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Applicability of the Analytical Hierarchy Process (AHP) in Decision Making for Integrated Urban water System in a city

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Abstract: ***The urban water system is a complex and dynamic for planning of an integrated framework. This paper illustrates Analytical Hierarchy Process (AHP) technique as a decision-making tool for the municipality's urban water based on four different criteria i.e. economic, environmental, social, and sustainability to support stakeholders and water utility experts. Due to insufficient funds for the urban water planning, prioritization problems arise and for this hierarchical network represents with prioritization criterion to implement an alternative solution. Saaty's analytical hierarchy process (AHP) hypothesis is explaining in the study with Multi-Criteria Decision Analysis (MCDA) and adoptable the alternatives through highest priority value. According to the AHP theory, all required criteria are ranking and preparing the list of alternatives to select the most prioritized solution to carry out in the plan of the urban water policy. Along with a consistency, a check of the final judgment is still carrying out by sensitivity evaluation of the synthesis model even if there are changes in decisions. The study find out the best workable solutions for existing issues in the urban water structure by promoting an interface between water users and stakeholders to reach a sustainable strategy in the city. AHP technique not only finds the important of each criterion but still comparing the criteria weights regarding objectives and alternatives. This application of AHP will ease the policymakers and stakeholders in the governing process for next-generation urban water system planning and designing by providing a framework and support to prepare a city master plan.***

Index Terms: Analytical Hierarchy process, Mufti-criteria, Decision Analysis, Urban Water System, Framework, Urbanization

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I. INTRODUCTION

From the report of the World Health Organization (WHO, 2017), the world population has crossed over 7.5 billion and people migrate from rural localities to urban localities. With the growth of population, urbanization, climate variation and industrialization, developing cities will experiences loads of land use land change (LULC) that will affect permeability and a substantial increase the runoff in the urban water system. As the runoff increases, groundwater recharge is less effective and the city's water bodies receiving more water during and after the rain events. This will change the completely urban hydrological cycle in the region i.e. temperature expansions, uneven rainfall events, droughts, and floods and enhance the pressure on the urban water policy of the city.

To mitigate these problems, the city's urban water system needs to be improving and transforming. Nevertheless, it is not possible to operate and maintain massive urban water structure within the city owing to limited funds and budget for City's Municipal Cooperation. In this condition prioritization require, fulfilling these requirements, we need to design a system in an organized manner. And the purpose of this study is to describe AHP as a decision-making tool and MCDA method is useful to assess integrated urban water system dealing with the numerous and conflicts objectives. This study proposes a framework to measure priorities and criterion weights and deals with the questions i.e. how should priorities be determined for the city planning and what are the basic requirements for the potential urban water system. The city's urban water system should provide secured drinking water, proper water distribution system, reliable wastewater management, effective storm water management, drought and flood control systems to sustain a hygienic and sustainable environment in the city. Each of this system needs a complex infrastructure in the city. If one of the system either not in a position or not functioning, it will suffer lakhs of people living in the city i.e. water-borne diseases, flooding, and drought and polluted water bodies.

II. LITERATURE REVIEW

AHP established by Thomas Saaty (1980)[18] is an efficient mechanism for multi-criteria decision analysis (MCDA). He deal with multi-faceted decision-making problems and will help the decision makers to set priorities and compile the best solutions. It decomposes the aim into sub problem hierarchy.

After that decision makes computes the comparative significance of its various constraints by pair wise comparisons. AHP find out the weights or priorities to calculate a score for each alternative. These priorities set on the weight scale and stress the important of the reliability of the comparisons of alternatives.

The SWARD (the sustainable water industry asset resource decision) that provide a means whereby water services provide could more incorporate the sustainability principle into the decision making process. It involved seven phases for sustainability assessment of an urban water system including option generation, criteria, and indicators selection preferred selected options and implementation [11].The applications of different methods of MCDM for assessment of sustainable integrated urban water systems and pointed out their limitations such as double counting, under-counting and independence [14].

