# Strategic Evaluation Tool for Surface Water Quality Management Remedies in Drinking Water Catchments

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**Section A: Review of evaluation approaches for surface water quality management remediation options**

**Table S1.** Review of evaluation approaches for surface water quality management remediation options.

| References | Location | Study Approach | MCDA Technique | Weighting Method | Ranking Method | Evaluation Of NPS | | Uncertainty Analysis | | Stakeholder Involvement | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Yes | No | Yes | No | Yes | No | |
| Ji et al. [1] | Tianjin, China | Water Resources Allocation | inexact two-stage stochastic programming model | Probability distribution | Optimization | | ✓ | ✓ | | | ✓ | Inexact Two-Stage Stochastic Programming for Water Resources Allocation under Considering Demand Uncertainties and Response |
| Xu et al. [2] | Xiaoqing River Watershed | Water Supply Management | Stochastic Multi-Objective Chance-Constrained Programming Model | Various weight combinations and probabilistic levels. | Log-normal distribution | | ✓ | ✓ | | | ✓ | A Stochastic Multi-Objective Chance-Constrained Programming Model for Water Supply Management in Xiaoqing River Watershed |
| Casadei et al. [3] | Lake Trasimeno, Central Italy | Water Resources Management | SimBaT Decision Support System | Hydrological model | Short-term probabilistic assessments | | ✓ | ✓ | | | ✓ | Integrated Water Resources Management in a Lake System: A Case Study in Central Italy. |
| Walker et al. [4] | Danube Catchment, Serbia | Water Quality Management | PCA approaches | Weighted aggregation | Average rank | | ✓ | | ✓ | | ✓ | Multi-criterion water quality analysis of the Danube River in Serbia: a visualisation approach |
| Jaiswal et al. [5] | Benisagar Catchment, India | Catchment Asst & Prioritization | Fuzzy, Analytic Hierarchy Process (AHP) | Geometric mean method | Clustering of final priorities | | ✓ | ✓ | | | ✓ | Prioritizing susceptible areas in a watershed for soil conservation measures |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| Fan et al. [6] | Taizi Catchment, China | Catchment Water Management | Integrated Risk Asst (IRA), GIS | Simple weight method | 'One-Out, All-Out' (OOAO) | ✓ | | ✓ | | ✓ | Integrated risk assessment methodology for effective restoration management |
| Haider et al. [7] | Ravi River, Pakistan | Water Quality Management | Fuzzy Set | Simple additive weighting | Fuzzy OUTASTAR | ✓ | ✓ | | | ✓ | Framework to evaluate different WQM options (Wetland types) to meet the water quality objectives of natural rivers |
| Rahman et al. [8] | Northern Gaza | Water Management | AHP | Weighted Linear Combination and PROMETHE E II | MeTHod | ✓ | | ✓ | | ✓ | Impact Assessment and Multicriteria Decision Analysis of Alternative Managed Aquifer Recharge Strategies Based on Treated Wastewater in Northern Gaza |
| Malik et al. [9] | Lidder Catchment Himalayas | Catchment Asst & Prioritization | Remote Sensing & GIS | Knowledge-based weights | Weighted linear combination | ✓ | | ✓ | | ✓ | Prioritizing watersheds for natural resource conservation and management |
| Gallego-Ayala et al. [10] | Incomati Catchment, Mozambiq ue | Catchment Water Planning | AHP | Pairwise comparison | AHP | ✓ | | ✓ | ✓ | | Stakeholders' preferences regarding development of water resources management plans |
| Yu et al. [11] | Yongding Catchment, China | Catchment Water Management | Multi-objective evaluation | Multi-level, stepwise weighting | Principle component projection approach | ✓ | | ✓ | | ✓ | Evaluating multi-objective scenarios to support decision-making for effective river ecological restoration by artificial recharge |
| Zhang et al. [12] | Bowen Basin Queenslan d, Australia | Water Management | AHP, fuzzy TOPSIS | Pairwise comparison | Fuzzy TOPSIS- | ✓ | ✓ | | | ✓ | Identify better mine water management practices for reducing raw water use |
| Chang et al. [13] | | Catchment Water Management | Fuzzy theory | Pairwise comparison | Fuzzy theory | ✓ | | ✓ | | ✓ | Sampling frequency for river water quality monitoring network |
| Badar et al. [14] | Dal Lake Catchment, Himalaya | Catchment Asst & Prioritization | Remote Sensing and GIS | Knowledge-based weights | GWLF model | ✓ | | ✓ | | ✓ | Conservation and management strategies of Dal Lake ecosystem |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| Do et al. [15] | Xindian river Catchment, Taiwan | Catchment Water Management | AHP | Simple weight | AHP method - Expert Choice software | ✓ | | ✓ | | ✓ | Sampling frequency for river water quality monitoring network |
| Hughey [16] | Tasman rivers Catchment, New Zealand | Catchment Water Management | River Values Assessment System | Weight Summation | Relative importance ranking | ✓ | | ✓ | | ✓ | Improved policies and rules around water and river use, development and conservation. |
| Roozbahani et al. [17] | Melbourne, Australia | Water Management | PROMETHEE with Precedence Order in the Criteria | Additive Utility Function | PROMETHEE with Precedence Order in the Criteria (PPOC) | ✓ | | ✓ | | ✓ | Storm water management |
| Biswas et al. [18] | Chittagong Hill Tracts, Bangladesh | Catchment Water Planning and Management | AHP | Pairwise comparison | AHP | ✓ | | ✓ | | ✓ | Evaluate management strategies for mountain watersheds |
| Colin et al. [19] | Vineyard catchment, France | Catchment Water Management | Fuzzy Set | Simple weight method | Fuzzy Rule-Based Mode | ✓ | ✓ | | | ✓ | Simulate the impact of land use changes on water and mass transfers |
| Calizaya et al. [20] | Lake Poopo basin, Bolivia | Catchment Water Management | Saaty's analytical hierarchy process AHP | Pairwise comparison | Utility Value | ✓ | | ✓ | ✓ | | A tool to support stakeholders in managing their water resources |

