Perceived Diversity of Complex Environmental Systems: Multidimensional Measurement and Synthetic Indicators

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Summary

The general attitude towards the sustainable management of environmental resources is evolving towards the implementation of ‘participatory’ (as opposed to the classical ‘command and control’) and, especially at local scale, ‘bottom up’ (as opposed to the classical ‘top down’) approaches. This progress pushes a major interest in the development and application of methodologies able to ‘discover’ and ‘measure’ how environmental systems tend to be perceived by the different Stakeholders. Due to the ‘nature’ of the investigated systems, often too ‘complex’ to be treated through a classical deterministic approach, as typical for ‘hard’ physical/mathematical sciences, any ‘measurement’ has necessarily to be multidimensional.

In the present report an approach, more typical of ‘soft’ social sciences, is presented and applied to the analysis of the sustainable management of water resources in seven Southern and Eastern Mediterranean Watersheds. The methodology is based on the development and analysis (explorative factor analysis, multidimensional scaling) of a questionnaire and is aimed at the ‘discovery’ and ‘measurement’ of a latent multidimensional ‘underlying structure’ (‘conceptual map’).

It is the opinion of the authors, that the identification of a set of ‘consistent’, ‘independent’, ‘bottom up’ and ‘shared’ synthetic indicators (aggregated indices) could be strongly facilitated by the interpretation of the dimensions of the emerging ‘underlying structure’

Keywords: Participative Approach, Cognitive Map, Factor Analysis, Indicators of Sustainability, Sustainable Water, Management

JEL Classification: C13, C42, D74, Q01, Q25

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We would like to thank all OPTIMA partners for fruitful discussions and for taking care of the compilation of the Questionnaires, by Interviewing local Stakeholders.

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1 INTRODUCTION

In recent years, '*sustainable development*' has become a fundamental policy concept in the fields of environment, economic and social development. Nevertheless, the term is one of the most intangible and difficult to define in practical terms. Sustainability is perceived by many to be an abstract concept - impossible to be defined univocally and impossible to be put into practice. Common to most 'sustainable development' definitions is a split between these two words: while development looks like an intention, to be sustainable seems to be a restriction. Irrespective of the vagueness and variability surrounding the philosophy of sustainability, the concept seems to have filled a critical void in modern environmental thinking.

Environmental sciences have typically to assess the impact of human activities on complex natural systems (e.g., complex webs of linear or non-linear interactions containing difficult to define pathways and multiple feedback loops). Furthermore, in the framework of sustainable development, environmental compatibility has to be complemented by economic efficiency and social equity (another potential dimension that is often absent from the sustainability dialogue is the emotional or psychical health of the community). This makes any approach towards a 'consistent' deterministic mathematical formulation hardly feasible. The sustainable study of environmental systems tends to give value to the study of complex interrelationships rather than compartmentalised and narrow fields of focus or specialties. The notion of sustainability offers therefore a forum for looking 'holistically' at the 'big picture', in a climate that glorified the specialist and the reductionist.

Furthermore, in order to 'optimise' the management of natural resources one has, as a matter of facts, to analyse and frequently to reconcile conflicting demands (often by different Stakeholders). Recent EU legislation (e.g., 2001 White Paper on 'European Governance' or, in relation to environmental legislation, the 'Water Framework Directive' - 2000/60/EC) tends to force the implementation of 'participatory' approaches, where different Stakeholders are not only informed, but also directly involved in different phases of the decision process. This concern is variously articulated using the language of public participation, community empowerment, decentralised decision-making, and democratic governance. It becomes therefore mandatory, especially at local level, the development of efficient approaches aimed at the 'discovery' and 'measurement' of how complex environmental systems tend to be perceived by different Stakeholders. Due to the 'complexity' of the investigated systems, any 'measurement' is necessarily multidimensional.

While the 'classical' approach tends to postulate a set of indicators and measure diversity on the base of this 'a priori' ('top down', as opposed to 'bottom up') postulated set (by introducing 'ad hoc' metrics and/or weighting schemes), the present report presents an alternative methodology that, on the contrary, tends to 'bring to the surface' the underlying multidimensional structure, as perceived by the Stakeholders (the so-called 'conceptual map'), as well as to support the introduction of a 'consistent' set of synthetic indicators (aggregated indices).

Although environmental science tends to be recognized as a 'hard' physical/mathematical science, the methodology is based on interviewing Stakeholders, an approach more typical of 'soft' social sciences. Schematically, the applied procedure is as follows:

- generate and submit to Stakeholders of concern a Questionnaire, containing a list of Issues thought to comprehensively cover the topics inherent to the system under investigation, and ask them to score the perceived criticality of each single Issue (e.g., by means of a scale, anchored to: 'Extremely Unimportant' and 'Extremely Important');

- analyse the Questionnaires (e.g., explorative factor analysis) aiming at the 'discovery' of any latent multidimensional 'underlying structure'. The procedure allows the extraction of an 'optimal' number of orthogonal (i.e., independent) dimensions (typically, expressed as weighted sums of subgroups of Issues).
- interpret the discovered 'underlying structure' and use this reduced set of new dimensions in further analysis (e.g., cross-comparisons, construction of 'synthetic indicators').

