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# SMALL HYDROPOWER SITE SELECTION USING SPATIAL- FUZZY EXPERT SYSTEM: A CASE STUDY

**Priyabrata Adhikary[1], Pankaj Kr Roy[2] and Asis Mazumdar[3]**

[1]Mechanical Engineering Department, Gargi Memorial Institute of Technology, Kolkata- 700144. Email: priyabrata24@gmail.com
[2,3]School of Water Resources Engineering, Jadavpur University, Kolkata- 700032. Email: [2]pk1roy@yahoo.co.in, [3]asismazumdar@yahoo.com

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**Abstract:** Selecting the appropriate small hydropower project site in which to invest is a critical task involving different factors and policies. Small hydropower projects are emerging as a solution for sustainable, green, environment friendly and long term, cost effective source of renewable energy in India for the future. Hence such decision-making can be viewed as a multiple criteria analysis problem with correlating criteria and alternatives. This task should take into consideration several conflicting aspects because of the increasing complexity of the social, technological, environmental, and economic factors. Traditional single criteria decision-making approaches cannot handle the complexity of such systems. Multi criteria methods (MCDA) provide a better and flexible tool. This paper aims to evaluate applicability of multi criteria decision aid to decision makers during the small hydropower project planning and development. To the best of the author's knowledge this novel approach for application of MCDA to small hydropower project planning and development scenario is absent in renewable energy literatures due to its assessment complexity.

**Keywords:** Small hydropower, MCDA, Fuzzy Expert System, Site selection, GIS.

## 1. INTRODUCTION

In India, the total installed power generating capacity during June 2014 was reported as 2,49,488 MW out of which only 40,730 MW is through hydro power. The identified small hydro power potential sites are 14300 MW (approx.) and installed are 2150 MW (approx.). The cost of clean-green-friendly small hydroelectricity is relatively low i.e. Rs2.5/KWH (approx.), compared to others and thus making it a competitive source of renewable energy as demonstrated [1, 2]. It is much more advantageous over conventional large or medium hydropower projects. Some industries, like oil refining, health care and power generation have (24x7) type continuous schedules almost from the day they start. When a company needs to move from 5-day operations to 7-day operations, the strategy can result in significant human relations and operational problems if not handled properly, and needs critical decision makings.

Small hydropower projects (SHP) (i.e. up to 25MW in India) are more advantageous than conventional medium or large hydropower projects. Small hydropower plant requires very less flow or head compared to conventional hydropower plants. Reservoir is also not required for small hydropower projects as they are mostly run-off-river type. Environmental and social impacts of small hydropower projects are also negligible compared to conventional medium or large hydropower projects [3, 4]. There are normally four phases for engineering work required to develop a small hydropower project.


Fig.1 SHP- Project Implementation Stages

**Pre-Feasibility Analysis and Reconnaissance Surveys:** A quick and inexpensive initial examination, the pre-feasibility analysis, determines whether the proposed project has a good chance of satisfying the proponent's requirements for profitability or cost-effectiveness, and therefore, merits the more serious investment of time and resources required by a feasibility analysis. It is characterized by the use of readily available site and resource data, coarse cost estimates, and simple calculations and judgments often involving rules of thumb. For large projects, such as for hydro projects, a site visit may be required. Site visits are not usually necessary for small projects involving lower capital costs [13, 14].

**Feasibility Analysis:** A more in-depth analysis of a project's prospects, the feasibility study must provide information about the physical characteristics, financial viability, and environmental, social, or other impacts of the project, such that the proponent can come to a decision about whether or not to proceed with the project. It is characterized by the collection of refined site, resource and equipment cost data. It typically involves site visits, resource monitoring, energy audits, more detailed computer simulation, and the solicitation of price information from equipment suppliers [13, 14].

**Engineering and Development:** If, based on the feasibility study, the project proponent decides to proceed with the project, and then engineering and development will be the next step. Engineering includes the design and planning of the physical aspects of the project. Development involves the planning, arrangement, and negotiation of financial, regulatory, contractual and other non- physical aspects of the project. Some development activities, such as training, customer relations, and community consultations extend through the subsequent project stages of construction and operation. Even following significant investments in engineering and development, the project may be halted prior to construction if financing cannot be arranged, environmental approvals cannot be obtained, the pre-feasibility and feasibility studies "missed" important cost items, or for other reasons [13, 14].

