Summary of Manish Ramaiah's Thesis

Title: Role of treated wastewater in mitigating urbanization impacts and maintaining regulatory ecosystem services

During the past 4-5 decades, environmentally friendly and sustainable urbanization are much sought after. This is because urbanization offers several opportunities for growth in the economic, educational, societal, and technology sectors. It offers benefits to society in terms of better living standards, healthcare facilities, and employment opportunities. Such seemingly desirable characteristics are dampened by the downsides of often unplanned and haphazard urbanization. The streaming migration into the urban areas and the consequent overcrowding reduces the green cover and leads to environmental degradation.

In any research endeavor aiming to recognize the importance/relevance of urban green spaces' existence, a deeper understanding of the impact of land surface temperature (LST) on human thermal comfort is an important requirement. While the impact of urbanization on LST has been widely studied to monitor the urban heat island (UHI) phenomenon, the sensitivity of various urban factors such as urban green spaces (UGS), built-up area, and water bodies to LST is not sufficiently resolved for many urban settlements.

Research Questions

1. Are the current UGS maintenance practices adequate in Panaji and Tumkur cities experiencing frequent LULC alterations?
2. What quantity of water is required daily for hedge-plants, grass-cover (lawns) and different species of trees in the city parks/gardens and, what are their present carbon biomasses and sequestration potential?
3. How can treated wastewater (=recycled water) be a dependable alternative to currently drawn groundwater for maintaining UGS as well as controlling LST in these cities?

Objectives

1. To evaluate the influence of UGS in combating LST/maintaining microclimate
2. To calculate/estimate water requirements of UGS in terms of regulatory ecosystem services
3. To monitor/assess the ecological and economic benefits of treated wastewater (recycled water)

Methodology:

As an outcome of careful considerations and consultations, this work was planned for analyzing the landscape and microclimate features of two traditional cities in India currently being developed as smart cities. It was also the aim of this endeavor to collect data on UGS maintenance practices in these cities and their possible ecosystem services. Remote sensing techniques for satellite image analyses, key-informant questionnaire-based data collection, field visits, and measurements comprised the study methodology (Fig 1). Since little to null information on water requirement or carbon sequestration potential of UGS was available from these two Indian cities proposed to be developed as smart cities, the following major aspects were covered for this study. Landsat-8 satellite data was used to evaluate the response of different land covers on LST (Fig 2). Landsat 8 satellite has Operational Land Imager (OLI) and Thermal Infrared Sensor (TIR).

