Jordan Journal of Civil Engineering, Volume **15**, No. **3**, **2021**

An Integrated Model of Water Conservation Strategies in Drought-prone Areas of Marathwada Region Using FAHP Technique

Aboli A. Ravikar [1]***, Deepa A. Joshi*** [2] ***and Radhika Menon*** [3]

[1] Student, Department of Civil Engineering, Dr. D.Y. Patil Institute of Technology, Pimpri, Pune, India. E-Mail: ravikaraboli2@gmail.com
[2] Professor, Department of Civil Engineering, Dr. D.Y. Patil Institute of Technology, Pimpri, Pune, India. E-Mail: joshi.deepa13@gmail.com
[3] Professor, Department of Mathematics, Dr. D.Y. Patil Institute of Technology, Pimpri, Pune, India E-Mail: radhika.tharoor@gmail.com

ABSTRACT

Water conservation simply means using less water, avoiding or minimizing the wastage of water and/or recycling water, so that it can be used again for different purposes. In dry parts of India, conserving water is of prime importance and so, different techniques need to be adopted. In this paper, a model of water conservation strategies and systems in the residential home, using the city of Aurangabad as a basis, has been explored using the multi-criteria decision-making technique. The Fuzzy Analytic Hierarchy Process (FAHP) is applied to structure the decision problem into a hierarchy framework and thereby five criteria were used to evaluate the elements. The paper is intended to present an integrated model of the major options in residential water conservation in 4 different degrees using a case study. Applications of all the technologies/systems obtained from FAHP are used to address the entire lifecycle of water, right from its arrival on site to its use and eventual expenditure. The study also compares the financial implications among the different systems, where it is found that the payback period is least for plumbing fixtures and highest for wastewater treatment system. It is also observed from the case study that around 39.13% of water savings is achieved after the up-gradation of the existing plumbing fixtures. It is found that dependence on municipal water supply is reduced by 67.30% after recycling water in various sectors in house. The greywater generated in house is completely being used in water closets and outdoor use. Various internal purposes are satisfied from the harvested rainwater and savings of around 86.75% are achieved. As all of the water requirements are satisfied from the technologies used, less than 40% of wastewater is discharged in the municipal system. So, it is expected that the proposed system will enable occupants to be aware of their water usage and control and reduce water usage levels.

KEYWORDS: Fuzzy analytic hierarchy process (FAHP), Fuzzy logic, Green building, Sustainability, Water conservation.

INTRODUCTION

Worldwide, water is of greater concern than any other natural resource. Water pollution is one of the contributing factors to water scarcity; when water is scarce, people may become desperate, drinking potentially contaminated water. Only 1.2% of fresh water is drinkable and accessible without sophisticated, expensive technology (Cook, 2011). With the increase in population, the demand for water also increases and the infrastructure also spreads. This in turn leads to pollution and so, in response to this, a green building movement emerges. Sustainability and integrated design are the two main aspects of green building which are quite essential in planning and are also necessary when designing any project. Savings that occur in all sectors when building green are remarkable. The initial building costs can be no more than those of a conventional structure; but because a green building is more efficient, savings continue throughout the entire lifetime of the

Received on 19/10/2020.
Accepted for Publication on 9/6/2021.

structure. In addition to environmental and economic benefits, green buildings also enhance comfort and health of occupants by improving air quality, thermal conditions and the overall work. Water conservation is one of the aspects in green building and its objective is to reduce water use and protect its quality. Sustainable solutions are required that meet current and projected demand and preserve natural and human cycles.

Need of the Study

Water scarcity due to least rainfall and improper management of water systems in cities, such as Aurangabad, Jalna, Beed, Latur…etc of Marathwada region, has led to drought issues and threatened high standard of living. The growing awareness of impact of water quality and its availability has led us to use water sparingly and adopt more efficient water usage and conservation techniques.

Also, the water infrastructure right now in Aurangabad region cannot support the current demand and changes are required to be implemented from the ground up. This has also enabled the powerful lobby of water tank mafias to expand their business illegally in the region. To overcome the problem of water scarcity, it is of utmost importance to conserve and wisely use the available water. Through the implementation of water conservation and management strategies, the issues associated with increased water demand can be eliminated, but the cost of water is also an important factor when considering the scarcity and importance of potable water.

Objectives

The main objectives of the study are:

i. To investigate the various water conservation and management strategies for residential houses.
ii. To develop criteria and weights for selecting the most suitable water conservation strategy using the FAHP technique.
iii. To propose a comprehensive design solution model using the strategies for the particular area of concern.

In this paper, a model of water conservation strategies and systems in residential homes, using the city of Aurangabad as a basis, has been explored using a multi-criteria decision-making tool. The Fuzzy Analytic Hierarchy Process (FAHP) has been applied to structure the decision problem into a hierarchy framework and thereby five criteria were used to evaluate the elements. The model would address the entire lifecycle of water from its arrival on site to the use of the water and eventual expenditure. Based on the body of knowledge in the field and the research findings, a comprehensive design solution will be proposed. The design will also evaluate the different systems in terms of: catchment, treatment, filtering, reuse and returning the used water into nature. It is expected that the proposed system will inform occupants of their water usage and simultaneously control and reduce water usage levels.

