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ORIGINAL RESEARCH PAPER

Optimization of Financial Expenditure to Improve Urban Recreational Open Spaces Using Pinch Analysis: a Case of Three Indian Cities

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Abstract

Recreational open spaces (ROS) like parks and playgrounds are vital aspects of a sustainable and healthy urban life. With rapid urbanization in developing countries, open spaces have become a scarce resource. The research objective of this study was to alleviate the existing condition of ROS by optimizing the expenditure cost incurred in providing pertinent infrastructure, services, and maintenance features. To achieve this, the application of a two-step method involving structural equation model (SEM), principal component analysis, and pinch analysis for cost optimization is proposed. This novel approach contributes towards the identification of various gaps between service planning and provision using SEM, while aiding in the optimization of financial provision for appropriate infrastructure development through graphical representation of pinch analysis. The financial expenses regarding the existing infrastructural amenities, maintenance, and services aspects were analyzed against the performance score of the open spaces using a primary study of ROS in three Indian cities of Mumbai, Bengaluru, and Chennai. In addition to recommending certain policy implementation, the study concludes by endorsing the use of the demonstrated framework for a holistic decision-making process to improve the recreational amenities of developing cities. The proposed framework is equally applicable to different cities of various developing countries.

Keywords Recreational open spaces · Cost optimization · Structural equation models · ROS performance · Pinch analysis · Developing countries

Abbreviations

ROS	Recreational open spaces
SDG	Sustainable development goals
UN	United Nations
ULB	Urban local bodies
MCGM	Municipal Corporation of Greater Mumbai
BBMP	Bruhat Bengaluru Mahanagara Palike
CoC	Corporation of Chennai
SEM	Structural equation modeling
WHO	World Health Organization
PCA	Principal component analysis
SPSS	Statistical Package for the Social Sciences
KMO	Kaiser-Meyer-Olkin
CRF	Capital recovery factor
GFI	Goodness of fit
TLI	Tucker-Lewis index
CFI	Comparative fit index
RMSEA	Root mean square error of approximation
Sig	Significance
df	Degrees of freedom

Nomenclature

U	Performance score of the respective open space
N	Total number of identified evaluation criteria
a	Factor loadings for the specific criteria from the SEM
x	ROS variable
i	Index for the criteria
C	Cumulative ROS expenditure cost
c	Annual cost variable
n	Life tenure
t	Interest rate
A	Total annual cost expenditure

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Introduction

Recreational open spaces (ROS) are vital amenities for a sustainable and healthy urban life (Konijnendijk et al. 2013). The SDG 11.7 set by the United Nations prescribes the provision of universal, safe, accessible, and inclusive green and public spaces for a sustainable urban life by 2030 (UN-Habitat 2015). ROS include urban public amenities like parks, playgrounds, gardens, and specialized parks. Well-provisioned and well-maintained ROS are desirable recreational amenities that ameliorate the urban quality of life (Ives et al. 2017) and also contribute towards a sustainable ecosystem (Mexia et al. 2018). A robust management system with rational budget allocations and judicious fund utilizations greatly help in improving the condition of the ROS (Nigel et al. 2002).

In the Indian context, most open spaces are in derelict conditions, inappropriately designed, plagued with mismanagement, and with inaptly provisioned amenities (MMR-EIS 2012). Indian ROS management, which includes financial planning, budget allocations, expenditure for development, and maintenance, is undertaken by the ULBs of the particular city, like MCGM in Mumbai, BBMP in Bengaluru, and COC in Chennai. These ULBs undertake the ROS development and renovations with little analytical understanding of the existing condition and feasible requirements. The ROS management system in the Indian context is currently in dire need of incorporating an analytical framework of decision-making that incorporates the financial viability of various development and maintenance interventions. Decision-makers of the ULBs need to incorporate various qualitative and quantitative aspects, while undertaking management decisions with time-based goals. To achieve this, utilizing scenario analysis as a decision-making tool is essential to make data-driven informed decisions that could prevent significant losses to natural and monetary resources. There have been instances of various developed nations implementing simulation using multi-criteria analysis (Martinelli et al. 2014), scenario planning and optimization (Neema and Ohgai 2010), and management sciences (Phong and Xiao 2016) for capacity planning and facility allocation in ROS management. However, research in this respect in developing nations, especially in the Indian context, is sparse.

Research regarding planning for the open spaces has greatly focused on the user perceptions in the decision-making process (Xue et al. 2017). Furthermore, landscape design (Ahern et al. 2014), land-use and zoning (Tang and Wong 2008), cultural ecosystem service provision (Dickinson and Hobbs 2017), user comfort (Xue et al. 2017), universal access (Subramanian and Jana 2018), and accessibility (Žlender and Ward Thompson 2017) have played important roles in the research regarding open space management. The financial valuation of ROS has been undertaken using methods like house price costings (Luttik 2000) or residential value estimation (Jim and Chen 2010). Various studies have undertaken open space valuation using methods like ecosystem service valuation (Saarikoski et al. 2015), travel cost methods (Mayer and Woltering 2018), and non-market benefits' assessment (del Saz Salazar and García Menéndez 2007). Given the research regarding various forms of ROS valuation and management, studies especially focusing on financial planning and resource allocation for open spaces are limited (Maruani and Amit-Cohen 2007), especially focusing on the developing nation's context and their requirements.