**Construction and Commissioning:** Finally, the project is built and put into service. Certain construction activities can be started before completion of engineering and development, and the two conducted in parallel. Each step of this process could represent an increase in one order of magnitude or so in expenditure and a halving of the uncertainty in the project cost-estimate [13, 14].

Such small hydropower projects (SHP) can be classified according to their function, and based on source of water:

**Run-Off-River Project:** Those projects utilize the instantaneous river flow without a dam. A weir or a barrage is constructed across the river simply to raise the water level slightly and divert water into a conductor system for power generation. Such a scheme is adopted in the case of a perennial river [13, 14].

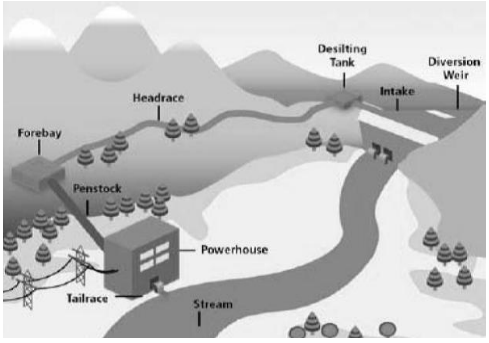


Fig.2: Run-Off-River Project

**Canal-Based Project:** Those small hydropower schemes are planned to generate power by utilizing the flow and fall in the canal. Those schemes may be planned in the canal itself or in the by-pass channel. These are low head and high discharge schemes. These schemes are advantageous due to low gestation period, simple layout, no rehabilitation problems and no socio-environmental problems [13, 14].

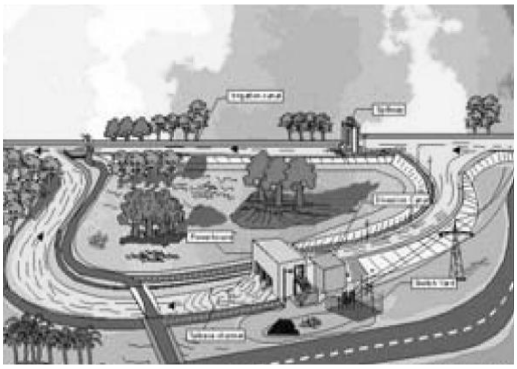

Fig.3: Canal-Based Project

**Dam-Toe Project:** In those plants, head is created by raising the water level behind the dam by storing natural flow and the powerhouse is placed at the toe of the dam or along the axis of the dam on either side. Water is carried to the powerhouse through a penstock [13, 14].

**Pumped Storage Project:** It is a method of keeping water in reserve for peak period power demands by pumping water that has already flown through the turbines back up to a storage pool above the power plant at a time when customer demand or tariff for energy is low, such as during the middle of the night. Water is then allowed to flow back through the turbine-generators at times when demand is high and a heavy load is placed on the system. Because pumped storage reservoirs are relatively small, construction costs are generally low compared with conventional hydropower facilities [13, 14].

