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Analytical Research on the Methodological Suitability of Multi-Criteria Analysis for the Scientific Evaluation of the Coastal Area

Mirjana Kovačić, Ante Mrvica, Marija Šimić Hlača

Coastal areas have always been more attractive than the inlands as they offer more opportunities and advantages. Nowadays a growing number of mutually (in)compatible economic and social activities have a significant impact on coastal development. Some countries are particularly aware of the lack of valuation and unplanned access to coastal area organization. As of 1995, owing to the numerous pressures on coastal areas, Croatia was forced to recognize that it needed an appropriate decision-making system.

The authors' focus is on the sustainable management of the coastal area. The purpose of the research is to propose coastal area evaluation criteria. The paper particularly aims to select a suitable method for the resolution of this problem.

Prior experience with the evaluation of an area's value justified the validity of the use of multi-criteria analysis. The method facilitates an overview and evaluation of the various aspects of the problem across different criteria. Several methods and techniques can be used to solve the problem, such as linear programming, AHP, ELECTREE, PROMETHEE, GAIA, scenario methods, and others in which the authors' experience in the area differs. Following research, the authors suggest using the PROMETHEE and GAIA methods.

KEY WORDS

~ Coastal area
~ Sustainability
~ Evaluation criteria
~ MCA

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1. INTRODUCTION

In recent years, Croatia has been facing deindustrialization, intensive development of tourism and massive apartment building along the coast. These processes and issues do not contribute to balanced development but rather diminish the value of the coastal area in the long term. Public administration has a distinctive management role and is responsible for making the relevant decisions. The decision-making process is never simple as it requires knowledge and experience, especially in the complex field of the management of the coastal area and its environment.

The paper defines the criteria and proposes a valuation model based on a holistic approach to coastal zone management, to reduce/prevent further devastation of the coastal area. The paper aims to justify the importance of coastal area evaluation and explore the suitability of multi-criteria analysis methods for defining the general model.

2. RECENT RESEARCH

For a very long time, coastal area has been in the focus of researchers worldwide, who have been exploring the legislative framework, the historical-geographical aspect, the socio-economic advantages of the area or the need to establish an integrated monitoring and protection system. There are consequently numerous analyses, studies, projects, plans, scientific papers, books, all of which have contributed to the better understanding of complex coastal processes.

The exploitation of coastal resources has been the subject of conflict for centuries and the reason for the adoption of legislation in the field concerned. Historically, governments

have always strived to regulate the exploitation of resources. While in absolute monarchies, the rulers decided who had the right to use the resources of a particular area, in feudal states, that right was most frequently bestowed only on the nobility. In Western Europe, spatial planning developed in recent centuries to regulate the use of space. The fundamental principle is that land resources are common and must be accessible to all on equal terms.

In the United States of America (USA), everyone had the right to use their real-estate as they pleased, but the system was not sustainable in the long-term. The coastal area has become a rare resource due to population growth and pressures. The need for the planned use of the coastal zone has emerged, and the first Coastal Zone Management Act was adopted in 1972 to force the States to take jurisdiction over coastal zone management. The purpose of the Act was to facilitate:

- coastal resource management;
- dealing with the consequences of natural disasters and
- mitigating negative impacts on valuable ecosystems.

After 1972, coastal zone management in the USA focused on institutional arrangements, while in Europe, all the necessary institutions already existed, but lacked an understanding of how different functions and activities interacted with the coastal zone.

Croatia is geographically a very specific country, due to its almost 5,000 km long coastline, 1,246 islands (Duplančić Leder, 2004), well-indented coast and more. Up until 1990, Croatia successfully protected and preserved its coastal area. The protection and preservation can be attributed to cooperation of many stakeholders, and especially to projects and spatial plans that did not allow intensive use of the coastal area. The development slowed down, but the coastal area was protected from the over-building of apartments and other potentially adverse influences over the last twenty years. It should be emphasized that spatial planning is the starting point, the beginning and the end of protection and overuse of the coastal area.