In the Indian context, open space management is majorly undertaken by various stakeholders that belong to the ULBs (Ministry of Urban Development India 2014). In some cases, the maintenance responsibilities are outsourced to private management entities (MMR-EIS 2012). The decisions taken by the stakeholders is largely ad hoc, without any data-driven analysis backing their interventions with respect to infrastructure provision and service expenditures. This causes a significant gap between the fiscal budget provisions and the actual fund utilization. Figure 1 represents the budget estimate provisioned by the cities of Bengaluru, Chennai, and Mumbai over the fiscal years from 2015 until 2018 for ROS management, respectively. The budget provision is bifurcated into revenue and capital expenditure. As seen in Fig. 1, the revenue expenditure exceeds the capital expenditure over the years in Bengaluru, while the capital expenditure exceeds in Mumbai. Revenue-based budget estimates are provisions made towards the day-to-day functioning of ROS management systems like maintenance costs and staff salary. The capital budget estimate is the provision made towards development and renovations of the ROS that entails the provision of amenities and services.

While the budget estimates funds earmarked for ROS management by the ULBs for the respective fiscal year is considerably large, the actual utilization of these funds is much lower. Figure 2 demonstrates the large gap between the budget estimate provision and the actual utilization of funds in Bengaluru from the years 2013 until 2017. Also, the gap between the fund provision and its utilization is increasing with each year since 2014 in Bengaluru. This trend highlights the severe lack of analytical decision-making in ROS management regarding financial planning, resource allocation, and fund utilization towards improving ROS. With the intention to devise an analytical decision-making framework for ROS management, a two-step approach that includes structural equation modeling, principal component analysis, and pinch analysis is proposed. Applicability of the proposed framework for appropriate ROS management is demonstrated through open spaces in three Indian megacities of Mumbai, Bengaluru, and Chennai. The proposed methodology is applicable to different cities all around the world.

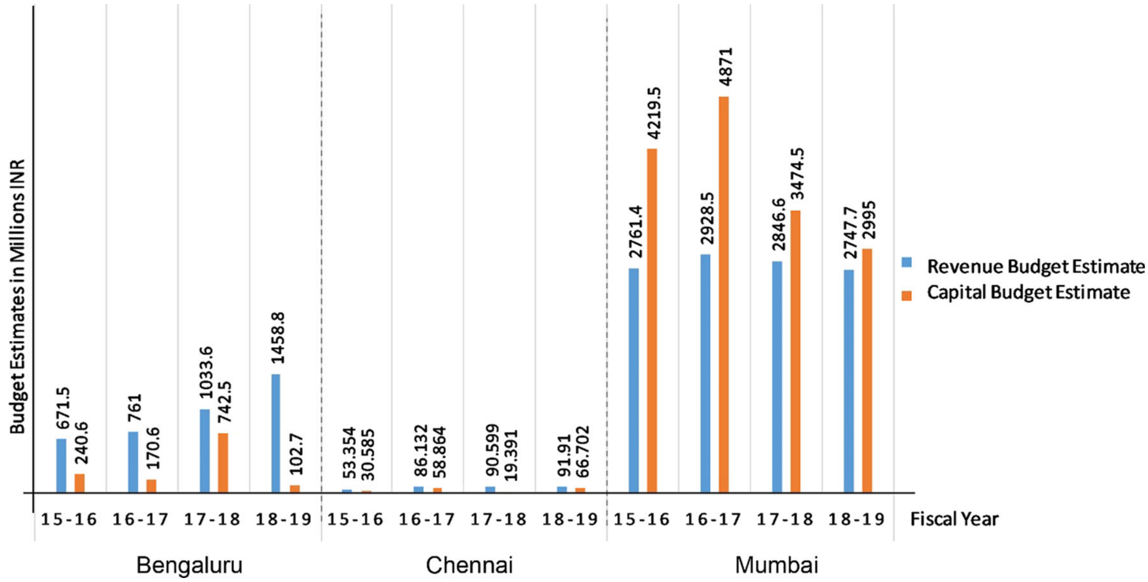


Fig. 1 Budget provisions for ROS management in Chennai, Bengaluru, and Mumbai (source: BBMP, COC, and MCGM budget reports)

Research Question

This research sets out to answer the following questions:

a) Can structural equation modeling method be utilized to derive the inter-relationship between the latent constructs of infrastructure, maintenance, and service regarding ROS?
b) How can SEM be utilized to assess the existential condition and performance score of ROS?
c) How can the expenditure cost to improve the ROS performance score be optimized?
d) Can the two-step framework be utilized for Indian ROS management?