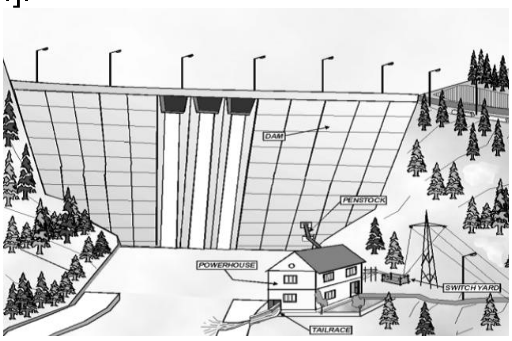


Fig.4: Dam Toe Project

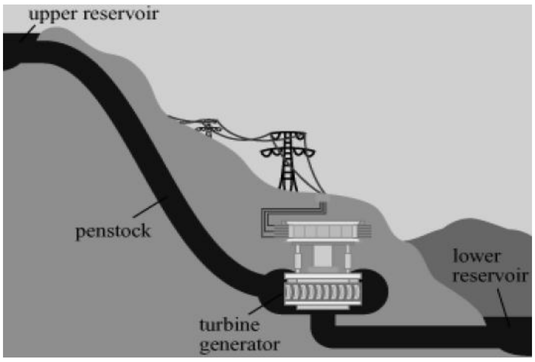


Fig.5: Pumped Storage Project

There are two basic components in all four types of SHP schemes; i.e., civil works (Diversion and intake, De-silting tank, Power channel, Fore-bay, Penstock, Powerhouse building, Tail race channel, etc.) and electro-mechanical equipment (Valves, Hydraulic Turbine, Generator, etc.) [5, 6]. Most of the components are same in different types of schemes; some components, however, are different. Based on various surveys and data collected, water power analysis, technical and financial details are worked out and a pre-feasibility or feasibility report and hence detailed project report (DPR) is prepared. This report is a comprehensive document containing project objectives, scope of project, location, topography, hydrology, geological aspects, environmental and socio-economic aspects, details of works such as civil, hydro-mechanical and electrical equipments, broad specifications of the civil works or structures, size of components, estimated cost of components, economical and financial analysis.

In general, evaluating small hydropower project (SHP) site is a complex analysis that can be defined as a multi-dimensional space of different indicators and objectives. The use of multi-criteria decision analysis (MCDA) or multi-criteria decision making (MCDM) or multi-criteria analysis (MCA) technique provides a reliable methodology to rank alternatives in the presence of different objectives and limitations [7, 8]. Even with the large number of available MCDA methods, none of them is considered the best for all kinds of decision-making situations. Different methods often produce similar as well as different results even when applied to the same problem using same data. There is no better or worse method but only a technique that fits better in a certain situation. These methods are gaining importance as potential tools for analyzing complex real-world problems due to their inherent ability to judge different alternatives on various criteria for possible selection of best or suitable alternatives. These alternatives may be further explored in depth for their final implementation. These methods can be used as empirical validation and testing tools of various needs. In addition they can be also applied to group decision making scenario as well as for uncertainty analysis. A review of various published literatures on sustainable energy planning indicates greater applicability of MCDA methods in changed socio-economic scenario. The methods have been very widely used to take care of multiple, conflicting criteria to arrive at better solutions Increasing popularity and applicability of these methods beyond 1990 indicate a paradigm shift in renewable energy planning, development and policy analysis. More research is still to be done to explore the applicability and potentiality of more MCDA methods to real-world planning and designing problems to reduce the gap between theory and practice. Many soft-wares (1000Minds, D-Sight etc.) have also been developed to facilitate such analysis or study. This paper on small hydropower project based decision making is an effort in that direction.

## 2. METHODOLOGY ADOPTED

The decision making processes are complex, as small hydropower site selection is more challenging today. Most people, when confronted with such problems, will attempt to use intuitive or heuristic approaches to simplify the complexity until the problem seems more manageable. In the process, important information may be lost, opposing points of view may be discarded, and elements of uncertainty may be ignored. Hence there is a need for simple, systematic, and logical methods or mathematical tools to guide decision makers in considering a number of selection attributes and their interrelations. MCDA method is a process of evaluating real world situations, based on various qualitative or quantitative criteria in certain, uncertain or risky environment to suggest an alternative, course of action, strategy and policy among the available options. MCDA method not only provides better-supported techniques for the comparison of product or project alternatives based on decision matrices but also has the added ability of being able to provide structured methods for the incorporation of project stake holder's opinions into the ranking of alternatives [9, 10]. A systematic methodology to combine quantitative and qualitative inputs from scientific studies of those criteria to rank small hydropower project alternatives has yet to be fully developed. Hence, decision makers often do not optimally use all available and necessary information in choosing between identified project or equipment alternatives.

Since human judgments on small hydropower plant site selection including preferences that are often vague, it is difficult to rate them in exact numerical values. In addition, in case of conflicting situations or criteria, a decision maker must also consider imprecise or ambiguous data, which is very usual in this type of decision problems. A more realistic approach is using linguistic assessments, fuzzy numbers and interval data instead of crisp values. Based on the concept of fuzzy logic and the MCDA or MCDM method, Fuzzy-MCDM method has been developed to provide a rational, systematic process by which to discover a best solution and a compromise solution that can be used to resolve the renewable energy problem.