METHODS AND TECHNIQUES

Fuzzy Analytic Hierarchy Process (FAHP)

Fuzzy Analytic Hierarchy Process (FAHP) embeds the fuzzy theory to basic Analytic Hierarchy Process (AHP), which was developed by Saaty. Since basic AHP does not include vagueness for personal judgments, it has been improved by benefiting from fuzzy logic approach. In FAHP, the pair-wise comparisons of both criteria and the alternatives are performed through the linguistic variables, which are represented by triangular numbers (Ayhan, 2013). By using FAHP method, we can help a decision-maker make more efficient, flexible and realistic decisions based upon the available criteria and alternatives (Dwi Putra et al., 2018). Therefore, the authors wish to apply the FAHP method to select water conservation and management strategies.

The basic steps involved in FAHP application are as follows:

i. Modeling the problem into manageable sub-problems as a hierarchy of goals at the top, criteria or evaluating parameters at the next level and alternative choices to be made in reaching the goals at the bottom.
ii. Each branch is then further divided into an appropriate level of detail. (At the end, the iteration process transforms the unstructured problem into a manageable problem organized both vertically and horizontally under the form of a hierarchy of weighted criteria).
iii. Listing the attributes against alternatives in a matrix along with their respective values.
iv. Assigning numerical weightage to each attribute

from the questionnaire survey by converting the verbal scale into a fuzzy triangular scale of 1 to 9.

Table 1. Linguistic scale and the corresponding triangular fuzzy numbers

Saaty Scale	Definition	Fuzzy Triangular Scale
1	Equal Importance	(1, 1, 1)
3	Moderate Importance	(2, 3, 4)
5	Strong Importance	(4, 5, 6)
7	Very Strong Importance	(6, 7, 8)
9	Extreme Importance	(9, 9, 9)
2	The intermittent values between two adjacent scales	(1, 2, 3)
4		(3, 4, 5)
6		(5, 6, 7)
8		(7, 8, 9)

v. Pair-wise comparison of each attribute against all others is done (in a matrix) in terms of relative importance.

vi. The geometric mean of fuzzy comparison values of each criterion is calculated.

vii. The fuzzy weight (attribute weightage) is obtained and the consistency of the matrix is checked.

viii. Pair-wise comparison of each technology against all others is done with respect to each attribute and the priority vectors are obtained.

ix. The overall composite weight of each alternative is computed based on the weightage obtained from step vii, as a normalized linear combination of attribute weightage and priority vector.

x. The ranking is as per the overall weightage of alternatives. The higher the weightage, the higher the ranking (Yaparla et al., 2011).

METHODOLOGY

As the study is focused on creating a model of water conservation strategies for drought-prone areas of Marathwada region, the steps involved are shown with the help of a flowchart:

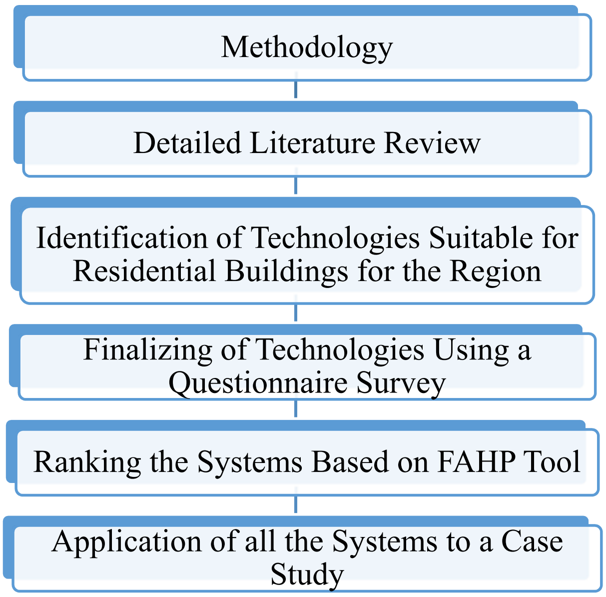

Figure (1): Methodology flowchart

i. Understanding the scenario of water conservation strategies from the secondary information gathered from literature search of books, research papers, professional articles… etc.

ii. Identification of technologies; identification of ten technologies is undertaken using internet, market survey, household survey, talking to a number of people, for finding out the suitable water conservation solutions. The technology alternatives selected are obtained through primary data collection gathered from information obtained from discussions with key informants.