The performance indices for a framework of an urban water system computed by AHP and the Fuzzy approach calculated final indices. These techniques used in Kathmandu, Nepal for showing the water infrastructure including water supply and wastewater system [13]. A composite index called SIUWM (the sustainability index for integrated urban water management), for sustainability assessment of city's urban water services in developing countries such as South Africa. It has four components i.e. social, economic, environmental and technical with sets of sets of sustainability indicators. It highlighted the decision-making models (GDM) to incorporate the stakeholder contribution in the decision-making processes relating to sustainability assessment of an urban water system [10].

The group decision-making (GDM) models as sustainability assessment were used for sustainability assessment and prioritization of development scenarios for a small town's urban water system by well-known MCDM method [16].AHP is computation technique that combines both qualitative and quantitative exploration. They based it on a structured model by matrix conclusion. Assessment method included water resources vulnerability with AHP determined the index system, making of decision matrix by comparing indices of the same level one by one[20]. The importance AHP as likely decision-making technique in water resources management linked to the drainage rehabilitation. GIS and AHP integration might be valuable in decision-making and in managing huge data for executing vector as well spatial analysis for efficient water resources management [3]. The basic requirements of a city framework make out from the literature review flow diagram shown in fig 1.1.

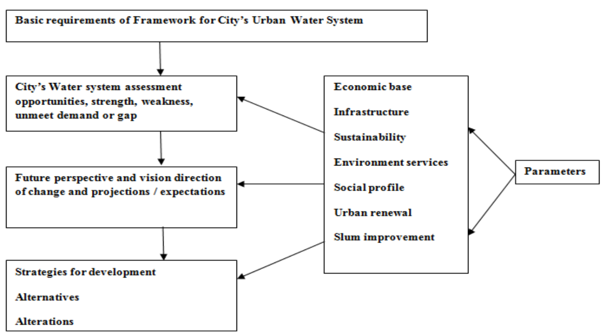

Fig 1.1 Flow Diagram for Basic requirements of city framework

III. DATA AND METHODOLOGY

A. Study Area

Raipur is the largest city and capital of Chhattisgarh state in India. Before 1 November 2000, it was a part of Madhya Pradesh state. Raipur city is administrative by the Municipal Corporation of Raipur (RMC) and headquarters of Raipur district, district map shown in fig 1.2[12]. On the east, side of the city Mahanadi river run and on the southern side has dense forests. The city has an affluence of lakes (nearly 157) and natural water bodies. Raipur has a tropical wet and dry type of weather i.e. composite climate zone of the country; hence, temperature remains moderate during the year. The Raipur Urban agglomeration is having population growth rates higher than the whole state [9]. This requires planning, development, and level of services for the urban water system. Otherwise, it is likely to result in the polluted existing surface water bodies and underground water sources of water supply for the population in the city [4].

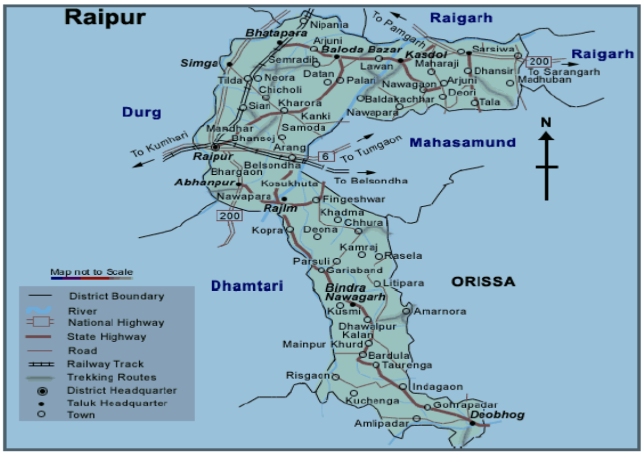

Fig 1.2 Administrative Map of Raipur (Source: goggle map)

