewater in irrigating UGS to mitigate urbanization impacts.

One of the essential tasks of this study was to evaluate the importance of UGS in cities. Thus an extensive literature review was performed and published in a review paper entitled “Urban Green Spaces and Their Need in Cities of Rapidly Urbanizing India: A Review”. In the next step, the UGS of Panaji and Tumkur were evaluated to address the adverse effects of UHI and elevated LST using Landsat data. Land surface features play an essential role in regulating UHI and LST. Panaji having more UGS and blue spaces, has low LST as compared to Tumkur. The results of the case study are published in paper entitled “Land Cover Influences on LST in Two Proposed Smart Cities of India:

Comparative Analysis Using Spectral Indices". Lastly, the daily water requirement and carbon sequestration potential of UGS in Panaji and Tumkur were evaluated, 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.

The average daily water requirements of 34 different tree species, hedge-plants and grass-cover were calculated following standard methods. The larger the canopy/crown area, higher the volume of water required. The water requirements for the entire UGS in Panaji and Tumkur were estimated. The UGS of 1.86 km^2 in Panaji city requires 6.24 million liters of water daily. This volume is under 50% of the14 MLD total treated wastewater (=recycled water which is environmentally safe) produced and available year-round in Panaji. Currently, over 99% of this treated wastewater is drained into a polluted creek. Notwithstanding the wide variance between 34 different tree species (covering 4012 individual trees), the weighted mean of CO_2 sequestered per tree averaged 55 kg y^{-1}. For 23 tree species, the Carbon Sequestration Rates (CSR) estimated in this study are first reports. These rates are well within the ranges reported for many 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 the UGS regulatory ecosystem services viewpoint, numerous ecological and economic advantages are highlighted.

The outcomes of this thesis are policy-relevant and aligned well with the ongoing Smart-Cities Mission and Jal Jeevan Mission of the Government of India. This research is demonstrating the importance of wastewater use in the future, which can help to minimize the risk of UHI and improved regulatory ecosystem services. This research can also provide essential knowledge to implement SDGs goal number 6 and 11.

The examination committee recognized that this thesis presents important findings in the current scenarios of the Smart Cities Mission of GoI. In addition to the excellent academic knowledge in the research, his academic records throughout the Ph. D. course was good. Based on these evidences, the committee reached to a conclusion that Manish Ramaiah is eligible for the degree of Doctor of Philosophy (Environmental Science).