After conducting the questionnaire survey, ten technologies/systems have been considered for the present study: NB: Non-beneficial attribute; B: Beneficial attribute; T: Technology, T1- Aerators; T2- Siphonic dual flush systems; T3- No-tank toilets; T4- Drip irrigation systems; T5- Rainwater treatment using natural filter; T6- Rainwater treatment using artificial / man-made filters; T7- Greywater treatment using sand filters; T8- Mesh filter bag; T9- Membrane Batch Reactor (MBR) method; T10- Sequencing Batch Reactor (SBR) method.

iii. Order of preferences has been set through a questionnaire survey based on the following five criteria:

i. Time Factor.
ii. Social Factor.
iii. Technology Factor.
iv. Economic Factor.
v. Performance Factor.

iv. Ranking of the technologies is carried out using A Multi-criteria Decision Making (MCDM) tool which enables the user to select the appropriate choice of technology in different contexts. Fuzzy Analytical Hierarchy (FAHP) process is the MCDM tool primarily used for the analysis.

v. Using the results of FAHP, all the methods/ strategies are applied to the existing Aurangabad residential row house project to provide a complete water management solution that would address the entire lifecycle of water.

FAHP APPLICATIONS

FAHP is applied to the selected ten technologies and the steps involved in this technique are explained with the help of the flowchart given below:

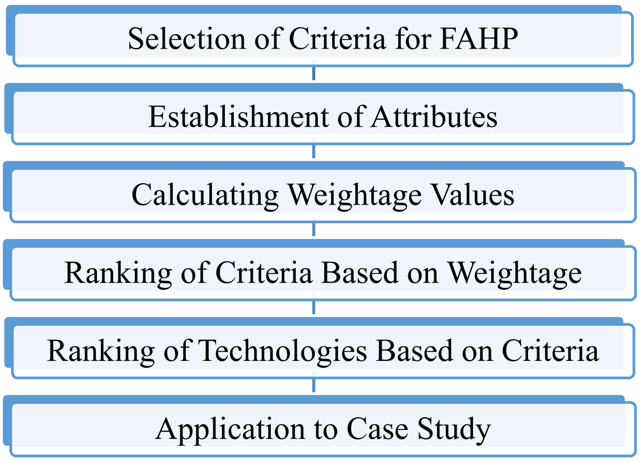

Figure (2): Steps involved in FAHP technique

Hierarchy Decomposition of Attributes

In this hierarchical structure, the technology alternatives in sustainable water conservation and management are considered to be characterized by five main attributes in level 1: (time, social, technology, economic and performance) factors under which sub-groups are grouped hierarchically. The description of attributes of each level is given in Table 1. The time factor is characterized by the construction/installation time and frequency of maintenance time. The attribute social factor is characterized by suitability to different socio-economic strata and ease of acceptance of the technology. Technological factors are characterized by space requirement for installation /construction, requirement of specific arrangements for installation and possibility of self-maintenance. Economic factor is characterized by two sub-attributes; initial cost or cost of construction and maintenance cost, while performance factor is characterized by ability to treat/ conserve water and durability of technology at level 2 (Yaparla et al., 2011).