The water distribution to Raipur city is from both surface water bodies and groundwater. The raw water source for treatment plant is Kharun River. It originates from village Pankibhat located south of Raipur district and a tributary of the river Sheonath. About 20 percent drinking water for the city population is providing by these bore wells. The water supply and distribution system have maintained by (PHED) Public Health Engineering Department and RMC both. RMC takes water from Kharun River (a tributary of Mahanadi, Non-perennial River) 135 MLD, Ravi Shankar dam and tube wells (1400 tube wells) for supply in the city. The level of groundwater in the city varies from 60 to 90 m. During summer, water is supply through Ravi Shankar dam built on the Mahanadi River near Dhamtari district. For water distribution purpose, they divide the city into 32 water distribution zones and each zone has own water storage. In the city, there is one water treatment plant near Ravan bhata in the south. The present capacity of the treatment plant is to serve population about 8 lakhs with a design capacity of 47.67 MLD. The augmentation is increasing the capacity of the plant by 80 MLD [7], [8].

From the various draft report on Raipur city, we classify the following key challenges by us in four different criteria as shown in Table1.1

Table 1.1Key challenges in the Raipur urban water system

Criteria	Key challenges
Economic	• About more, the 50,000 connections are unauthorized in the city with high non-revenue water (NRW). • RMC does not have proper funds and budget for new water supply schemes in the city. • Current financial management system does not meet the demands of the existing and future sanitation requirements
Environmental	• Untreated sewage disposed into water bodies all over the city. This will affect the health of urban poor and weaker section population living in the slum. • There is lack of collection, transportation and disposal of a solid waste system in the city. • Unsystematic dumping of solid waste in open places and storm water drains and indiscriminate management of the dump sites receiving the waste from the entire city and is short of treatment and critical scientific disposal • Higher risk due to offensive septic tanks and seepage management leading to pollution of the water bodies/water supply distribution system and prevalence of water-borne diseases
Social	• The city having large slum area; this will affect the preparation for an improvement plan due to the shortage of exact data from the slum area. • Insufficient and poorly designed, operated & managed individual and public toilets in the urban poor areas resulting in open defecation and harsh health impacts • Underprivileged maintenance and non-integration of the existing stormwater drainage network, cause to be it under-utilized leading to a considerable number of water logging regions and hence unsanitary conditions • Poor quality of water supplied or accessed in numerous areas in the city • In the monsoons, garbage-clogged surface drainage and open nallahs than water overflow on to the roads causing traffic congestion.
Sustainability	• Demand-supply of the water gap of the city will be severe for future. • The present sewerage system is not fully functional, not connected with many households with the system • The present Institutional and administrative Framework of RMC is not implement satisfactorily to govern the sanitation improvement and management services

B. Analytical Hierarchy Process (AHP)

AHP is very manageable and vigorous tool because of its calculated weighted index and their ultimate ranking are get by pair-wise comparison of both the criterions and alternatives used in the hierarchy. Therefore, AHP is an MCDA technique that gives permission to both objectives and subjective parameters of the hierarchy in a decision-making process. Therefore, hierarchy can relate the elements of one level with the immediate below level. The primary use of the AHP is the outcome of the alternatives in multidisciplinary leve. It also allows faction decision-making where members of a group may use their knowledge, skills and experience to simplify the crisis into a hierarchy and solving by the AHP steps. In addition method, also provide ease of to not building a complicated expert system for their calibration and validation.

Using multi-criteria, method for the framework of integrated urban water system include the following advantages;

(a) Allow for the included many criteria (either qualitative or quantitative).
(b) Objectives, criteria, and alternatives are translucent, allowing for open conversation. Decision-making process is participatory.
(c) It can carry the measure of each criterion out regarding each other.
(d) It is possible to calculate partial and global scores, which can be informative for policymaking.

