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MCDM methods are used to pick penstock materials in small hydropower infrastructure

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Abstract: *Small hydropower (SHP) is a potentially clean and secure energy source. One of the most difficult tasks is selecting the right substance for different parts of SHP projects in general, and penstock in particular, because civil works components add significantly to the total cost of the project. A systematic and efficient strategy for selecting the best material does not exist in the literature, so engineers use several factors to make such a decision. The realism of materials with different properties has increased rapidly in recent years, complicating the material choice procedure. In the current research, "an attempt has been made to use multiple criteria decision making (MCDM) methods to solve the material selection problem for penstock in SHP installations. To pick the best material, COPRAS methods are used. Four alternative materials were considered, including polyvinyl chloride (PVC), high density polyethylene (HDPE), glass reinforced polymer (GRP), and mild steel (MS), as well as five evaluation attributes/scales such as yield strength, durability, thickness, cost, and material and maintenance costs". Case studies were examined and incorporated into the research. When compared to other materials, COPRAS methods are found to be most appropriate for penstock GRP.*

Keywords: *risk assessment, RAMCAP methodology, COPRAS methods*

1. INTRODUCTION

Various types of substances have become available in recent years, and material selection is critical in building and other disciplines. Material selection with the lowest cost and highest performance is a difficult job [1]. Material selection in any discipline necessitates a grasp of practical demands and performance criteria. As more materials become available, decision-making procedures become more laborious and complex [2,3]. The material selection process's goals are to choose the best material for its cheap cost, long life, minimal upkeep cost, light weight, and good performance. An MCDM problem can be used to pick an object alongside more than two choices and attributes/criteria. A penstock has a closed conduit that transports water from a forebay or surge reservoir to the turbine. Penstocks are designed to endure high water pressure, particularly water hammer. They are extremely expensive and serve a vital role in the irrigation system. Penstock is laid upon the ground, embedded in concrete, or buried in the earth depending on the site conditions. Bends, joints for expansion, manholes, fitting pieces, reducer or expander, and trumpet mouth intakes are all characteristics of penstocks. Penstock flow is pipe flow, with losses computed using the Darcy Weisbach equation.

$$\text{Headloss} = fLV^2(2gD)^{-1} \text{----------------(1)}$$

"where f is the coefficient of friction of the inner surface of the penstock and depends on the material, L is the length of the penstock (m), V is the velocity in the penstock (m/s), g is the gravity coefficient (m/ s2) and D is the diameter (m)".

Small hydropower: Small hydropower is a renewable energy technology that has been used in the nation since the early twentieth century. It is a tried and true source of vitality. Hydroelectricity is created when the pressure of water is transformed into mechanical power using a hydraulic turbine, and that electricity is used to fuel a generator that produces electricity [6]. The available power is proportionate to the end result of the head and exhaust. P denotes the mechanical power generated on the turbine shaft. (in W). A small hydropower project's fundamental components can be generally classified as (i) building work and (ii) electrical equipment. Diverter and intake - needed to divert the flow of water in river or stream to intake channel, aqueduct - supplied to convey diverted water coming from the rear of the dam to the front via the drain - are typical civil works for tiny hydropower schemes. Boring Tank - A significant quantity of alluvial soil is required to reduce water erosion. Forbe - It is a simple structure installed at the end regarding a water conduit to satisfy the initial water demand and absorb the water. Unexpected shutdown of generating machines Penstock - a pipe that transports water from the forebay to the windmill. Spillage provisions - In the event of a flood or partial load, the intake entry flow ought to be spilled as soon as feasible. A power plant building is a unit that generates electricity, and a tailrace channel is a straightforward water conduit that transports water generated by the turbine and restores it to the running stream. Inlet valves, turbines, draught tube, barriers, generator, management and protection equipment, and substation for transferring electricity to transmission line are the major electromechanical components of a power plant. The major components in terms of cost are the penstock, turbine, and generator. As a result, penstock was suggested for screening in order to increase selectivity.