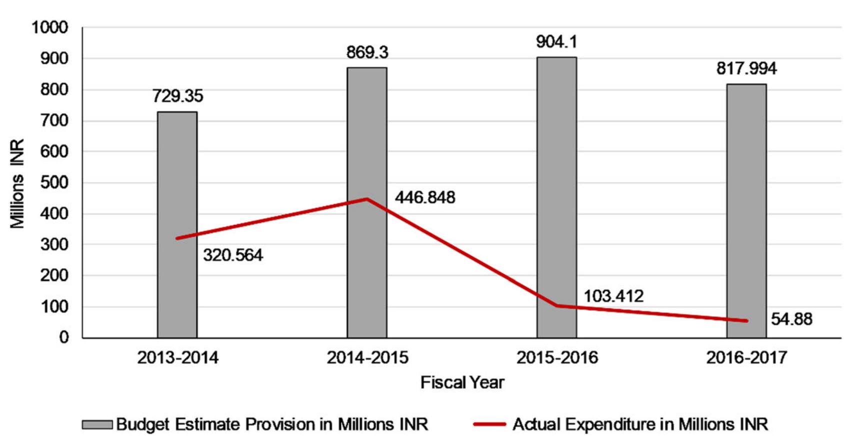
In this study, the authors test the derived two-step framework to improve the condition of ROS with the intention to achieve the SDG 11.7 of providing accessible, sustainable, and usable green open spaces that improve the urban quality of life, while utilizing resources rationally.

Proposed Framework

The proposed two-step framework is a novel approach for ROS management, especially for the context of developing nations, as represented in Fig. 3. The initial step involves deriving the ROS performance score. A primary survey is undertaken with the intention to derive the performance evaluation criteria, verified using the statistical method of principal component analysis. Using the structural equation modeling approach, the inter-relationship between the latent variables of ROS infrastructure, maintenance, and service is derived based on the data collected for the performance criteria identified earlier. The second step involves deriving the annual costing details of the identified criteria and optimizing the expenditure to improve the performance score of the selected ROS.

SEM, a statistical modeling technique using multivariate procedures (Livote 2009), has been used for assessing various aspects regarding urban open spaces like visitor perception (Deng et al. 2017), quality and design of open spaces (Wu

Fig. 2 Bengaluru budget estimates and actual expenditure in millions INR (source: BBMP Budget reports)



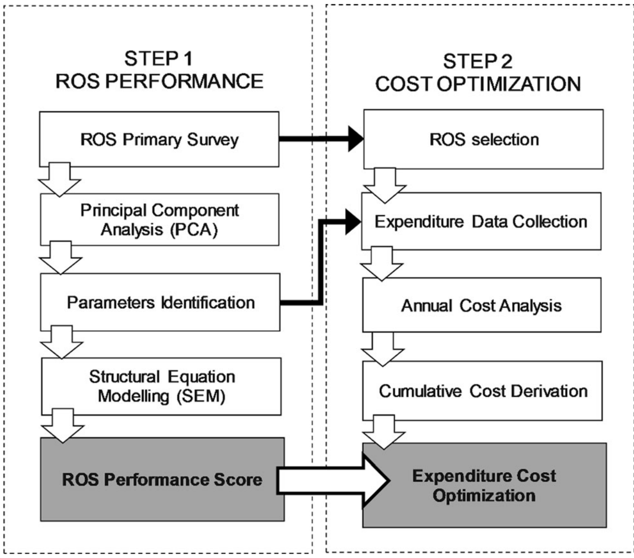


Fig. 3 Two-step framework to improve ROS performance at optimized expenditure

and Song 2017), and open space usage (Wan et al. 2018). SEM as a statistical tool combines multiple regression and factor analysis to derive the relationship between measured variables and constructed latent variables (Jeon and Hong 2015). The use of SEM for ROS management is a novel approach as it can utilize observed data from the primary survey to derive their effect on the latent variables and their interrelationships (Wu and Song 2017).

In the context of urban planning in general (Cao et al. 2011) and ROS management in particular (Wood et al. 2018), spatial optimization has been the primary focus. Literature review regarding financial management of open spaces reflect studies that focus on their economic valuation (Koohsari et al. 2014), alternate funding mechanisms (Pinkston 2015), and examples of park management reports by cities in the global north (Harnik et al. 2009). Research regarding the cost optimization of amenities provision and services in ROS has not been undertaken, especially in the context of a developing nation like India, where the sustainable utilization of resources is of utmost importance.

Study Area

A primary survey of 51 ROS that included parks, gardens, playgrounds, and other open spaces of varied sizes from Mumbai, Bengaluru, and Chennai was undertaken from September to December 2015. ROS data that included aspects like amenities provision, surroundings, services provision, maintenance quality, and functional hours were collected with 1 day allotted per ROS for the survey. Nineteen open spaces from Mumbai, 17 from Bengaluru, and 15 from Chennai were studied. The selected cities are tier I cities with similar population density and ULB management structure. The available ROS area per capita in these three cities, like many others, is much below the WHO recommended 9 m^2 per person (Ministry of Urban Development India 2014). Also, many of the open spaces in Indian cities are plagued by mismanagement and lack of maintenance, making them susceptible to encroachment and dilapidation (Bharath et al. 2018). The studied ROS data was further classified based on their areas into small size with area less than 1.5 acres, medium size with area between 1.5 and 3 acres, and large size with area above 3 acres, to be utilized during the cost-optimization stage.