The Long-Term Development Program and Plan for the Spatial Planning of the Adriatic Area from 1967 is the first spatial planning document for the systematic reflection on the state and developmental possibilities of the Croatian coast. This document, conceived as a complex regional plan, should have served as the basis directing the economic development of the Adriatic area. It analyzed the characteristics of extant construction, estimated the spatial possibilities for the development of tourism (depending on the accommodation capacity of the coast), and established the methodology for the development of spatial plans for tourist areas. Essential characteristics of the preexistent construction in the Adriatic area are:

- geologic position and traffic connections of the Adriatic coast to the sources of tourist demand;
- agreeable climate and
- attractiveness of the coastal area.

The plans covered the entire Adriatic coast of the former Yugoslavia and:

- identified the most suitable locations for public ports, nautical tourism ports, and nautical centers;
- introduced a systematic approach to integrated coastal zone planning and management.

The document supersedes the Regional Development Plan for the Adriatic Region of Croatia. It envisioned approximately 60% of the tourist capacity on the mainland and 40% on the Croatian Adriatic islands.

- The Southern Adriatic Regional Spatial Plan (1968) and the Upper Adriatic Coordination Regional Spatial Plan (1972) covered the entire Adriatic coast of the former Yugoslavia. Developed in the framework of the United Nations Development Program (UNDP) it placed special emphasis on the high suitability of the Croatian part of the Adriatic for the development of tourism. Particular comparative advantages include:
  - the geographic position of the Adriatic coast with respect to the sources of tourist demand, especially in terms of accessibility;
  - exceptional natural attractiveness, especially due to the climate, landscape, and the sea as the main motivating factors for tourists to visit the Adriatic,
  - preexistent tourism structure that needs to be refurbished and adapted to the quality and the magnitude of the natural potential.

In 1978, the UNDP launched the Adriatic III project, which placed a particular focus on ecology and was the cornerstone of integrated coastal management.

In 1977, the UN supported the establishment of the PAP / RAC Centre (Priority Action Program / Centre for Regional Activities) in Split, which became operational in 1978.

Despite this, environmental and spatial planning legislation has not been consistent in addressing coastal issues in a sustainable and integrated manner. The Croatian Physical Planning Program tried to solve the problem. The main goal was to create spatial preconditions that would improve the quality of life and help achieve balanced development. The fundamental determinants of development are:

- focusing spatial development priorities by improving the organization of previously constructed spaces and
- creation of preconditions favorable for economic development and halting the process of depopulation on the mainland and the islands.

Although the Decree provides for the protection of the Croatian coast in accordance with the Regulation on the Protection of the Coastal Sea Area (2004), the fact is that the Regulation is frequently violated due to capital interests. The Decree regulates planning and landscaping in the 1,000 m wide land and 300 m wide sea belt area.

It also prohibits the planning of nautical ports, coastal embankments and berth constructions outside the construction area. Berths should be available only at locations published in official maritime publications.

3. ANALYSIS OF DEVELOPMENTAL FEATURES AND PRESSURES ON THE COASTAL ZONE

In the broader sense, the coast is the area where the influences of different natural geographic elements intersect. In contrast, in the narrow sense, the coast consists of the land and the sea from the lowest tide level to the zone under the influence of the waves. The coastal area may include the entire catchment area, large ecosystems, national parks, and even entire inland regions, while from the seaside, it may include a marine domain where an economic zone can be declared.

Where the sea and the mainland meet, a complex community of natural, economic, and social life is established in which the quality of life depends on the mutual tolerance of its members. The awareness of resource constraints has stimulated numerous surveys that seek to identify a long-term solution to the problem of overexploitation of coastal resources. These issues were first systematically addressed in 1972 in a report by the Club of Rome. The results are published in the books The Limits to Growth and Beyond the Limits.