There are following steps in Analytic Hierarchy Process (AHP) [18];

(1) Derive a model for the aim: define the goals, criteria, and alternatives into the hierarchy.
(2) Extract priorities or weights for each criterion: The magnitude of criteria compare in the pair wise matrix to derive their weights. Saaty (1980) suggested using the scale presented in Table1.2 to perform pair wise comparisons. Then check the consistency of result using Table 1.3 to reviewing it in means of proportionality and transitivity.
(3) Develop limited priorities or preferences for each alternative: evaluate local priorities regarding all criterions. Also, check and normalize uniformity if required.
(4) Model Synthesis: All alternatives priorities are finding then coalesced as a weighted sum to set up the overall priorities of the alternatives. The utmost overall priority of an alternative considers as the superlative choice.
(5) Execute Sensitivity analysis: A study will perform to test the alteration in the result when weights of the criteria changes to recognize the rationale following the obtain results.
(6) Assemble a Final Decision: Based on the synthesis and sensitivity analysis, it can make the best suitable judgment

Table 1.2Pair-wise comparison scale for AHP preferences Saaty 1980

Numerical Rating	Verbal Judgment
9	Extremely preferred
8	Very strongly to extremely
7	Very strongly preferred
6	Strongly to very strongly
5	Strongly preferred
4	Moderately to strongly
3	Moderately preferred
2	Equally to moderately
1	Equally preferred

Table 1.3Average Random Consistency Index (Ri) Saaty's and Vargas 1984

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

IV. RESULTS AND DISCUSSION

Von Winterfeldt (1980)[21] stated for decision making that the structuring procedure look for to characterize the environment part as the aim of the decision problem and the decision makers or experts as subjective values. Basic concept of structuring activities is identifying or creating problem factors and relating those factors by influence relations, additional relation, and hierarchy relation. The architecture of the selected model for MCDA has been configuring based on four most important major criteria: economic, social, sustainability and environmental problems and interface linking them. This model includes the recognition and selects the different simple level aspects that will influence the concern issues of the study. The primary step in an AHP modeling is to construct a hierarchy for the required objectives.

It also called this assessment modeling, and it comprises structure a hierarchy to scrutinize the decision. Fig 1.3 shows the proposed hierarchy for integrated urban water system comprising the criteria and alternatives used in the method.

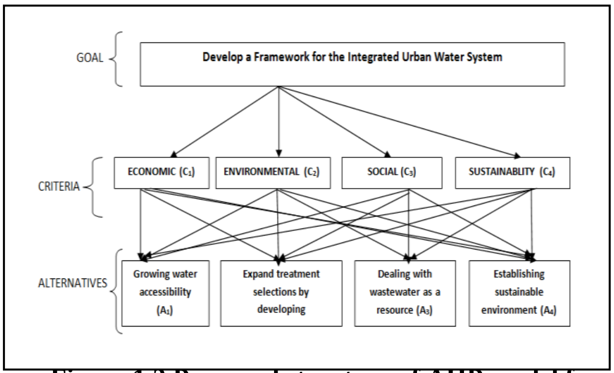

Figure 1.3 Proposed structure of AHP model for integrated urban water system

For this study, we used important data from the RMC draft report for the AHP method. For the Integrated urban water system in the city, here we identify three basic criteria i.e. economic (C_1), environmental (C_2), social (C_3) and sustainability (C_4) criterion from reviewed of the city's report. These criterions represent the assessment variables that influencing urban water system conditions shown in Table 1.4. Four alternatives presented in Table 1.5 influencing the criteria are select; verifying the extreme character of these alternatives to solve an urban water system problem.

