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Ranking of Storm Water Harvesting Sites Using Heuristic and Non-Heuristic Weighing Approaches

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Abstract: Conservation of water is essential as climate change coupled with land use changes influence the distribution of water availability. Stormwater harvesting (SWH) is a widely used conservation measure, which reduces pressure on fresh water resources. However, determining the availability of stormwater and identifying the suitable sites for SWH require consideration of various socio-economic and technical factors. Earlier studies use demand, ratio of runoff to demand and weighted demand distance, as the screening criteria. In this study, a Geographic Information System (GIS) based screening methodology is adopted for identifying potential suitable SWH sites in urban areas as a first pass, and then a detailed study is done by applying suitability criteria. Initially, potential hotspots are identified by a concept of accumulated catchments and later the sites are screened and ranked using various screening parameters namely demand, ratio of runoff to demand and weighted demand distance. During this process, the opinion of experts for finalizing the suitable SWH sites brings subjectivity in the methodology. To obviate this, heuristic (Saaty Analytic hierarchy process (AHP)) and non-heuristic approaches (Entropy weight, and Principal Component Analysis (PCA) weighing techniques) are adapted for allotting weights to the parameters and applied in the ranking of SWH sites in Melbourne, Australia and Dehradun, India. It is observed that heuristic approach is not effective for the study area as it was affected by the subjectivity in the expert opinion. Results obtained by non-heuristic approach come out to be in a good agreement with the sites finalized for SWH by the water planners of the study area. Hence, the proposed ranking methodology has the potential for application in decision making of suitable storm water harvesting sites.

Keywords: stormwater harvesting; rainfall; surface runoff; GIS; suitable sites; Saaty AHP; entropy weight method; PCA; decision making

1. Introduction

Scarcity of water is a major concern for the world. There is need to integrate the allocation and management of water supply, wastewater resources and stormwater in order to sustainably manage the scarce resource [1]. A concept is introduced by utilizing stormwater through Storm Water Harvesting (SWH) and treat it as a resource, rather than a problem, to reduce the pressure on fresh water assets [2]. This idea is promoted through public forums [3] and SWH schemes are implemented on international [4].

Although the SWH has the best potential to reduce the pressure on fresh water assets, the approach to determine the potential SWH sites is not yet fully developed [5]. With the knowledge of geospatial technologies, efforts have been made to find the robust technique to shortlist and finalize the suitable sites for SWH. Thus, there is a need for a screening tool that can identify the potential suitable sites for

SWH. Different researchers have identified and analyzed different approaches for shortlisting sites. The decision-making framework (DMF) that is appropriate for SWH scheme is primarily based on technical feasibility and financial costs with a focus on neighborhood-scale development [6]. Recently, the focus of the researchers is to investigate the analogy of urban water supply and its associated energy consumption nexus [7].

Geomatics techniques prove to be the best option to explore the suitability of sites as well as the availability of locations for SWH [8]. Geographic Information System (GIS) facilitates the swift screening of potentially suitable SWH sites in the urban areas. It enables obtaining various parameters in spatial format, which decides the suitability for SWH sites. In India, the methodology to select potential sites for water harvesting were identified by adopting International Mission for Sustainability Development (IMSD) and Indian National Committee on Hydrology (INCOH) guidelines in GIS environment [8,9]. In [9], various parameters, i.e., Geomorphology map, Land Use Land Cover (LULC), road, drainage and lineaments maps were prepared and the knowledge based weights were assigned to all the parameters to compute the ranking of the sites in the GIS environment.

Singh et al. [10] defined some of the criterion for the site selection for various types of storage tanks, i.e., water harvesting structures, check dams, percolation tanks and farm ponds. The criterion suggested for water harvesting structures are that the slope should be less than 15 percent, land use class should be similar to agricultural area and type of soil should be silt loam with low infiltration capacity. In the approach [10], the suitable sites were selected by integrating all the parameters in the GIS environment.

Satellite images, Digital Elevation Model (DEM) and soil map are essential to ascertain and assess the parameters suitable for SWH sites. With GIS techniques, spatial maps of LULC, soil, topography and runoff can be prepared and thus hydrological parameters can be computed and analyzed to cope for the increase in demand of water. The reservoir capacity can be computed by analyzing demand and runoff and subsequently deciding the structure that can be proposed for SWH. The focus should be to design the SWH structures considering the systematic and cost-effective design on a city wide scale. Furthermore, a GIS based screening methodology for identifying suitable SWH sites were developed [11]. Various screening parameters such as Demand, ratio of Runoff to Demand and weighted Demand distance were evaluated for site selection.