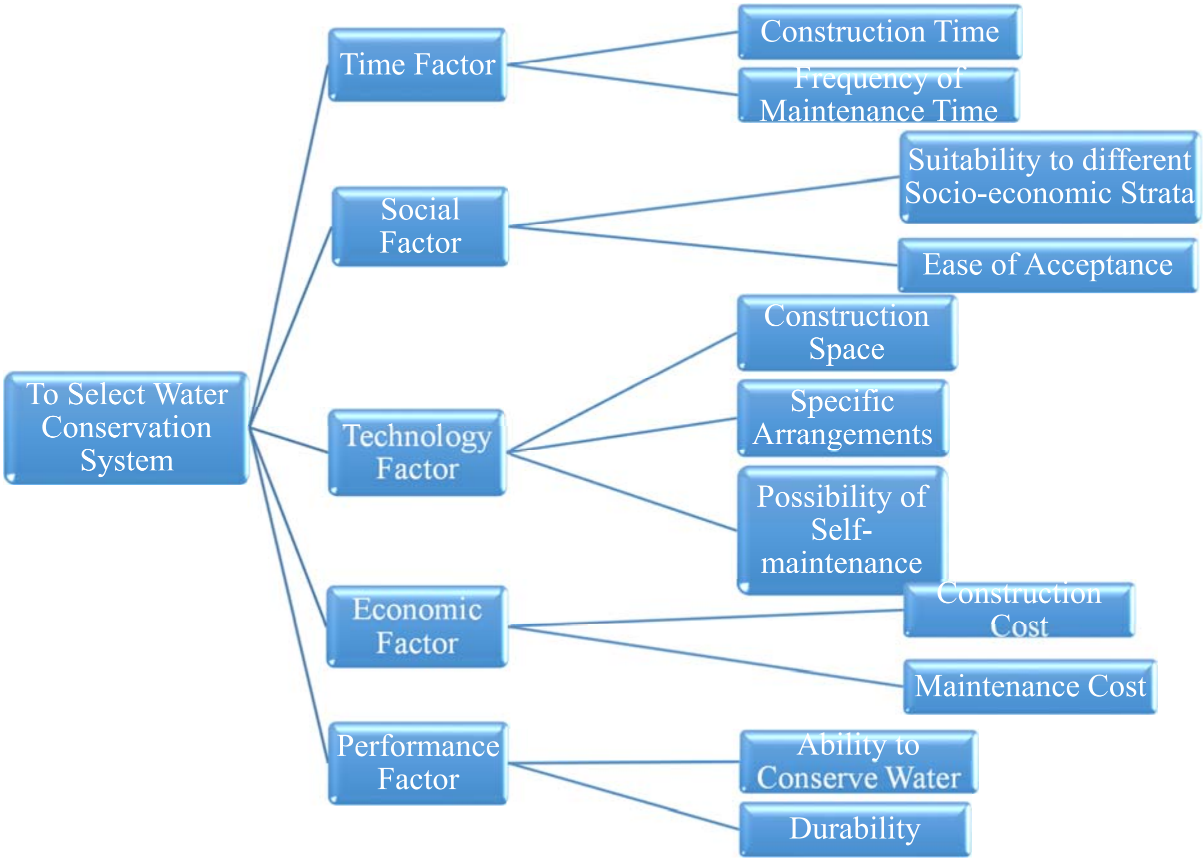

Figure (3): Hierarchic structure of criteria and sub-criteria

Table 2. Criteria selected for AHP and their characteristics

Criterion Characteristics	**Criterion**	**Name**	**Description**
Time factor (C1)	$C1_A$	Installation / construction time	Time required for installation or construction of the technology measured in hours
	$C1_B$	Frequency of maintenance time	Time interval between two maintenances measured in months
Social factor (C2)	$C2_A$	Suitability to different socio-economic strata	Suitability to majority class of the people
	$C2_B$	Ease of acceptance of technology	Technology acceptable without much lifestyle changes
Technological factor (C3)	$C3_A$	Construction Space requirement	The additional space requirement in ft^2 which consumers have to allot
	$C3_B$	Requirement of specific arrangements	Need for specific arrangements like power supply, pipeline connection, storage … etc.
	$C3_C$	Possibility of self-maintenance	Ability to maintain the technology by users themselves
Economic factor (C4)	$C4_A$	Construction cost	Initial amount invested on a technology usually in Rs
	$C4_B$	Maintenance cost	Amount spent for maintenance usually measured in Rs/year
Performance factor (C5)	$C5_A$	Ability to conserve/treat water	Amount of water conserved or quality of treatment
	$C5_B$	Durability	Determines the life of the technology usually measured in years

Attribute Comparison

For AHP comparison, attributes are established and compared using a 5-point scale, in which 1 stands for 'VERY LOW', 2 stands for 'LOW', 3 stands for 'MEDIUM', 4 stands for 'HIGH' and 5 stands for 'VERY HIGH. The values are then classified as beneficial and non-beneficial attributes. Beneficial attributes are those the higher values of which are desired, whereas non-beneficial attributes are those the lower values of which are preferred. The values are given in Table 3.

Table 3. Values of beneficial and non-beneficial attributes

Criteria	Technology	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
C1A	NB	1	2	2	2	3	3	4	2	5	5
C1B	NB	4	2	2	3	3	3	3	5	2	2
C2A	B	5	4	4	4	3	3	3	4	2	2
C2B	B	5	4	5	5	4	4	3	4	3	3
C3A	NB	1	2	1	2	3	3	3	1	5	5
C3B	NB	2	3	3	4	4	4	5	2	4	4
C3C	B	3	1	1	3	3	3	2	3	1	1
C4A	NB	1	3	2	2	2	3	3	2	5	4
C4B	NB	1	3	2	2	2	3	3	2	5	4
C5A	B	4	4	5	5	4	4	3	2	5	4
C5B	B	2	4	3	3	3	4	3	2	5	4

Criteria Weightage

During the judgments, the weights were attributed through a questionnaire survey which was distributed to experts in the same field residing in Marathwada region. To illustrate the judgments made by the decision-makers, Table 4 shows the matrix used to calculate the weights of the main criteria. In this case, the inconsistency was 0.0271 and the results were considered acceptable.

As fuzzification means, converting linguistic term into membership function, the matrix values are converted into fuzzy numbers with the help of Saaty scale. The process further involves finding the reciprocal values and geometric means to calculate the weightages.

Table 4. Criterion weightage values

Criterion	Time Factor	Social Factor	Technology Factor	Economic Factor	Performance Factor	Priority Values
Time Factor	(1,1,1)	$(\frac{1}{6},\frac{1}{5},\frac{1}{4})$	$(\frac{1}{3},\frac{1}{2},\frac{1}{1})$	$(\frac{1}{8},\frac{1}{7},\frac{1}{6})$	$(\frac{1}{9},\frac{1}{8},\frac{1}{7})$	0.043
Social Factor	(4,5,6)	(1,1,1)	(2,3,4)	$(\frac{1}{5},\frac{1}{4},\frac{1}{3})$	$(\frac{1}{3},\frac{1}{2},\frac{1}{1})$	0.179
Technology Factor	(1,2,3)	$(\frac{1}{4},\frac{1}{3},\frac{1}{2})$	(1,1,1)	$(\frac{1}{6},\frac{1}{5},\frac{1}{4})$	$(\frac{1}{6},\frac{1}{5},\frac{1}{4})$	0.074
Economic Factor	(6,7,8)	(3,4,5)	(4,5,6)	(1,1,1)	(1,2,3)	0.462
Performance Factor	(7,8,9)	(1,2,3)	(4,5,6)	$(\frac{1}{3},\frac{1}{2},\frac{1}{1})$	(1,1,1)	0.326
CI: 0.0304						**CR: 0.0271**

CI: Consistency Index, CR: Consistency Ratio.