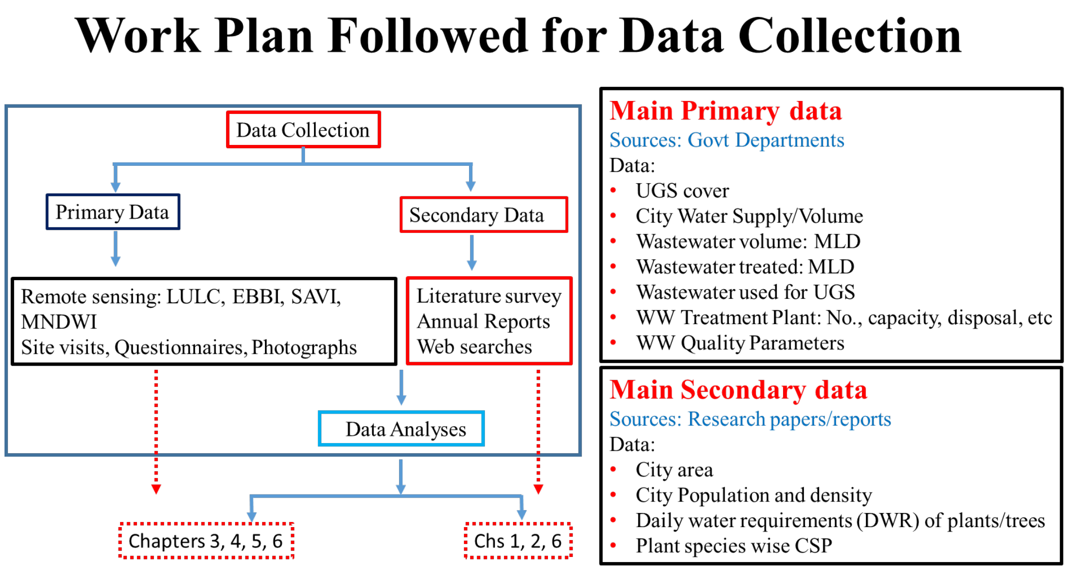

Fig 1. Overall methods used and approaches made for this study

Key-informant questionnaire-based and personal field surveys for the collection of information on current practices of UGS maintenance were carried out with the aim of estimating the water requirement of the trees, groundcover (=lawn), and hedge-row plants. During the 2019 visits to various government agencies and public parks in Panaji, it became evident that the borewell water extracted from mostly within the garden premises was supplied only to the lawn and hedge-row plants. It is to be noted that the trees were not watered in any of the parks. It was recognized that the amount of water supplied was sub-optimal. Therefore, the option of exploring whether a part of the current 14 million liters daily (MLD) treated water available for free from the city's sewage treatment plant (STP) could be opted for watering the current UGS area, including trees which are vital for balancing the UHI impacts.

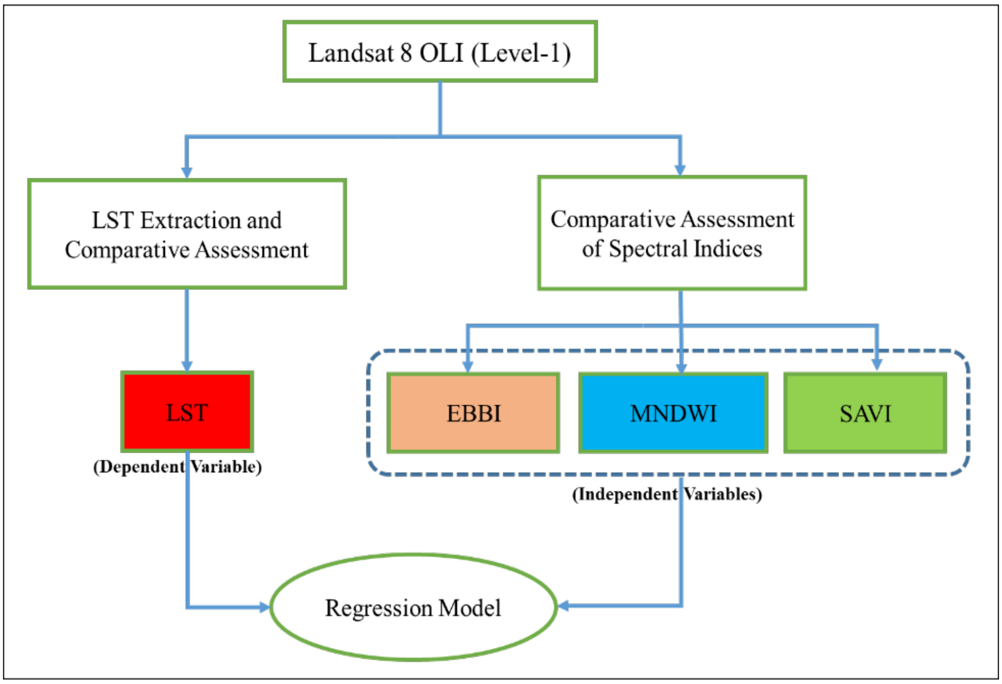

Fig 2. Flow chart of the methodology used for analyzing the land use land cover changes

The repertoire of literature has not paid enough attention to the need of water for UGS plants for their acceptable performance. This is especially true for almost all UGS of most Asian countries. An estimate of water requirements of trees in the green infrastructures is variously helpful. More than pruned/trimmed hedge rows of ornamental or medicinal plants or neatly made grass-lawns, it is the fast-growing tall trees which drawdown the atmospheric CO_2 copiously, produce oxygen, and thicket particulates on their foliage. They cool the land surface better, shade the buildings below their crown/canopy, and help pedestrian thermal comfort when in sufficient numbers. For these key urban services trees play, keeping them water stress-free is vital. In this regard, to ensure a realistic and reliable estimation of the daily water requirement, several available methods were considered before finally adopting the formula of Kjelgren et al (2016), widely applicable for all types of plant species across the globe. Evapotranspiration rates suitable for the region were derived in this study for calculating the daily water requirements (DWR) of trees, hedge rows, and groundcover (Fig 3).