Data Analysis

The data collected from the primary survey of the 51 ROS included information regarding their location, built profile, amenities provision, natural landscape elements, layout, maintenance, and basic amenities like drinking water and toilets, furniture, and recreational amenities provision. With the intention to derive the latent variable constructs for the SEM, an initial PCA was undertaken with the data collected. Of the various aspects studied, 17 factors were selected for the data analysis. These 17 factors were further clubbed into the three variables of infrastructure, services, and maintenance (Table 1). Seven factors included under infrastructure variable were lighting, seating, play equipment, shading devices, outdoor gym, boundary wall, and dustbin provision. Three factors that represented under services variable were toilets provision, number of female toilets, and drinking water. The maintenance variable included seven factors of landscape elements like trees, grass/lawn, shrubs, and flowering plants, cleaning, composting and security staff provision.

PCA was undertaken to validate the relevance of the selected factors for each of the three variables of infrastructure, service, and maintenance, respectively, using the SPSS software. Table 1 represents the PCA results for the studied ROS, detailing the goodness of fit for the models. Kaiser-Meyer-Olkin (KMO) test for sampling adequacy signified a generally acceptable level for the three variables of infrastructure, service, and maintenance. The Bartlett's test of sphericity to check the homogeneity of data variance was found to be significant (Sig) at 99% with the degrees of freedom (df) mentioned in Table 1 for the respective variables. Table 1 also denotes the communalities or the proportion of each variable's variance explained by the respective factors followed by the loadings or the correlation coefficients between the variables and factors. The results confirmed the feasibility of the three latent variables of infrastructure, service, and maintenance.

To test the relationship between the three latent variables of infrastructure, service, and maintenance, and the 17 criteria for ROS, SEM was undertaken using IBM SPSS (Statistical

Table 1 Principal component analysis results for the 51 ROS studied

Infrastructure		Service		Maintenance	
KMO	0.74	KMO	0.67	KMO	0.76
Bartlett's test of sphericity		Bartlett's test of sphericity		Bartlett's test of sphericity	
App. chi-square	142.18	App. chi-square	39.04	App. chi-square	110.48
df	21	df	3	df	21
Sig.	0.00	Sig.	0.00	Sig.	0.00
Communalities					
Lighting	0.73	Toilet presence	0.71	Trees	0.67
Boundary wall	0.67	No. female toilets	0.75	Shrubs	0.59
Seating	0.66	Drinking water	0.58	Grass	0.61
Play equipment	0.72			Flowering plants	0.71
Shading devices	0.46			Cleaning staff	0.70
Outdoor gym	0.63			Composting	0.39
Dustbin	0.79			Security staff	0.66
Loadings					
Cumulative loading 66.46%		Cumulative loading 68.09%		Cumulative loading 61.59%	
Component 1 (50.18%)		Component 1 (68.09%)		Component 1 (45.50%)	
Lighting	0.687	Toilet presence	0.844	Trees	0.805
Boundary wall	0.575	No. female toilets	0.863	Shrubs	0.764
Seating	0.768	Drinking water	0.765	Grass	0.423
Play equipment	0.803			Flowering plants	0.824
Shading devices	0.503			Cleaning staff	0.578
Outdoor gym	0.736			Composting	0.438
Dustbin	0.825			Security staff	0.800

Package for the Social Sciences) and Amos. The path diagram representing the structural equation model along with the respective factor loadings is seen in Fig. 4. SEM herein includes latent variables and observed factors, with either direct or indirect paths among them that are calculated using multivariate techniques, such as regression and path analysis to estimate the multiple cross relationships while accounting for the measurement error (López-Mosquera and Sánchez 2011).

Results and Discussion

The structural equation model, as illustrated in Fig. 4, demonstrates the relationship between the latent variables of infrastructure, service, and maintenance, derived using the 51 ROS data collected with a primary survey in three Indian cities. Also, the factor loadings of the individual criteria represent their weightage. Table 2 denotes the total direct and indirect effects of the derived latent variable and the 17 performance criteria using the structural equation model as shown in Fig. 4. Results in Table 2 were generated using the statistical package Amos wherein the effects are derived using methods illustrated by Bollen (1987). The model has an RMSEA value of 0.063, which is well below the maximum acceptable value of 0.08 for real-world scenarios (Loehlin 2004). The model shows a significantly high positive impact of infrastructure variable on the maintenance latent.

With the intention to corroborate if the latent variables and performance criteria derived using SEM and PCA were relevant to the ROS performance, a linear regression model was used where the relationship between the latent variables and the dependent variable of total ROS users was tested. This was undertaken with the underline assumption that the greater footfalls being an indicator of higher ROS performance (Sreetheran 2017). The total ROS user footfalls as recorded for the 51 open spaces studied was regressed on the derived variables of infrastructure, services, and maintenance of the respective ROS using IBM SPSS. The result of this linear regression model is as shown in Table 3. The model has an R^2 value of 0.446 with significant impact of the latent variables on the total ROS users' visitation numbers.