Traditional weighting methods in optimum small hydropower site selection are not recommended as it requires social and environmental impact analysis for its approval. Delphi Weighting Method is very popular in these cases. It is a semi-structured communication method, developed as a systematic, interactive forecasting method which relies on engineers, managers or experts. In the standard method, the experts answer the queries in two or more phases. After each phase, a facilitator provides an anonymous summary of detailed forecast report of the experts. Thus, experts are encouraged to revise their earlier answers in light of the replies of other members of their panel. During this process the range of the answers will decrease and the group will converge towards the "correct" solution. Finally, the process is stopped after a pre-defined stop criterion. The mean or median scores of the final phase or rounds determine the final results. Delphi is based on the principle that decisions from a structured group of individuals are more accurate than those from unstructured groups and has been mentioned as "collective intelligence". The technique can also be adapted for use in meeting individuals and is then termed as mini-Delphi. The main objective of "Delphi Method" was to combine expert opinions on likelihood and expected development time, of the particular technology, in a single indicator.

The small hydropower site selection process includes a detailed evaluation of project needs which are then measured against the merits of potential locations. The process typically includes selecting and evaluating communities, project site analysis and acquisition, and may include negotiating tax incentives. The process includes various steps such as: Define project criteria, Evaluate communities, Create short list of communities based upon project criteria, Negotiate tax incentives, Site acquisition etc. The success of a site selection program can be directly attributed to diligent project preparation, along with an objective, methodical, and detailed process for the location evaluation. Developing the project-specific plan and checklist is usually a relatively short step in relation to the full location evaluation process [11, 12]; yet, it has proven time and again to be among the most important determinates of overall project success. Site selection checklists vary, often greatly, by industry, function, and company. There are potentially various factors that could be compiled into a master checklist that would cover all of these scenarios. Successful site selection projects result in the identification of a location with the optimal balance of operating costs, business conditions, infrastructure, and risk. Regardless of which and how many factors ultimately make up the site selection checklist, what is most important to the project is to ensure that the site selection team adopts an appropriate decision-making framework and criteria weighting scheme so that the factors on its checklist are evaluated within a company- and project-specific context. And, of course, it will also be critically important to ensure that the location data collected for each of these factors on the checklist are also project-specific as well as accurate. Here GIS plays a crucial role.

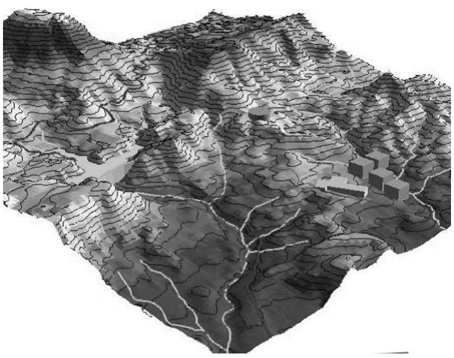

Fig.6: Digital Elevation Model-GIS

The input data for GIS (Geographic Information System) based SHP planning and developments are the hydrologic (soil type, land-use, vegetation), topographic (area, slope) and topologic (relationship, network) information and the digital elevation model for the river basin. First, the river course is automatically divided into equal segments using the usual tools of GIS. Second, at each division point going down from the upstream and using a specially developed GIS tool and the DEM (Digital Elevation Model) as shown in Fig.6, the basin area up to the determined section is calculated. With the catchment area applying the usual methods of hydrological calculations, the monthly basin runoff is computed. With the elevation drop and runoff for each section, the stream power can be easily calculated. This procedure is performed for each river segment from the upper to the lower reaches of the river and estimates all of the potential. It is absolutely clear that multiple environmental considerations reduce the likelihood that a site may be developed to its physical potential. Therefore, screening out sites within parks and other environmentally sensitive or excluded areas will result in the actual hydropower potential. Analyzing the application of GIS software for potential assessments, the common ArcGIS tools developed by ESRI (Environmental Systems Research Institute) are generally used. Especially suitable tools are ArcGIS Spatial Analyst and the recently developed ArcGIS extension, ArcHydro, which allows the user to set a number of hydrological parameters used by hydrologic models as input data. Several identified schemes, are very close to each other, distant only by a few hundred meters, with very similar results. This does not really matter as the objective of the GIS tool is not to identify precisely the location of the proposed schemes, but rather zones of interest. However, in such cases, the increased number of installations in a given zone makes consulting the results on the maps more complicated. The user needs to spend more time sorting them by multi criteria analysis techniques to get the optimized solution. The assessment is done by collecting information or values for certain attributes which are also known as attribute of assessments [13, 14]. Collection of all attributes of the assessment is called the Universe of Assessment. It is not absolute that more and more criteria are helpful for small hydropower site selection decision-making problem. The hydro power site selection process includes a detailed evaluation of project needs which are then measured against following attributes survey or investigation ($x_i$):

