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Analytical Hierarchy Process Based Decision Support System for Ensuring Sustainable Service Delivery by Piped Water Supply Schemes in Rural Areas of India

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Abstract: The Ministry of Jal Shakti, Government of India aspires to provide piped water supply in all households by the year 2024. At present approximate 18.33% households have been provided with piped water supply, which is much less that the target set to be achieved by the year 2017. With the present methodology for scheme implementation and various reasons associated with poor coverage nd service delivery, it is impossible to achieve the targets. The present research work proposes aDecision Support System based on the Analytical Hierarchy Process (AHP), a Multi-Criteria Decision Making tool for scheme implementation, which could help implementing government and multi-lateral agencies in achieving the desired targets. This will help Central and State Governments for safety of funds to the tune of INR23,000 Crore required to be invested in rural water supply schemes by the year 2030.

Key-words – Rural Drinking Water, Analytical Hierarchy Process, Jal Shakti, Service Delivery, Slip-back

I. INTRODUCTION

In the year 1949, the Environmental Hygiene Committee (Bhore Committee) established by the Parliament of India recommended the target of covering 90% population of the country with drinking water supply within a time span of 40 years i.e. by the year 1989. But according to the report on the evaluation of the National Rural Drinking Water Programme (NRDWP) conducted by the Lok Sabha Committee on Estimates, it was found that despite the huge investment of 1.67 Lakh Crores in drinking water supply sector since 1st Five Year Plan (1951-1956), only 75% of the households were covered by the year 2015. According to the report, annually on an average 1.4 Lakh habitations slip back from fully covered category to partially covered category. (Lok Sabha, 2015)

The Ministry of Jal Shakti, Government of India has set an ambitious target of habitation coverage, which is presented in the following Table.

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Table 1: Targets set in Strategic Plan for Rural Drinking Water in India

	2017	2022
Coverage of rural households with piped water supply	55%	90%
Number of rural households having piped water supply with a household connection	35%	80%
Number of households using public taps	<20%	<10%
Number of households using hand-pumps or other safe and adequate private water sources	<45%	<10%

Source: MDWS, 2011

The following Table depicts comparative habitation coverage with Piped Water Supply schemes:-

Table 2: Number of habitations covered with Piped Water Supply schemes

	Total No. of Habs.	No. of habs. covered with PWSS	%	Total No. of HHs	No. of HHs provided Tap connections	% (Ach.) (Tar.)
India	1726031	747413	43.30 %	179085336	30483394	(17.02 %) (35%)
Madhya Pradesh	128061	23420	18.29 %	10910151	1171042	(10.73 %) (35%)

Source: IMIS-MDWS, 2017

It is evident from Table: 2, that country has missed the targets to be achieved by the year 2017 by a huge gap and is far behind the targets set in strategic vision by the year 2022.

Table 3: Non-functionality of schemes

	Total Number of Schemes*	Number of Non-functional Schemes	Percentage
India	6514165	229253	3.52%
Madhya Pradesh	647695	63312	9.77%

Source: IMIS-MDWS, 2017

Table: 3 depicts the percentage of non-functional schemes in India and in the State of Madhya Pradesh. This non-functionality of schemes aggravate the already poor coverage status and has far-reaching implications for the sector. In a 16 country study on assessment of rural water service delivery models, World Bank (2017), found that 30% to 40% of water supply scheme became non-functional within few years after commissioning or function below expected service levels.

Parsai (2016) conducted an assessment of 16 PWSSs in four districts of the State of Madhya Pradesh and found that the schemes were either non-functional or partial functional.

According to online MIS of Ministry of Jal Shakti, (IMIS-MDWS, 2018) nationally 97.64% sources of water supply schemes are ground water based, whereas only 2.36% sources are surface water based. Heavy dependence on the ground water sources, because of erratic rainfall and excessive run-off and limited capacity to store rain water, the availability of surface water round the year has put limitation on the feasibility of those schemes. According to Eswar (2017), evapotranspiration (Evaporation and Transpiration) phenomena is responsible for water loss and it is very high in Punjab, Haryana and the upper Ganges states Uttar Pradesh, Uttarakhand and Bihar almost equal to annual rainfall and in some places in the northern plains, it is higher than the annual rainfall.