Using the SEM derived factor loadings for the criteria identified and the existing condition of the ROS, the performance score of the respective open space (U) was calculated. For deriving the same, the following notation is introduced:

$$U = \sum_{i \in N} a_i x_i \quad (1)$$

where N is the total number of identified evaluation criteria; a represents the factor loadings for the specific criteria from the

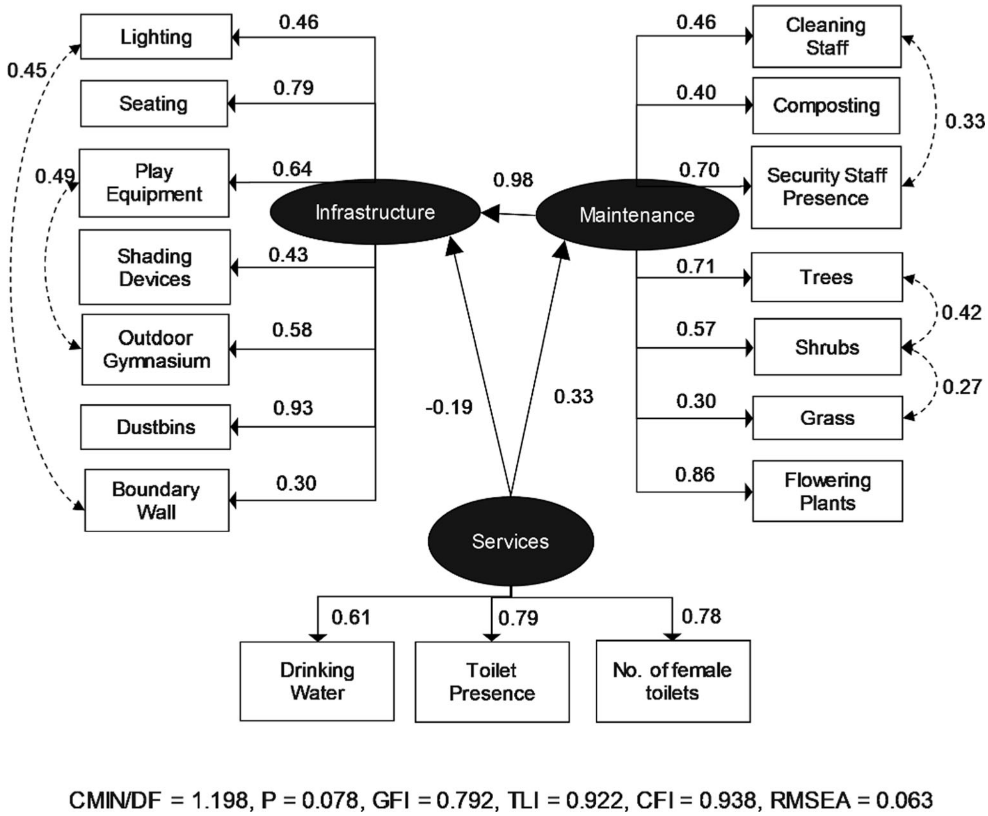


Fig. 4 Structural equation model showing the relationship between infrastructure, services, and maintenance aspects of 51 ROS studied in three Indian cities

Table 2 Total effects of the SEM with indirect effects and the direct effects highlighted

	Service	Maintenance	Infrastructure
Maintenance	0.334*	0	0
Infrastructure	0.137	0.979**	0
Lighting	0.063	0.452	0.462**
Benches	0.109	0.775	0.792**
Play equipment	0.088	0.629	0.643**
Gazebo/shading devices	0.059	0.419	0.428*
Outdoor gym	0.079	0.565	0.577**
Dustbin	0.127	0.906	0.926**
Boundary wall	0.042	0.297	0.304
Toilet presence	0.79***	0	0
Number of female toilets	0.778	0	0
Drinking water	0.608***	0	0
Cleaning staff presence	0.154	0.459	0
Composting	0.132	0.395**	0
Security guard	0.235	0.702***	0
Trees	0.236	0.707***	0
Shrubs	0.192	0.574***	0
Grass/lawn	0.101	0.302*	0
Flowering plant	0.288	0.862***	0

***Significant at 99%

**Significant at 95%

SEM; x is the ROS variable, with i representing index for the criteria. It should be noted that x_i is bounded by a minimum and maximum values ($x_i^{min} \leq x_i \leq x_i^{max}$).

The first step in the proposed two-step framework concludes with the derivation of the ROS performance score. The second step involves the optimization of the expenditure cost incurred in increasing the ROS performance score with the rational provision of infrastructure, services, and maintenance aspects for the ROS development. To achieve this, a selection of 9 ROS was made from the 51 open spaces studied that belong to small, medium, and large sizes, three each from Mumbai, Bengaluru, and Chennai. This paper sets out to demonstrate the cost optimization of comparable sized ROS across the three cities. The expenditure cost data collection for the 17 criteria identified with PCA was undertaken. With an extensive review of ULB reports, budget documents, work receipt orders, and other financial documents for each fiscal year from 2012 until 2017 of the three cities, the annual expenditure cost estimates for the respective criteria were collated (see Table 4). The derived expenditure cost was collated using the capital recovery factor at 10% interest rate for criteria specific life tenure. Using the annual cost estimate for all the ROS criteria, the total annual expenditure cost for improving the ROS from the existing performance score to the maximum feasible score was undertaken as follows.

$$C = \sum_{i \in N} c_i x_i \quad (2)$$

Table 3 Linear regression results showing the relationship between the SEM derived latent variables and the total ROS users studied

