Chapter 5
Detail Methodology

Abstract The present study utilized the MCDM and ANN technologies to estimate the severity of water shortage in different locations. The MCDM methods like AHP and FLDM method was utilized where the results of both were ensemble to find the priority values of the considered input parameters of the indicator. The indicator was provided with cognitive ability by inducting the ANN model for estimation of final value of the index. The index was tested for Eighteen scenarios in total. Three study areas having different level of urban population and six various climate change scenarios are produced and the index was estimated for each of the scenarios. The performance metrics of the model and sensitivity analysis of the index was also carried out.

Keywords Multi criteria decision making · Artificial neural network · Index

5.1 MCDM

The objective of the framework is to estimate the severity of water shortage in different locations due to change in urbanization and climatic pattern. The urbanization and climate change on the other hand depends upon various factors:

$$\mathrm{WS} = \mathrm{f}(\mathrm{u}, \mathrm{c}), \quad \text{where}\, \mathrm{u} = \mathrm{f}(\mathrm{a}) \text{ and } \mathrm{c} = \mathrm{f}(\mathrm{b}). \tag{5.1}$$

where u and c are dependent function of urbanization and climate change and u and c are again dependent on a and b respectively. The a and b parameters are independent of any variable but represents the factors which effects the change in climate and urban density.

The a and b parameters can be identified by an extensive literature survey and discussions with the experts in related field.

As MCDM methods are widely popular to provide solution to the present type of multi-criteria decision making problems. That is why to assign weights of importance various other factors has to be conceptualized first. The present investigation

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used their strengths to find the difference of influence or importance of each of the a and b parameters.

In the present study the weight of importance were determined by Analytical Hierarchy Process (AHP) and Fuzzy Logic Decision Making (FLDM) as both the methods are applicable and considers both qualitative and quantitative variables. Thus AHP and FLDM method was adopted to find the weight of importance for each of the parameters. The steps below provide the methodology adopted to determine the weights of importance for each of the a and b parameters by MCDM methods.

Although a and b parameters can influence U and C separately but as WS is a dependent function of U and C all the a and b parameters are compared in a single pair-wise comparison matrix.

5.1.1 Selection of Criteria

In the present study the weights of importance of the a and b parameters are required to be estimated. So, all these parameters are considered as alternatives. To find the weights of importance some criteria has to be identified with respect to which the alternatives will be compared and the difference in importance can be determined. In this regard the following factors are considered as Criteria.

(i) *Expert Survey* A survey was carried out within experts of related fields where participants were asked to suggest about the a and b parameters. The participants were also requested to provide their estimate about the most and least important parameter in this aspect. According to the response received from the experts a score was calculated and assigned to the factors according to Eq. 5.2.

If ‘A’ is number of experts which mentioned the parameter and ‘e’ be the number of expert which has referred it as most important parameter and e′ be the number of expert who have mentioned the parameter as not at all important then,

$$\mathrm{SE} = (\mathrm{Ax}(\mathrm{e}/\mathrm{e}')). / \mathrm{At} \tag{5.2}$$

where SE is the score assigned to the parameter and At is the total number of experts consulted regarding the present problem.

The score was then normalized and according to the score the top ten parameters were determined.

(ii) *Literatures Review* The literatures were also surveyed to find the citation of the parameters in related studies. If the number of literatures which mentioned the parameter is l and the total number of literatures surveyed be L then the score, SL, is calculated by Eq. 5.3.

$$\mathrm{SL} = (\mathrm{l}/\mathrm{L}) \tag{5.3}$$

This score was also normalized and the parameters are ranked accordingly in a descending manner.

(iii) *Stakeholders Survey* The stake holders or the people who are dependent on the water resources of a region for sustenance of their socio-economic status a survey were conducted among some local people of different regions about the impact of the considered parameters on the intensity of water shortage.

After the survey the importance given to the considered parameter by the local people was utilized to rank the parameters according to their importance. The score which helped to decide the rank of a certain parameters is given by Eq. 5.4.

$$\mathrm{Ss} = (\mathrm{s}/\mathrm{S}) \tag{5.4}$$

where s is total number of local participants who have given importance to the parameter and S is the total number of participants of the survey.