Table1.4 Proposed criteria and their description

Notations	Criteria	Description
C_1	Economic	This criterion refers to all costs required for executing the development plan for the urban water system of the city. This measured qualitatively decision of experts for plan.
C_2	Environmental	This criterion refers to the potential impacts of the development plan on the city's water resources. This criterion refers to the probable health and hygiene issues that may arise after implementing the plan for those who involve in water reuse and recycling, wastewater and sewage treatment and result in concerns over public health among water users.
C_3	Social	This criterion refers to the facility of master plans to reach reasonable and sustainable solutions for water supply and demand in slum or blighted area of the city from the future generations' perspective. This also gives an extra penalty for plans in which there are no significant efforts to preserve the limited resources for the future generations.
C_4	Sustainability	This criterion refers merely aim to capitalize on the economic benefits of water and hygiene services in the short term, regardless of the long-term environmental and social impacts. This also refers to the ability of each scenario to match the quality of water supplied and consequences of wasting water. The greater know the water use importance, the better the quality of water supplied. This criterion also refers to the potential decrease in water consumption that may occur by implementing each of the criteria

Table 1.5 Development alternatives for City's urban water system

Notations	Alternatives	Description
A_1	Growing water accessibility	Through improved water system efficiency; demand site management; storm water harvesting couples flood and storm water management, recharge drinking water aquifers; reusing storm water for non-portable uses; leak detection; reduction in water losses. Grey-water/rainwater reuse can use less energy-intensive technology and with economic expenditure and develop natural/green infrastructure to promoting maximum productivity and inhabitant biodiversity within a catchment.
A_2	Expansion treatment selections by developing technologies	Make the natural system more efficient and reliable. We need to upgrade infrastructure and develop technologies in real time controls to observe and performance regulation for urban water system such as a decentralized system; constructed wetlands for treatment ; bio-infiltration basins; managed aquifer recharged system and Vacuum Sewer Collection Systems.
A_3	Dealing with wastewater as a resource	Through resource recovery in which decayed organic wastes, different recyclable materials such as glass, paper, and metals are separate from other waste streams at the source for separate collection. Nutrient recovery by nitrogen fixation and energy recovery from the feces at the source and designing "next-generation sanitation" to the take advantage of the recovery of nutrients and energy
A_4	Establishing sustainable environment	Requirement to develop a sustainable surroundings that integrates factors including administration support; sufficient authorized and administrative frameworks that flexible to local conditions, institutional arrangements, and financing opportunities for water organizations; the accessibility of required skills and capacities; and socio-cultural acceptance for users

The subsequent step in the AHP method is to obtain the relative priorities (weights) for the criteria. This is supposed to be relative because these priorities for define criteria are calculated regarding each other. First, we practice the pair-wise comparison for the criteria showing Table1.6 with a weighted index W (or priority weight). To rank the prioritization of the criteria, we used 9 values of classification from 1 to 9 based on pair-wise comparison scale given by Saaty 1980, so here we consider that $C_1$is very strongly, strongly and moderately important than the C_2, C_3 and C_4 will contain the value 6, 4 and 2 respectively. Next C_4 followed by C_2 and C_3 will contain 6 and 4 values and C_3 is equally to moderately important to C_2 contain value 2.

Table1.6 Pair wise comparison matrix for the criteria

Criteria	C_1	C_2	C_3	C_4	W
C_1	1	6	4	2	0.482
C_2	1/6	1	1/2	1/6	0.064
C_3	1/4	2	1	1/4	0.111
C_4	1/2	6	4	1	0.344
λ_{max} =4.072		CI=0.024		CR=0.026	

Since CR less than 0.1, we can confirm that the comparison is consistent and thus acceptable. In a next step calculate the relative priorities or preferences of the each alternatives (A_1, A_2, A_3, A_4) shown in Table1.7, Table 1.8, Table1.9 and Table1.10 regarding each criterion C_1, C_2, C_3 and C_4 with their weighted index W. After that Table 1.11 shows the limited Priorities (or preferences) of the alternatives regarding each criterion.

