# APPLICATION OF MORPHOLOGICAL ANALYSIS TO POLICY FORMULATION FOR WASTEWATER TREATMENT*

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Wastewater treatment, water protection and conservation, and rational water use are important elements of water management. The goals of water management are achieved by implementation of a set of appropriate policy measures creating a coherent policy. However; policy formulation is a complex decision-making problem involving a large number of stakeholders and many possible measures.

The objective of this work is to implement a method for facilitating decision-making and identify suitable policy measures for the location and operation of wastewater treatment facilities. This type of problem is very complex and is usually formulated with many contradictory requirements. It is an example of a so-called wicked problem, for which the application of traditional multi-objective decision-making approaches has clear limitations.

In this paper, Morphological Analysis (MA), an approach applicable to wicked problems, is used to structure policy measures relevant to the problem of the location and operation of wastewater treatment facilities. The application of MA enables identification and selection of stakeholders, decision-making criteria and policy measures to tackle legal, financial, technical, social and environmental aspects of wastewater treatment. A case study is presented to illustrate the identification of criteria and policy measures applicable to the location and operation of wastewater treatment facilities. Use of MA allows the decision-making process of identification and selection of appropriate policy measures to be structured and accelerated while simultaneously minimizing conflicts among stakeholders.

***Key words*:** morphological analysis, wastewater treatment, policy measures, sustainable development, and stakeholders

## 1. Introduction

Wastewater treatment, water protection and conservation, and rational water use are important elements of water management. Water management is a universal problem whose effective resolution is essential, both for developed and underdeveloped countries. It is a complex problem involving many individuals and organizations with overlapping roles. Its resolution requires implementation of many policy measures creating a coherent policy. It is usually a very difficult issue and therefore water management can be considered a classic wicked problem (Rittel, 1972; Rittel and Webber, 1973). Tackling wicked problems related to wastewater treatment, an important aspect of water management requires making decisions on the location, construction, operation and maintenance of treatment facilities.

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This research examines the problem of formulation of water management policy with respect to wastewater treatment in an underdeveloped country. The study consists of identification and formulation of appropriate measures that could form a coherent and comprehensive strategy for sustainable development. This policy should take into account features specific to wastewater treatment in the country: lack of a development strategy, a very modest existing sewage network, problems with implementation of environmental laws and regulations such as the Water Framework Directive (WFD) and EU legislation, lack of participation of non-governmental stakeholders and deficiencies in skills and professional competences.

**2. Problem Statement**

The problem is to propose an approach enabling the formulation of the wastewater treatment policy, composed of the set of the specific of policy measures. The identification and formulation of a huge set of policy measures for wastewater treatment often are conflicting. In consequence, it calls for the development of appropriate approach to fit in decision making process. Therefore, the appropriate method must be able to cope with this problem. The policy formulation in wastewater treatment is a problem where many possible solutions exist. Morphological analysis is an approach successfully used for solving the problems where many alternatives are possible (Zwicky, 1969).

The main objective of this paper is to demonstrate the applicability of morphological analysis to formulation of a wastewater treatment policy composed of a set of specific policy measures supporting the requirements of sustainable development.

**3. Morphological Analysis approach**

Morphological analysis (MA) is an approach first proposed by F.Zwicky in 1943 for design of aerospace systems. MA is a well-known, powerful general method for formulating, structuring and studying complex problems (Zwicky and Wilson, 1967).

In principle, MA is based on the "divide and conquer technique" (Levin, 2012), which tackles a problem using two basic approaches: "analysis" and "synthesis" – the basic method for developing (scientific) models (Ritchey, 1991). This technique is a decomposition method that breaks down a system into subsystems with several attributes and selects the most valuable alternative (Yoon and Park, 2007). In other words, MA systematically categorizes the possible combinations of subsystems. The strength of the technique lies in its ability to provide structured models for complex problems into simpler problems, rather than offering solutions (Pidd, 1996). More recently, Coyle and McGlone (1995) applied MA to regional problems in the southwest Pacific, and Coyle and Yong (1996) to the South China Sea. MA has been extended and applied by a number of researchers in the U.S.A. and Europe to the fields of futures studies, policy analysis, strategy modeling and analyzing organizational and stakeholder structures (Coyle et al., 1994; Rhyne, 1995; Ritchey, 2011; Eriksson and Ritchey, 2002).