## Section B. Review of sub-criteria correlated to surface water quality catchment management

**Table S2.** Review of Sub-criteria correlated to surface water quality catchment management.

| Criteria | | | Sub-criteria variables | References |
|---|---|---|---|---|
| Water quality objectives | Physical | 1 | pH (Acidity) | [21–23] |
| | | 2 | pH (Alkalinity) | [21–23] |
| | | 3 | Turbidity/ Total Suspended Solids | [21–23] |
| | | 4 | Odour | [7] |
| | | 5 | Temperature (summer season) (TS) | [23] |
| | | 6 | Temperature (winter season) (TW) | [23] |
| | | 7 | Salinity | [22,23] |
| | Chemical | 1 | Total Dissolved Solids (TDS) | [21] |
| | | 2 | Dissolved Oxygen (DO) | [6,21–23] |
| | | 3 | Chemical Oxygen Demand | [6,21,23] |
| | | 4 | Biochemical Oxygen Demand | [6,21,22,24,25] |
| | | 5 | Nitrates ($NO^-_3$) | [22,24] |
| | | 6 | Nitrites ($NO^-_2$) | [21,24] |
| | | 7 | Ammonia ($NH_3$) | [6,21] |
| | | 8 | Phosphorus (P) | [6,21,24] |
| | Biological | 1 | Coliforms (Coli) | [21] |
| | | 2 | Invertebrate (INV) | [6,7,22,23] |
| | | 3 | Plankton count | [7,23] |
| | | 4 | Chlorophyll-a (Chl-a) | [23] |
| | | 5 | Algae (Alg) | [6,22,23] |
| | | 6 | Fish | [6,7,22,23] |
| Environmental objectives | Ecological indicators | 1 | Biodiversity (BD) | [18,24,26–31] |
| | | 2 | Nutrients (NT) | [18,28,30,31] |
| | | 3 | Water quality (WQ) | [6,18,29–32] |
| | | 4 | Pesticides | [27] |
| | | 5 | Heavy metals (HM) | [23,24,27] |
| | | 6 | Conservation (CNS) | [18,26,31] |
| | Flow and morphological Indicators | 1 | Water allocation (WA) | [28,30] |
| | | 2 | Water quantity (WQN) | [7,28,30] |
| | | 3 | Environmental flow (EF) | [6,7,22,23,26] |
| | | 4 | Morphological conditions (MC) | [6,22,23] |
| | | 5 | Soil erosion (SE) | [18,26] |
| | | 6 | Condition of riparian area (CRA) | [23,26] |
| | | 7 | Debris/ Floating waste (FW) | [23,33] |
| Economic objectives | Cost | 1 | Water quality treatment cost (WQTC) | [34] |
| | | 2 | Water quality monitoring cost (WQMC) | [34] |
| | | 3 | Drinking water bill cost (DWBC) | [32] |
| | | 4 | Incidents/Waterways Screening Cost (WSC) | [26] |
| | | 5 | Project/Investment Cost (IC) | [26,28,33] |
| | | 6 | Maintenance Cost (MC) | [26,28] |
| | Value | 1 | Restoration (RS) | [7,34] |
| | | 2 | Recreation (RC) | [7,26] |

