Challenges and opportunities for storage and infiltration-based LIDs in coastal catchments of Chennai, India

Bakkiyalakshmi Palanisamy, Ph.D.[1], Rutwik Borkar[2], Krushil Modi[3], Sreethu S[3], Shubham Shaurabh[4], Balaji Narasimhan, Ph.D.[5*]

[1]Associate Professor, Department of Agriculture Engineering, Saveetha Engineering College, Chennai, India. Email: bakkiyalakshmip@saveetha.ac.in

[2]104, Bharat, Ayodhyanagari, Dombivli(East), Maharastra, India; Email: rutwikb96@gmail.com

[3]Research Scholar, Department of Civil and Environmental Engineering, Indian Institute of Technology-Madras, Chennai, India. Email: krushilmodi1996@gmail.com / sreethunov17@gmail.com

[4]Research Scientist, Disaster Preparedness and Emergency Response Div., Remote Sensing Application, National Remote Sensing Centre, Shadnagar, Telangana, India. Email: shaurabhshubham@gmail.com

[5]Professor, Department of Civil and Environmental Engineering, Indian Institute of Technology-Madras, Chennai, India. Email: nbalaji@iitm.ac.in*

Highlights

- Out of three months of monsoon rainfall in coastal catchments of Chennai, India is concentrated within 1.5 months
- Non-infiltration-based LIDs were found to be suitable to reduce urban runoff
- Potential of augmented infiltration-based LIDs is being evaluated in the catchments

Introduction

Urbanization-climate feedback influences weather extremes particularly in coastal cities, resulting in irregular pattern of seasonal rainfall (Shephard and Burian 2003). Low-lying coastal catchments receive rainfall-runoff loading generated upstream; the storm drainage networks that carry these urban runoff loads may not cope with ever-increasing population and extreme weather anomalies (Lian et al. 2013; Kulkarni et al. 2013). Engineered structural and non-structural measures such as Low Impact Development techniques (LIDs) treat water generated over urbanized catchments and improve aquifer recharge potential of the urban areas (Newcomer et al. 2014; Mooers et al. 2018).

In urbanized coastal catchments with less permeable soil and shallow groundwater table, the movement of water is impeded both vertically and longitudinally, which eventually leads to wasteful discharge of urban runoff to sea. In those areas, Infiltration enhancement measures may not be suitable as it will lead to more water ponding on the surface due to low permeability of the soil profiles. Understanding the hydrological processes with respect to infiltration capabilities of urban coastal cities becomes an essential practice for efficient storm water management.

Therefore, the objectives of this study were to (1) study challenges in implementation of LIDs in urban catchments that have dry-weather periods of more than 6 months and less permeable soils; and (2) discuss opportunities that lie within these challenges for stormwater management using LIDs.

Methodology

Study Area

Pallikaranai and Velachery (Figure 1) catchments in Chennai, India were selected, which are drained by east-flowing rivers that run between Pennar and Cauvery. The climate of the area is tropical to subtropical, with a mean monthly temperature varying from 24°C to 31°C and an annual average rainfall ranging from 1,250 mm in the eastern part of the basins to 762 mm on the western side (Yadav et al. 2018). Lakes and water bodies form significant part of the depression storages in the catchments, covering 6% of the total watershed area. Geological formations in the study basins are mainly bands of alluvium in the upstream and along the coast, and hard rock formations in the remaining areas. Of these, alluvium formations and porous hard rock in 10–20 m thick weathered zone give higher potential for groundwater recharge (IWS 2007).