2. PENSTOCK MATERIAL

The penstock is a tube that connects the intake mechanism to the hydro engine. The energy that is potential in the water is transformed with kinetic energy as it travels down the penstock. Penstock design includes a number of characteristics such as diameter, thickness, and losses [9]. Each one of these is computed independently. The penstock is intended to withstand maximum pressure during normal or unusual operating conditions, mainly owing to the phenomenon that water causes hammer. Steel and cast iron, concrete with reinforcement, precast plastic, and glass fiber-reinforced plastic are all elements used in penstock design. There are two types of penstock form and construction: single and double. A single has a single circuit for circulating and turning, whereas a double has two simultaneous circuits for circulating and turning. The single type is significantly less expensive, whereas the dual type provides greater operational flexibility, resulting in a faster operational response when the turbine is needed. Penstocks are long pipes that transport water from the reservoir for hydroelectricity to the generators inside the power plant. They are typically constructed of steel, and water moves under high pressure through the penstock. Penstock is a pipe made of cement, polyvinyl chloride (PVC), or steel that has been correctly calculated for the possible flow rate and head. Medium-density polyethylene (MDPE), high-density polyethylene (HDPE), rigid PVC (poly-vinyl chloride), and mild steel pipes are frequently used materials for penstock design in most small-scale businesses and micro-hydro projects. Their appropriateness, availability, and cost. Only steel should be used for high head penstocks, but the necessary steel strength ought to be established. Lower heads can be made of wire-reinforced timber, wood that has been laminate fiberglass, plastic, concrete, or mild steel. A a penstock is used to transport the water from where it comes to the power loom's hydraulic turbine. It is an essential component of the micro hydro system because it converts water's potential energy into kinetic energy. Depending on the natural characteristics of the property, penstock material, ambient temperature, and environmental issues, it can be exposed or buried beneath. Multiple variables such as diameter, thickness, water velocity, and cross-sectional area are taken into account when constructing penstock.

At various sites, penstock choice of materials, alignment, design, and implementation add differently to project costs. It is primarily determined by geography and geography, as well as the technique of construction and the material. As a result, penstock material and associated parameters such as surface roughness, construction pressure, joining technique, pounds and ease of installation, availability, and maintenance are carefully chosen [6,8]. Choosing the best material for mechanical, electrical, thermal, and chemical applications is a critical job [9,10]. Material selection is an important consideration in hydropower construction. Many new materials are being used in modern life to reduce weight; lower costs and improved performance are accessible [11,12]. An MCDM problem is optimal material selection in hydropower engineering from numerous alternatives based on different properties. Numerous factors must be considered when choosing appropriate materials, ranging from mechanical, electrical, and physical characteristics to resistance to corrosion and economic considerations. The degree of hardness toughness, thickness, rigidity, strength, and creep resistance is the most prevalent material properties encountered [13-15]. Material selection and MCDM method analysis are performed in this research to determine the most appropriate method and substance for penstock within SHP installations..

3. COPRAS METHOD

COPRAS were first proposed by Zavatskas and Kaklauskas (1996). A solution is determined using the COPRAS technique, which has a higher resolution rate. Describe the values and weights of alternative techniques and criteria in sufficient detail. The significance of the versions examined in the criterion setting this approach implies direct and proportional dependence and utility. Weights of scales and estimates of Soft's alternatives are used as numerical statistics in traditional cobras. However, under many circumstances, real-world decision-making issues arise. Smooth input is insufficient for handling. On the other hand, accurate knowledge is difficult to acquire. These factors also contribute to the accuracy of the findings. “Alternative techniques and criteria values and compute the weights correctly The significance of versions examined in descriptive criteria setting this approach is direct and proportional bias and examines usability. The significance, order of priority, and extent of use of alternatives are determined in five steps: D is the weighted normal choice matrix. 2. Normalized weighted description of the option Symbol values are calculated. 3. Substitutes' benefits S+j and disadvantages S -j Describe and calculate the Qj values of the options under consideration. The extent to which substitute aj is used 5. Choosing the most important option.”

To pre-qualify bidders' five window replacement variants Based on the findings of the multi-criteria evaluation, the first option is superior, and the third version is essentially the second best. The usage percentage is 100%. The contractor's final selection is the next stage. Pre-qualification criteria were met after taking into account candidate bids. Following the completion of the technical evaluation, the final exam of the final short-listed contractors will be held in order to grant the contract. The technical score will be used to connect price proposals. Table 1 displays the evaluation factors.