The term sustainable development was defined in 1987 by the World Commission on Environment and Development, which published the so called Brundtland Report - entitled "Our Common Future" (WCED, 1987). The report contains a well-known definition of development. Goodland and Ledec (1986) define sustainable development as "a model for social and structurally economic transformations that optimize today's benefits without jeopardizing the potential for similar benefits in the future." According to scientists Bojö, Mähler and Unemo (1990), economic development in specific areas (region, nation, globally) is sustainable if total inventories (human capital, physically renewable capital, ecological wealth and exhaustive wealth) are not steadily diminishing (Filipić, Šimunović, 1993).

Over the last couple of decades, increased littoralisation and relocation of economic activity from the continental area to the coast have led to pollution of the coastal areas. As littoralisation is often accompanied by a crisis of congestion and pollution of the coast and the sea, reasonable planning is paramount for sustainable development. Economic and capital pressures are growing stronger and more inhumane. Authors (Phillips et al., 2006; Newton et al., 2012; Batista et al., 2014) stress the need to evaluate the coastal area, ensure its reasonable use and stop unplanned construction, especially the development of mass tourism apartments and hotel resorts. Marine Spatial Planning (MSP) is a reasonable option that enables coastal management to better plan and use the coastal area in an appropriate manner (Papageorgiou, 2016).

Due to the value of natural resources, the MSP promotes the concept of sustainable development as being of the utmost importance for the coastal areas. Therefore, the following is required:

- identify a minimum 100 m wide land belt, where construction will be prohibited, taking into account areas exposed to direct and negative impacts of climate change and natural risks;
- ensure that national legal instruments include criteria for the sustainable use of the coastal zone:
  - determine the boundaries of areas where urban development and other activities are restricted or entirely prohibited;
  - limit the expansion of the urban area and create new transport infrastructure;
  - ensure that coastal area care is regulated by law and one of its leading management activities;
  - grant all citizens free access to the coast, and
  - restrict or completely prohibit the movement and parking of motor vehicles, as well as the movement and anchoring of yachts and vessels in particularly sensitive coastal areas and broader waters.

Although Croatia adopted several regulations (Protocol for Integrated Coastal Zone Management, etc.) on coastal zone management, their implementation is questionable.

Integrated coastal zone management (ICZM) can be defined as a dynamic sustainability process, that takes into account the fragility of coastal ecosystems and landscapes, the diversity of activities and uses, the maritime orientation of individual activities and uses, and their impact on the sea and the coast. The principles of integrated coastal zone management indicate that:

- coastal area can solely be considered a unique resource system, requiring specific management and planning to conserve resources for long-term use;
- all levels of government within the state must participate in the regulation of coastal zone planning.

Integrated management implies a holistic approach to sustainable coastal development and a sophisticated resource management process adaptable to and focused on sustainable

coastal development. It requires an understanding of the relationship between coastal resources, their use, and the impact of construction on the coastal environment.

Croatia evidently still lacks effective integrated management capable of and responsible for coastal zone management.

Particular attention should be paid to hydrological, geomorphological, climate, environmental, socio-economic, and cultural systems, which must be taken into account to preserve the adequate reception capacity of the coastal area. This alone could prevent a variety of negative impacts from making themselves manifest. Connecting local and regional self-government units and involving citizens in the decision-making process would contribute to a better understanding of the value of coastal space. The development of land-use strategies, plans, and programs regulating urban development and socio-economic activities must be free from interests and other pressures. Authors (Fabiano et al., 2009, Diedrich et al, 2010, Palazon et al, 2016) stress that the risks associated with different human and economic activities need to be assessed to eliminate/reduce their negative impact.

4. METHODOLOGICAL APPROACH

The methodological approach to problem solving includes the selection of the appropriate method, definition and evaluation of criteria, as well as the establishment of the general coastal zone evaluation model.

4.1. Multi-Criteria Analysis

Several methods can be used to solve the problem of coastal zone valuation, depending on different stakeholder preferences. In addition to economic (market) methods (Jin et al., 2003), non-market and other methods and techniques have also been used. Scenario methods view development as unrestricted, intensive, selective, and sustainable development. However, special attention is paid to linear programming, AHP, ELECTREE, PROMETHEE and GAIA, where the authors' experiences vary (Brans et al., 1986; Zeleny, 1992, Nikolić and Borović, 1996), and GIS (Kitsiou et al., 2002). Linear programming methods allow problem resolution at the operational level (Roubens, 1982), while the PROMETHEE method (Brans and Vincke, 1985) is characterized by (Vincke, 1992):

- coverage of criteria;
- an estimated higher-ranking relationship;
- use of higher-ranking relationship.