(iv) *Sponsor's Preference* A allocators of government fund or industrial units or some non-governmental organizations are involved in funding projects for sustenance of the water resources in different regions of the World. The feedback from these people is also included. Equation 5.5 was utilized to estimate the score of the parameters with respect to Sponsor's preference.

$$\mathrm{SSsp} = (\mathrm{p}/\mathrm{Ssp}) \tag{5.5}$$

where SSsp is the score to be assigned, p and Ssp is respectively total number of sponsors who have given highest importance to the parameter and number of sponsors discussed for the survey.

(v) *Data Availability* The parameters were also compared based on the data availability. There are three kinds of data that can be retrieved which represents the status of the parameter: Primary, Secondary and Calculative. Primary data is the dataset which are prepared based on the sample survey.

Secondary data are historical data stored in databases and various reports. Calculative datasets are not directly/readily available and has to be calculated based on some premade equations. The score assigned to the parameters with respect availability of data is given in Eq. 5.6.

$$\mathrm{Sda} = (\mathrm{aPri} + \mathrm{bSec} + \mathrm{cCal})/(\mathrm{a} + \mathrm{b} + \mathrm{c}) \tag{5.6}$$

where a, b, c are any constants less than 1 and (a + b + c) = 1

Pri, Sec and Cal are the number of primary, secondary and calculative data sources available for the parameter. The score is normalized and based on the normalized score the parameters are arranged from most to least important factors.

According to the AHP and FLDM method the criteria are first compared with each other to find the difference of importance between them. Thus a (5 × 5) matrix was formulated and each of the criteria is compared with the other criteria with respect to its importance over the other parameter.

If total number of experts surveyed be At, total number of literatures surveyed be L, the total number of stakeholders and sponsors surveyed be S and Sp respectively and the total number of sources for retrieval of dataset of related parameters be D, then

$$\text{for Expert Survey} = E/(At + L + S + Sp + D) \tag{5.7}$$

$$\text{for Literatures Survey} = L/(At + L + S + Sp + D) \tag{5.8}$$

$$\text{for Stakeholders Survey} = S/(At + L + S + Sp + D) \tag{5.9}$$

$$\text{Sc for Sponsor's Preference} = Sp/(At + L + S + Sp + D) \tag{5.10}$$

$$\text{Sc for Data Availability} = D/(At + L + S + Sp + D) \tag{5.11}$$

where Sc is the score assigned to the criteria.

The score of the criteria are then normalized and ranked in a descending manner.

The rank of the criteria is utilized to find the difference of importance between the criteria in the comparison matrix of both AHP and FLDM.

5.1.2 Selection of Alternative

The eight different a and b parameters were selected as the alternatives. All the parameters are measurable, independent of each other, real and is a direct function of the decision objective.

5.1.3 Aggregation Methods

In the present investigation AHP and FDM is utilized for identifying the weight of importance of the parameter as both of these methods can consider both quality and quantitative parameters in the process of decision making. A 5 × 5 matrix of criteria is developed to find the weights of the criteria. The comparative rating was given as per Saaty scale for the AHP method and Zadeh scale for the FLDM method.

If C is the Criteria matrix and A is the alternative matrix then,

$$C = \{m, m\} \tag{5.12}$$

where,

$$m = \{At, L, S, Ssp, D\} \tag{5.13}$$

The scale proposed by Saaty is used to rate the pair-wise importance of each of the criteria.

Again the alternatives are compared with each other based on their importance over each other with respect to each of the criteria and thus,

$$A = \{a, b:a, b\} \quad (5.14)$$

where,

a = Frequency of Peaks in Annual Water Demand curve for Domestic Consumers (Dd), Frequency of Peaks in Annual Water Demand curve for Agriculture Consumers (Da), Frequency of Peaks in Annual Water Demand curve for Industrial Consumers (Di), Percentage Impervious Area (last 10 years) (A), Annual Average Area of Canopy (Ac) and Frequency of Troughs in Annual Water Quality Index curve (WQI)

b = Frequency of Troughs in Annual Hyetograph (P) and Frequency of Peak in Annual Hydrograph (Q)

The importance was determined by the rank achieved by the alternatives with respect to the criteria. The rating for depicting importance was given according to the Satty scale.

The geometric sum of each of the rows are calculated and normalized to find the weight of importance of the alternatives with respect to the criteria. Thus for each criteria, alternatives will have separate weight of importance. Ultimately a 5×8 matrix was drawn where weight of criteria is multiplied by the weight of alternatives for that criterion and averaged to find the weight of importance of the alternatives.