Existing MCDM techniques are used in the analysis to determine the best penstock material. The integrated method's schematic flow to find the best option for the most suitable option. The criteria for assessment and alternatives examined in the decision order framework are presented in the first step. Weights are established and used for the MCDM process with the help of a decision hierarchy. The pairwise comparison matrices are built in the second stage to determine the criterion weights and approximate the geometric average from the values. Finally, the decision makers accept the weights. COPRAS are used to identify and rank the best alternative.

Table 1 lists the attributes/criteria for optimal choice of material based on a study of the literature. In this research, consideration was also given to elements such as durability, thickness, functionality, and material maintenance. In the past, very few researchers examined the cost of optimal material selection. In this study, "five attributes/criteria for four alternative materials are investigated for penstock material selection as described below. 1. Yield strength (YS): This is the most significant parameter used in penstock design. 2. Life (L): Effective existence of the substance they serve under all conditions in the environment. 3. Thickness (T): The distance between the top and bottom surfaces of the material. As the thickness increases, the volume of the material increases. 4. Expenditure (C): It is an investment in purchase of material. 5. Maintenance Cost (MC): Cost incurred to keep it in proper working condition before any major defect occurs".

4. RESULT AND DISCUSSION

TABLE 1. Given a data set

Materials	YS(Mpa)	L(year)	T(mm)	C($/m)	MC($/m/year)
PVC	26	12	40	863.59	17.26
HDPE	34	25	46	1239.61	37.19
GRP	138	40	8	470.42	7.05
MS	252	50	9	630.65	37.84

The data collection for Penstock material is shown in Table 1. In the above table, the YS (Mpa), L(year), T(mm), C($/m)and MC($/m/year) of the return of "PVC, HDPE, GRP, and MS' are displayed. The other numbers are calculated using the above table.

TABLE 2. Normalized data

Materials	YS(Mpa)	L(year)	T(mm)	C($/m)	MC($/m/year)
PVC	0.0578	0.0945	0.3883	0.2695	0.1737
HDPE	0.0756	0.1969	0.4466	0.3869	0.3743
GRP	0.3067	0.3150	0.0777	0.1468	0.0710
MS	0.5600	0.3937	0.0874	0.1968	0.3809

Table 4: Given the normalised data calculated from the data set, "each value is determined by dividing the same value on the data set by the sum of the column of the above tabulation".

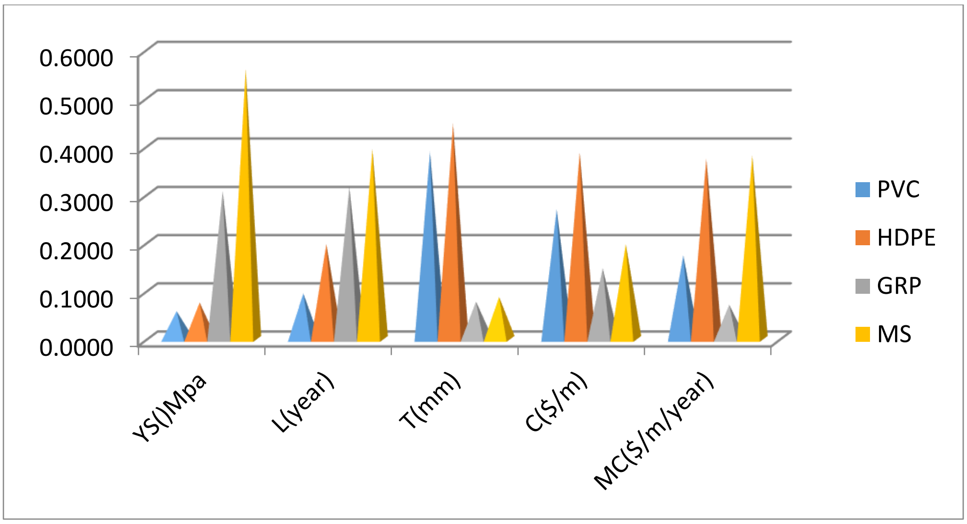

FIGURE 1. Gives the normalized data

Figure 2 depicts the normalised data derived from the data set; each value is calculated by dividing the same value on the data set by the sum of the columns in the above tabulation.