The carbon stock and sequestration potential were worked out for 32 different tree species, hedge plants, and groundcover grasses. These plants/trees are grown in the seven different parks/gardens from where detailed data was collected. All trees were identified to their species level with the help of plant taxonomists and by referring to the literature. Standard methods of Ravindranath and Ostwald (2008) and Lahoti et al., (2020) were used for deriving the carbon stock and sequestration rates (Fig 4).

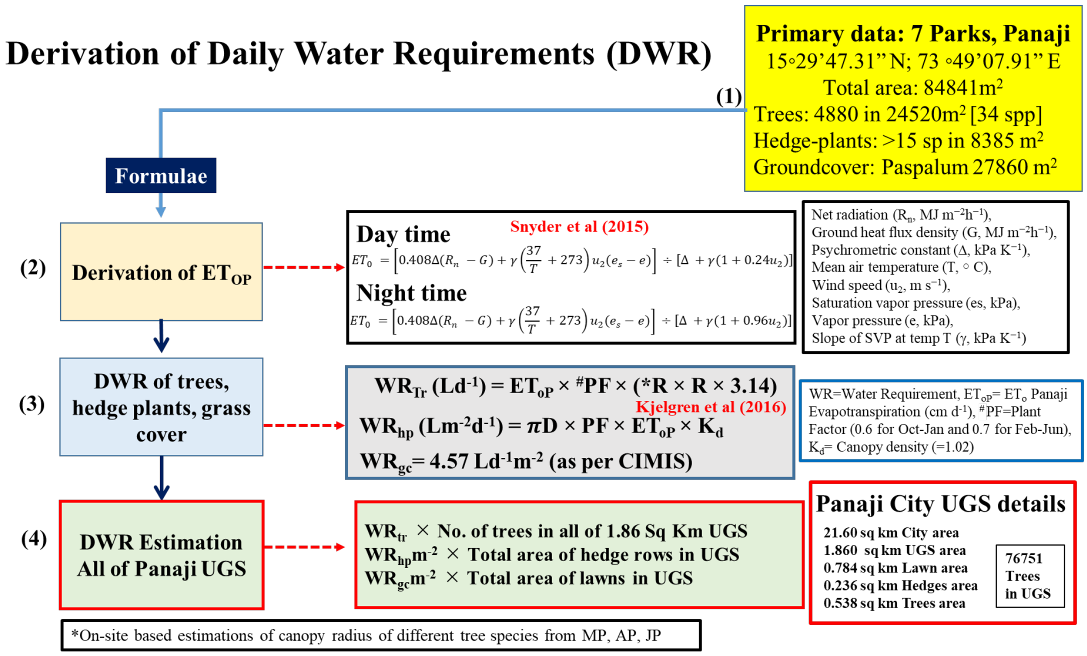

Fig 3. Derivation of daily water requirements of trees, hedge-plants and grass cover using field data and the local evapotranspiration rate derived during this study