As per the decentralised approach adopted under NRDWP Guidelines (2013), inside the village, it is the PRI or its sub-committee i.e. Gram Panchayat/Village Water and Sanitation Committee (GPWSC / VWSC) / Pani Samiti that is to take over the responsibility for in-village drinking water management and distribution. Government has to play the role of facilitator and with the help of NGOs/CBOs and civil society to build the capacity of local community/ PRIs to manage the in-village water supply systems and sources and transfer existing drinking water supply systems to communities and PRIs for management, operation and maintenance.

It is clear from Figure: 1, that the State of Madhya Pradesh has failed miserably in transferring completed schemes to Gram Panchayats / VWSCs. It shows lack of community participation in scheme planning, execution and operation and maintenance. According to Parsai (2016) in the State of Madhya Pradesh, average annual expenditure on O&M of Rural Drinking Water Supply assets is INR159.25 Crore. Whereas funds to the tune of INR257.45 Crore are required annually for O&M. Hence there is a gap of INR98.20 Crore (40% of total funds required for O&M annually).

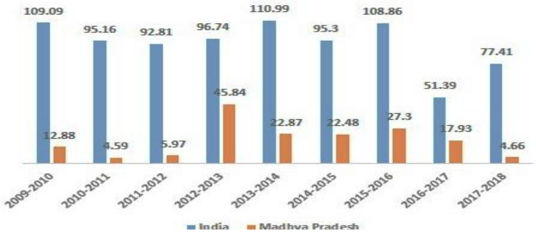


Figure:1 Year wise Percentage of Schemes handed over to Gram Panchayats / VWSCs

Source: www.indiawater.gov.in

Though sufficient literature is available on above mentioned factors in isolation, there doesn't exist any framework/methodology, which considers all factors simultaneously or covers the entire service delivery cycle. In this multi-stage process starting from need assessment to operation & maintenance, where multiple factors are involved, an efficient decision making framework/methodology is required.

For the selection of best alternative option for ensuring sustainability of water supply schemes, various approaches/methodologies have been studied and published. Bhattarai (2009) applied Analytic Hierarchy Process in order to monitor the sustainability status of project through multiple criteria, consisting of various indicators on technical, socio-environmental, financial and institutional aspects in Nepal. Nhu (2014) has demonstrated the application of eight step process of Analytical Hierarchical Process method in rural water supply investment based on the alternatives, criteria and priorities. Majumdar (2015) has explained application of Multi Criteria Decision Making through AHP in the field of water quality, urban water management and reservoir operation. Swamy et.al. (2016) has applied AHP to urban drinking water sector in India for assessing determinants of PPP project performance and found stakeholder consent, project structure, baseline info and tariffs as top four parameters.

The present study proposes to develop a methodology based on Analytical Hierarchical Process (AHP) as developed by Saaty (1990) for ascertaining relative importance of factors and their prioritisation for ensuring sustainable service delivery by piped water supply schemes in rural areas of India.

II. OBJECTIVES

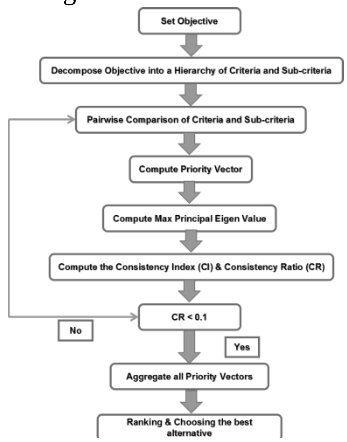
- To identify factors responsible for sustainable service delivery by PWSSs
- To ascertain relative importance of factors

III. METHODOLOGY

The review of national and international literature was done for identification of factors influencing sustainability of PWSSs. Based on the identified factors, structured interviews through questionnaire were conducted for comparative analysis of factors by sector experts. Collected information were analysed through Analytical Hierarchical Process (AHP) for arriving at ranking and relative weights of various factors.

IV. DATA ANALYSIS

Figure 2 highlighted procedure applied for assigning priorities and rankings to criteria and



sub-criteria.