R^2	Adjusted R^2	Std. error of the estimate	*F* change	Sig. *F* change	
.446	.410	63.06250	12.602	.000	
	Unstandardized coefficients *B*	Std. error	Standardized coefficients Beta	*t*	Sig.
(Constant)	98.510	8.831		11.156	.000
Infrastructure	17.977	12.706	.219	1.415	.164
Services	26.172	9.167	.319	2.855	.006
Maintenance	28.101	12.894	.342	2.179	.034
Dependent variable: total ROS users					

$$CRF = \frac{t(1+t)^{n}}{(1+t)^{n}-1} \quad (3)$$

$$A = C \times CRF \quad (4)$$

where C is the cumulative ROS expenditure cost; c represents annual cost variable; n is life tenure; t denotes interest rate; CRF is the capital recovery factor; and A denotes the total annual cost expenditure.

Cost Optimization

Using the derived cumulative cost that will be incurred to improve the ROS performance score, the optimization process of cost minimization is undertaken to provide for the specifically required criteria in a stage-wise manner. The overall objective is to minimize the investment, subject to satisfying a desired ROS performance score ($U_{\min}$). The final optimization problem is expressed as:

$$\text{Minimize } C = \sum_{i\in N} c_i x_i$$

Subject to

$$U_{\min} \geq \sum_{i\in N} a_i x_i$$

$$x_i^{\min} \leq x_i \leq x_i^{\max}$$

where $x_i^{\min}$ represents the present status of each variable and $x_i^{\max}$ is the maximum possible value of each variable.

It may be noted that the above optimization problem is a knapsack problem. A knapsack problem is a combinatorial optimization problem where given a set of variables, each with

Table 4 annual expenditure cost estimates for the respective criteria

Sr.	Criteria	Data	Estimated weightage (see Table 2)	Life years	CRF (i = 10)	Annual cost INR	Units
1	Lighting	Y/N	0.46	20	10	551,000	Per 1000 sqm
2	Benches	Y/N	0.79	40	10	324,250	Per 1000 sqm
3	Play equipment	Y/N	0.64	10	10	12,614,720	1 set
4	Shading devices	Y/N	0.43	40	10	2,223,500	1 gazebo
5	Outdoor gym	Y/N	0.58	10	10	8,959,670	1 set
6	Dustbin	Y/N	0.93	5	10	1,727,500	Per 1000 sqm
7	Boundary wall	Y/N	0.3	40	10	3,679,000	Per 1000 sqm
8	Toilet presence	Y/N	0.79	20	10	262,150	Per 1000 sqm
9	Female toilets	Y/N	0.78	40	10	112,000	Per 1000 sqm
10	Drinking water	Y/N	0.61	40	10	281,600	Per 1000 sqm
11	Cleaning staff	Y/N	0.46			6,000,000	Per 1000 sqm
12	Composting	Y/N	0.4			72,000	1 unit
13	Security guard	Y/N	0.7			180,000	Per 1000 sqm
14	Trees#	Score	0.71			3600	Per 1000 sqm
15	Shrubs#	Score	0.57			1,800,000	Per 1000 sqm
16	Grass/lawn#	Score	0.3			180,000	Per 1000 sqm
17	Flowering Plant#	Score	0.86			2,100,000	Per 1000 sqm

Note: # Score is recorded between 1 to 5, where 1 indicates lowest importance and 5 indicates highest importance a weight and a value, the objective is to determine the collection of these variables, subject to a maximum value so that the total value is more than or equal to a given limit and the total weight is minimized. In the context of this paper, the overall cost is minimized subject to a given ROS score. Such a problem can be solved using various numerical techniques. In recent times, techniques of pinch analysis have been extended to solve such problems. Pinch analysis, originally proposed as a thermodynamic tool for energy conservation (Linnhoff et al. 1982), has recently been extended to various non-energy and non-conventional domains due simple and efficient algebraic procedures as well as enhancement of physical understanding though graphical representations. Techniques of pinch analysis were successfully demonstrated for aggregate production planning (Singhvi and Shenoy 2002), industrial risk management (Tan et al. 2016), selection of financially profitable projects (Roychaudhuri et al. 2017), analysis of health-care sector (Basu et al. 2017), biochar-based carbon management (Tan et al. 2018), etc. Tan et al. (2016) demonstrated the application of pinch analysis to knapsack problem for reduction of industrial risk along through environmental management. Other applications of pinch analysis to address knapsack problem include transport sector planning (Walmsley et al. 2015), environmental risk management (Wang et al. 2017), and municipal solid waste management (Jia et al. 2018).

Appropriate presentation of different options is the most critical portion of the analysis. In terms of pinch analysis, it represents the supply composite curve. In this paper, supply composite curve is depicted with the *x*-axis showing the ROS performance score in percentage and the *y*-axis showing the investment in millions INR required for the improvement process. The cost optimization process is explained using the detailed case review of R.M.K. grounds in Chennai. This is a medium sized ROS with a performance score of 22.2%. Figure 5 shows the supply composite curve illustrating the cost optimization undertaken for this particular ROS with each improvement criteria and cost involved enumerated in the graph with a supporting image of the actual condition of the ROS. The optimization process involves providing and improving the trees in the ROS followed by the provision of female toilets and composting facility. Provision of seating benches, drinking water, lawn, outdoor gym, play equipment, dustbin, landscape elements, and shading devices follow. The optimization process also provides a hierarchical allotment of amenities in a manner to minimize the cost incurred while reaching optimum ROS performance score. The process could also be utilized to identify the feasibility of a particular criteria provision by observing its position in the provision list order. The future scope of this research could include providing a time-based goal assessment, while optimizing the cost expenditures to improves ROS performance.