Upon identifying the screening parameters, the parameters can be allocated weights based on existing practices such as Analytic hierarchy process [12], Principal Component Analysis [13–17], and entropy weight method [18]. In the AHP method [12], the weights are decided through pairwise comparisons. The method is based upon the opinion from the experts to define the relative scales. Then, the comparison is made between parameters on an absolute scale representing one parameter is more dominant with respect to the other. This method is adopted worldwide for group decision making in the fields such as business, shipbuilding, industry, government, healthcare and education, etc. It represents the decision that best suits the requirements of decision makers and does not a "correct" decision. Thus, it represents a comprehensive and rational framework that evaluates the solutions by representing and quantifying its elements that describes the overall goals.

In this concept, the planners structured their decision problem into a hierarchy that defines the problem in a simpler and systematic manner. The elements involved in the hierarchy can correlate any aspect of decision problem, good or bad, tangible or intangible, well or poorly understood, or anything that applies to the decision at hand. Once the hierarchy is built for the problem, the planners decide the importance of the elements by comparing the elements between each other with respect to their impacts.

However, there are limitations in adopting Saaty AHP methodology for allotting weights to the parameters [19–27]. Some of the major drawbacks are (i) the computations made by the AHP are always guided by the decision maker's experience and may involve the subjective judgments of individuals that constitute an important part in the decision process [27]; (ii) the different methods of designing the hierarchies of the same problem may lead to contrasting results [23,24]; and (iii) the structure of the hierarchy follows the perception of the individual (or the group of individuals) and there is no possible alternative to this problem formulation [25].

The Principal Component Analysis can be defined as a linear combination of optimally-weighted observed variables. This method removes the subjective decisions and totally depends on the data sets. In PCA, the most common used criterion for solving the number of components is to compute eigenvectors and eigenvalues [13–17]. Weights are decided using eigenvalues.

The Entropy Weight method determines the weights associated with the information of values of all the screening parameters. The evaluation through the entropy method for determination of weight is claimed to be a very effective method for evaluating indicators [18,28,29].

The use of different weight allocations methods is yet to be explored in ranking of storm water harvesting sites. It is also not known how these different weighing approaches can help the water planners. Hence, it is decided to explore the potential of these approaches for screening the potential sites for SWH in two case studies, in Melbourne, Australia [11], and in Dehradun, India. The case study in India also includes a step-by-step illustration of ranking methodology. For comparative purposes as well as to assess the merits and demerits of using heuristic versus non-heuristic approaches, the screening parameters are adopted. This paper is organized in following subsections, i.e., methodology used, results, discussion and conclusions.

2. Methodology

The methodology for adopting weight allocation methods to rank SWH sites essentially involves three steps: (i) identification and evaluation of screening parameters; (ii) normalization to a common scale; and (iii) assigning weightage to the normalized parameters by using heuristic and non-heuristic approaches. Details of these three steps are discussed below.

2.1. Identification and Evaluation of Screening Parameters

The methodology used for shortlisting as well as finalizing suitable sites for SWH with the integration of remote sensing and GIS is described [11]. The screening parameters discussed for shortlisting SWH sites are demand, ratio of runoff to demand and weighted demand distance. Variation of these screening parameters with radial distance from each identified hot spot needs to be established as a part of relative ranking of storm water harvesting sites. The process as such involves the following steps:

(i) Identification of hot spots,
(ii) Estimation of runoff,
(iii) Estimation of demand,
(iv) Weighted demand distance.

In step (i), with the use of DEM, the flow accumulation map is generated and the accumulated catchments are marked on the map. The points/locations of the intersections of the accumulated catchments can be the potential hotspots for the SWH structures where the flow can be trapped.

In step (ii), using precipitation, runoff can be computed using the Natural Resources Conservation Service- Curve Number (NRCS-CN) method [30]. Runoff coefficients for different combinations of pervious-impervious layers and soil type for Indian conditions are described [31]. The surface runoff can be computed by integrating the Land Use Land Cover map with the soil map of the area in the GIS environment [32].

The physical distance from the site to the demand is very critical for considering the economic feasibility.

In step (iii), various demands are considered at different radii of influence, i.e., domestic, irrigation, industrial, commercial and for public uses. All demands are summed up to compute the total demand.

Ratio of runoff to demand assesses the match between the required runoff and the associated demand. It indicates the feasibility of whether the demand can be covered with the available runoff water.

In step (iv), weighted demand distance gives preference to sites close to high demand areas to minimize transport and water infrastructure costs. Thus, the parameter is computed for all the shortlisted potential hotspots.

All of the parameters are computed and analyzed at different radii of influence.

2.2. Normalization to a Common Scale

The inconsistency in the methodology is because of the variability in judging the parameters like high demand, high ratio of runoff to demand and low weighted demand distance, and also the range of the parameters varies differently. The methodology is proposed keeping in view all of these problems. Thus, to address this gap, all of the parameters are transformed to a common range and scale. This will help the water planners to make a quick decision in finalizing the suitable site for SWH.