Figure 2: Analytical Hierarchy Process

Source: Saaty, 1980

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- **Decomposition of objective into a hierarchy of criteria and sub-criteria**

As recommended by Saaty, 1987 a hierarchy of criteria and sub-criteria was constructed as shown in Figure 2. It indicates that user agreement, user contribution, trained manpower, local institutions and information sharing come under Social Preparedness stage and so on.

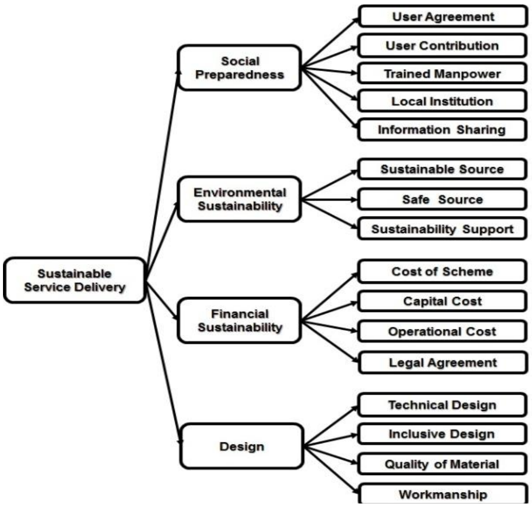

Figure: 2 Hierarchy of Criteria and Sub-criteria

Source: Author

- **Preparation of scale**

In the pairwise comparison process, the element in each **row** is compared with the elements in each **column**, one by one, in respect of a common element in the next higher level (entered in the top left corner of the matrix). Two questions require answers:

- Is the importance of the element in the row greater or less than that of the element in the column? (Does it carry more or less weight or does it matter more or less?); and
- How much more or less important is it? (By how much does it matter more or less?).

For the second question, a value is assigned according to the Fundamental Scale of the AHP as mentioned in Table:4.

Table 4: Fundamental Scale for Pairwise Comparison, (Saaty, 2012)

Intensity of Importance	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favour one activity over another
5	Strong importance	Experience and judgement strongly favour one activity over another
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance is demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation

- **Pairwise comparison of criteria and Sub-criteria**

The 17 experts were given a questionnaire for pair-wise comparison of criteria and sub-criteria. Pairwise comparison was carried out for the criteria with respect to the overall objective once; thereafter, sub-criteria were compared to one another in pairwise fashion with respect to each criterion and so on down to the lowest level of the hierarchy.

Having completed the pairwise comparisons, a set of matrices were prepared. These comprise one matrix for the criteria with respect to the overall objective and a number of matrices, one for each criterion in respect of which the alternatives are ranked.

- **Criteria Comparison Matrix**

Based on the comparison wise responses given by expert – 1, following Table depicts pair wise criteria comparison.

Table 5: Responses given by Expert – 1

	Criteria	Social Preparedness	Environmental Sustainability	Financial Sustainability	Design
	A	B	C	D	E
1	**Social Preparedness**	1.0000	1.0000	1.0000	3.0000
2	**Environmental Sustainability**	1.0000	1.0000	3.0000	5.0000
3	**Financial Sustainability**	1.0000	0.3333	1.0000	5.0000
4	**Design**	0.3333	0.2000	0.2000	1.0000
	Total	**3.3333**	**2.5333**	**5.2000**	**14.0000**

Source: Survey data

The Table 5 highlights the construction of matrix for criteria comparison based on the responses given by an expert. First 1's are entered on the diagonal in B1, C2, D3 and E4, because each criterion weighs exactly 1 when compared to itself. Thereafter, process of pairwise comparison commences.

If expert gives more importance to social preparedness over design and says it is more important than design by 3 times, then 3 is entered in Cell E1.

- **Normalising the Matrix**

The next step is to normalise the matrix by dividing each value in every column by the sum of the values in that column. The normalised matrix is highlighted in Table 6. This matrix now contains the values of each element of the comparison matrix divided by the sum of the column in which the element appears.