Topography ($x_1$) is a field of planetary science comprising the study of surface shape and features of the Earth. It is also the description of such surface shapes and features (especially their depiction in maps). The topography of an area can also mean the surface shape and features. It has application in many diverse fields such as the energy production, agriculture and construction, etc.

Geology ($x_2$) is the science comprising the study of solid Earth, the rocks which it is composed of, and the processes by which they change. Geology gives insight into the history of the Earth, as it provides the primary evidence for plate tectonics, the evolutionary history of life, and past climates. In modern times, geology is commercially important for mineral and hydrocarbon exploration and exploitation and for evaluating water resources. The geology of an area changes through time as rock units are deposited and inserted and deformational processes change their shapes and locations. These structural regimes broadly relate to convergent boundaries, divergent boundaries, and transform boundaries, respectively, between tectonic plates. It has application in different diverse fields.

Meteorological ($x_3$) phenomena are observable weather events which illuminate, and are explained by the science of meteorology. Those events are bound by the variables that exist in Earth's atmosphere; temperature, air pressure, water vapor, and the gradients and interactions of each variable, and how they change in time. Different spatial scales are studied to determine how systems on local, regional, and global levels impact weather and climatology. Meteorology has application in diverse fields such as energy production, transport, agriculture, etc.

Raw materials ($x_4$) are first harvested from the earth and divided into a form that can be easily transported and stored, then processed to produce semi-finished materials. These can be input into a new cycle of production and finishing processes to create finished materials, ready for distribution, construction, and consumption. Material is anything made of matter, constituted of one or more substances.

Transport or communication ($x_5$) facilities are vital infrastructures of connectivity. Transport system comprises several modes including Road, Rail, waterways, etc. Development of roads facilitates utilization of natural resources lying unutilized in different hills, mountains, forests and mines. Transport system widens the size of the market.

Environmental ($x_6$) surveyors use surveying techniques to understand the potential impact of environmental factors on construction developments, and conversely the impact that construction developments will have on the environment.

Load survey ($x_7$) system to determine the load characteristics of various customer classes in an electric utility company. The actual power consumption of customers is collected by intelligent meters. Sampling theory and then statistical analysis is performed to find the power consumption model of each customer class based on the power measurement of field tests. If data are missing, imputation is done on a manual basis using a ratio based on previous year's data. It has application in many diverse fields such as the energy production, construction projects, etc.

The theory that underlies taxation ($x_8$) is that charges are imposed to support the government in exchange for the general advantages and protection afforded by the government to the taxpayer and his or her property. The existence of government is a necessity that cannot continue without financial means to pay its expenses; therefore, the government has the right to compel all citizens and property within its limits to share its costs. The state and federal governments both have the power to impose taxes upon their citizens.

Wage labor ($x_9$) is the socioeconomic relationship between a worker and an employer, where the worker sells their labor under a formal or informal employment contract. These transactions usually occur in a labor market where wages are market determined. In exchange for the wages paid, the work product generally becomes the undifferentiated property of the employer, except for special cases.

## 3. THEORY AND CALCULATIONS

The main advantage of the fuzzy logic method is to control the processes that are too complex to be mathematically modelled. The membership functions must be optimally determined to design an efficient vague fuzzy set theory for a problem. Many factors related to Run-off River or hydro power are subjective and difficult to quantify in this type of process such as Water Level or Depth is at “Below Danger Level-Danger Level-Above Danger Level”. Similarly the water flow rate is “Slow-Normal-Fast”, “Standard– High– Maximum” etc. Still fuzzy logic enables the evaluator or the decision maker to incorporate this information in the environment performance evaluation system which is imprecise, vague and subjective [15, 16]. Therefore, the vague fuzzy set theory method is a very suitable method for small hydro electric power generation site selection problem.