Equations are proposed for all the parameters as follows:

(a) Demand:

$$D_1 = \alpha\, D_L + \beta, \tag{1}$$

$$D_2 = \alpha\, D_U + \beta, \tag{2}$$

where D_1 is lower value of range, D_2 is upper value of range, D_L is lowest demand of the area, D_U is highest demand of the area, and α and β are constants.

(b) Ratio of Runoff to Demand (RTD):

$$RTD_1 = \gamma\, RTD_L + \delta, \tag{3}$$

$$RTD_2 = \gamma\, RTD_U + \delta, \tag{4}$$

where RTD_1 is lower value of the range, RTD_2 is upper value of the range, RTD_L is lowest value of ratio of runoff to demand of the area, RTD_U is the highest value of ratio of runoff to demand of the area, and γ and δ are constants.

(c) Weighted Demand Distance:

$$WD_1 = \zeta\, WD_L + \eta, \tag{5}$$

$$WD_2 = \zeta\, WD_U + \eta, \tag{6}$$

where WD_1 is lower value of the range, WD_2 is upper value of the range, WD_L is lowest value of inverse weighted demand distance of the area, and WD_U is the highest value of inverse weighted demand distance of the area, ζ and η are constants.

Thus, by solving the above equations (1, 2, … , 6), α, β, γ, δ, ζ and η constants can be computed. After computing the constants, all the values of parameters of different sites are transformed to a new scale that ranges from D_1 to D_2 for demand, RTD_1 to RTD_2 for ratio of runoff to demand and WD_1 to WD_2 for inverse weighted demand distance by applying the following equations:

(a) For, demand;

$$D_S = \alpha\, D_C + \beta, \tag{7}$$

(b) Ratio of runoff to demand;

$$RTD_S = \gamma\, RTD_C + \delta, \tag{8}$$

(c) Weighted demand distance;

$$WD_S = \zeta\, WD_C + \eta, \tag{9}$$

where D_S is scaled demand, D_C is computed demand for each site, RTD_S is scaled ratio of runoff to demand, RTD_C is computed ratio of runoff to demand for each site, WD_S is scaled inverse weighted distance and WD_C is computed inverse weighted distance for each site.

Thus, by solving the above equations, each value of different parameters for all the shortlisted sites transforms into a common scale.

2.3. Determination of Weights

2.3.1. Saaty Heuristic Approach

The analytic hierarchy process (AHP) is a representation of complex problems by organizing and analyzing them in a more structured manner. It was developed by Thomas L. Saaty in the 1970s and has been applied worldwide for solving the complex problems [12].

The following three-step procedure provides a good approximation of the synthesized priorities.

Step 1: Sum the values in each column of the pairwise comparison matrix.

Step 2: Divide each element in the pairwise matrix by its column total.

The resulting matrix is referred to as the normalized pairwise comparison matrix.

Step 3: Compute the average of the elements in each row of the normalized matrix.

These averages provide an estimate of the relative priorities of the elements being compared.

Computing the vector of criteria weights

(a) Creating a pairwise comparison matrix A.

Let A = m $\times$ m matrix; m = evaluation criteria; each entry a_{jk} represents the importance of j^{th} criteria with respect to k^{th} criteria.

The relative importance between two elements or criteria is by allotting them weights on a scale from 1 to 9.

(b) Once the matrix A is built, the normalized pairwise comparison matrix A_{norm} is formed, by making the sum equal to 1 of the all of the entries in the column of the matrix A, i.e., each entry a' of the matrix A_{norm} is computed as

$$a'_{jk} = \frac{a_{jk}}{\sum_{l\,=\,1}^{m} a_{lk}}. \tag{10}$$

(c) Finally, the criteria weight vector w (that is an m-dimensional column vector) is formed by averaging all the entries along the row of matrix A_{norm}, i.e.,

$$w_j = \frac{\sum_{l\,=\,1}^{m} a'_{jl}}{m}. \tag{11}$$

The AHP converts individual evaluations of relative importance of one parameter over another to numerical values, which can be analyzed over the entire range of the problem [33]. A numerical weight or priority is derived using a matrix of such comparisons between various parameters.

2.3.2. Non-Heuristic Approaches

Principal Component Analysis (PCA) Method

PCA is defined as a linear combination of optimally-weighted observed variables. In PCA, the most common used criterion for solving the number of components is to compute eigenvectors and eigenvalues. To solve the eigenvalue problem, the following steps are followed.

Let A be a n $\times$ n matrix and consider the vector equation

$$A\,\vec{v} = \lambda\,\vec{v}, \tag{12}$$

where λ represents a scalar value.

Thus, if $\vec{v} = \vec{0}$, it represents a solution for any value of λ. Eigenvalue or characteristics value of matrix A is that value of λ for which the equation has a solution with $\vec{v} \neq \vec{0}$. The corresponding solutions $\vec{v} \neq \vec{0}$ are called eigenvectors or characteristic vectors of A.