For a comparative analysis of the cost optimization process, three parks each from Mumbai, Bengaluru, and Chennai classified based on their sizes into small (≈ 1.5 acres), medium (≈ 2.5 acres), and large (≈ 4 acres) were selected for optimization. The case-wise, city-wise comparison was undertaken for ROS having similar areas as the literature suggests a significant relationship between the open space acreage and the ROS quality (Maroko et al. 2009; Rigolon 2016, 2017). Figure 6 illustrates supply composite curves for various parks.

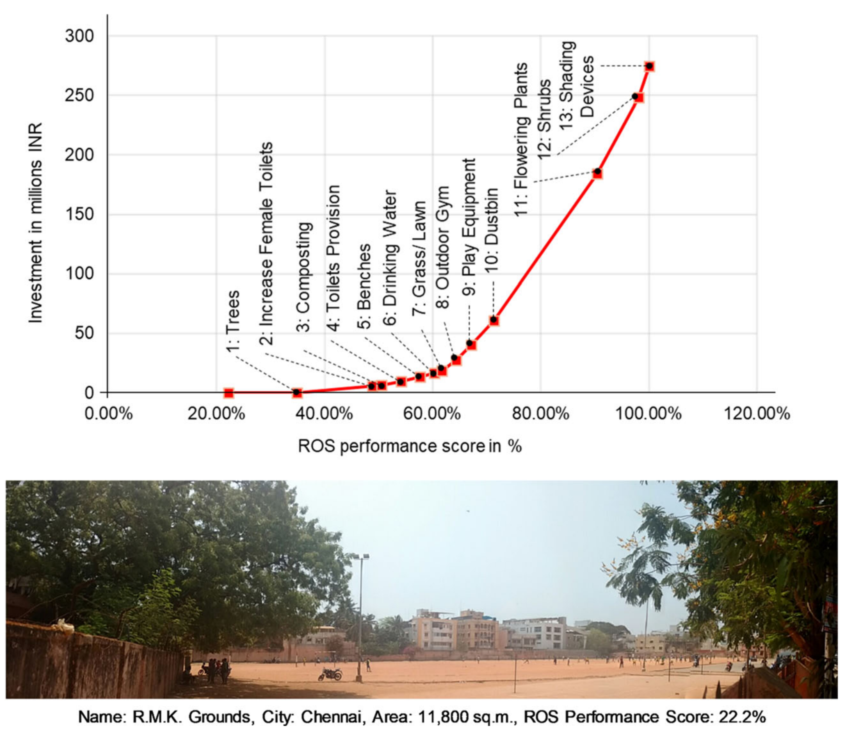


Fig. 5 Expenditure optimization to improve ROS performance score showing stage-wise investment through supply composite curve for R.M.K. grounds in Chennai