**4. Methodology**

The methodology of this work consists of problem definition, and formulation and identification of policy measures for the problem of the location and operation of wastewater treatment facilities.

Policy formulation process in wastewater treatment is a problem for which many possible solutions exist. The MA approach consists of analysis of all possible combinations of input variables followed by identification of the most promising solution. The identified policy measures are transformed into criteria. The criteria were categorized and used in the morphological analysis tool to build the morphological field.

The basic procedure of the morphological analysis consists of the following stages:

Stage 1. Feasibility study and definition of the problem.

Stage 2. Development of the morphological field, which consists of identification and specification of the essential parameters or variables of the problem and generation of the design alternatives or values for each parameter or component (i.e. a morphological class).

Stage 3. Cross-consistency assessment (CCA) (Ritchey, 2011). CCA involves evaluation of the feasibility of all combinations of all values of the variables. CCA assesses compatibility for each value via pair-wise comparison (one pair-wise value from one column or morphological class with another pair-wise value from another morphological class).

Stage 4. Specification of zero fields that correspond to incompatibility (i.e., unknown, infeasible and impossible combinations of values).

Stage 5. Specification of fields with already known solution where the compatibility of the values from one morphological class corresponds to the compatibility of the values from another morphological class.

Stage 6. Compilation of a list of all admissible compositions or production of a list of clusters (one independent value for each parameter, while taking into account compatibility for each two values in the composition obtained). The result of the application of the morphological analysis is a reduced set of feasible combinations of the variables. The reduced set is then the subject of analysis by the stakeholders involved in policy formulation.

## 5. Application of MA Method: Case of Wastewater Treatment Facilities for Kosovo

Application of the morphological analysis method is illustrated with a case study scenario of the construction and operation of wastewater treatment facilities in an urban area of Kosovo with more than 10 000 inhabitants. The decision-supporting tool for the wastewater treatment plant (WWTP) is applied to the region in southern Kosovo around the Lepenc river basin, which includes the area between the three municipalities of Ferizaj, Kaçanik and Hani i Elezit. The case is a small to medium-sized WWTP for water systems management. The decision-making can be classified as a complex problem because of the capital and operational costs involved. The morphological analysis application model, which contains a multidimensional matrix for identification and selection of appropriate policy measure variants, is based on a methodological approach, which includes the following steps:

Step 1. Definition of the problem – This step represents the formulation and identification of policy measures for the problem of the location and operation of wastewater treatment facilities.

Step 2. Development of the morphological field – The main task of this step is identification of the most relevant dimensions (parameters) of the problem regarding the goal and objectives for building a wastewater treatment facility. The developed morphological field "parameters" or "variables" are set in the header in the spreadsheet table and the generated "values" or "states" of possible alternatives are placed under each parameter. Figure 1 presents the morphological field developed for the WWTP. There is no theoretical limit to the number of values for each parameter but experience suggests that a maximum 6 values and 7 parameters be used for this trial (Coyle, 2001; Ritchey, 2011).

For practical purposes, and focusing on environmental aspects, the seven types of parameters, marked with (P), are symbolically designated as follows: $P_1$ = implement legislation, $P_2$ = water quality, $P_3$ = employee profile, $P_4$ = size and location, $P_5$ = water infrastructure, $P_6$ = capacity building, $P_7$ = monitoring.

Referring to the above classification, it follows that the morphological field potentially contains (6x6x6x5x6x6x3) formally possible configurations, a total of 116,640 configurations, which are designated by the matrices [$P_1V_{1\ldots6}$; $P_2V_{1\ldots6}$; $P_3V_{1\ldots6}$; $P_4V_{1\ldots5}$; $P_5V_{1\ldots6}$; $P_6V_{1\ldots6}$; $P_7V_{1\ldots3}$;], where all V(s) may be assumed as taking the specific values 1, 2, 3, 4, 5 and 6. In this case, there are clearly too many combinations to enable a reasonable choice.