(i) Compute the determinant of $A - \lambda I$

With λ subtracted along the diagonal, this determinant starts with λ^n or $-\lambda^n$. It is a polynomial in λ of degree n.

(ii) Find the roots of this polynomial

By solving det $(A - \lambda I) = 0$, the n roots are the n eigenvalues of A. It makes $A - \lambda I$ singular.

(iii) For each eigenvalue λ, solve $(A - \lambda I)x = 0$ to find an eigenvector x.

Eigenvalues are used to decide weights in proportions to total of eigenvalues.

Entropy Weight Method

In this approach, the individual elements or criteria are assigned weights by determining entropy and entropy weight. Based on the principle of information theory, entropy is a measure of lack of information regarding a system. If the information entropy of the indicator is small, the amount of information provided by the indicator will be greater and the higher the weight will be, thereby playing a more important role in the comprehensive evaluation [34]. The steps involved in the entropy weight method are (i) formation of the evaluation matrix; (ii) normalization of the evaluation matrix; and (iii) calculation of the entropy and the entropy weight

Let there be m parameters to be evaluated in a problem, n categories of evaluation criteria, and then the evaluation matrix is $X = (x_{ij})_{mxn}$, where x_{ij} represents the actual value of j-th criteria for the i^{th} parameter. The calculation of entropy weight is as follows.

(i) Normalize the evaluation matrix, X to obtain $R = (r_{ij})_{mxn}$ where r_{ij} is the j^{th} evaluating object for i^{th} indicator and $r_{ij} \in [0,1]$. This will in turn generate a positive indicator for the variables:

$$r_{ij} = \frac{x_{ij} - \min\{x_{ij}\}}{\max\{x_{ij}\} - \min\{x_{ij}\}}. \tag{13}$$

(ii) Calculate entropy weight value '*H*'. the j-th index value of information entropy is computed as

$$H_j = -K\sum_{i=1}^{m} f_{ij} \ln f_{ij}. \tag{14}$$

Here, $f_{ij} = \frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}}$, $f_{ij} \epsilon [0,1]$.

where, K is a positive constant, relevant to the number of sampling stations, s of the system. When the samples are completely in disordered state, $K = 1/\ln(s)$.

(iii) Calculate the j-th index weight as,

$$W_i = \frac{1 - H_i}{m - \sum_{i=1}^{m} H_i}. \tag{15}$$

3. Case Study Application and Results

Firstly, the methodology is applied on Melbourne city to check results obtained from heuristic and non-heuristic approaches and then to Dehradun city.

Ranking of the potential sites

The main concern of the study is to rank the suitable shortlisted sites according to the various approaches and thus obtain the final site ranking of sites, which are done according to the various approaches discussed earlier by allotting weights to the parameters.

3.1. Application of Methodology to Melbourne City

The study area is a part of the City of Melbourne (COM), where all the water and waste water services are provided by the City West Water. The study area includes residential, industrial areas, public parks and commercial land and covers an area of about 26 km^2. Further SWH site specific details about Melbourne are elaborated [11]. The methodology is applied to Melbourne sites shortlisted for SWH. The set of data taken as shown in Table 1 is as follows. The ranking of sites according to high demand, high ratio of runoff to demand and low weighted distance had already been computed in the work.

Table 1. Sites shortlisted for Storm Water Harvesting in Melbourne city [11].

Site ID	Possible Options	Demand (ML)	Ratio of Runoff to Demand	Weighted Distance (m)
	76b	49.07	1.3	300
	43c	6.18	29.4	283
43	43b	5.82	31.2	277
	46d	7.47	14	256
	47d	7.47	9.6	256
	44c	6.43	62.6	255
44	44b	6.18	65.2	250
28	28b	6.18	15.8	243
	47c	6.84	10.5	218
	46c	6.84	15.3	217
12	12b	15.88	14.4	210
46	46b	5.82	18	182
47	47b	5.82	12.4	182
14	14b	125.6	1.8	182
69	69b	11.62	81.6	175
	29d	31.65	4.2	136
	52b	13.7	8.5	134
	17d	53.79	1.3	112
	41d	30.65	2.2	103
26	26b	19.35	2.6	87
39	39b	19.35	1.6	87
	29c	28.92	4.6	80
	78b	13.07	1.5	70
	41c	28.92	2.3	67
52	52a	5.33	21.9	0
76	76a	5.3	11.8	0
29	29a	23.14	5.8	0
78	78a	5.3	3.7	0
77	77a	5.3	3.2	0
17	17a	23.14	3	0
41	41a	23.14	2.9	0
20	20a	23.14	2.8	0
9	9b	28.67	1.3	0

ML: Million Litres.