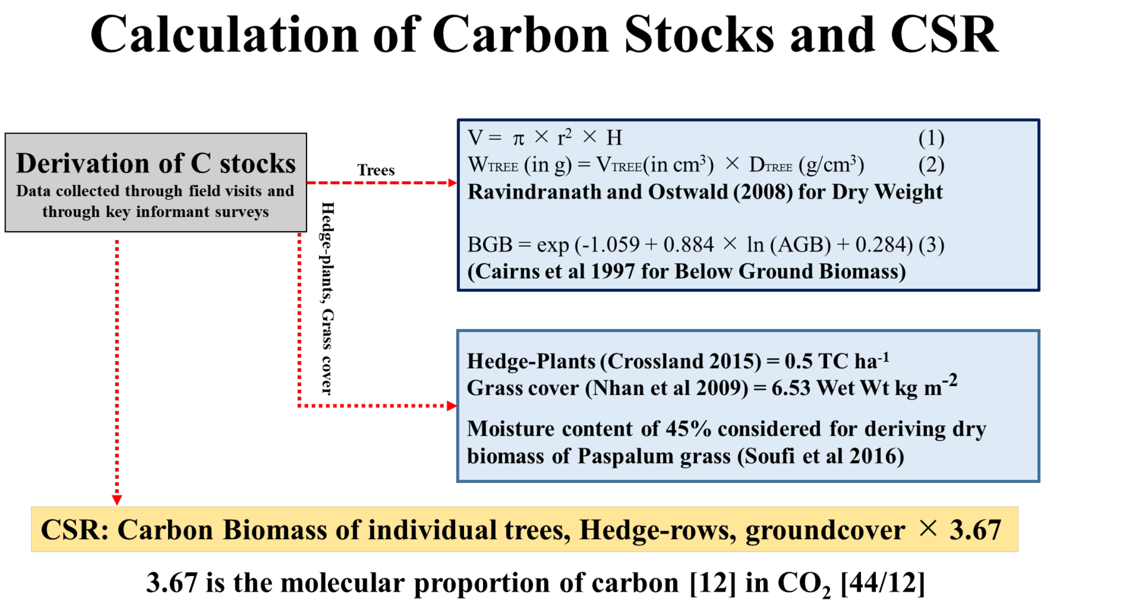

Fig 4. Flow chart of different steps followed for calculation of carbon stocks and carbon sequestration rates (CSR)

Regulatory (and some cultural) services are fulfilled by the UGS. For any UGS management system, the aim of achieving acceptable ecosystem performance and deriving many of its invaluable services continuously must be the top priority. Such priorities help wholesome, long terms benefits and returns from the UGS. Ideally, there would be a better and balanced diversity of plant, grass, and tree species in the well-kept parks with groundcover, hedge rows, and trees. All these varieties drawdowns hold and sequester enormous quantities of carbon.

The role of UGS in LST reduction and regulation of microclimate parameters are well known. This study explored as to why the use of treated wastewater/recycled water can indirectly add up to ecosystem services such as the elimination of groundwater extraction and significant compensation of evapotranspiration losses and, at the same time protect water stress-free status as well as reduce LST impacts.

Highlights of Main Results

A. LULC Changes and Spectral Indices

1 The multivariate regression model developed in this study was useful to note a strong negative correlation between MNDWI and LST with a value of 0.83 for Panaji. This relationship is useful to infer that because of large areas of water bodies in the region have been helpful in keeping a check on the LST. With 35% coverage in the grid, the maximum percentage share of cooling surfaces are water bodies in Panaji occupying 21.60 km^2 area and much smaller city than Tumkur with 48.60 km^2. Together with substantial green cover in around the city, Panaji city currently has this highly advantageous feature of expansive watershed.

2 On the contrary, the much larger Tumkur city with highly scarce areas of water bodies experiences persisting highs of LST. Therefore, many discomforts in the urban dwellings are experienced. It is thus possible to point out that the UGS and water bodies can help in bringing down the LST, as well as facilitating healthy living conditions and aesthetic appeal. Therefore, the significance of ecosystem services (green spaces and water bodies) should be given priority in the decision-making process of sustainable and vibrant (smart) city development.

B. Water Requirements in the UGS

1 Knowledge of regional evapotranspiration (ET_o) is vital for deciding on water management for irrigating the UGS. In this study, the ET_o for Panaji (ET_{oP}) and Tumkur (ET_{oT}) were calculated for every month of the year by assembling a variety of atmospheric data. Using the annual average evapotranspiration rate of 0.889 cm d^{-1} in Panaji region, the water requirement for different plant types was calculated.

2 Daily requirement of water was found to be higher by 3-4 liters/tree (than the annual average of ~ 25 liters/tree) in different parks during the warmer months beginning mid-February to mid-June. During the somewhat cooler months in Goa,

the water requirement was lower than the annual average. Water requirement for every m^2 area of groundcover is 4.57 liters and for every m^2 row of hedge-plants, it is 6.77 liters d^{-1}.

3 The water currently applied for hedge area of 236,287 m^2 and the ground cover area of 784,465 m^2 in all 17 parks totals 2.66 MLD. At 6.77 LPD m^{-2} for hedge plants and 4.57 LPD m^{-2}, the daily demand is 5.34 MLD. A total of over 80000 trees needs 1.77 MLD. From this information, the total daily volume of water required for the entire UGS of 1.86 km^2 in Panaji city is 7.10 million liters. This volume is much lower (about 50%) than the total treated water of 14 MLD produced and drained into a polluted creek.