Table 6: Normalisation of Matrix

Normalised Matrix				
Social Preparedness	0.3000	0.3947	0.1923	0.2143
Environmental Sustainability	0.3000	0.3947	0.5769	0.3571
Financial Sustainability	0.3000	0.1316	0.1923	0.3571
Design	0.1000	0.0789	0.0385	0.0714
Total	**1.0000**	**1.0000**	**1.0000**	**1.0000**

- **Computation of Priority Vector (Prioritisation)**

The priority vector (eigenvector), that is the relative importance of the criteria, is now calculated by averaging the rows in the normalised matrix. As can be seen in Table 7, the priority vector shows not only which criteria are most and least important, but also how much more important one is relative to another. In other words, Environmental Sustainability is the overriding consideration and carries almost 40.72 per cent of the total weight, while Social Preparedness is appx. 4 times more important than Design (27.53% vs. 7.22%).

Table 7: Prioritisation of Criteria

Normalised Matrix					**Row Average**
Social Preparedness	0.2753	0.3947	0.1923	0.2143	0.2753
Environmental Sustainability	0.4072	0.3947	0.5769	0.3571	0.4072
Financial Sustainability	0.2453	0.1316	0.1923	0.3571	0.2453
Design	0.0722	0.0789	0.0385	0.0714	0.0722
	1.0000	**1.0000**	**1.0000**	**1.0000**	**1.0000**

- **Computation of Max Principal Eigen Values**

A feature of the AHP that distinguishes it from other techniques is its ability to test the consistency of judgement of participants throughout the process and the opportunity to reconsider judgements until acceptable consistency is achieved. The consistency of a matrix is measured against the principal eigenvalue of the matrix. The principal eigenvalue of a consistent positive reciprocal matrix is equal to the sum of the diagonal elements of the matrix. In AHP, the diagonals are always equal to 1, so the principal eigenvalue is equal to the number of elements on the diagonal if, and only if, the matrix is consistent.

In the Table 6, columns add up to 3.3333, 2.5333, 5.2000 and 14.0000 respectively for social preparedness, environmental sustainability, financial sustainability and design respectively. The averages of the rows are 0.2753, 0.4072, 0.2453 and 0.0722 respectively for social preparedness, environmental sustainability, financial sustainability and design respectively as presented in Table 8. The principal eigenvalue (denoted by λ_{max}) is now obtained as follows:

λ_{max} = (3.3333x0.2753)+(2.5333x0.4072)+(5.2000x0.2453)+(14.0000x0.0722) = 4.2356

- **Computation of Consistency Index and Consistency Ratio**

$$C_i = \frac{\lambda_{max} - n}{n - 1}$$

The principal eigenvalue for a consistent matrix in this example should be equal to 4 (the sum of the diagonal values). The judgements are therefore not consistent.In this case, the measure of consistency requires consideration. If the inconsistency is large, then there might be a computational error or the judgements are unacceptably inconsistent. In order to obtain a measure of the inconsistency, the concept of a consistency index (Ci) and random consistency index (Ri) is introduced. The consistency index of a matrix is determined by following equation:-

Where: $\lambda max$is the principal eigenvalue and $n$is the number of elements in the diagonal

The Ri is obtained from a table that was compiled by Saaty and Kearns, (2013) in following Table

Table 8: Random Consistency Index

Size of Matrix	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Ri	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Source: Saaty, 1980

Finally the consistency ratio, C_r is obtained by following equation

$$C_r = \frac{C_i}{R_i}$$

As recommended, Cr should not be more than 0.10 or 10 per cent. Above mentioned process was repeated for calculation of consistency ratio for all four criteria and 16 sub-criteria.

V. RESULTS

The consistency in judgements of experts were assessed through calculation of Consistency Ratio for all four criteria and sixteen sub-criteria, which are highlighted in the Table 10.