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|---|---|---|---|---|
| | | 3 | Capability of monetary fund (CMF) | [25,28,33] |
| Social objectives | Recreational indicators | 1 | Fishing, Boating, Camping (FBC) | [7,26] |
| | | 2 | Access to water course (AWC) | [24] |
| | | 3 | Impact on human health (IHH) | [24,29,33] |
| | | 4 | Visual amenity (VA) | [27] |
| | Cultural and Spiritual Indicators | 1 | Job opportunity (JO) | [7,25–28,30,31] |
| | | 2 | Responsibility (RSP) | [24,33] |
| | | 3 | Heritage values | [27] |
| | | 4 | Willingness to pay (WTP) | [33] |
| | | 5 | Willingness to change behavior (WCB) | [18,24] |
| | | 6 | Willingness for conservation activities (WCA) | [34] |

**Section C: The Application of Euclidean Distance by the In-center of Centroids**

This method is based on ranking two trapezoidal fuzzy numbers by comparing both values of the in-center of centroids. The advantage of this method is considered to be easy and representative of a straightforward calculation among other clustering analysis methods, as well as being satisfactory for users [35]. The basic operation in this method involves splitting the area of the fuzzy trapezoid number into three parts. The first, second, and third parts consist of a triangle, a rectangle, and a triangle, respectively (Figure S1). Azman et al. [35] discussed in details the definitions of fuzzy number membership and the operation process.

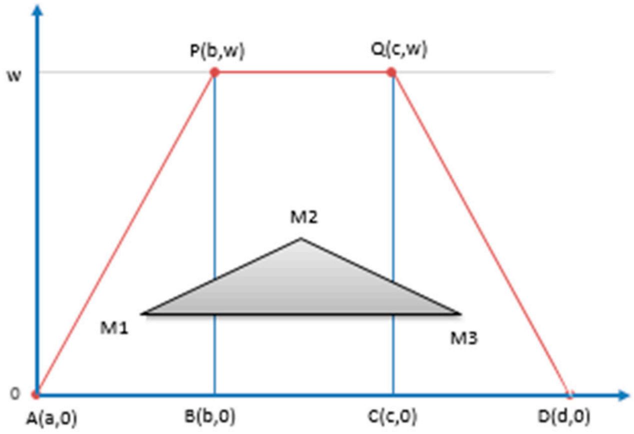


**Figure S1.** In-center of centroids.

The following is an application for the Euclidean Distance by the In-center of Centroids (EDIC) ranking method using the outcomes from the aggregation of Strategies 1 and 2 from Table 9 in the text. The ranking process can be summarized as the following:

**Step 1:** Calculate the area of each shape. The area for triangle is equal to width*height, while the area for rectangle is equal to ½*base*height; see Table SC1 below:

**Table S3.** Area calculation for each shape of the trapezoidal fuzzy number.

| Area of the shapes | Strategy 1 | Strategy 2 |
|---|---|---|
| $A_{\Delta APB} = \frac{1}{2}(b-a)w$ | $= \frac{1}{2}(5.75-4.97)\times 1$<br>$= 0.39$ | $= \frac{1}{2}(6.52-5.52)\times 1$<br>$= 0.5$ |
| $A_{\Delta BCQP} = (c-b)w$ | $= (6.65-5.75)\times 1$<br>$= 0.9$ | $= (7.52-6.52)\times 1$<br>$= 1$ |
| $A_{\Delta CQD} = \frac{1}{2}(d-c)w$ | $= \frac{1}{2}(7.32-6.65)\times 1$<br>$= 0.34$ | $= \frac{1}{2}(8.52-7.52)\times 1$<br>$= 0.5$ |

**Step 2:** Calculate the centroids area for triangle and rectangle. The centroid of a triangle is located at a distance of 1/3 its height and 1/3 its base. The centroid of a rectangle is located at a distance of ½ its height and ½ its base, see Table S4 below:

**Table S4.** Calculation of the centroids area.

| Area of centroids | Strategy 1 | Strategy 2 |
|---|---|---|
| $\Delta\, \boldsymbol{APB}, \boldsymbol{M_1} = \frac{\mathbf{1}}{\mathbf{3}}(\boldsymbol{b}-\boldsymbol{a}), \frac{\mathbf{1}}{\mathbf{3}}\boldsymbol{w}$ | $= \frac{1}{3}\ (0.39), \frac{1}{3}\ \times 1$<br>$= 0.13{,}0.33$ | $= \frac{1}{3}\ (1), \frac{1}{3}\ \times 1$<br>$= 0.33{,}0.33$ |
| $\Delta\, \boldsymbol{BCQP}, \boldsymbol{M_2} = \frac{\mathbf{1}}{\mathbf{2}}(\boldsymbol{c}-\boldsymbol{b}), \frac{\mathbf{1}}{\mathbf{2}}\boldsymbol{w}$ | $= \frac{1}{2}\ (0.9), \frac{1}{2} \times 1$<br>$= 0.45{,}0.5$ | $= \frac{1}{2}\ (1), \frac{1}{2} \times 1$<br>$= 0.5{,}0.5$ |
| $\Delta\, \boldsymbol{CQD}, \boldsymbol{M_3} = \frac{\mathbf{1}}{\mathbf{3}}(\boldsymbol{d}-\boldsymbol{c}), \frac{\mathbf{1}}{\mathbf{3}}\boldsymbol{w}$ | $= \frac{1}{3}\ (0.34), \frac{1}{3} \times 1$<br>$= 0.11{,}0.33$ | $= \frac{1}{3}\ (1), \frac{1}{3} \times 1$<br>$= 0.33{,}0.33$ |

**Step 3:** Determine the distance from each simple shape's centroid to the reference axes (x & y). Refer to Table S4 below:

**Table S4.** Distance to axes using the aggregated examples from Table 6.

| Distance to axes | Strategy 1 | Strategy 2 |
|---|---|---|
| $\boldsymbol{M_1} = \frac{\mathbf{1}}{\mathbf{3}}(\boldsymbol{b}-\boldsymbol{a}) + \boldsymbol{a}, \frac{\mathbf{1}}{\mathbf{3}}\boldsymbol{w}$ | $= 5.1{,}0.33$ | $= 5.85{,}0.33$ |
| $\boldsymbol{M_2} = \frac{(\boldsymbol{c}+\boldsymbol{b})}{\mathbf{2}}, \frac{\boldsymbol{w}}{\mathbf{2}}$ | $= 6.99{,}0.5$ | $= 7.02{,}0.5$ |
| $\boldsymbol{M_3} = \frac{\mathbf{1}}{\mathbf{3}}(\boldsymbol{d}-\boldsymbol{c}) + \boldsymbol{c}, \frac{\mathbf{1}}{\mathbf{3}}\boldsymbol{w}$ | $= 6.76{,}0.33$ | $= 7.85{,}0.33$ |

**Step 4:** Multiply each simple shape's area by its distance from centroid to reference axes as shown in Table S5 below:

**Table S5.** Multiplication of area with distance.

| Shape | Area (A) | X | AX | S1 | S2 |
|---|---|---|---|---|---|
| **APB** | $\frac{1}{2}(b-a)w$ | $\frac{1}{3}(b-a)+a$ | $\left[\frac{(b-a)w}{2}\right]\left[\frac{(b-a)+a}{3}\right]$ | 0.75 | 2.17 |
| **BCQP** | $(c-b)w$ | $\frac{(c+b)}{2}$ | $[(c-b)w]\left[\frac{(c+b)}{2}\right]$ | 5.58 | 7.02 |
| **CQD** | $\frac{1}{2}(d-c)w$ | $\frac{1}{3}(d-c)+c$ | $\left[\frac{(d-c)w}{2}\right]\left[\frac{(d-c)+c}{3}\right]$ | 0.83 | 1.42 |
| **SHAPE** | **Area (A)** | **Y** | **AY** | **S1** | **S2** |
| **APB** | $\frac{1}{2}(b-a)w$ | $\frac{1}{3}w$ | $\left[\frac{(b-a)w}{2}\right]\left[\frac{w}{3}\right]$ | 0.13 | 0.17 |
| **BCQP** | $(c-b)w$ | $\frac{w}{2}$ | $[(c-b)w]\left[\frac{w}{2}\right]$ | 0.45 | 0.5 |
| **CQD** | $\frac{1}{2}(d-c)w$ | $\frac{1}{3}w$ | $\left[\frac{(d-c)w}{2}\right]\left[\frac{w}{3}\right]$ | 0.11 | 0.17 |

**Step 5:** Sum the products of each simple shape's area and their distances from the centroid to the reference axes as shown in Table S6 below:

**Table S6.** Total shape AX.

| Total shape A(X,Y) | Strategy 1 | Strategy 2 |
|---|---|---|
| $= \boldsymbol{APB} + \boldsymbol{BCQP} + \boldsymbol{CQD}$ | 7.16, 0.69 | 10.61, 0.84 |

**Step 6:** Sum the individual simple shape's areas to determine total shape area as shows in *Equation* S1 and Table S7 below:

$$\sum_{A} = \left[\frac{1}{2}(b-a)w\right] + [(c-b)w] + \left[\frac{1}{2}(d-c)w\right] \quad \text{(S1)}$$

**Table S7.** Total shape area.

| Total shape area | Strategy 1 | Strategy 2 |
|---|---|---|
| $= \frac{(\boldsymbol{d}+\boldsymbol{c}-\boldsymbol{b}-\boldsymbol{a})\boldsymbol{w}}{\mathbf{2}}$ | = 1.63 | = 2 |

**Step 7:** Divide the summed product of areas and distances by the summed object total to find the in-centre on the total shape, as shown in Table S*8* below.

**Table S8.** The in-center of the total shape.

| Alternatives | $(\bar{x_0}) = \frac{(\boldsymbol{d^2 - cd + 3c^2 - 2b^2 - ab})}{\boldsymbol{3d + 3c - 3b - 3a}}$ | $(\bar{y_0}) = \frac{(\boldsymbol{d + 2c - 2b - a})\boldsymbol{w}}{\boldsymbol{3d + 3c - 3b - 3a}}$ |
|---|---|---|
| **Strategy 1** | 4.40 | 0.42 |
| **Strategy 2** | 5.30 | 0.42 |

**Step 8:** Raking the function of the trapezoidal fuzzy number shown in Table S9 below. $R^2$ is the Euclidean distance from the in-center of the centroids.

**Table S9.** Ranking function and the euclidean distance from the in-center of the centroids.

| Alternatives | Ranking Function $\sqrt{\bar{x_0}^2 + \bar{y_0}^2}$ | $R^2$ | Rank |
|---|---|---|---|
| **S1** | $\sqrt{4.40^2 + 0.42^2}$ | 4.42 | 1 |
| **S2** | $\sqrt{5.30^2 + 0.42^2}$ | 5.31 | 2 |

According to the results ($R^2$) from Table S9, S2 rank ahead of S1.

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