Step 3. Cross-Consistency Assessment – To reduce the problem space, decision elements are compared pair-wise in terms of their control criteria. Each condition is compared with another one

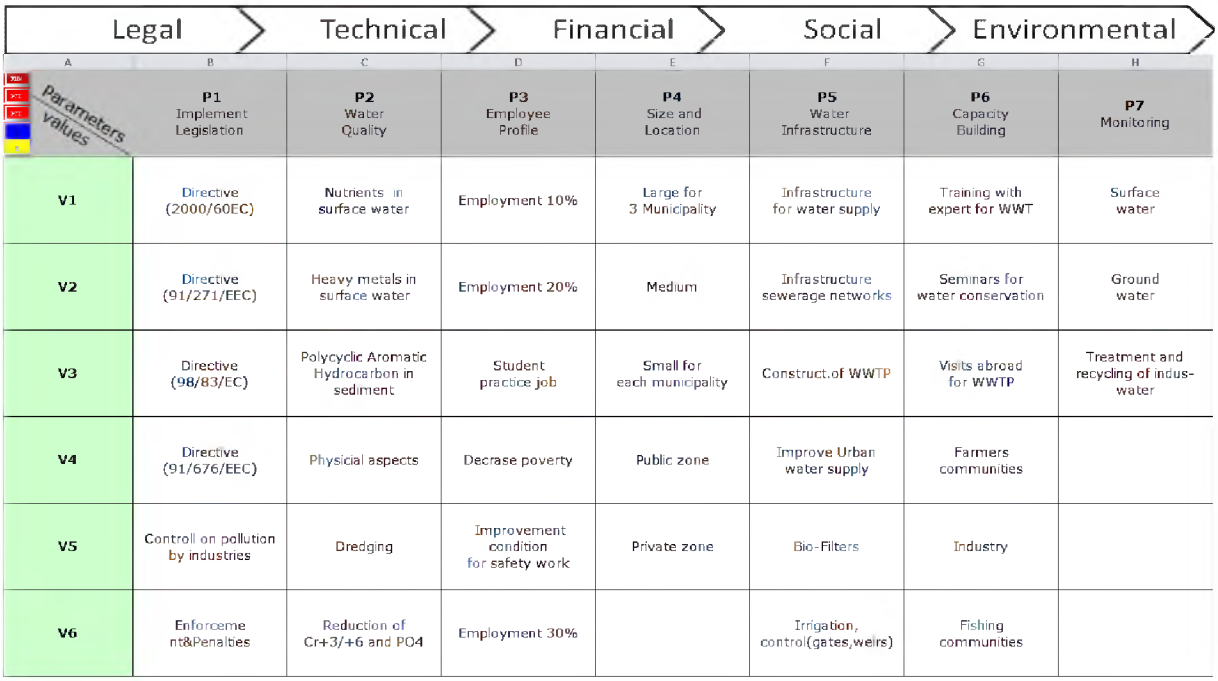


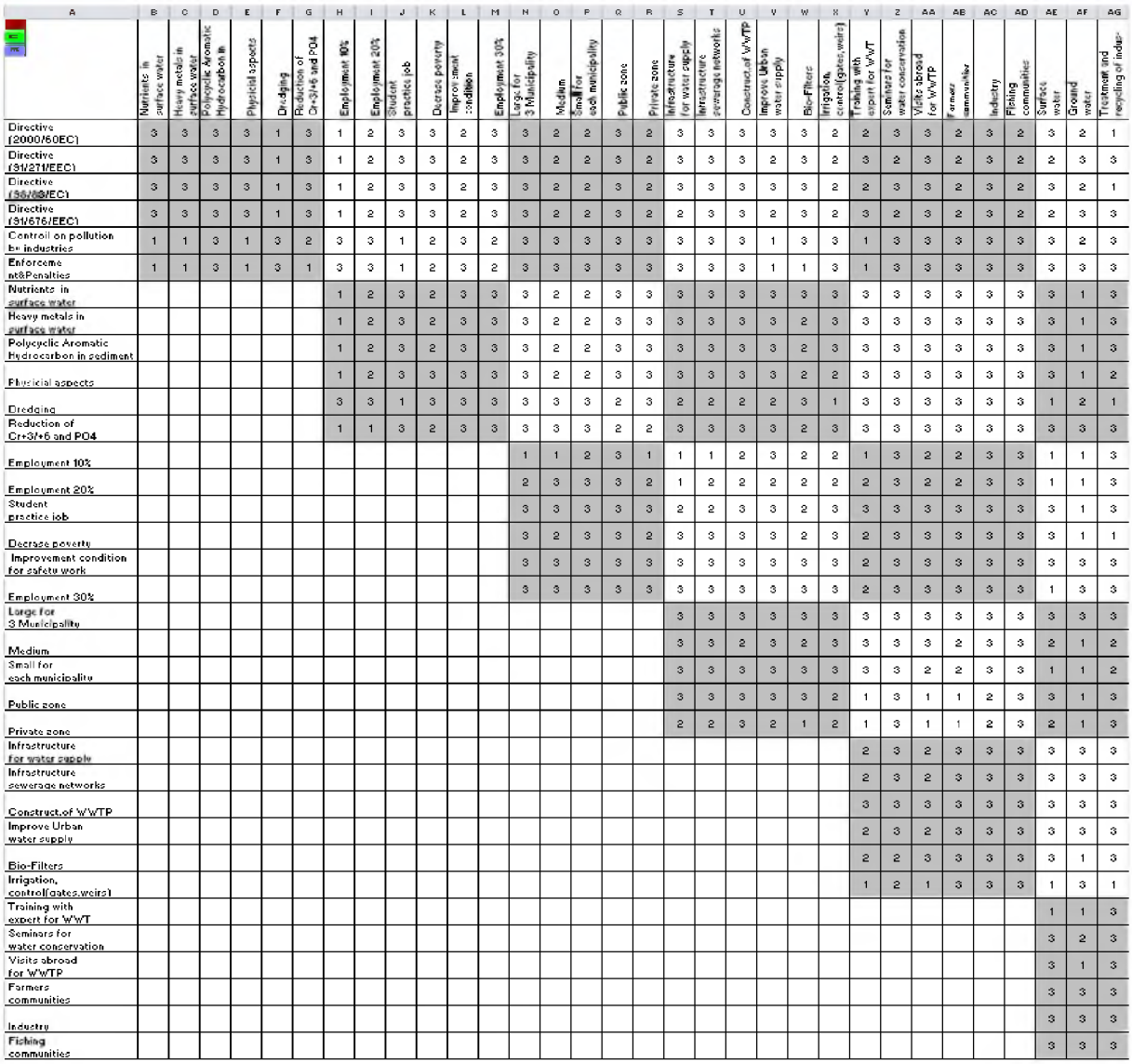

Figure 1. Development of the morphological field with seven parameters and their ranges of values

and evaluated for internal consistency, which is noted in a matrix called the cross-consistency assessment matrix. One or more parameters can be chosen as the input driver or independent variable to display only possible combinations that include these conditions. The problem space thus becomes the solution space. The problem space enables the acquisition of comprehensive information about entire groups of objects and phenomena. The assessment is done by comparing each and every one of the cells in the matrix to answer the question: can these two conditions coexist? Figure 2 presents the cross-consistency matrix for this study using the following three assessment keys: "3" = Denotes a combination which is a good fit, or best fit, or optimal pair; "2" = Indicates a possible combination, could work, but not optimal; "1" = Denotes a combination which is manifestly impossible or a very bad idea. The cross-consistency assessment (CCA) matrix reduces the total problem space to an internally consistent solution space. Reduction of the cross-consistency assessment in a multidimensional matrix is done in order to find an approximation for an optimal solution.

The morphological field contained a total of 116,640 formal configurations and using CCA reduction as a filter, we reduced the matrix to 10 006 possible combinations, which included the best-fit combinations (marked with "3") and could-work combinations (marked with "2"). Using only best-fit combinations (marked with "3") reduced the matrix to 233 combinations.

A "parameter-block" is the two dimensional block of cross-refernced values between two paramters, shown as alternate white and shaded blocks in Figure 2. In some cases, all the cells in the blocks will have "3" (number three) in them, meaning that these two blocks do not constrain each other, i.e., all combinations between the value pairs are possible. However, if there are two many "unconstrained" blocks in a field then the field will not be reduced significantly, so we will have to deal with a very large solution space. On the other hand, if two many "1" numbers are entered, than it will risk choking the model, and no solution will be obtained. The process is iterative. Poorly and non-adequately defined parameters immediately make the process very hard, so there is a need to turn back and reformulate parameters and values.