The following methods are used in conjunction with PROMETHEE I and II:

- PROMETHEE III - gives the interval order of alternatives;
- PROMETHEE IV – is an extension of the previous method to continuous sets of alternatives;
- PROMETHEE V - allows the elaboration of a complete survey taking into account additional issues such as cost constraints, geographical diversification of problems, and more.

When the PROMETHEE method is applied to MCA problems, there are two potential outcomes - partial, and complete ranking of alternatives. However, given the existence of other options that cannot be linked, additional geometric information on the behavior of options is needed according to specific criteria. The GAIA method is a geometric representation of the results obtained using the PROMETHEE method. The multidimensional problem is reduced to a two-dimensional one, allowing for simple presentation. When the number of dimensions is reduced, there is a specific loss of information. To minimize the loss of data, the plane in which the geometric representation is given is determined with the two most characteristic values of the co-variation matrix.

4.2. Criteria Definition and Evaluation

All factors, both positive and negative, must be taken into account when deciding how to use the coastal zone. Countries that have managed to preserve their coastline are under pressure to subject their coastal region to intense development. That is especially true of underdeveloped, developing, and transitioning countries which are under constant pressure from capital interests. It is therefore essential to recognize environmental risks, prevent devastation, preserve local benefits, and the coastal area now and in the future. The coastal area should be evaluated in order to set developmental goals and establish the criteria for its potential use. Objectives can be grouped into several basic qualitative determinants of development:

- Economic - systematic coastal zone valorization based on the principles of sustainable development to prevent the overuse of coastal space for commercial / tourism purposes;
- Social - raising the standard of living in the coastal area, while observing the principles of spatial organization and the needs of the people who live and work there;
- Environmentally-friendly and sustainable development of the coastal area:
  - the coastal area should be rationally used and protected in all elements and stages of use;
  - negative environmental impact should be minimized;
  - interaction between individual centers and activities in space should be based on cooperation;
  - the coastal area should be organized in keeping with the principle of openness and integration, which should be evident in all organizational elements: economic, service, institutional, transport and other functions;

- the sort of development that fosters long-term harmonization of the scope and dynamics of production and consumption activities with the scope and dynamics of processes taking place in the coastal zone should be encouraged.

• Functional-organizational - implementation of a theoretically based and practically feasible coastal zone evaluation model.

The objectives defined above allow the identification of coastal zone evaluation criteria. In 2017/2018, the authors conducted a comprehensive study of criteria for general models of coastal area evaluation. The research took into account the stated theoretical premises and past analyses of the criteria. The goal of the research was to determine, evaluate, and rank the criteria and sub-criteria identified, rank the proposed groups of criteria and recommend other criteria or sub-criteria. For each of the identified sub-criteria, the extent of the impact on the coastal area was determined by establishing the maximum or minimum impact. E.g. spatial plan is a sub-criterion of particular importance and must have the condition of maximum since the goal is to plan the use of the coastal area with maximum respect for its natural features. Legislation, frequent changes, and inconsistencies, also have the condition of maximum, since, in the long run, they can be detrimental to the development of the area in terms of redevelopment and more. Of course, the environmental criterion has a minimum requirement when it comes to specially protected areas. However, investment in environmental protection must be maximized, since it does not matter if polluters (such as oil and other industries, and cruisers) generate pollution without paying the adequate fines and being obligated to invest in appropriate green technology.