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Table 1.7 Pair wise comparison matrix for C_1

C_1	A_1	A_2	A_3	A_4	W
A_1	1	1/3	1/5	1/7	0.057
A_2	3	1	1/3	1/5	0.122
A_3	5	3	1	1/3	0.263
A_4	7	5	3	1	0.558
λ_{max}=4.120 CI=0.040 CR=0.044					

Table 1.8 Pair wise comparison matrix for C_2

C_2	A_1	A_2	A_3	A_4	W
A_1	1	4	5	2	0.473
A_2	1/4	1	1/2	1/4	0.084
A_3	1/5	2	1	1/5	0.
A_4	1/2	4	5	1	0.
λ_{max}=4.171 CI=0.057 CR=0.063					

Table 1.9 Pair wise comparison matrix for C_3

C_3	A_1	A_2	A_3	A_4	W
A_1	1	2	3	2	0.406
A_2	1/2	1	3	2	0.288
A_3	1/3	1/3	1	1/3	0.098
A_4	1/2	1/2	3	1	0.208
λ_{max}=4.123 CI=0.041 CR=0.046					

Table 1.10 Pair wise comparison matrix for C_4

C_4	A_1	A_2	A_3	A_4	W
A_1	1	3	3	7	0.505
A_2	1/3	1	1/3	3	0.141
A_3	1/3	3	1	7	0.301
A_4	1/7	1/3	1/7	1	0.053
λ_{max}=4.165 CI=0.055 CR=0.061					

Table1.11 Limited Priorities (or preferences) of the alternatives with respect to each criterion

ALTERNATIVES	C_1	C_2	C_3	C_4
A_1	0.057	0.473	0.406	0.505
A_2	0.122	0.084	0.288	0.141
A_3	0.263	0.107	0.098	0.301
A_4	0.558	0.336	0.208	0.053
	CR=0.044	CR=0.063	CR=0.046	CR=0.061

In this next step, here it should find out the overall priority called absolute priority for every alternative; Priorities that consider not only our primary selection of alternatives for every criterion but also the reality that all criterions have a special weighted index. Here we are applying all the values provided in the model, for model synthesis. Now listed the alternatives organized by overall priorities or preferences as follows shown in Table 1.12

Table 1.12 Overall priority or preference

Synthesis of model					
ALTERNATIVES	C_1	C_2	C_3	C_4	overall priority
A_1	0.057	0.473	0.406	0.505	0.276
A_2	0.122	0.084	0.288	0.141	0.144
A_3	0.263	0.107	0.098	0.301	0.248
A_4	0.558	0.336	0.208	0.053	0.332

These in general priorities will be close influence by the weighted indices given to the relevant criteria. Sensitivity analysis permits us to distinguish how vigorous is our original decision and what are the drivers (i.e., which criterion influenced the original results). This is a main component of the procedure and without performing sensitivity; analysis should make no ultimate decision without performing sensitivity analysis. To perform a sensitivity analysis, it is compulsory to alter the weights of the criterion and see how they will change the overall priorities of the alternatives.

We will examine these following scenarios shown in Table1.13

1. First scenario; original priority
2. Second scenario; all criteria have the same weighted index
3. Third scenario; economic criterion weighted index leading regarding each equally preferred alternatives
4. Fourth scenario; environment criterion weighted index leading regarding each equally preferred alternatives
5. Fifth scenario; social criterion weighted index leading regarding each equally preferred alternatives
6. Sixth scenario; sustainability criterion weighted index leading regarding each equally preferred alternatives.

Table 1.13 Sensitivity analyses for each criterion

Alternatives	C_1	C_2	C_3	C_4	Overall priority					
					(i)	(ii)	(iii)	(iv)	(v)	(vi)
Criteria Weights	0.482	0.064	0.111	0.344						
A_1	0.057	0.473	0.406	0.505	0.276	0.360	0.260	0.398	0.376	0.409
A_2	0.122	0.084	0.288	0.141	0.144	0.158	0.146	0.134	0.202	0.153
A_3	0.263	0.107	0.098	0.301	0.248	0.193	0.216	0.164	0.161	0.229
A_4	0.558	0.336	0.208	0.053	0.332	0.289	0.379	0.305	0.262	0.211

We found the highest overall priority for alternative A_1 in all scenarios that is growing water accessibility for the urban water system in Raipur city. The second priority is meet with alternative A_4 i.e. establishing the sustainable environment. We suggest these two alternatives should into the first place to meet future urban water system demand in the city.