Table 9: Consistency Ratio calculated for Criteria and Sub-criteria

		Sub-Criteria Comparison			
	Criteria Comparison	**Social Preparedness**	**Environmental Sustainability**	**Design**	**Financial Sustainability**
Expert	**4x4**	**5x5**	**3x3**	**4x4**	**4x4**
1	0.0882	0.0830	0.0000	0.0820	0.0940
2	0.0107	0.0982	0.0817	0.0344	0.0758
3	0.1008	0.1051	0.0000	0.0182	0.0151
4	0.0602	0.0808	0.0000	0.0931	0.1027
5	0.1035	0.0975	0.0000	0.0325	0.0551
6	0.0512	0.0522	0.0344	0.0650	0.0550

7	0.0064	0.0870	0.0000	0.0182	0.0591
8	0.0144	0.0892	0.0000	0.0923	0.0551
9	0.0541	0.0969	0.0000	0.0606	0.1068
10	0.0655	0.1037	0.0532	0.0817	0.0649
11	0.0922	0.1002	0.0000	0.0785	0.1066
12	0.1043	0.1047	0.1072	0.0606	0.0611
13	0.1090	0.0000	0.0000	0.0940	0.0624
14	0.0962	0.0708	0.1000	0.0686	0.0746
15	0.0689	0.0990	0.0000	0.0931	0.0463

It is clear from the Table 9, that the consistency ratio for all criteria and sub-criteria are less than 0.10, which means that inconsistency in judgements of all 15 experts is less than 10 percent.

After calculation of consistency ratio, priorities and rankings as computed from procedure mentioned in Data Analysis section are highlighted in Table 10.

Table 10: Priority and Ranking of Criteria and Sub-Criteria

S. No.	Criteria	Priority	Ranking
A	Social Preparedness	41.88%	1
B	Environmental Sustainability	28.23%	2
C	Financial Sustainability	19.70%	3
D	Design	6.84%	4
	Sub-criteria		
A	**Social Preparedness**	**Priority**	**Ranking**
A.1	User Agreement	43.72%	1
A.2	User Contribution	23.55%	2
A.3	Trained Manpower	15.81%	3
A.4	Local Institution	9.15%	4
A.5	Information Sharing	5.22%	5
B	**Environmental Sustainability**	**Priority**	**Ranking**
B.1	Sustainable Source	44.12%	1
B.2	Safe Source	40.43%	2
B.3	Sustainability Support	12.49%	3
C	**Design**	**Priority**	**Ranking**
C.1	Technical Design	38.16%	1
C.2	Inclusive Design	30.19%	2
C.3	Workmanship	16.46%	3
C.4	Quality of Material	12.87%	4
D	**Financial Sustainability**	**Priority**	**Ranking**
D.1	Cost of scheme	41.30%	1
D.2	Legal Agreement	30.67%	2
D.3	Capital Cost	19.02%	3
D.4	Operational Cost	5.93%	4

VI. CONCLUSION

Based on the assessment of consistency of judgements for 17 experts through computation of consistency ratio, the judgements of 02 experts were found inconsistent and were removed from the final analysis. Following the 15 expert's consistency analysis, the entire exercise resulted in assessment of priorities and ranking of criteria and sub-criteria for ascertaining feasibility of Piped Water Supply Scheme in rural areas. Table 11 highlights priorities and rankings of criteria and sub-criteria.

It is evident from the Table 11, that among four criteria, the environmental sustainability with 41.88% weightage is the most important criteria for sustainable service followed by social preparedness (27.53%), Financial Sustainability (19.70%) and Design (6.84%).

The Environmental Sustainability criteria includes three indicators. The indicator Sustainable Source (44.12%) is ranked as the most important indicator. If source doesn't last up to major part of design life of scheme, sustainable service delivery cannot be guaranteed. It is followed by safe source indicator (40.43%). If users of scheme are not satisfied with the tangible quality (taste, odour and colour) of water from particular source, they would hesitate from being part of the scheme.

Under environmental sustainability dimension, sustainability effort (12.49%) is the last important indicator, which highlights cohesiveness among community members for a common cause.