TABLE 3. Gives weight matrix

PVC	0.20	0.20	0.20	0.20	0.20
HDPE	0.20	0.20	0.20	0.20	0.20
GRP	0.20	0.20	0.20	0.20	0.20
MS	0.20	0.20	0.20	0.20	0.20

Table 4 displays the weight of the data set; the weight is the same for all values in the data set in table 1. To get the next value, multiply the weight by the prior table.

TABLE 4. Weighted normalization decision matrix

PVC	0.01	0.02	0.08	0.05	0.03
HDPE	0.02	0.04	0.09	0.08	0.07
GRP	0.06	0.06	0.02	0.03	0.01
MS	0.11	0.08	0.02	0.04	0.08

The weighted normalisation decision matrix is shown in Table 5. 'It is determined by multiplying the weight and performance value in Tables 3 and 4'.

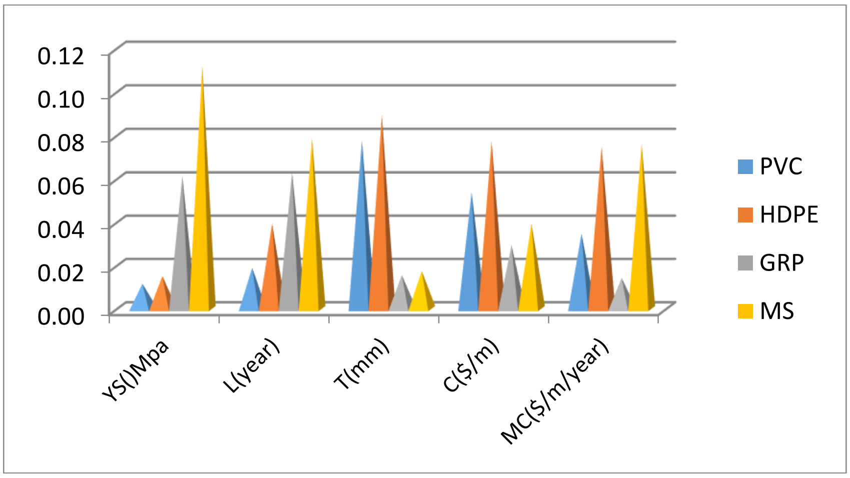

FIGURE 2. Weighted normalization decision matrix

The weighted normalisation decision matrix is shown in Figure 2.

TABLE 5. Value of Bi, Ci, Min(Ci)/Ci, and Qi

Materials	**Bi**	**Ci**	**Min(Ci)/Ci**	**Qi**
PVC	0.108	0.089	0.4914	0.199
HDPE	0.144	0.152	0.2862	0.197
GRP	0.140	0.044	1.0000	0.326
MS	0.208	0.116	0.3771	0.278

The values of Bi, Ci, and Qi are shown in Table 6. The Bi is the total of the Specific strength, Specific Modulus, and Corrosion resistance. The Ci is determined by adding the cost categories together. Qi is derived from Bi and Ci.