In case of FLDM, the pair-wise rating was performed with the help of littoral fuzzy ratings. The fuzzy rating was then converted to crisp rating by the application of theory of maximization. The weight of importance of the criteria and alternative in case of FLDM is estimated by Eq. 5.15.

$$W = \mathrm{Norm}\{\mathrm{Avg}(r/R)\} \quad (5.15)$$

where W is the weightage of importance, r is the score of the littoral rating of the row alternative with respect to the column alternative and R is the maximum score of the row.

Avg indicates the average value of the r/R of a row. The normalization of the average value of each row is taken as weight of importance of the alternatives or criteria represented by the row.

All the other steps for comparing the criteria, alternative and resultant super matrix is similar to the AHP method.

5.1.4 Determination of Priority Values

The priority value was determined with the help of the average of the results from AHP and FLDM method.

5.2 Water Limitation Index

After the weight of importance is determined an index was developed with the help of the weight and the magnitude of the a and b parameters. The weighted average of all the parameters is proposed as the index for representation of the vulnerability of water resources or severity of the water shortage problem. The function is represented in Eq. 5.16.

$$V = \frac{\sum_{i=1}^{9} w_i \times D_i}{\sum_{i=1}^{9} w_i} \tag{5.16}$$

where V is the Water Limitation index, w_i is the weightage of importance of the a and b parameters as determined in the previous section.

5.3 ANN

The present study aims to develop index for representation of the impact of climate change and urbanization on availability of water resources.

In this regard some algorithms have to be prepared so that V can be automatically calculated once the values of the a and b parameters of the area of interest is given as input. Due to the popularity of ANN, in mapping non-linearity and unknown relationships the said algorithm is applied to estimate the Water Limitation Index (V). Another reason for applying ANN is to remove the requirement of repeated application of the MCDM methods once a new alternative is added. In the present study the ANN models were applied to predict the decision for the new alternative based on the existing knowledge that was gained from the available set of data.

As only normalized data is fed to the model the impact due to the difference of scale will be absent and thus the same model can be used for different locations.

5.3.1 Input and Output

The input to the model was selected to be:

As *a* parameters:
Frequency of Peaks in Annual Water Demand curve for Domestic Consumers (Dd),
Frequency of Peaks in Annual Water Demand curve for Agriculture Consumers (Da),
Frequency of Peaks in Annual Water Demand curve for Industrial Consumers (Di),

Percentage Impervious Area (last 10 years) (A),
Annual Average Area of Canopy (Ac) and
Frequency of Troughs in Annual Water Quality Index curve (WQI)
As *b* parameters
Frequency of Troughs in Annual Hyetograph (P) and
Frequency of Peak in Annual Hydrograph (Q)
The *output of the model* is the Water Limitation Index or V.

5.3.2 Topology

The number of hidden layers is responsible for quick learning of the problem but also increase the load on the computational infrastructure. That is why, selection of an optimal number of hidden layers is important for efficient performance of the neural network models and in the present study the said task was performed with the help of genetic algorithms where 50 generations were produced from 40 populations. The cross over rate was fixed at 0.8 whereas the mutation rate was controlled within 0.2.

5.3.3 Training

In development of the ANN model a training dataset is required to be provided. The dataset for training is the normalized representation of the magnitudes of the input variables in a specific location. That is why if different situations of the normalized output of the input variables are fed to the index and then the interrelationship between the input and output variable can be mapped the neural model then an universally acceptable modelling framework can be prepared which can be applied to any location of the World for the analysis of the severity of water shortage.

Thus the neural model is trained with a normalized set of data representing different situations of the input variables and the corresponding results of the situation which are calculated by the index.

A combinatorial search algorithm was used to train the ANN model and the architectural pattern of polynomial neural networks was followed to perform the iterations for identifying the optimal weights of the input variables.

5.3.4 Performance Metrics

The following performance metrics are analysed to find the accuracy of the model:

- Maximum Negative Error

- Max Positive Error
- Mean Absolute Error
- Root Mean Square Error
- Standard Deviation of Residuals
- Correlation Coefficients

5.4 Sensitivity Analysis

The sensitivity analysis was performed with the help of Multiple Input One output Tornado method developed by SensIt Limited. The range for the input variables were varied between 0 and 1. The impact of each input is then observed on the output and the results were compared with the weights of the variables found from the MCDM analysis.