3.1.1. Saaty Heuristic Approach

The Saaty AHP [12] method is difficult to apply on Melbourne city as no such survey to decide the relative weights of screening parameters from water planners of Melbourne city was reported. For this, a survey was done at the Dehradun site, and it was considered desirable to give equal weightage to all the screening parameters.

For Melbourne city, considering all the parameters with equal weights, the ranking is done in two parts, first with a non-zero value of weighted distance and the other with zero value of weighted distance. In the case of Inamdar et al. [11], two types of sites are reported. For certain sites, the hot spots and the demand clusters are located at the same spot, making the value of parameter weighted demand distance be zero.

Sites ranked for non-zero value of weighted distance.

The ranking corresponding to this approach is shown in Table 2 for the non-zero value of weighted distance.

Table 2. Sites ranked for non-zero value of weighted distance for Melbourne city.

Rank	Possible Options	Scaled Demand	Scaled Inverse WD	Scaled RTD	Centroid (m)
		10 Intercept	5 Intercept	0 Intercept	
1	69b	5.25	20.81	100.00	42.0
2	41c	19.63	100.22	1.25	40.4
3	14b	100.00	18.92	0.62	39.8
4	29c	19.63	79.31	4.11	34.4
5	78b	6.46	94.70	0.25	33.8
6	17d	40.31	48.52	0.00	29.6
7	44b	0.73	6.03	79.57	28.8
8	26b	11.68	70.64	1.62	28.0
9	39b	11.68	70.64	0.37	27.6
10	44c	0.94	5.36	76.34	27.5
11	41d	21.07	55.25	1.12	25.8
12	29d	21.90	34.94	3.61	20.2
13	52b	6.98	35.89	8.97	17.3
14	43b	0.43	2.67	37.23	13.4
15	46b	0.43	18.92	20.80	13.4

Notes: WD: Weighted Demand Distance, RTD: Ratio of Runoff to Demand.

For the zero value of weighted distance, the ranking is computed by considering two parameters, i.e., demand and ratio of runoff to demand with equal weights, as shown in Table 3.

Table 3. Sites ranked for zero value of weighted distance for Melbourne city.

Rank	Possible Options	Scaled Demand	Scaled RTD	Center Point (m)
		10 Intercept	0 Intercept	
1	52a	0.02	25.65	12.84
2	29a	14.83	5.6	10.22
3	9b	19.43	0	9.71
4	17a	14.83	2.12	8.47
5	41a	14.83	1.99	8.41

3.1.2. Non-Heuristic Method

Sites Ranked According to the PCA Method

In this approach, the Principal Component Analysis method is applied to compute the eigenvectors and eigenvalues of the data sets available for the potential hotspots. Then, the eigenvalues are used to compute the weights for the respective parameters.

The weights computed for the Melbourne city are 0.150, 0.253 and 0.598 for the parameters demand, inverse weighted distance and ratio of runoff to demand, respectively. The rank corresponding to the computed weights are represented in Table 4.

Table 4. Comparative study of ranks of potential hotspots for Melbourne City.

Rank	Saaty AHP Method	Entropy Weight Method	PCA Method
1	69b	14b	69b
2	41c	69b	44b
3	14b	41c	44c
4	29c	44b	41c
5	78b	44c	29c
6	17d	17d	78b
7	44b	29c	43b
8	26b	78b	43c
9	39b	41d	26b
10	44c	26b	14b
11	41d	39b	39b
12	29d	29d	17d
13	52b	76b	41d
14	43b	52b	46b
15	46b	43b	52b
16	43c	43c	29d
17	12b	12b	12b
18	76b	46b	46c
19	47b	47b	47b
20	46c	46c	28b

Notes: AHP: Analytic hierarchy process, PCA: Principal Component Analysis.

Sites Ranked According to Entropy Weight Method

In this, the weights are computed for the parameters according to the entropy weight method and the sites are ranked accordingly. The weights computed for the Melbourne city are obtained as 0.423, 0.228 and 0.350 for the parameters Demand, Inverse weighted distance and Ratio of runoff to demand, respectively. Thus, sites are ranked with these weights and are represented in Table 4.

3.2. Application of Methodology to Dehradun city

The study area is Dehradun, capital city of state Uttarakhand and is of national importance. District Dehradun is situated in the northwest corner of Uttarakhand state and extends from North Latitude 29°58′ to 31°02′30″ and East Longitude 77°34′45″ to 78°18′30″. Uttarakhand is 86 percent covered with mountains and 65 percent is covered with forests. The state is popular, as its northern part is occupied by glaciers and Himalayan peaks. The two India's largest rivers i.e., the Ganga and Yamuna, emanate from the glaciers of Uttarakhand. These rivers are fed by myriad lakes, glacial melts and streams. The Dehradun district is at an altitude of 640 m above Mean Sea Level (MSL) and covers an area of approx. 3088 km^2.