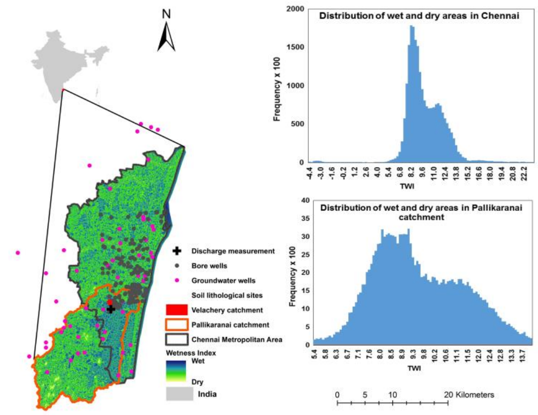

Figure 1. Location of Chennai city, Velachery and Pallikaranai catchments. Topographic wetness index calculated from DEM to illustrate the nature of topography and susceptibility to flow accumulation in the area

Assessment of Rainfall Pattern in Study Area

To evaluate the annual and seasonal distribution of rainfall over major seasons in the basin, precipitation concentration index (PCI) (Oliver 1980) was used. Rainfall in the study area was obtained from the Public Works Department (IWS 2017) and from the Indian Meteorological Department (Pai et al. 2014) for 1974–2013. Green roof and rain water harvesting structures (RWH) were used as LID measures in the study. The soil hydraulic properties of a green roof for the study area were determined using Hydrus-1D version 4.16 simulation model based on an extensive green roof setup by Vijayaraghavan and Raja (2014) for the region. We tested monsoon and non-monsoon hydrology of a green roof and RWH structures of both domestic scale (RWH1) and commercial scale (RWH2) at the catchment scale using the EPA Storm Water Management Model (SWMM) version 5.1 for the Velachery catchment. For local scale modeling, VS2DI was selected and for catchment scale modelling SWMM was chosen. Flow measurement at channels was made with a current meter to develop rating curves for the observation points for discharge measurements to validate the outflow values from numerical models.

Results and discussion

The PCI values indicated that the rainfall distribution is highly irregular throughout the year; the non-

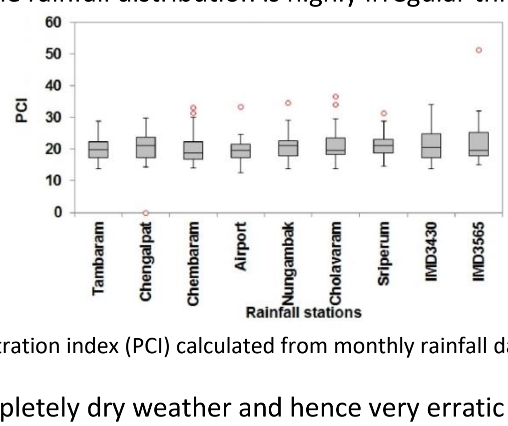

Figure 2. Annual Precipitation concentration index (PCI) calculated from monthly rainfall data collected for the years 1974–2013 in and around Chennai city

monsoon days experience completely dry weather and hence very erratic rainfall, with highest variation within a year (Figure 2) of 3 months in the NE monsoon, at least 1–1.5 months received rainfall. Green roof numerical modeling showed 14% of the peak rainfall was retained by the green roof substrate without any delay in the peak in the extensive setup. The intensive setup delayed the peak rainfall by 4 days and retained 92% of the water storage in the growing medium but significant delay in runoff was achieved with both RWH structures (rain barrels and underground storage tanks) (Figure 3). Therefore, when there is no need for urban recharge, but the goal of stormwater management is to store water primarily for human consumption, RWHs are better suited than infiltration-based LIDs.