The Social Preparedness dimension covers five indicators namely User Agreement, User Contribution, Trained Manpower, Local Institution and Information Sharing. Among these, User Agreement (43.72%) is the most important indicator. If scheme is executed based on the real demand of users and their agreement on the same, probability of scheme success enhances. If all prospective users or committee thereof agree to the present and projected cost related of PWSS including capital expenditure, operation, maintenance, breakdown and expansion, it shows their willingness to operate and maintain scheme in longer duration. It is followed by User Contribution (23.55%), where all users contribute genuinely towards the partial cost of PWSS (for capital expenditure) and recurring cost for operation and maintenance. It clearly indicates a sense of ownership among users on various components of scheme. Third important indicator under Social Preparedness dimension is availability of Trained Manpower (15.81%) from local water user community itself. It helps in smooth operation and maintenance of scheme and reduces the incidences of wear and tear. Fourth important indicator is availability of local institution (9.15%) for management of water supply scheme. An empowered and active community based institution is present locally for managing affairs of PWSS on regular and long term basis. The fifth and last important factor is Information Sharing (5.22%). If information related to all stages of PWSS (Need assessment, Planning, Execution, Commissioning, Handing over and operation) are shared with all stakeholders especially with users voluntarily, it enhances their willingness to get involved in scheme.

The Financial Sustainability dimension includes Cost of Scheme, Capital Cost, Operational Cost and Legal Agreement. Among these, the cost of scheme (41.30%) is the most important indicator, which includes entire cost of a scheme (Present and Projected) capital cost, operational cost and costs towards breakdown (major/minor) or future expansion in monetary and non-monetary terms. It also covers coping costs associated with fulfilling water needs from multiple sources in case piped water supply scheme alone doesn't provide sufficient water for household needs. It is followed by indicator of legal agreement (30.67%), which legally binds all stakeholders of a scheme viz. policy makers, scheme planners, executing agencies (Govt./Contractors) and primary users or any institution thereof during all stages of a scheme (Demand generation, Planning, Execution, Commissioning, Handing over and operation) especially during the handing-over process. This legal agreement clearly defines and minimises confusion on the roles and responsibilities of different stakeholders. Third indicator under financial sustainability is partial capital cost of scheme (19.02%), which majority of users are supposed to pay before the scheme execution. It indicates affordability and willingness of users to pay for using improved services. The operational cost (5.93%) includes financial resources required to operate and maintain scheme. If users are able to pay towards operational cost of scheme on longer term, chances of sustainable service delivery by scheme are enhanced.

Among the four dimensions, design dimension is least important. If user community is prepared and water source is environmentally sustainable and scheme is financially sustainable, users are least bothered about the design aspect of scheme. Design dimension includes four indicators namely technical design, inclusive design, quality of material and workmanship. Among these four, technical design (38.16%) is the most important indicator. If technical aspects of design such as single source fulfilling user's needs, proximity of water point to user's houses, less time is invested in fetching water from water point, less crowd at water point, sufficient pressure at tail-end, daily activity of fetching water doesn't affect livelihood activities and scheme components are least vulnerable to damage from other activities in village. The indicator of inclusive design (30.19%) includes coverage of households from difference social categories such as Scheduled Caste, Scheduled Tribe, Other Backward Class and General. It also includes coverage of institutions with water supply such as school, Anganwadi Centre and Health Centres etc. The workmanship (16.46%) is the third important indicator, which is about proper installation of scheme components and quality of civil works such as pipeline laying, over-head tank etc. Then comes the quality of material (12.87%) used in scheme such as pipes, valves, tap, cement and sand etc.

RECOMMENDATION

Analytical Hierarchical Process is a strong mathematical tool to convert individual judgements into logical decisions. This mathematical tool may help implementing agencies in planning and implementing schemes delivering sustainable service delivery. Considering the local context, analysis of factors under four categories namely social preparedness, environmental sustainability, financial sustainability and design is of utmost importance for ensuring sustainable service delivery by these schemes. At present, there does not exist any established or proven methodology/approach, which considers all factors simultaneously and logically. Working of State run implementing agencies is influenced by technical rigour, whereas development agencies (local or multilateral) focus more on social aspect. In order to plan and design schemes delivering sustainable service delivery over a long period of time, a methodology or approach is required, which is based on rigorous analytical tool and considers social, technical, financial and environmental dimensions simultaneously. The methodology presented in this paper may further be developed in the form a Decision Support System to be implemented by concerned stakeholders. If implemented properly, this would safeguard financial and environmental investment and most importantly will ensure sustainable service delivery by these schemes.

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