Ranking of Criteria

After comparison of attributes at each level, priority values have come up showing that the initial cost or construction cost is given most preference, as people preferred to have low-cost technology. The maintenance cost also plays an important role. Economic factor is followed by performance factor, wherein the ability to treat or conserve water is given the next priority, followed by durability of the technology as users want the technology to sustain for a long period. Then comes the social factor which is among the important factors. Suitability to different socio-economic strata is given preference as the technology must be affordable to all the classes of society, which is then followed by the ease of acceptance of the technology. Technology factor follows the social factor, wherein possibility of self-maintenance is highly preferred compared to the other two factors as it is desirable that users should be able to maintain the system by themselves. Among the sub-attributes of the time factor, construction time is preferred over the frequency of maintenance time, as it is desired to construct or install a system in the minimum possible time.

Table 5. Criterion-and sub-criterion priority value and ranking

Criterion Number	Priority Value	Ranking
C1A	0.0362	7
C1B	0.0069	10
C2A	0.1601	3
C2B	0.0177	8
C3A	0.0140	9
C3B	0.0062	11
C3C	0.0499	5
C4A	0.4065	1
C4B	0.0530	4
C5A	0.2160	2
C5B	0.0410	6

Ranking of Technologies

As this proposal involves major options in residential water conservation in 4 different degrees, comparing them on a multitude of criteria *viz*. existing home fixture replacement, rainwater harvesting, “down-cycling” water with a grey water reuse system and off-the-grid, on site catchment, treatment and reuse, the technology selected will be from each head. It is found out that use of aerators in faucets and taps is most preferred. No-tank toilets are preferred over siphonic dual flush systems, as cost plays an important role for every technology. Drip irrigation system is preferred for gardening purpose, but since there is minimal landscape available for houses in the region, watering can be directly done with aerator-fitted taps. It is well known that it is important to treat or filter rainwater after its collection which can be done using natural filters or artificial filters and it is found that use of natural filters is preferred over artificial filters. The mesh filter bag method of primary treatment of greywater is most preferred, followed by treatment using sand filters. Using of Canna plants gives added advantage for greywater treatment. As there are very limited options for treating black water in individual residential buildings, SBR method is preferred.

Table 6. Criterion weights and ranking of technologies

	C1A	C1B	C2A	C2B	C3A	C3B	C3C	C4A	C4B	C5A	C5B	Weight	Rank
T1	0.0362	0.0034	0.1601	0.0177	0.0140	0.0062	0.0499	0.4065	0.0530	0.1728	0.0164	0.9362	1
T2	0.0181	0.0069	0.1280	0.0141	0.0070	0.0040	0.0164	0.1341	0.0174	0.1296	0.0328	0.5084	8
T3	0.0181	0.0069	0.1280	0.0177	0.0140	0.0040	0.0164	0.2032	0.0265	0.2160	0.0246	0.6754	3
T4	0.0181	0.0045	0.1280	0.0177	0.0070	0.0031	0.0499	0.2032	0.0265	0.2160	0.0246	0.6986	2
T5	0.0119	0.0045	0.0960	0.0141	0.0046	0.0031	0.0499	0.2032	0.0265	0.1728	0.0246	0.6112	5
T6	0.0119	0.0045	0.0960	0.0141	0.0046	0.0031	0.0499	0.1341	0.0174	0.1728	0.0328	0.5412	7
T7	0.0090	0.0045	0.0960	0.0106	0.0046	0.0024	0.0329	0.1341	0.0174	0.1296	0.0246	0.6726	4
T8	0.0181	0.0027	0.1280	0.0141	0.0140	0.0062	0.0499	0.2032	0.0265	0.0864	0.0164	0.5655	6
T9	0.0072	0.0069	0.0640	0.0106	0.0028	0.0031	0.0164	0.0813	0.0106	0.0864	0.0410	0.3303	10
T10	0.0072	0.0069	0.0640	0.0106	0.0028	0.0031	0.0164	0.1016	0.0132	0.1728	0.0328	0.4314	9

Based on the preferences obtained for technologies in all four degrees, a water management model is proposed with the help of a case study. The model would address the entire lifecycle of water from its arrival on site, to the use of the water, treatment and eventual expenditure.

A Case Study

Aurangabad, the headquarter of Marathwada, was selected as it is best suited among the different selection criteria in terms of relevance. Water conservation in such developing areas could impact a large number of occupants. Also, it was observed that there was twice a week municipal water supply in the area and water prices are relatively high, which created a need to save and manage water. Currently, the household selected for the study is paying a tax amount of Rs 4050 annually. This amount is charged for ½ inch connector pipe. One of the most important aspects of sustainable water conservation is the ability for it to be financially feasible with a minimum payback period. This is a financial tool used to calculate savings *vs*. initial cost of an investment over a period of time. Assuming an expected lifespan for the house at 50 years, anything beyond that value will be considered a loss.