Criteria and sub-criteria are as follows:

• institutional and political (physical plan, marine spatial planning, views and regional developmental policy, acts, and legal framework), 20%

• natural and physical (geomorphologic and oceanographic characteristics, hydrographic, microclimate characteristics), 15%

• environmental (nature parks, susceptibility to human activities, estimated adverse impacts on the environment, monitoring of the coastal area, value of investments into environmental protection), 25%

• technical and technological (development of traffic and other infrastructure, vicinity of city centers, safety conditions), 10%

• economic (developmental possibilities, investments, taxes, concession fees, external costs), 15%

• social and cultural (direct and indirect benefits, level of urbanization, increased/decreased quality of life in the local community, social and cultural aspects of the region), 15%.

4.3. General Model Using the PROMETHEE Method

Criteria have been identified, ranked and their weight calculated based on the global analysis and development of the general model. The equation for criteria weight based on internecine ranking is:

$$w_j = \frac{\sum_{k=1}^{n} R_{jk}}{\sum_{j=1}^{m} \sum_{k=1}^{n} R_{jk}}; \quad (1)$$

$$R_{jk} \in \{m - i : i \in (1,..,m)\}$$

where R_{jk} is the rank of the criterion according to the expert ranking and its value is:

R_{jk}= m-1 for the most important criterion

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R_{jk}= 0 for the least important criterion

n – total number of experts,
m – total number of criteria,
w_j – weight calculated for the criterion j^{th}.

The above equation is used for criteria ranking.

The environmental criterion ranks the highest, followed by the institutional and political criterion, owing to the exceptionally high influence of the Act and policies on coastal zone use. The environmental criterion is of utmost importance. Its role is to prevent damage and overuse of natural resources.

Normalized property values were calculated using a more straightforward approximate procedure. Each element of the matrix was divided by the sum of the corresponding column values. Then the weights were calculated as average values of elements in individual lines, i.e. the equation system was not solved directly.

The definition of the general model was followed by the execution of the above described operations and then, as a result, by the calculation of the weight criterion vector. The following expression was used to obtain the weights of criteria whose importance ratio is contained in matrix A:

$$(A - 6 \cdot 1) \cdot W = 0 \quad (2)$$

$$w_i > 0, i = 1,2,...,6 \quad (3)$$

$$\sum_{i=1}^{6} w_i = 1 \quad (4)$$

Where:

$$A = \begin{vmatrix} a_{11} & a_{12} & \dots & a_{16} \\ a_{12} & a_{22} & \dots & a_{26} \\ \dots & \dots & \dots & \dots \\ a_{13} & a_{62} & \dots & a_{66} \end{vmatrix} = \begin{vmatrix} w_1/w_1 & w_1/w_2 & \dots & w_1/w_6 \\ w_2/w_1 & w_2/w_2 & \dots & w_2/w_6 \\ \dots & \dots & \dots & \dots \\ w_6/w_1 & w_6/w_2 & \dots & w_6/w_6 \end{vmatrix}, \quad (5)$$

$$W = \begin{vmatrix} w_1 \\ w_2 \\ \dots \\ w_6 \end{vmatrix}, \quad (6)$$

$$I = \begin{vmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{vmatrix} \quad (7)$$

Where the solutions are sought through the use of additional conditions of non-negativity and the normalization of the values of solution components, where:

I - unit matrix

W - vector of criteria weights.

Since not all criteria have the same weight, based on their mutual rankings, a weighted preference index obtained by the application of the equation used to calculate the weight criterion was introduced.

The function of the $P_j(a,b)$ preference in the general model is of type III, since it allows the decision-maker the progressive preference of "a "over "b "during the progressive growth of the difference between functions of the f(a) and f(b) criteria. The preference intensity is linearly increased until the difference equals parameter "*p* ", that can be determined in specific cases, and after that value, the preference is strict.

The criteria weights W_j are specific for each criterion j =1...6,.., hence, multi-criteria index of preference for $a, b \in A$ is defined as:

$$\Pi(a,b) = \frac{\sum_{j=1}^{6} W_j P_j(a,b)}{\sum_{j=1}^{6} W_j} \quad (8)$$

where A is the set of possible alternatives, i. e. the rank of coastal area evaluation.