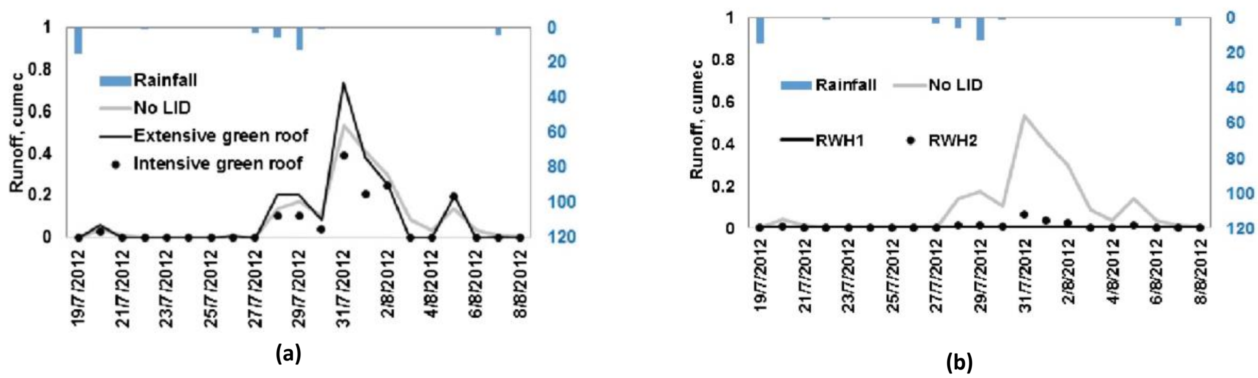

Figure 3. Event-based analysis of runoff from Velachery catchments for rainfall events with fewer than 10 antecedent dry days. Plots compare runoff from urbanized scenario with (a) green roof (b) rain water harvesting structures RWH1 and RWH2

Conclusions and future work

We deduce the following conclusions, and identify the challenges and potential solutions for implementing LIDS in the chosen study area:

- According to the soil distribution across Chennai, within first 5 m of the profile, there is little hope of using any infiltration LIDs, except where augmented infiltration-based LIDs could be facilitated as recharge structures.
- With increasing number of structures with smaller footprint areas RWH1 provided more storage of water than did RWH2 with larger footprints
- Works are in progress with 1D and 2D numerical modeling with SWMM and VS2DT software a into the design of LIDs to enhance infiltration while reducing peak and volume of catchment runoff

References

IWS. 2007. Micro Level Study, Chennai Basin. Chennai: Public Works Department, Government of Tamil Nadu.

Kulkarni, A. T., Mohanty, J., Eldho, T. I., Rao, E. P., and Mohan, B. K. 2014. A web GIS based integrated flood assessment modeling tool for coastal urban watersheds. Computers and Geosciences, 64: 7-14.

Lian, J. J., Xu, K., and Ma, C. 2013. Joint impact of rainfall and tidal level on flood risk in a coastal city with a complex river network: a case study of Fuzhou City, China. Hydrology and Earth System Sciences, 17(2): 679.

Mooers, E. J. 2018. Low-impact development effects on aquifer recharge using coupled surface and groundwater models. ASCE Journal of Hydrologic Engineering, 23(9): 04018040-1-04018040-11.

Newcomer, M. E., J. J. Gurdak, L. S. Sklar, and L. Nanus. 2014. Urban recharge beneath low impact development and effects of climate variability and change. Water Resour. Res. 50 (2): 1716–1734. https://doi.org/10.1002/2013WR014282

Oliver, J. E. 1980. “Monthly precipitation distribution: A comparative index.” Prof. Geogr. 32 (3): 300–309. https://doi.org/10.1111/j.0033-0124.1980.00300.x

Pai, D. S., L. Sridhar, M. Rajeevan, O. P. Sreejith, N. S. Satbhai, and B. Mukhopadhyay. 2014. Development of a new high spatial resolution (0.25° × 0.25°) long period (1901–2010) daily gridded rainfall data set over India and its comparison with existing data sets over the region. MAUSAM 65 (1): 1–18

Shepherd, J. M., and Burian, S. J. 2003. Detection of urban-induced rainfall anomalies in a major coastal city. Earth Interactions, 7(4): 1-17.

Vijayaraghavan, K., and F. D. Raja. 2014. “Design and development of green roof substrate to improve runoff water quality: Plant growth experiments and adsorption.” Water Res. 63 (Oct): 94–101. https://doi.org/10.1016/j.watres.2014.06.012.

Yadav, B. P., Das, A. K., Singh, K. V., and Manik, S. K. 2018. Rainfall statistics of India–2017.