Monetary Model Assumptions

i. Water prices are on an exponential climb.
ii. The family is ready to invest 2% of its annual income.
iii. Family income remains stable.
iv. Lifespan of the house is 50 years.

The household selected for this project was a prototypical row house system from Aurangabad. The houses in Marathwada region are more of prototypical bunglows and row houses and less of flat systems. The house selected is a 2BHK with built-up area of 950 sq.ft. and is a seven-year old construction. For the city of Aurangabad, the average household occupancy of 2.61 average family size is 3.17 (India Census Bureau, 2011). For the case study, a typical family of two parents and two children was selected. The annual income of the family is 10 lakh rupees.

Out of the ten technologies, use of aerators, tankless toilets, rainwater harvesting using natural filters, greywater treatment using sand filters, mesh filter bag and treatment of blackwater using SBR method will be applied in the case study for water management and conservation.

Appliance Level Systems

The current total water usage of the household with the existing fixtures and upgraded fixtures is calculated. After the calculations, upgradation in the fixture is suggested by considering parameters like full time equivalent (FTE), flowrate, duration of flow and number of times of use. The proposed upgradation and the result obtained are presented in a Table 7.

Table 7. Breakdown of water usage in case-study house

Sr.no.	Areas of water usage		Water usage (liters/day)	
	Indoor	**Outdoor**	**Existing Fixtures**	**Upgraded Fixtures**
1.	Faucets/ Taps		80	20
2.	Water Closets		152	104
3.	Showers		192	144
4.	Kitchen Sinks		96	48
5.	Laundry		95	54
6.	Cooking & drinking		28	28
7.		Gardening, Cleaning &Car Washing	24	08
		Total	**667**	**406**

Existing fixtures of faucets and taps with a flow rate of 6 LPM-8 LPM are being suggested for upgrading by using foam flow aerators and straight shower flow aerators of flow rates of 2-4 LPM. The full flush toilet system is suggested to be replaced with no-tank toilet system. A tankless toilet is any toilet that does not rely on a tank of water to clear its bowl. Instead, tankless toilets receive water directly from a supply line at a high enough pressure, so that a single flush can carry human waste through the drainage system (Jamrah and Ayyash, 2008). These are easily available on online shopping sites or in nearby retail stores. Installation time is between 1-2 hours and frequency of maintenance time for these systems is after every 24-36 months. Since these systems are not much costly, they are suitable for almost every type of people. There is no much lifestyle change required in getting habitual to the upgraded fixtures and so they are easily acceptable by people. Space required for installation of aerators is minimum and for tankless toilets, a standard space is required for the construction of the toilet (i.e., around 12 sq.ft.). No extra space is required.

Considering the proposed upgraded fixture system, the following conclusions are drawn in terms of water conservation, cost and payback period.

i. The ability to conserve water using the proposed upgraded systems is 39.13% and durability is around 3-5 years.
ii. Cost and payback period play an important role. Payback period is calculated by dividing the initial amount invested for a system by the annual saving achieved using the same and so, payback period of upgraded fixtures comes out to be 5.67 years.

Rainwater Catchment, Treatment and Storage

Rainwater harvesting is a process of collection of rainwater from surfaces on which rain falls, filtering it and storing it for multiple uses (Internet, 2021). Harvested rainwater is a renewable source of acceptable quality that is used for different purposes, including drinking, cooking, watering gardens and indoor and outdoor cleaning. Water catchment is an innovative way to not only decrease reliance on potable water, but to also to engage the building site. Typically, there are two different catchment options on site for residential homes: ground and roof. Ground systems are typically of simplest installation, but the hardest to control and use later. There is no viable option for redirecting the water to storage or interior usage. The second system is the most flexible and has the advantage of engaging the seldom used roof area of a home. A major advantage to both of these systems is that catchment requires almost no money upfront. The only additional cost would be to keep up the roof and for the secondary plumbing required (Cook, 2011). For this house, water requirement in faucets/taps and laundry is to be satisfied with rainwater.

In the current study, the rainfall data of 20 years is taken and the rooftop area for harvesting rainwater is considered so that rainfall potential is calculated using Nissen Formula. Annual water demand is also calculated considering parameters, like *per capita* demand, population and number of days in a year. The results are shown in Table (8).

Table 8. Annual rainwater potential and demand of water

Number of persons	Total annual rainwater harvesting potential (liters)	Total annual demand of water (@ 70 liters)	Remark
04	32632	25550	Demand is satisfied with rainwater and 7082 L water is further left for future use

Storage: For storage, there are two main options: surface storage and underground storage. Area of storage tank is calculated from daily dischar8uige and the rainwater harvesting potential. The results are tabulated in Table (9).