5.5 Scenario Analysis

Three locations were selected having different level of population density. All the three locations are situated beside the river. The name of the locations and river is given below:

1. Farakka Township on River Ganges
2. Mahi River Dam on Mahi River
3. Vaigai Dam in River Periyar

5.5.1 Farakka Township

The Farakka Barrage diverts water from the Ganga to the Bhagirathi distributary (which becomes the Hooghly downstream) via a feeder canal that is 41 km (25.5 miles) long and 300 m (0.2 miles) wide and has locked gates (Figs. 5.1, 5.2 and 5.3).

The River Ganga (Ganges) originates at the Gangotri Glacier of the Uttaranchal Himalayas at an altitude of about 5 miles. It flows through the plains of North India, breaks into its first distributary, the Hooghly, 11 miles before it enters Bangladesh as the Padma River. The Padma eventually joins with the Jamuna (of the Brahmaputra) and Meghna (of the Barak) in Bangladesh and branches into an intricate net of distributaries, all of which finally pour into the Bay of Bengal. The Ganga has a length of over 1,620 miles and drains an area of nearly 405,600 square miles in northern India, Bangladesh, Nepal, and southern Tibet.

Fig. 5.1 Figure showing the location of Farakka Township

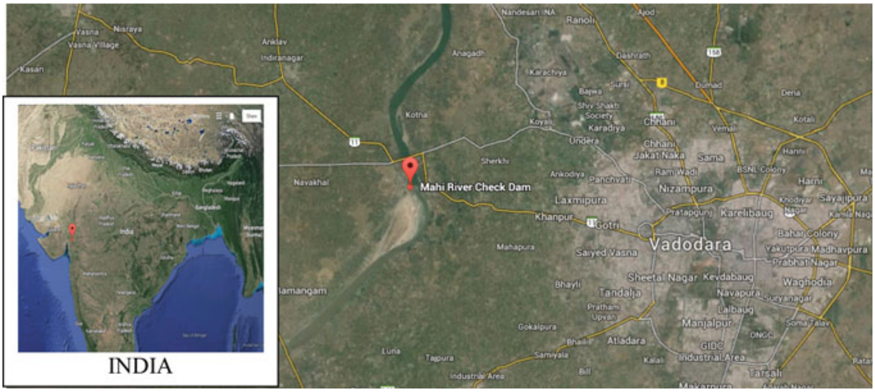

Fig. 5.2 Figure showing the location of Mahi River Dam on River Mahi

Rivers are a dominant force behind Bangladeshi cultural and economic identity. Roughly 60 % of the Bangladeshi population are farmers, who depend heavily on cycles of flow and siltation. Fish constitute as high as 80 % of the Bangladeshi diet. The world's largest delta formation, the mighty mangrove forests of the Sundarbans, lies mostly in Bangladesh.

In addition to the three main rivers Padma, Meghna and Jamuna, about 55 smaller rivers and tributaries enter Bangladesh from India, and three from Myanmar. 94 % of Bangladesh's aboveground freshwater supply thus originates from outside its political boundaries. As the lowermost riparian state of the Ganga-Brahmaputra-Meghna basin, Bangladesh is most vulnerable to ecological degradation and water withdrawal upstream. Total Area of the Farakka township is 3.7 km^2, Population Density is 5,439.5 inh/km^2 [2011]—Change in 2011 from 2001 is −0.91 %/year.