Step 4. Specification of zero fields – The fourth step is to eliminate the infeasible combinations from the matrix. When a multidimensional matrix of pairs has been fully scored then there remains the task of pulling out those configurations having no pair(s) scored '1'. These are specified as zero fields, indicated as a red box.



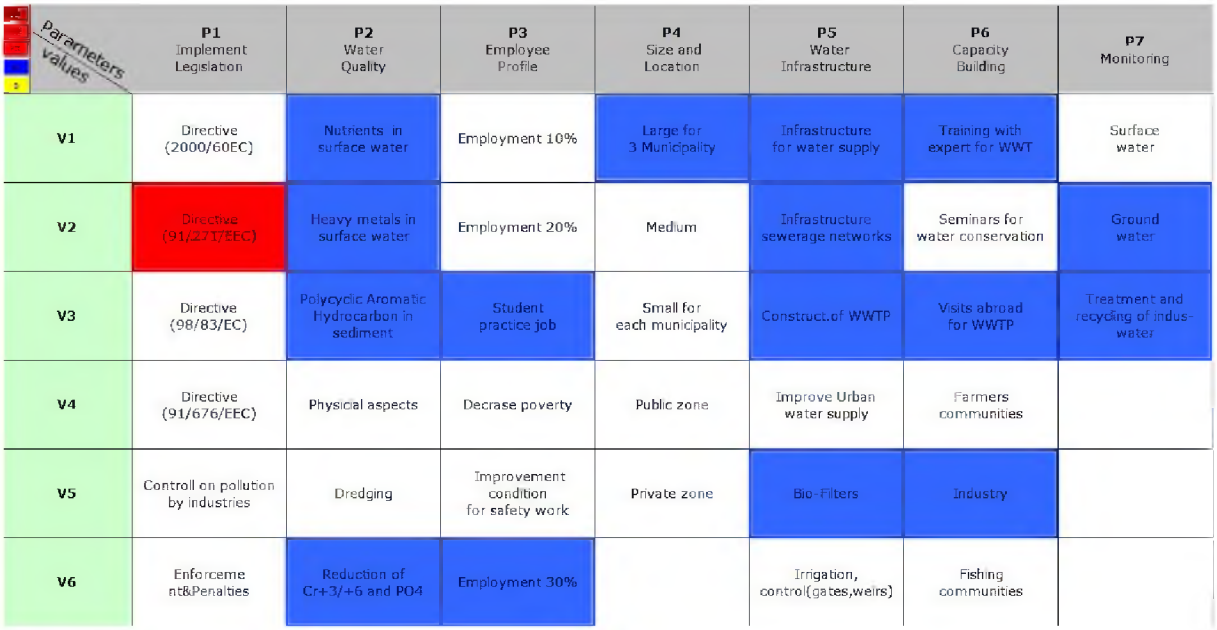
| | Nutrients in surface water | Heavy metals in surface water | Polycyclic Aromatic Hydrocarbon in | Physicial aspects | Dredging | Reduction of Cr+3/+6 and PO4 | Employment 10% | Employment 20% | Student practice job | Decrase poverty | Improvement condition | Employment 30% | Large for 3 Municipality | Medium | Small for each municipality | Public zone | Private zone | Infrastructure for water supply | Infrastructure sewerage networks | Construct.of WWTP | Improve Urban water supply | Bio-Filters | Irrigation, control(gates,weirs) | Training with expert for WWT | Seminars for water conservation | Visits abroad for WWTP | Farmers communities | Industry | Fishing communities | Surface water | Ground water | Treatment and recycling of indus |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Directive (2000/60EC) | 3 | 3 | 3 | 3 | 1 | 3 | 1 | 2 | 3 | 3 | 2 | 3 | 3 | 2 | 2 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 3 | 3 | 2 | 3 | 2 | 3 | 2 | 1 |
| Directive (91/271/EEC) | 3 | 3 | 3 | 3 | 1 | 3 | 1 | 2 | 3 | 3 | 2 | 3 | 3 | 2 | 2 | 3 | 2 | 3 | 3 | 3 | 2 | 3 | 2 | 3 | 2 | 3 | 2 | 3 | 2 | 2 | 3 | 3 |
| Directive (56/68/EC) | 3 | 3 | 3 | 3 | 1 | 3 | 1 | 2 | 3 | 3 | 2 | 3 | 3 | 2 | 2 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 3 | 3 | 2 | 3 | 2 | 3 | 2 | 1 |
| Directive (91/676/EEC) | 3 | 3 | 3 | 3 | 1 | 3 | 1 | 2 | 3 | 3 | 2 | 3 | 3 | 2 | 2 | 3 | 2 | 2 | 3 | 3 | 2 | 3 | 2 | 3 | 2 | 3 | 2 | 3 | 2 | 2 | 3 | 3 |
| Controll on pollution by industries | 1 | 1 | 3 | 1 | 3 | 2 | 3 | 3 | 1 | 2 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 1 | 3 | 3 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 3 |
| Enforcement&Penalties | 1 | 1 | 3 | 1 | 3 | 1 | 3 | 3 | 1 | 2 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 1 | 1 | 3 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Nutrients in surface water | | | | | | | 1 | 2 | 3 | 2 | 3 | 3 | 3 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 1 | 3 |
| Heavy metals in surface water | | | | | | | 1 | 2 | 3 | 2 | 3 | 3 | 3 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 1 | 3 |
| Polycyclic Aromatic Hydrocarbon in sediment | | | | | | | 1 | 2 | 3 | 2 | 3 | 3 | 3 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 1 | 3 |
| Physicial aspects | | | | | | | 1 | 2 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 1 | 2 |
| Dredging | | | | | | | 3 | 3 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 3 | 2 | 2 | 2 | 2 | 3 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 1 | 2 | 1 |