4 Tumkur city has much smaller UGS area (1.9 km^2 in a total of 48.60 km^2) and the water applied daily to the estimated hedge area of 117497 m^2 and the ground cover area of 389,952 m^2 is 1.2 MLD. However, the requirement for hedge plants is about 0.8 MLD and for groundcover, 1.78 MLD. Apparently, the daily supply for hedge plants and groundcover falls short by 1.53 MLD (or 46.57%) of the requirement. The city is diverting its untreated sewage effluent to an industrial zone. When the city considers processing its wastewater, the plant demand at under 3.5 MLD, including that of ~ 40000 trees can easily be met.

C. Carbon Sequestration Potential

1 Dry weight and carbon biomass of 34 different tree species was derived by following Ravindranath and Ostwald (2008). Carbon sequestration rates from these trees were also calculated. These results were obtained from a total of 4012 trees in 24,991 m^2 area in three parks of Panaji city.

2 Notwithstanding the wide differences between the tree species in each of the three parks, the weighted mean of CO_2 sequestered per tree averages 55 kg y^{-1}. With this rate, the CSR ha^{-1} is 78.82 tons. This rate was used for estimating the per ha carbon sequestration potential of trees in the UGS of Panaji and Tumkur cities. The volume of CO_2 sequestered by 76751 trees in Panaji UGS is as much as 4221.31 tons y^{-1} ha^{-1} at 55 kg $tree^{-1}$ y^{-1}. In Tumkur city UGS, 38152 trees sequester 2098 tons $ha^{-1}y^{-1}$.

3 Further, weighted averages of carbon biomass and sequestration potential of groundcover and hedges were also derived from all seven surveyed parks in Panaji. These were used to get an estimate of their carbon stock and sequestration rates in the UGS of Panaji and Tumkur cities. The hedge row carbon biomass averages 13.18 tons ha^{-1} and the fixation/sequestration of CO_2 is equivalent to 48.38 tons ha^{-1} y^{-1}. Similarly, the groundcover, occupying over 42% of the UGS, with carbon biomass averaging 14.69 tons ha^{-1} sequesters 53.92 tons of CO_2 ha^{-1} y^{-1}.

4 Even as a minor contributor, the combined CSP of existing trees, groundcover, and hedge rows in the UGS of Panaji and Tumkur apparently neutralize the carbon footprint respectively of over 6900 and 3200 Indians at a per capita emission of 1.94-ton. Even with its insufficient green cover, Tumkur city's UGS contribute to carbon footprint reduction. This aspect ought to receive the attention it deserves.

5 While the exact CO_2 sequestration rates may require more accurate measurements to pinpoint the impact trees can create, it is undeniable that in our global fight against climate change, addition of inputs and data from studies like these can aid in the mitigation measure as well as in fulfilling the local/regional plans and needs.

D. Regulatory Ecosystem Services Using Treated Water

1 In this chapter, an overview of the regulatory ecosystem services offered by UGS is presented. This is done with a view of evaluating how the use of treated water is more pragmatic for sustainable management of UGS.
2 Using the data collected from the STP in Panaji and by noting the quality of treated water achieved for safe discharge, it is possible to safely use the treated water for UGS purposes.
3 The ecological and economic advantages of using the treated water are listed and discussed. For instance, complete stoppage of groundwater extraction -currently practiced in most parks in Panaji (and some parks of Tumkur)- is possible by using just about half of the volume of treated water currently drained out into an already polluted creek (as mentioned earlier). In fact, quite an amount of money invested on processing can be justified when this safe resource can be put back to advantageous uses.
4 Other advantages such as compensation of daily evapotranspiration losses, enhanced thermal comforts, and additional employment opportunities are discussed in brief. Further, some of the challenges or bottlenecks associated with the UGS in general and the delivery of treated water at the parks/destination are touched upon.
5 In the end, the UN SDGs met through the sustainable management of UGS and eco-friendly application of treated water are included.

Important outcomes of this research work:

- Spectral indices of relevance in recognizing the factors influencing the microclimate and LST. These were derived for Panaji and Tumkur, the two cities proposed to be developed as smart cities under India's National Smart Cities Mission, 2015.
- Identification of the need for UGS expansion in Tumkur city experiencing high and persistent LST (one paper published).
- Monthly evapotranspiration rates for Panaji and Tumkur and application of these regional ETo for calculating the daily requirement of water by the trees, hedge-plants, and groundcover in the UGS of Panaji and of Tumkur.
- Daily water requirements and carbon stocks of 34 tree species.
- Evaluation of the feasibility and challenges of using the treated water (A review Paper published).