The above methodology is applied for the study area Dehradun. Firstly, the supervised classification is done to generate the LULC map. For applying the NRCS-CN method on the study area, the LULC and soil maps are merged together to form a reclassified image that interprets the curve number [32]. From the table described [31], the runoff coefficients values are allotted to different combinations of LULC and soil maps for Indian conditions.

The data for the study area is prepared for the areas of different combinations of land use and soil type with the knowledge of monthly rainfall data for 25 years, and monthly runoff (mm) is computed for the study area [32]. By delineating DEM, the accumulated catchments are marked on the LULC map, which is also the interpretation for potential hotspots for SWH. Points A, B, C, . . . , H are the eight potential hotspots shortlisted for the study area as shown in Figure 1.

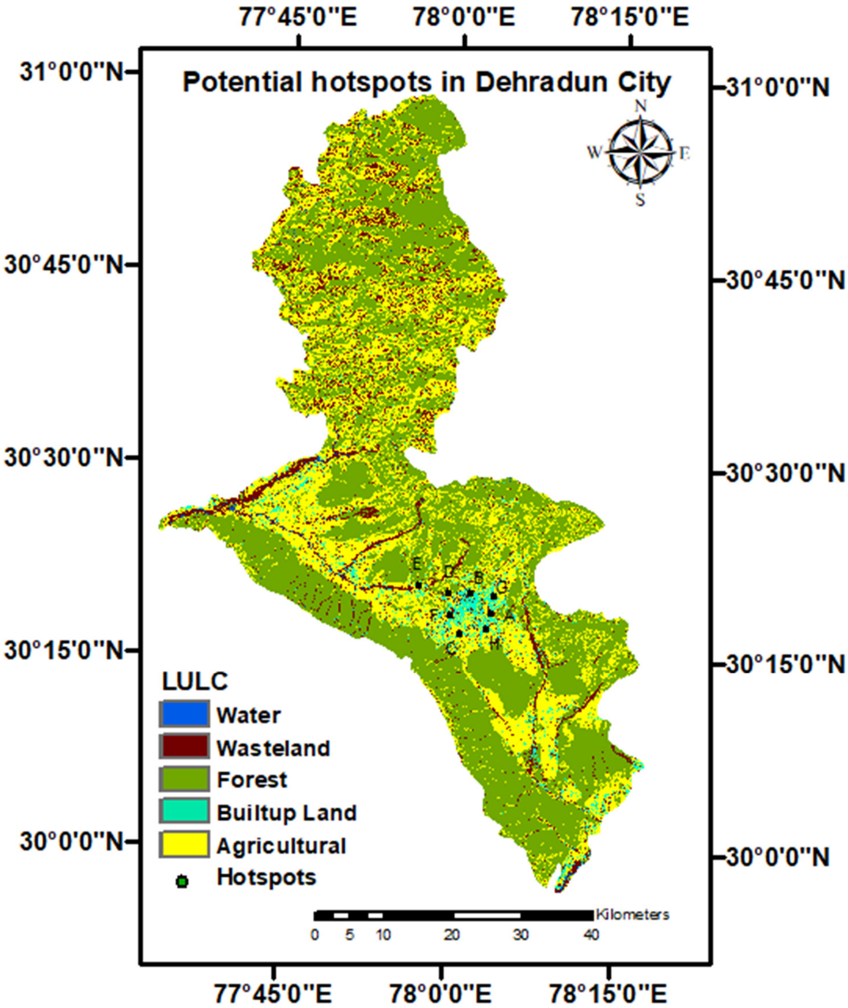

Figure 1. Potential hotspots in Dehradun city.

A radius of influence is drawn for each potential hotspot at a radius of 200 m, 400 m, 600 m, 800 m and 1000 m. The spatial demand is generated for each radius of influence for the sites and the runoff is computed accordingly. Thus, 40 combinations are formed for eight shortlisted sites with different radii of influence suitable for SWH as shown in Table 5.

3.2.1. Saaty Heuristic Approach

Saaty AHP method is applied on the study area as all planners suggested the same weights for all the parameters. Thus, the parameters are allotted the same weight and the ranking is done accordingly as shown in Table 6. By solving all the equations in the proposed methodology, the scaled demand, scaled inverse weighted demand distance and scaled ratio of runoff to demand are calculated for all of the data available for the study area by considering equal weights for all of the parameters.

Table 5. Sites shortlisted for Storm Water Harvesting in Dehradun city.