| Reduction of Cr+3/+6 and PO4 | | | | | | | 1 | 1 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 3 | 3 | 3 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Employment 10% | | | | | | | | | | | | | 1 | 1 | 2 | 3 | 1 | 1 | 1 | 2 | 3 | 2 | 2 | 1 | 3 | 2 | 2 | 3 | 3 | 1 | 1 | 3 |
| Employment 20% | | | | | | | | | | | | | 2 | 3 | 3 | 3 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 2 | 2 | 3 | 3 | 1 | 1 | 3 |
| Student practice job | | | | | | | | | | | | | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 3 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 1 | 3 |
| Decrase poverty | | | | | | | | | | | | | 3 | 2 | 3 | 3 | 2 | 3 | 3 | 3 | 3 | 2 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 1 | 1 |
| Improvement condition for safety work | | | | | | | | | | | | | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Employment 30% | | | | | | | | | | | | | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 1 | 3 | 3 |
| Large for 3 Municipality | | | | | | | | | | | | | | | | | | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Medium | | | | | | | | | | | | | | | | | | 3 | 3 | 2 | 3 | 2 | 3 | 3 | 3 | 3 | 2 | 3 | 3 | 2 | 1 | 2 |
| Small for each municipality | | | | | | | | | | | | | | | | | | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 3 | 3 | 1 | 1 | 2 |
| Public zone | | | | | | | | | | | | | | | | | | 3 | 3 | 3 | 3 | 3 | 2 | 1 | 3 | 1 | 1 | 2 | 3 | 3 | 1 | 3 |
| Private zone | | | | | | | | | | | | | | | | | | 2 | 2 | 3 | 2 | 1 | 2 | 1 | 3 | 1 | 1 | 2 | 3 | 2 | 1 | 3 |
| Infrastructure for water supply | | | | | | | | | | | | | | | | | | | | | | | | 2 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 |
| Infrastructure sewerage networks | | | | | | | | | | | | | | | | | | | | | | | | 2 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 |
| Construct.of WWTP | | | | | | | | | | | | | | | | | | | | | | | | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Improve Urban water supply | | | | | | | | | | | | | | | | | | | | | | | | 2 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 |
| Bio-Filters | | | | | | | | | | | | | | | | | | | | | | | | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 1 | 3 |
| Irrigation, control(gates,weirs) | | | | | | | | | | | | | | | | | | | | | | | | 1 | 2 | 1 | 3 | 3 | 3 | 1 | 3 | 1 |
| Training with expert for WWT | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | 1 | 3 |
| Seminars for water conservation | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 3 | 2 | 3 |
| Visits abroad for WWTP | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 3 | 1 | 3 |
| Farmers communities | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 3 | 3 | 3 |
| Industry | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 3 | 3 | 3 |
| Fishing communities | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 3 | 3 | 3 |