For the city's urban water system, the stakeholders and policy makers should prefer alternative A_1 and then A_4, since it will contribute to sustainable urban water system while satisfying economic, environmental, social and sustainable criteria. From the long-term point of view, delivery of an urban water system needed following:

(1) It must be economical sustainable at function and maintenance level.

(2) The government should also develop regulatory surroundings.

From the assessment, we can conclude that A_1 and A_4 both alternatives are equally preferable for the framework as shown in Fig 1.4. We categorizing the alternatives based on the compromise solutions according to performing the city's urban water system under various prescribed scenarios. As a result, the AHP framework is more significant and efficient in facilitating an analytic insight into the decision-making problem. Now decision makers (DMs) are better know to make the ultimate preference for alternatives.

This new framework will support flexible and efficient urban water system becomes the leading worldwide paradigm.

The future city's urban water systems necessitate overcoming the disputes described above and to design, control, and supervise water systems in vitally different ways. This will need that decision makers, investigators, engineers, and educationalists adopt new perspectives to solve the problems.

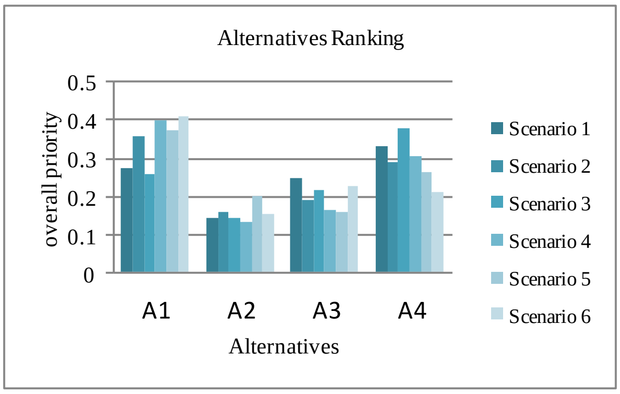

Fig 1.4 Alternative preference with respect to scenario

V. CONCLUSION

This paper presents a proposal for a framework based on MCDA using AHP as a tool. After discussing the concept of decision-making, we determined criteria weights and priorities based on the objectives of the framework, their criteria, and alternatives. We set our four different criteria for an integrated urban water system, which are economic, environmental, social, and sustainability. It comprises four alternatives that satisfying each criteria of study area. Each criterion has at least one-criterion weights associated with it. To implement the framework, it requires overall priories for the defined criteria weights, which depend on either policymakers or stakeholders. The appraisal framework should be validating. Therefore, the MCDA approach should screen and implementing through the decision makers who are the stakeholders of the urban water system and water utility experts. It is now understandable that the framework is only a multi-criterion relieve, to manage data, support discussion and visualize straightforward approach the different phases under study and it does not find the "optimal technology" [5].

This should be noticeable that the evading of inconsistencies is an imperative task in decision-making. Inconsistent decision-making might distress the assessment consequences and ranking of alternatives; in this study, it did not [6] This should further encourage the take part of all influenced organizations and institutions, which is the key factor for introducing the principles of integrated urban water management.

Strategic decisions support is a compound in mounting urban water and wastewater systems in a more sustainable direction [16]. However, the study shows that in a deal with the decision-making systems of a multi-hierarchy and multi-variable level, AHP provides a prominent tool through synthesizing different options and at last gives both qualitative and quantitative research, and the process itself is, in fact, a method of understanding the complicated system.

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