Table 9. Storage tank design and volume

	Daily discharge of rainwater	Volume	Volume of storage tank (per day)
Cum.	0.064	0.25	1.0*0.5*0.5
Litres	64.813	250	1.0*0.5*0.5

Filters play an important role, as the design, construction and maintenance aspects of these determine the effectiveness of rainwater harvesting. As PVC drums are light-weight, easy to transport and easy to install, hence in the present case study, PVC drum filter is proposed.

The container is filled with filtering material. It can be coarse gravel, smaller gravel, sand and wire mesh with coarse gravel at the bottom and smaller gravel above it. The topmost layer must be of sand. All layers are usually 15 cm deep. The time required for constructing of rainwater harvesting system using PVC surface storage tank is about 2-3 days. It is maintained by removing the mesh on top of the sand after every rain and cleaning it under a running tap. A drum filter costs around Rs 1000. If kept in the shade and maintained properly, PVC drums can last over 6-10 years. The payback period for rainwater harvesting system is 6.79 years, which is typically within the lifespan of the building.

Greywater Systems

This section explores a concept known as "down-cycling of water". This method of water conservation increases the effectiveness of the water brought on site by allowing it to go through several stages of use. After initial use, the water is referred to as greywater, which is non-potable, but still viable in low-risk uses in a home. This greywater comes from the drains of sinks or showers and is not fit for drinking, but can be used in other ways in the home. For our scenario, 166 litres/day greywater is generated and is completely used with required treatment in toilets, laundry and for outdoor purposes. From the preferences of technologies concluded from AHP, initial treatment is done using a mesh filter bag that removes away large particles, such as hair, lint… etc. immediately. It is easily available and requires minimum time for installation. But it requires frequent maintenance, as it needs to be cleaned up after every 15 days or a month. It is highly suitable and easily acceptable by people, as it doesn't require major lifestyle changes. It is required to be placed on the mouth of pipeline from where the greywater is introduced into the underground water tank. Once the greywater has been pre-treated, it can be filtered using a very simple soil box, also called soil filter, consisting of four layers of materials, like sand beds, fine particles, coarse-size brick beds, charcoal beds… etc.

Another way of treating the greywater is using a wetland, where the water is retained at a level close to the surface, allowing aquatic plants such as reeds and Canna plants to flourish. Subsurface wetlands are considered better for treating greywater, as they lower the chance of odour escaping and there is less chance of freezing during cold weather and lower human contact, which is potentially dangerous.

In the present case study, dimensions of the tank are calculated based on the quantity of water to be treated which comes out to be 1*0.5*1 cum. Around 500 litres of water can be accommodated to treat greywater. Extra arrangements of pipeline are required to transfer the treated greywater from the underground tank to the overhead talk and then to the required areas of use. The construction time for sand filter is around one week and it requires maintenance after every month. It is moderately suitable to different socio-economic strata, as the cost of construction is pretty more. Quality data showed that greywater treatment is necessary and public acceptance survey indicated that the majority of people oppose greywater reuse (Jamrah and Ayyash, 2008). Adopting such systems saves water to a higher extent and is durable for 10-15 years if maintained properly. The payback period collectively for the greywater treatment systems is 23.47 years.

The quality and type of treatment would totally depend on the area of usage of greywater. If greywater is to be used in toilets, then only primary treatment is also acceptable. Biological treatment is a viable option for apartments or industries, where production of greywater is huge.

On-site Water Treatment

A crucial component of water conservation for the study is the end product. This section deals with black water, that comes from the toilet or kitchen sink and contains high levels of solids, bacteria or other chemical contaminants, making it not fit for use in the home. Currently, there are only a few options available for treating the black water released from residential houses.

In the present case study, water demands are completely satisfied with the other stated options and there is no need of treating and reusing the wastewater. For houses with higher water demands, Sequencing Batch Reactor (SBR) process for residential buildings is preferred over other wastewater treatment processes. Treated black water is only suitable in toilets where there is minimum human contact with water. The sequencing batch reactor (SBR) is a fill-and-draw activated sludge system for wastewater treatment (Joustra, 2010).

In this system, wastewater is added to a single “batch” reactor, treated to remove undesirable components and then discharged. Equalization, aeration and clarification can all be achieved using a single batch reactor. To optimize the performance of the system, two or more batch reactors are used in a predetermined sequence of operations. The size of the SBR tanks themselves will be site-specific; however, the SBR system is advantageous if space is limited at the proposed site.

Depending on their mode of operation, SBRs can achieve good BOD and nutrient removal. For SBRs, 98 per cent of purification is achieved in just six hours without any chemical treatment. The payback period is around 48 years; though being a big number, but it is less than the lifespan of a house.

CONCLUSIONS

1. Basics

Water conservation and management are among the most important aspects in drought-prone areas. Innovative and sustainable techniques need to be adopted. FAHP technique proved to be successful in developing a model from users’ perspective. It was found that among various criteria, users preferred to have a system which is economic and less costly, followed by a system with great ability to treat/ conserve water. Social factor was placed third, as no major lifestyle changes are desired while adopting a system or a technology. Also, it should suit most of people living in the society. Social factor is followed by technology factor, in which space requirements and extra arrangements for installation… etc. were given less preference. Time factor got the least preference that involved the time of construction or the frequency of maintenance time. If water conservation strategies are applicable in a mid-range residence such as the Aurangabad case study, that can imply that those same systems might be applicable to other areas where water is more than a commodity.