**Fuzzy Set:** Let $U = \{u_1, u_2, \ldots\ldots, u_n\}$ be the universe of discourse. The membership functions for the fuzzy sets can take any value from the close interval [0, 1]. Fuzzy set A is defined as the set of ordered pairs $A = \{(u, \mu_A(u)): u \in U)\}$, where $\mu_A(u)$ is grade of membership of element u in set A. The greater value of $\mu_A(u)$ is the greater of truthness of the statement that ‘the element u belongs to set A’.

**Vague Set:** Again let U be the universe of discourse, then a vague set A in U is characterized by two membership functions given by:

(i) A truth membership function, $t_A : U \rightarrow [0, 1]$ and

(ii) A false membership function, $f_A : U \rightarrow [0, 1]$

where $t_A(u)$ is a lower bound of the grade of membership of u derived from the 'evidence for u' and $f_A(u)$ is a lower bound on the negation of u derived from the 'evidence against u' and $t_A(u)+ f_A(u) \leq 1$. Thus the grade of membership of u in the vague set A is bounded by a sub-interval $[t_A(u), 1-f_A(u)]$ of [0, 1]. This indicate that if the actual grade of membership is μ(u), then $t_A(u) \leq \mu_A(u) \leq 1-f_A(u)$. The vague set A is written as $A = \{< u, t_A(u), f_A(u) > |: u \in U\}$, where the interval $[t_A(u), 1-f_A(u)]$ is called the vague value of u in A and is denoted by $V_A(u)$.

**Mean Vague Value:** Let E be an universe and X be an vague set of E. Then the mean vague value of the vague set X is a fuzzy set $\mu_{vs}$ of E given by the membership function:
$\mu_{vs}(x) = [t_A(x) + \{1-f_A(x)\}] / 2$

**Weighted Impact Value (WIV):** Let μ be a fuzzy set of a finite set X. Suppose that to each element $x \in X$, there is an associated weight $W_x \in R+$(set of all non-negative real numbers). Weighted Impact Value (WIV) of the fuzzy set μ is the non-negative number WIV(μ) given by: $WIV(\mu) = [\mu_{vs}(x). W_x]$

**Total Impact Value (TIV):** Let μ be a fuzzy set of a finite set X. Suppose that to each element $x \in X$, there is an associated weight $W_x \in R+$(set of all non-negative real numbers). Then the 'Total Impact Value' (TIV) of the fuzzy set μ is the non-negative number TIV(μ) given by: $TIV(\mu) = \sum[\mu_{vs}(x). W_x]$ where $[\mu_{vs}(x). W_x]$ is the Weighted Impact Value (WIV).
The weight of each attributes are prefixed by a group of water power engineering experts before commencement of case study.

**Fuzzy Decision Making Methodology:**

Let a group of options is "O" where
$O = \{o_i\}$, for (i= 1,2,…..,P).
And a group of goals associated with each options is "G" where
$G = \{g_{j / } o_i\}$, for (j= 1,2,…..,Q).

Again a group of constraints associated with each options is "C" where $C = \{c_{k / } o_i\}$, for (k= 1,2,…..,R).

Then the fuzzy decission is:
$D = Max \{D(o_i)\}$
where $D(o_i) = Min \{\mu(g_{j / } o_i), \mu(c_{k / } o_i)\}$

## 4. SMALL HYDRPOWER PROJECT SITE SELECTION– A CASE STUDY

Exact commercial data are not publicly accessible, but given are generated data based on provided relations between various parameters which are very close to an actual small hydropower project site data.

The data collected from 100 people for an attribute μ(xi) reveals that more or less 70 people are in support of the truthness of attribute and the rest 30 people are in support of falseness [17, 18]. But in support of trruthness, evidence for $t(x_i)$ found 50 people and against $f(x_i)$ is 20 people. So it is set such that $\mu(x_i) = 0.7$ but $t(x_i) = 0.5$ and $f(x_i) = 0.2$.

If the vague fuzzy set be X of the universe U, where $U = \{x_1, x_2, ……, x_9\}$, then the vague fuzzy set X will be: X = {(x1, 0.7, 0.2), (x2, 0.65, 0.15), (x3, 0.5, 0.5), (x4, 0.6, 0.3), (x5, 0.45, 0.15), (x6, 0.6, 0.2), (x7, 0.4, 0.5), (x8, 0.2, 0.7), (x9, 0.8, 0.1)}. TIV = 370.00.
Now after the completion of survey at three sites based on the above logic the data are arranged in tabulated form for calculation and decission

making as shown in Table 1 for first loaction ($L_1$). Similarly assuming TIV for other two locations, $L_2$ and $L_3$ are 1220 and 870. Now one has to apply the decision making method for selection of the best suitable site location of the project proposed [18, 19]. The river flow rate and project cost for all three locations are estimated and tabulated in Table 2.