ID	Radius of Influence (RI) (m)	Total Area (m^2)	Urban Area (m^2)	Urban Runoff Volume (ML) (Monthly)	Water Demand (ML) (Monthly)	Ratio of Runoff to Demand	Weighted Distance
A	200	125,663.7	93,765	39.3	4.5	8.8	4.2
A	400	502,654.8	313,553	157.4	15	10.5	9.6
A	600	1,130,973	534,297.6	354.1	25.5	13.9	15.9
A	800	2,010,619	956,866.5	629.5	45.7	13.8	19.7
A	1000	3,141,593	1,443,163	983.6	68.9	14.3	25
B	200	125,663.7	4915	39.3	0.2	167.6	8.1
B	400	502,654.8	108,944.4	157.4	5.2	30.2	13.4
B	600	1,130,973	465,995	354.1	22.3	15.9	20.4
B	800	2,010,619	982,995	629.5	46.9	13.4	26.1
B	1000	3,141,593	1,770,438	983.6	84.6	11.6	28.1
C	200	125,663.7	62,829.9	39.3	3	13.1	6.3
C	400	502,654.8	170,539.4	157.4	8.1	19.3	11.6
C	600	1,130,973	309,677	354.1	14.8	23.9	16
C	800	2,010,619	495,541.5	629.5	23.7	26.6	25.5
C	1000	3,141,593	831,424	983.6	39.7	24.8	28.7
D	200	125,663.7	11,413	39.3	0.5	72.2	141.2
D	400	502,654.8	29,059.4	157.4	1.4	113.4	13
D	600	1,130,973	87,418.9	354.1	4.2	84.8	19.4
D	800	2,010,619	251,187.5	629.5	12	52.5	28.9
D	1000	3,141,593	738,246	983.6	35.3	27.9	36.8
E	200	125,663.7	36,676	39.3	1.8	22.5	6.5
E	400	502,654.8	205,243	157.4	9.8	16.1	9.9
E	600	1,130,973	309,245	354.1	14.8	24	11.7
E	800	2,010,619	420,560	629.5	20.1	31.3	18
E	1000	3,141,593	557,655	983.6	26.6	36.9	22.6
F	200	125,663.7	9102	39.3	0.4	90.5	139.5
F	400	502,654.8	180,030	157.4	8.6	18.3	13
F	600	1,130,973	537,586	354.1	25.7	13.8	15
F	800	2,010,619	1,005,158	629.5	48	13.1	20.7
F	1000	3,141,593	1,741,692	983.6	83.2	11.8	29.7
G	200	125,663.7	58,561.5	39.3	2.8	14.1	2.2
G	400	502,654.8	218,306.4	157.4	10.4	15.1	8.9
G	600	1,130,973	619,860	354.1	29.6	12	9.5
G	800	2,010,619	1,192,337	629.5	56.9	11.1	12.9
G	1000	3,141,593	1,932,770	983.6	92.3	10.7	17
H	200	125,663.7	31,584.1	39.3	1.5	26.1	5.8
H	400	502,654.8	245,109.6	157.4	11.7	13.4	8.5
H	600	1,130,973	587,960.8	354.1	28.1	12.6	10.9
H	800	2,010,619	1,026,758	629.5	49	12.8	18.1
H	1000	3,141,593	1,572,652	983.6	75.1	13.1	22.7

Table 6. Comparative study of ranks of potential hotspots for Dehradun city.

Rank	Saaty AHP Method		Entropy Weight Method		PCA Method	
	ID	RI (m)	ID	RI (m)	ID	RI (m)
1	B	200	B	200	B	200
2	G	1000	D	400	D	400
3	G	200	G	200	D	600
4	B	1000	G	1000	G	200
5	F	1000	D	600	D	800
6	H	1000	B	1000	E	1000
7	A	1000	F	1000	H	200
8	D	400	H	1000	G	1000
9	G	800	A	1000	E	800
10	H	800	G	800	E	200
11	F	800	D	800	A	200
12	A	800	E	1000	B	1000
13	D	600	H	800	H	1000
14	B	800	C	1000	F	1000
15	C	1000	A	200	D	1000
16	A	200	H	200	B	400
17	G	600	F	800	C	1000
18	E	1000	A	800	A	1000
19	D	1000	D	1000	E	600
20	H	600	B	800	G	800

3.2.2. Non-Heuristic Method

Sites Ranked According to the PCA Method

In this approach, the Principal Component Analysis method is applied to compute the eigenvectors and eigenvalues of the data sets available for the potential hotspots. Then, the eigenvalues computed corresponds to the weights for the respective parameters.

The weights are computed for the Dehradun city are 0.118, 0.248 and 0.634 for the parameters Demand, Inverse weighted distance and Ratio of runoff to demand respectively. The rank corresponds to the shortlisted sites with corresponding weights are represented in the Table 6.

Sites Ranked According to Entropy Weight Method

In this, the weights are computed for the parameters according to the entropy weight method and the sites are ranked accordingly. The weights are computed for the Dehradun city and these turn out to be 0.297, 0.213 and 0.490 for the parameters Demand, Inverse weighted distance and Ratio of runoff to demand, respectively. Thus, ranks of various shortlisted sites are represented in Table 6.