2. Water Saving

The following conclusions are drawn from the case study after the application of the important technologies obtained from FAHP technique:

i. Around 39.13% of water saving is achieved after the proposed upgradation of the existing plumbing fixtures.
ii. It is also found that dependence on municipal water supply is reduced by 67.30% after recycling the water in various sectors in houses.
iii. The greywater generated in houses is completely

being used in the water closets and outdoor uses.

iv. Various internal purposes are satisfied from the harvested rainwater and savings of around 86.75% are achieved.

v. As all the water requirements are satisfied from the technologies used, less than 40% of wastewater is discharged in the municipal system.

3. Cost

After calculating the saving in water, the cost and payback period are calculated.

It is found that the payback period is least for plumbing fixtures and highest for wastewater treatment systems. Despite that viability of these technologies and systems is unclear, they proved to be an effective and worthy investment.

4. Impact

These water conservation systems have the ability to impact the entire water infrastructure and on a large scale alleviate some of the demand on limited potable water. Even though residential construction isn't the forerunner of water use and waste, it still has a big enough immediate impact to be able to change the current water situation while other sectors catch up.

REFERENCES

Afshar Sahraei Loron et al. (2015). "An integrated fuzzy analytic hierarchy process-fuzzy data envelopment analysis (FAHP-FDEA) method for intelligent building assessment". ISSN 1330-3651 (Print), ISSN 1848-6339, 383-389.

Ahmad Jamrah, and Safa Ayyash. (2008). "Greywater generation and characterization in major cities in Jordan". JJCE, 2. Corpus ID: 8189941.

Aminah Robinson Fayek. (2020). "Fuzzy logic and fuzzy hybrid techniques for construction engineering and management". J. Constr. Eng. Manage., 146 (7), 04020064. DOI: 10.1061/(ASCE) CO.1943-7862. 0001854.

"A sewage treatment plant for every home". https://www.thehindu.com/features/homes-and-gardens/design/a-sewage-treatment-plant-for-every home/article4749698.ece, 2021.

Awawdeh M. et al. (2012). "Rainwater harvesting assessment for a small-size urban area in Jordan". ISSN 2141-6613 ©2012.

Caryssa Joustra. (2010). "An integrated building water management model for green building". Scholar Commons.

Deepthi Yaparla et al. (2011). "Comparison of household level drinking water treatment technologies using analytic hierarchy process". IJAHP, 3 (1). ISSN 1936-6744.

Durgasrilakshmi Hari. (July 2019). "Estimation of rooftop rainwater harvesting potential using application of Google Earth Pro and GIS". IJITEE, 8 (9), ISSN: 2278-3075.

Falak, J. et al. (2020). "Evaluation of continuous improvement techniques using hybrid MCDM technique under fuzzy environment". Science Direct, 22 (4), 1295-1305.

Hamed Taherdoost. (2017). "Decision-making using the AHP: A step-by-step approach". IJEMS, 2. ISSN: 2367-8925.

Hatefi, S.M. (2019). "Intelligent building assessment based on an integrated model of fuzzy analytic hierarchy process and fuzzy preference degree approach (FAHP-FPDA)". Int. J. Optim. Civil Eng., 9 (1), 79-92.

Jadhav, P.A. et al. (November 2018). "Quantitative study of water consumption and greywater generation in Aurangabad city, Maharashtra (India)". IJRAT, 6 (11). E-ISSN: 2321-9637.

Jeffrey Cook. (2011). "Residential water conservation: A cross-comparative analysis".

Mega Ardisa Hapsari and Subiyanto Subiyanto. (2020). "Fuzzy AHP-based optimal design building-attached photovoltaic system for academic Campus". Article ID: 6508329, https://doi.org/10.1155/2020/6508329

Mochammad Sobandi Dwi Putra et al. (2018). "Fuzzy analytical hierarchy process method to determine the quality of gemstones". Article ID: 9094380.

Mustafa Batuhan Ayhan. (2013). "A fuzzy AHP approach for supplier selection problem: A case study in a gearmotor company". International Journal of Managing Value and Supply Chains (IJMVSC), 4 (3).

Peter A. Clark et al. (2012). "Slow sand water filter: Design, implementation, accessibility and sustainability in developing countries". Med. Sci. Monit., 18 (7), RA105-117.

Pooja Shrivastav et al. (July 2019). "Applicability of the AHP in decision-making for integrated urban water supply system in a city". IJRTE, 8 (2).

Sonali Manna. (2018). "Treatment of greywater for reusing in non-potable purposes to conserve water in India". IJAES, 13 (8), 703-716. ISSN: 0973-6077.

Sylvain Kubler et al. (2016). "A state-of the-art survey and testbed of fuzzy AHP (FAHP) applications". Article in Expert Systems with Applications. DOI: 10.1016/ j.eswa.2016.08.064