Now for a sustainable renewable energy or hydro power project "River Flow Rate" is the goal i.e. ($g_1$), and if "Total Impact Value" and "Project Cost" are two constraints i.e. $c_1$ and $c_2$, then fuzzy set for each characteristics will be:

$\mu(g_1 / L_i) = [0.6 / L_1, 0.8 / L_2, 0.7 / L_3]$;
$\mu(c_1 / L_i) = [1.0 / L_1, 0.4 / L_2, 0.95 / L_3]$;
$\mu(c_2 / L_i) = [1.0 / L_1, 0.9 / L_2, 0.8 / L_3]$ ;
Hence,
$D(L_i) = [0.6 / L_1, 0.4 / L_2, 0.7 / L_3]$ and fuzzy decission is:
$D = \text{Max}\ \{D(L_i)\} = 0.7 / L_3$

## 5. RESULTS AND DISCUSSION

Results reveal that site location ($L_3$) is the best suited site for the construction of small hydro power project within the zone on the river considered. It is well understood that the data scarcity problem in hydro power modeling for the estimation of proper site selection can be easily solved using vague fuzzy set theory. From the approximate data, the model is capable of generating reasonably accurate result. These results demonstrate that the fuzzy logic is a useful method for assessing or decision making in hydro power site selection and not enforced to evaluate with a crisp number.

## 6. CONCLUSION

The paper has dealt with the concept of vague fuzzy set theory and fuzzy decision making tool, both of which have vast potential to play an important role to tackle the uncertainty in perception of decision makers in hydro power site selection. The data and information so available from various sources are linguistic and imprecise. However, there could be other hidden parameters (non-technical) i.e. local constraints as politics, which will also influence the decision making.

Table 1: Decision Making Matrix

| Attribute Name ($x_i$) | Degree of Truth-ness $\mu(x_i)$ | Truth-ness Evidence $t(x_i)$ | Falseness Evidence $f(x_i)$ | Mean Vague Value $\mu_M(x)$ | Weighted Attributes $W_x$ | Weighted Impact Value (WIV) |
|---|---|---|---|---|---|---|
| $x_1$ | 0.73 | 0.70 | 0.20 | 0.75 | 10 | 75.00 |
| $x_2$ | 0.70 | 0.65 | 0.15 | 0.75 | 80 | 60.00 |
| $x_3$ | 0.50 | 0.50 | 0.50 | 0.50 | 10 | 05.00 |
| $x_4$ | 0.68 | 0.60 | 0.30 | 0.65 | 75 | 48.75 |
| $x_5$ | 0.60 | 0.45 | 0.15 | 0.65 | 30 | 19.50 |
| $x_6$ | 0.74 | 0.60 | 0.20 | 0.70 | 65 | 45.50 |
| $x_7$ | 0.48 | 0.40 | 0.50 | 0.45 | 85 | 38.25 |
| $x_8$ | 0.25 | 0.20 | 0.70 | 0.25 | 90 | 22.50 |
| $x_9$ | 0.86 | 0.80 | 0.10 | 0.85 | 65 | 55.25 |
| | | | | | **TIV** | **370.00** |

Table 2: Various Site Location Data

| Site Location | TIV | Flow Rate (Cusec) | Project Cost (Cr.) |
|---|---|---|---|
| $L_1$ | 370 | 1200 | 55.00 |
| $L_2$ | 1220 | 2000 | 75.00 |
| $L_3$ | 870 | 1500 | 60.00 |

## REFERENCES


[1] Adhikary, P., Roy, P.K. and Mazumdar, A., Safe and Efficient Control of Hydro Power Plant by Fuzzy Logic, International Journal of Engineering Science & Advanced Technology, Vol.2, No.5, pp.1270-1277, 2012.