4. Discussion

The storm water harvesting sites in Melbourne and Dehradun were ranked according to the different possible combinations of parameters with equal weights and then by applying various methods for assigning weights to the parameters for both the sites. All the potential hotspot sites both for Melbourne city and Dehradun city are evaluated using the combination of all three parameters. Tables 4 and 6 show the ranks of different sites in Melbourne city and Dehradun city. In this study, the main focus is to remove subjectivity from the approaches used for ranking water harvesting sites. A definitive approach based on principal components and entropy is introduced to assign the weights. Initially, the sites are shortlisted by using DEM for the study area and applying the concept of accumulated catchments. For the similar sites, different radii of influence are used in order to rank the sites. The use of different heuristics as well non-heuristic approaches is demonstrated using three screening parameters Demand, ratio of Runoff to Demand and weighted Demand distance. The top ranking sites are well captured in Tables 5 and 6 using PCA and entropy based approaches, as evident from the sites selected in the paper [11].

It is noted that the objective here is not to select the best site that has rank one in either of approaches. Instead, the utility of these approaches should be viewed in terms of screening of a few most feasible sites. With the allocation of weights, the ranking is done for the sites in Australia and India, and the suitable sites are thus matched with the sites suggested by Inamdar et al. [11] for the Australian site. For the Australian site, the sequence of finalizing suitable sites by Inamdar et al. [11] is based on ranking of sites using only one attribute at a time. To explain it further, the site having the highest rank for attribute Demand is "14b"; similarly, the site having the highest rank for attribute ratio of runoff to demand is "69b", and likewise for attribute weighted distance, the site is "52a". It is interesting to see that no aggregation of these attributes has been done by Inamdar et al. [11].

The top ranked sites for the Australian site through a non-heuristic approach comes out to be "14b", "69b", "41c", "44b", and "44c". It is interesting to observe that the sites finalized by our approach matches with the sites finalized by Inamdar et al. [11] with the help of planners.

The present approach considers a unified view of all attributes and provides an integrated score. This integrated score forms the basis for selecting a few top sites. This practice of aggregating attributes is widely used in literature [35,36]. It is needless to emphasize that ranking based on "n" attributes will create a pool of "n" options, whereas the present approach will provide only one aggregated score. Thus, the alternatives evolved in the present approach will provide a smaller pool for alternatives to be picked up.

Thus, this methodology reduces a large pool of data sets and also provides the reliable shortlisted sites suitable for stormwater harvesting. Once a pool of the top, say 5 to 10 sites, is identified, more rigorous analysis using financial, social, environmental aspects can be adopted to choose most appropriate sites suitable for a specific location. The results obtained by non- heuristic approaches, i.e., entropy weight method and PCA are in the good agreement with the results obtained by concerning various water planners of Melbourne city and Dehradun city. As a non-heuristic approach does not involve subjectivity and capture the sites of Inamdar et al. [11], certainly there is a merit in using non-heuristic approaches. Utility value of the study is that it provides a rational procedure to rank the sites and this procedure is consistent with a similar application in other disciplines. The work is significant as it removes the ad hoc approach of selecting the sites based on isolated attributes and subjectivity in ranking is also avoided using this approach.

Thus, this methodology reduces time and subjectivity in creating a set of few suitable storm water harvesting sites uses from which planners can take a quick and efficient decision in finalizing suitable sites for Storm Water Harvesting at a specific location.

5. Conclusions

The study focuses on screening a few suitable SWH sites within a region of interest using a GIS based robust methodology, which utilizes Demand, ratio of runoff to demand and weighted demand distance as screening parameters. A suitable site should fulfill the criteria of high demand, high ratio of runoff to demand and a low weighted demand distance. It was observed that, while allotting the ranks to the shortlisted sites, the same sites have obtained different ranks for different parameters and are also influenced by subjectivity in decision-making. This makes it difficult for the water planners to make a quick decision and hence completing the process of site selection for SWH. A new methodology is adopted that transforms the weight of all the parameters for the heuristic and non-heuristic approaches. Saaty AHP, PCA and entropy weight methods are applied for allotting weights to the parameters. The methodology is applied both for Melbourne city and Dehradun city. The results obtained by non-heuristic approaches, i.e., PCA and entropy weight method were good for Melbourne city as well as for Dehradun city. Thus, the proposed methodology has the potential of application in decision-making of suitable storm water harvesting sites. Change in climate and LULC may affect the precipitation patterns and runoff generated. This coupled with dynamic changes in the demand pattern may lead to re-evaluation of existing storm water harvesting sites. Furthermore, changes may also take place in the screening parameters. Under these conditions, the use of non-heuristic approaches can work as a potential tool to screen out several alternate options or augmentation of existing sites. It is also recommended to conduct further studies on sensitivity analysis of the ranking parameters and applications in different rainfall contexts such as in arid regions to strengthen the storm water harvesting site selection process.

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