The directed graph, with action nodes from *A*, is such that, for every $a, b \in A$, the sinuosity (a,b) has the value of its index of preference $\Pi(a,b)$, and is called an estimated graph of higher rank. Calculations can be facilitated by an appropriate software. The general model of coastal area evaluation using global analysis does not meet the key requirements in the case of individual coastal areas. For example, the most convenient criteria should be identified, taking into account other criteria at appropriate levels, that offer the highest protection of the coastal area. The best developmental scenario for individual coastal areas should be identified, as well as the requisite infrastructure and traffic solutions in terms of costs. Therefore, a specific analysis was carried out to introduce and rank sub-criteria. Based on the experts' evaluation, the following expression for sub-criteria was defined:

$$w_j = \frac{\sum_{k=1}^{n} w_{jk}}{\sum_{j=1}^{m} \sum_{k=1}^{n} w_{jk}} \quad (9)$$

where

$$w_{jk} = \frac{p_{jk}}{\sum_{j=1}^{m} p_{jk}} \quad (10)$$

n – the total number of experts, m – the total number of sub-criteria, ρ_{jk} – the evaluation of k^{th} expert for j^{th} sub-criterion, w_{jk} – the weight derived for j^{th} sub-criterion of k^{th} expert, w_j – weight calculated for j^{th} sub-criterion.

Using the above expression, an equation for obtaining sub-criterion weight was developed based on their mutual ranking:

$$R_{jk} \in \{ m - i : i \in (1,..., m) \} \quad (11)$$

where R_{jk} is the rank of sub-criterion j, according to the ranking of the k^{th} expert, as follows:

$$R_{jk} = m - 1 \text{ for the most important criteria}$$
$$R_{jk} = m - 0 \text{ for the least important criteria} \quad (12)$$

n – total number of experts, m – total number of criteria, weight derived for the j^{th} sub-criterion.

Further development of the model requires the input of real data about a specific coastal area.

5. THE APPLICATION OF THE GENERAL MODEL

The authors presented the general problem defining model. The model development process, data and documentation collection were conducted in parallel, with an emphasis on collaboration with experts and users. The general model does not provide answers as to which requirements are essential for individual areas, e.g. which activity is the most favorable. The process takes into account, in the multi-criteria sense, other appropriate level criteria that offer the best technological solution, reasonable construction costs and concession fees, relevant safety features and relatively lowest total costs of pollution prevention and area protection, have a positive impact on the local community, and acceptable indicators for other characteristics.

The presented model should be improved on the basis of the results obtained through its application, taking into account the potentially new conditions that may occur in the system.

Therefore, this paper analyzed the evaluation of the coastal area using the established criteria and sub-criteria to facilitate operative decision-making.

The model will be tested by applying the PROMETHEEI (I and II) and GAIA methods to a selected coastal area in the Northern Adriatic. That will be the subject of new research.

6. CONCLUSION

Coastal development requires the coexistence of ecosystems and production. Although the number of coastal areas that have adopted the principles of sustainable development as an all-encompassing developmental concept is limited, in this sense, the concept of sustainable development can also be considered a contemporary philosophy of coastal economy.

Tourism is becoming a significant economic activity, which, among other things, puts it in a position to define spatial requirements. This creates new conflicts that can only be overcome by proper valorization and monitoring of the coastal zone.

As the evaluation of the coastal area using various methods (survey, ranking, rating, MCA) was previously not well-researched, the research carried out by the authors strived to contribute to the evaluation of the coastal area by focusing on the issues, complexity, importance, valorization and protection of the coastal area.

The multi-criteria analysis allows the decision-makers to attribute weight values to each criterion, taking into account clearly defined objectives. Weight coefficients differ at different decision-making levels. The contribution of this research is the identification of criteria and sub-criteria for coastal area evaluation. The implementation of the defining criteria and sub-criteria allows the application of the holistic approach, and ensures the achievement of quality and efficiency of business operations in the coastal area. The model presented in this paper may serve as a theoretical basis for modeling individual coastal areas. The general model may be used to plan new activities and techno-technological solutions.

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