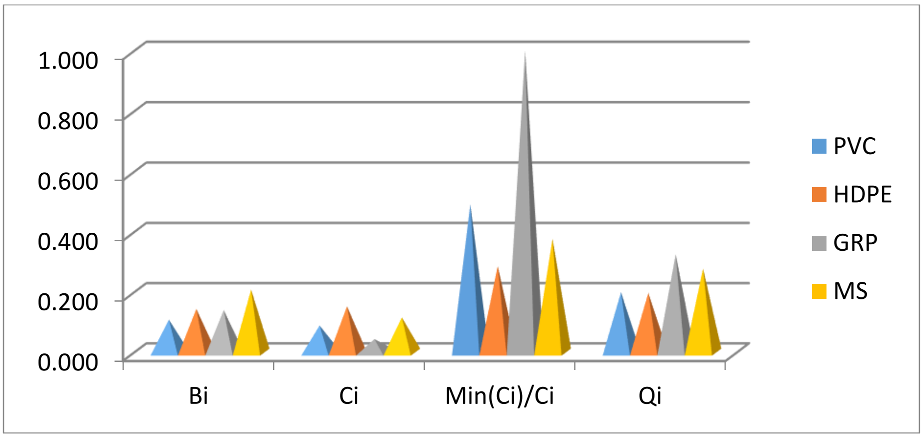

FIGURE 3. Bi, Ci, Min(Ci)/Ci, and Qi values

The values of Bi, Ci, and Qi are shown in Figure 3. The Bi is the total of the Specific strength, Specific Modulus, and Corrosion resistance. The Ci is determined by adding the cost categories together. Qi is derived from Bi and Ci.

TABLE 6. Ui value

Materials	**Ui**
PVC	61.2446
HDPE	60.4986
GRP	100.0000
MS	85.4715

Table 6 shows how Ui is determined using Qi. The PVC is 61.2446, the HDPE Ui is 60.4986, the GRP Ui is 100.0000, and the MS Ui is 85.4715.

TABLE 7. Ranking

Materials	**Rank**
PVC	**3**
HDPE	**4**
GRP	**1**
MS	**2**

Table 8 shows that the GRP is first, MS is second, PVC is third, and HDPE is fourth.

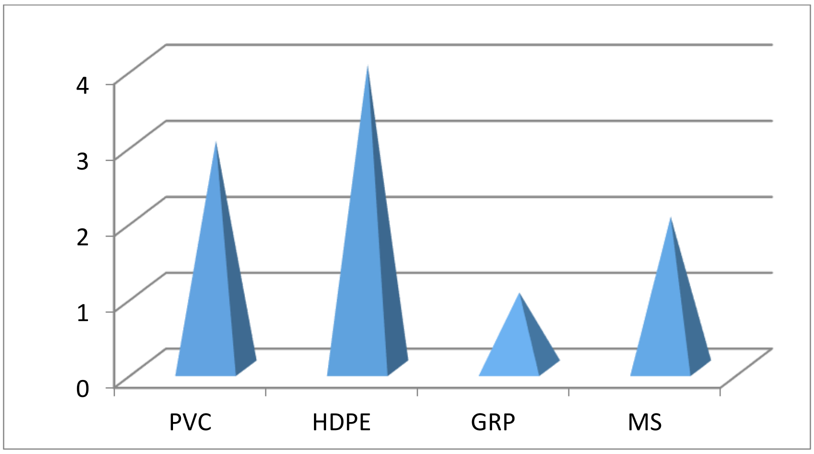

FIGURE 4. Ranking

Figure 5 shows that the GRP is first, MS is second, PVC is third, and HDPE is fourth. The material selection issue for penstock in small hydropower projects was solved using MCDM methods for ranking priorities. A method for optimal object ranking is created using COPRAS methods and the results for two case studies are given in Table 7. Table 7 assigns numbers 1, 2, 3, and 4 to various materials such as PVC, HDPE, GRP, and MS. Table 7 shows that GRP is rated first in COPRAS methods. These results are compared to their scores/values obtained using various ways of ranking alternative materials to determine the best material, as shown in Table 7. The rank depiction of MCDM methods is shown in Figure 4.

5. CONCLUSION

SHP serves a critical role in power generation for economic growth and development. The selection of penstock materials for hydropower plants has a direct impact on power production over the usable life of the plant because it contributes significantly to installation, operating, and maintenance costs. COPRAS MCDM methods are presented in this research to evaluate the optimal choice of material for penstock. The amounts of weight for the attributes/criteria were calculated using the COPRAS technique to determine the ranking of the items. The suggested method for integrating existing MCDM methods is found to be simple, suitable, and capable of finding the most suitable material among other options. The proposed method is applicable to choosing materials problems in SHP as well as other disciplines. Nevertheless, in the COPRAS method, the first and second-stage values/scores are very near to each other. GRP has a lengthy life and maximum yield strength while being relatively thin and inexpensive in comparison to other materials. MS is an appropriate material when material and upkeep costs are considered. The proposed technique clearly supports the choosing of the best substance for penstock.

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