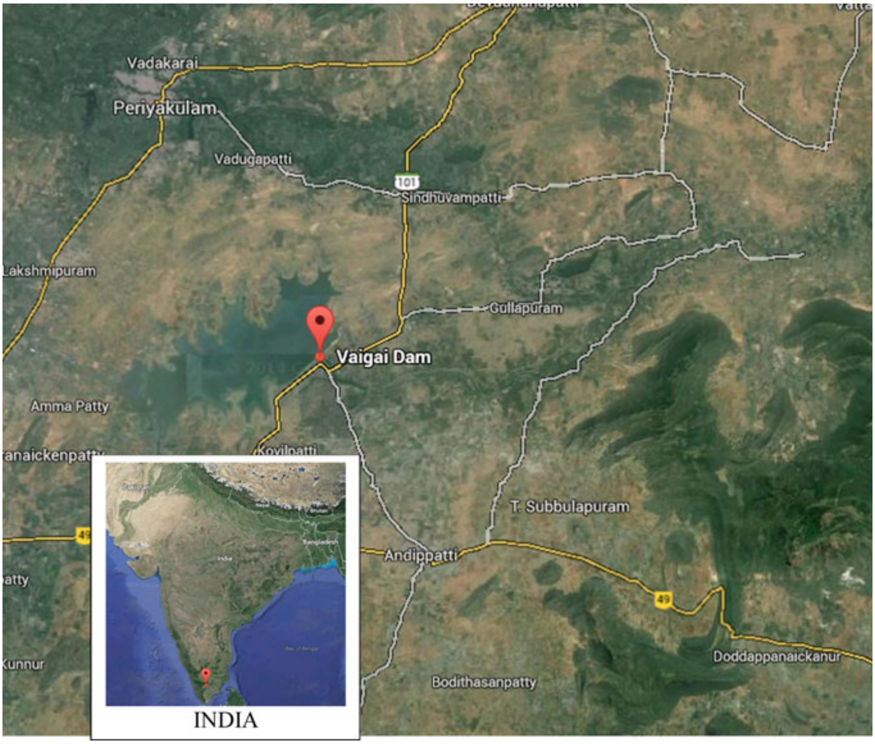

Fig. 5.3 Figure showing the location of Vaigai Dam on River Vaigai

5.5.2 Mahi Dam

Mahi River originates from Vindhyachal Hills, Madhyapradesh and meets in Bay of Khambhat. Its total length is 583 km and catchment area is 34,842 km^2. Bhadar is right bank tributary and Panam, Kun and Goma are left bank tributaries of Mahi river.

On Mahi river Kadana dam is situated at 25 km distance. Its catchment area is 25,520 km^2. Wanakbori weir is situated at 102 km on Mahi river having 30,665 km^2 catchment area.

There is Bhadar dam on river Bhadar at 19 km distance having 407 km^2 catchment area.

Hadaf and Koliyari are two subtributaries of Panam river. Panam dam is located on Panam river at Panam at distance of 83 km having catchment area 2312 km^2 Kabutri and Wankadi are subtributaries of Hadaf river. Hadaf dam is situated on Hadaf river having 508 km^2 catchment area. Umaria dam is also located on Hadaf river at 13 km distance having 73 km^2 catchment area.

Karad dam is situated on Karad river at 13 km distance having 130 km^2 catchment area. Goma dam is located on Goma river at 120 km distance having 175 km catchment area.

5.5.3 Vaigai Dam

Vaigai Dam on River Vaigai which originated from the longest Periyar River of Kerala—which empties at Periyar Lake—wherefrom water is being let out into Vaigai River. Over the centuries, the population explosion to manifold proportions, had it that Dams were to be constructed across the rivers, to regulate the flow and save water in reservoirs for irrigation and power generation purposes.

Unlike the ancient times, where Rivers were flowing in their natural course, these man-made developments changed the entire scenario. Border disputes and sharing of river waters between the riparian States have become political problems of today. The Mullai-Periyar Dam issue is a heated up dispute between Kerala State and Tamil Nadu. Result is Vaigai River has been left “high and dry” in the true sense of the phrase.

Tamilnadu built the Vaigai Dam, across the Vaigai River to feed irrigation waters to many areas like Theni, Kambam etc., which are on the upper portions of the River than Madurai City. This is also another reason why Vaigai River, which flows in the centre of present Madurai City, has gone dry.

All in all Vaigai River gets water, if only the Dams are full during rainy season and otherwise for many months in a year the river looks pathetic. Worse still if the monsoon fails and the Dams—Periyar and Vaigai—do not get any water at all.

The annual Chithirai Thirunall Festival, (during the hot summer month of April) conducted to enact the divine marriage of Meenakshi Amman with Sundareswarar, during which time the Kallazahar (Lord Vishnu) is brought to take a holy-dip in Vaigai River, is also getting jeopardized because of this. This is a famous festival at Madurai, when hundreds of thousands of people from various parts of not only Tamilnadu but also from other States converge at Madurai.

To tide over the crisis of acute water shortage, the authorities select a specific place in the middle of the river and pour water brought through hundreds of vehicles, to make an artificial pool. It is here Azhagar dips into Vaigai River—not to forego a religious ritual of centuries old!