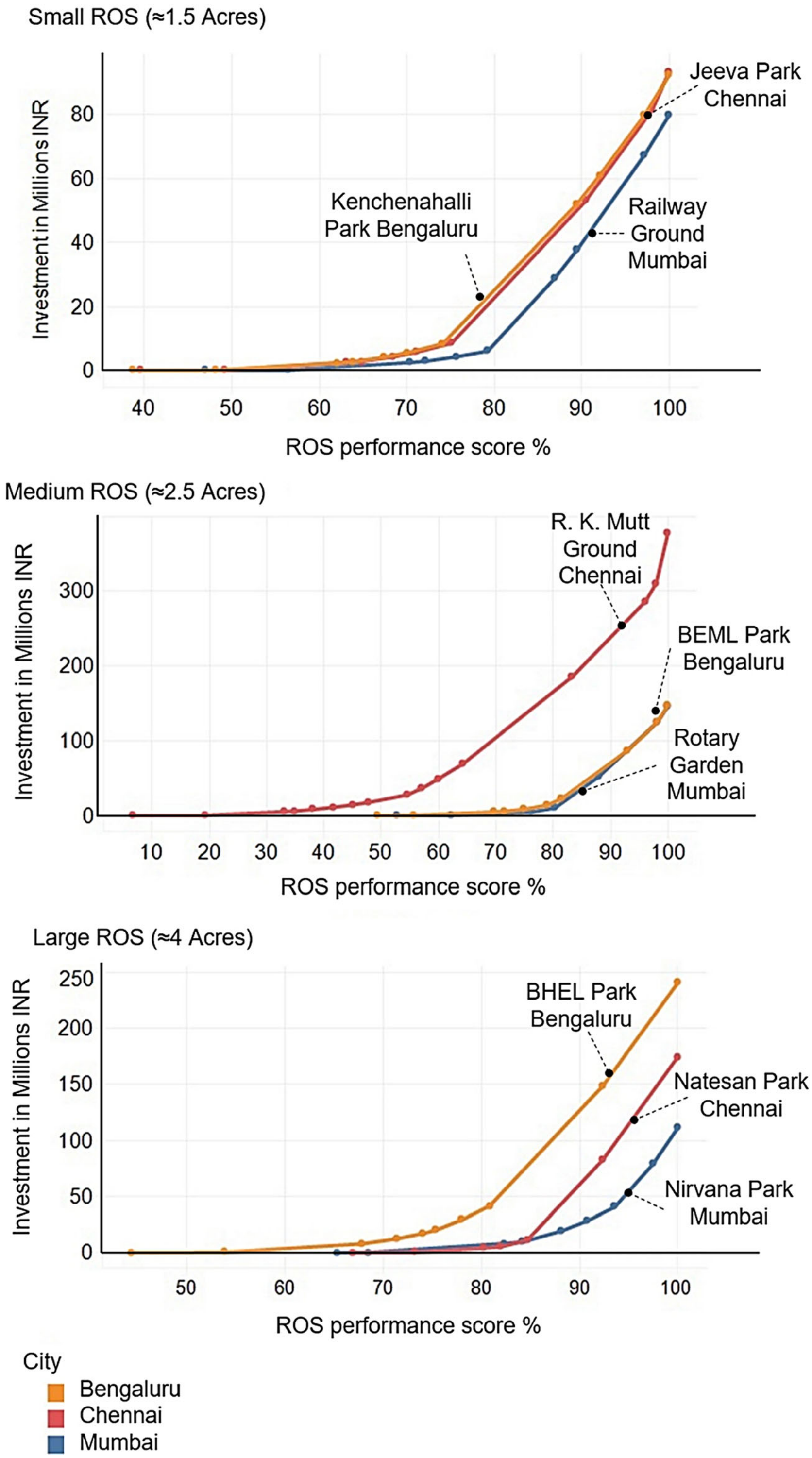


Fig. 6 Supply composite curves: performance score % of various sizes of ROS vs the investment expenditure in millions INR of three Indian cities

The small-sized ROS selected had ROS performance score percentage between 38 and 47%. For these ROS to achieve 100% performance score, the optimized costs are below 100 million INR. The case of Kenchenahalli Park and Jeeva Park show a similar starting performance score and final costs. While Kenchenahalli Park performed well in the landscape element provision and maintenance, it lacked in recreational amenities and basic service provision. In contrast, Jeeva Park performed low on landscape provision and maintenance while scoring high with amenities provision like play equipment, furniture etc. This can be observed from the respective park details in Fig. 7. For the medium-sized ROS, the R.K. Mutt

Fig. 7 Photographic evidence of selected ROS for cost optimization

grounds had the lowest score of 6.6%, and the optimized cost was the highest. The curve path of R.K. Mutt grounds depicts the inclusion of a majority of the criteria required. In the large-sized group, Natesan Park and Nirvana Park having similar scores of 66.9 and 65.3%, respectively, show a different curve path with the optimization process. This is a resultant of the existing amenities present, with Natesan Park requiring certain criteria improvements that are more expensive than those required by Nirvana Park. Figure 7 illustrates photographic evidence of the existing park condition collated during the primary survey and provides details regarding the ROS acreage and the derived performance score percentage. The choice of the ROS for optimization included cases which required different criteria for ROS performance score improvement, as seen from the graphs in Fig. 6 and photographs in Fig. 7. From the graphs in Fig. 6, it is evident that when the ROS performance score percentage is higher, the curve slope is more gradual as opposed to the cases which have an abysmally low score, showing a steeper graph slope and higher costs to reach the optimum performance score percentage.

Conclusion

The decision-making process and policies regarding ROS management need a multi-sectoral approach in order to undertake sustainable and data-driven development strategies, especially in the context of a developing country like India. The main contribution of this paper is the successful demonstration of the implementation of a two-step framework to develop and improve the existing condition of an open space with the aid of a primary survey and using statistical techniques, such as PCA, SEM, as well as cost optimization through pinch analysis.

The framework established herein is a novel approach to ROS management, as the extensive review of literature in research and industrial application revealed. Implementing this method of evaluation and scenario analysis as a policy mandate before undertaking the development and renovations of urban ROS would result in the rational, judicious, and transparent use of natural and financial resources. The cost optimization of expenditure regarding ROS can be used to assess the extent of improvement required, the relevance of undertaking specific amenities provision, the hierarchy of improvement criteria, and the magnitude of funding required. This study thus successfully validates the use of SEM to assess the existential condition and performance score of ROS, while demonstrating a significant relationship between ROS factors of infrastructure, service, and maintenance.

The future scope of this research could incorporate the implementation of time-based goal achievement by optimizing resource expenditure to achieve ROS performance improvement within a set time period and also provide for post-intervention validation mechanisms. The suggested framework could also be implemented in resource management of other urban public amenities, infrastructure projects, and in sectors like disaster management, transportation, and public health. In conclusion, the established novel framework for ROS management on implementation could significantly aid in ameliorating the existing conditions of ROS in urban India and other developing countries and help in achieving the SDG 11.7 of accessible and sustainable open spaces for everyone.

Compliance with Ethical Standards

Conflict of Interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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