[2] Adhikary, P., Roy, P.K. and Mazumdar, A., MCDA of Manpower Shift Scheduling for Cost Effective Hydropower Generation, International Journal of Emerging Trends In Engineering Development, Vol.7, No.2, pp.116-127, 2012.

[3] Adhikary, P., Roy, P.K. and Mazumdar, A., Selection of Penstock Material for Small Hydropower Project – A Fuzzy Logic Approach, International Journal of Advanced Scientific and Technical Research, Vol.6, No.2, pp.521-528, 2012.

[4] Adhikary, P., Roy, P.K. and Mazumdar, A., Selection of Hydro-turbine Blade Material – Application of Fuzzy Logic (MCDA), International Journal of Engineering Research and Applications, Vol.3, No.1, pp.426-430, 2013.

[5] Adhikary, P., Roy, P.K. and Mazumdar, A., Fuzzy Logic based User Friendly Pico-Hydro Power Generation for Decentralized Rural Electrification, International Journal of Engineering Trends and Technology, Vol.4, No.4, pp.507-511, 2013.

[6] Adhikary, P., Roy, P.K. and Mazumdar, A., Fuzzy Logic based Blade Angle control of Kaplan Turbine for a Hydropower Project, Proceedings of the ICERTSD 2013, Bengal Engineering and Science University, Shibpur, Howrah, India, Paper No: ICERTSD-13-109, 2013.

[7] Adhikary, P., Roy, P.K. and Mazumdar, A., Hydraulic Transient Analysis of Small Hydropower Project: A MCDM Application for Optimum Penstock Design, Proceedings of the IWMSID 2013, IIT, Bhubaneswar, india, Paper No: IWMSID/WRE/16, 2013.

[8] Adhikary, P., Roy, P.K. and Mazumdar, A., Indian Small Hydropower Project Planning and Development: A Review of DSS Tools, International Journal of Engineering Research & Technology, Vol.2, No.6, pp.1386-1391, 2013.

[9] Adhikary, P., Roy, P.K. and Mazumdar, A., Fuzzy Logic Based Optimum Penstock Design: Elastic Water Column Theory Approach, ARPN Journal of Engineering and Applied Sciences, Vol.8, No.7, pp.563-568, 2013.

[10] Adhikary, P., Roy, P.K. and Mazumdar, A., Optimum Selection of Hydraulic Turbine Manufacturer for SHP: MCDA or MCDM Tools, IDOSI - World Applied Sciences Journal, Vol.28, No.7, pp.914-919, 2013.

[11] Adhikary, P., Roy, P.K. and Mazumdar, A., Multidimensional Feasibility Analysis of Small Hydropower Project in India: A Case Study, ARPN Journal of Engineering and Applied Sciences, Vol.9, No.1, 2014.

[12] Adhikary, P. and Kundu, S., MCDA or MCDM Based Selection of Transmission Line Conductor: Small Hydropower Project Planning and Development, International Journal of Engineering Research and Applications, Vol.4, No.2, pp.357-361, 2014.

[13] Adhikary, P. and Kundu, S., Small Hydropower Project: Standard Practices, International Journal of Engineering Science & Advanced Technology, Vol.4, No.2, pp.241–247, 2014.

[14] Adhikary, P. and Kundu, S., RMU & LE: Optimal Solution for Small Hydropower, International Journal of Engineering Science & Advanced Technology, Vol.4, No.3, pp.300–306, 2014.

[15] Adhikary, P., Roy, P.K. and Mazumdar, A., Preventive Maintenance Prioritization by Fuzzy Logic for Seamless Hydro Power Generation, Journal of Institute of Engineers, India, Series-A, Vol.95, No.2, pp.97-104, 2014.

[16] Gau, W.L. and Buehrer, D.J., Vague Sets, IEEE, Transactions on Systems, Man and Cybernetics, Vol.23, pp.610-614, 1993.

[17] Sundareswaran, K., A Learner's Guide to Fuzzy Logic System, Chapter-5, Jaico Publishing House, New Delhi, pp.91-97, 2005.

[18] Zadeh, L.A., The Concept of a Linguistic Variable and its Application to Approximate Reasoning, Information Sciences, pp.199-249, 1975.

[19] Zadeh, L.A., Fuzzy Logic= Computing with Words, IEEE Transactions on Fuzzy Systems, Vol.4, No.2, pp.103-111, 1996.