Figure 2. Cross-consistency assessment (CCA) matrix for construction of a wastewater treatment facility

Step 5. Selection of a few polices that are obtained from the MA model – The fifth task is selection of a number of configurations that represent important combinations for this study. Three policies obtained from the MA model were selected in an attempt to find and explore practical instances for each combination in the real situation.

Step 6. Interpreting the results from the MA model. The final step is production of a list of clusters. The selection of the optimum alternatives was based on evaluation of the output information of the numerical solutions regarding the construction and maintenance of the WWTP. These important clusters then have to be presented to the all relevant stakeholders for future studies. Figure 3 presents the solution space (blue) with single driver input (red) that gives minimum field output by eliminating "2" from the matrix for construction of the wastewater treatment facility. In Figure 3, the value "2" and value "1" are omitted. Only value "3" are considered as the best combinations of the variables for building a coherent policy.

Figure 3 shows the totality of possible solutions of the given problem in a multidimensional morphological matrix. Any parameter (i.e. column) can be treated as an independent variable (e.g., as a driver) by selecting any of its values (i.e., V1 to V6), to see what values of the remaining parameters are valid for that driver.



| Parameters / values | P1 Implement Legislation | P2 Water Quality | P3 Employee Profile | P4 Size and Location | P5 Water Infrastructure | P6 Capacity Building | P7 Monitoring |
|---|---|---|---|---|---|---|---|
| V1 | Directive (2000/60EC) | Nutrients in surface water | Employment 10% | Large for 3 Municipality | Infrastructure for water supply | Training with expert for WWT | Surface water |
| V2 | Directive (91/271T/EEC) | Heavy metals in surface water | Employment 20% | Medium | Infrastructure sewerage networks | Seminars for water conservation | Ground water |
| V3 | Directive (98/83/EC) | Polycyclic Aromatic Hydrocarbon in sediment | Student practice job | Small for each municipality | Construct.of WWTP | Visits abroad for WWTP | Treatment and recycling of indus-water |
| V4 | Directive (91/676/EEC) | Physicial aspects | Decrase poverty | Public zone | Improve Urban water supply | Farmers communities | |
| V5 | Controll on pollution by industries | Dredging | Improvement condition for safety work | Private zone | Bio-Filters | Industry | |
| V6 | Enforceme nt&Penalties | Reduction of Cr+3/+6 and PO4 | Employment 30% | | Irrigation, control(gates,weirs) | Fishing communities | |

Figure 3. Solution space (blue) with single driver input (red) gives minimum field output without using "2" for construction of wastewater treatment facility

## 4. Discussion and Conclusions

The goal of the work has been the implementation of a method for facilitating decision-making and identification of suitable policy measures for building a coherent policy for wastewater treatment. The major stress is put on the decisions related to location, construction and operation of sustainable industrial wastewater treatment facilities. The Morphological Analysis (MA) method was used for formulating and structuring policy measures that address different aspects – legal, financial, technical, social and environmental – of the construction of a wastewater treatment plant. The presented methodology permits evaluation of a large number of policy measures. It can be concluded from the results that the analysis method can be applied to the decision-making process for construction of the case wastewater treatment plant. Use of the program, in a case study at the regional scale highlights the potential of the MA tool for structuring and investigating appropriate policy measures in an integrated platform, thus helping decision makers' decision-making processes, and reducing and minimizing conflicts among stakeholders. However, this work also highlighted difficulties in formulating, structuring, collecting and designing appropriate policy measures for a WWTP system, and developing a tool that perfectly fits local community needs. This work emphasizes also the importance of participation of various interest groups or stakeholders from various level and functional areas of society, involved in the policy formulation.

In a real-world situation such as that studied here, MA has proved to be a successful approach for resolving complex problems and it can be applied with multidisciplinary group decision makers. Future research can directly include integration of risk and uncertainty in all modifications of MA decisions.


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