The proposed methodology has been tested in the framework of Sustainable Water Resource Management. The application is part of the OPTIMA Project (Optimisation for Sustainable Water Management, 6th Framework Programme, INCO-MPC), where seven independent Middle East and North African Mediterranean Watersheds are modelled and investigated aiming at the identification of optimal water management practices.

In this report theoretical and practical aspects, related to both the general approach and the OPTIMA-specific application, will be presented.

2 THE USE OF INDICATORS

2.1 Definition and functions of indicators

The definition of an indicator, the various ways in which it may be developed, the different functions it may perform, and the criteria upon which its ability to meet policy requirements are best assessed may at first sight seem rather obvious and simplistic issues. However, it is, in practice, impossible to separate the definition of indicators from a discussion of the functions they perform.
Indicators are quantities that give a schematic and informative representation of the 'reality' of complex systems. There are many different definitions of indicators. The Organisation for Economic Cooperation and Development (OECD), proposes the following '*a parameter or a value derived from parameters, which provides information about a particular phenomenon*' /1/.

It has been noticed that there is often a tension between the different types of providers, users, applications and functions of sustainable development indicators /2/:

- technical indicators: aiming at a technical or science-based representation and modelling of complex human-environmental systems
- policy indicators: aiming at a policy or management-focused information with direct linkages into the stages of the decision-making process
- social indicators: aiming at a more general use for citizens, consumers, non-governmental organizations and other bodies, where the practical application is more in awareness-raising and agenda-setting.

An 'ideal indicator' would fulfil all these functions (see Figure 1).

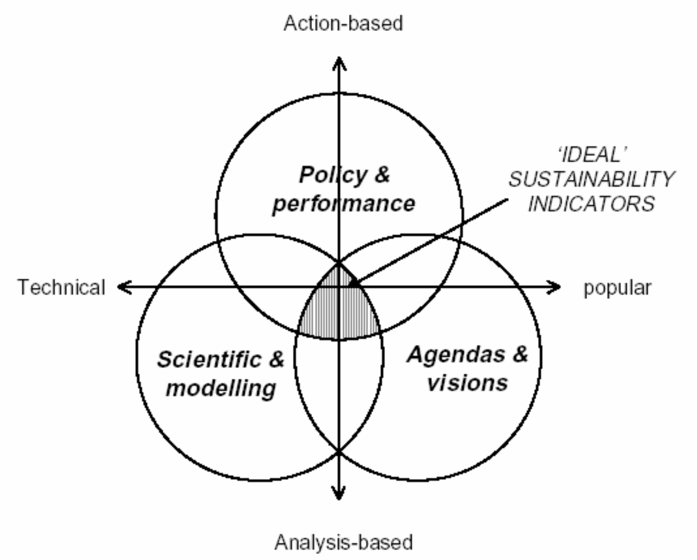


Figure 1: 'multifunctional' properties of an 'ideal' indicator, from /2/

Consequently, ideal indicators should be *'holistic'*: i.e., rather than measuring a single aspect, independently of others, sustainability indicators should illustrate the linkages between and among systems, /3/. For instance, a traditional indicator programme might rely on a single factor, such as unemployment figures to assess the health of the economy. A comparable sustainability indicator programme would gauge the overall economic condition of the community and review other factors such as income distribution, size of businesses, pollution levels and so on. Sustainability indicators are also distinguishable from traditional measures of progress by their measure of non-traditional aspects of 'quality of life'. This is a rather controversial point, see Section 5.1.

Sustainability indicators can rarely be considered as independent from each other; indicators designed to measure improvement in one capital asset often have simultaneous positive and negative impacts on other capital assets. For example, building new or modernising existing transport infrastructure will inevitably improve physical capital of local region, but will have potential negative impact on human health and the environment (i.e. natural capital). Schemes where indicators are used to measure various aspects of sustainability independently are therefore questionable.

2.2 PSR and DPSIR Frameworks

Many environmental issues are analysed through the 'Pressure-State-Response' (PSR) framework, proposed by the Organisation for Economic Cooperation and Development (OECD) in 1994. In 1996, the United Nations Commission on Sustainable Development (UNCSD) adapted the PSR model by extending the concept of pressures to 'driving force' indicators. This reflects those human activities that impact on sustainable development, either in a harmful or beneficial way, in a connected chain of causes and effects. This model has also been adopted by the European Environment Agency as DPSIR (driving forces, pressures, states, impacts, responses) /4/.

The DPSIR framework assumes cause-effect relationships between interacting components of the social, economic and environmental systems, which include:

- **D**riving forces of environmental change (e.g., industrial production);
- **P**ressures on the environment, or the result of driving forces (e.g., emissions of pollutants into the atmosphere, in relation with industrial production);
- **S**tate of the environment (e.g., air quality monitoring of concentrations of pollutants);

- **I**mpacts on population, economy, ecosystem (e.g., air-quality related health problems);
- **R**esponse of the society or the policy/business actions which follow (e.g., emission permits, emission reduction strategies).

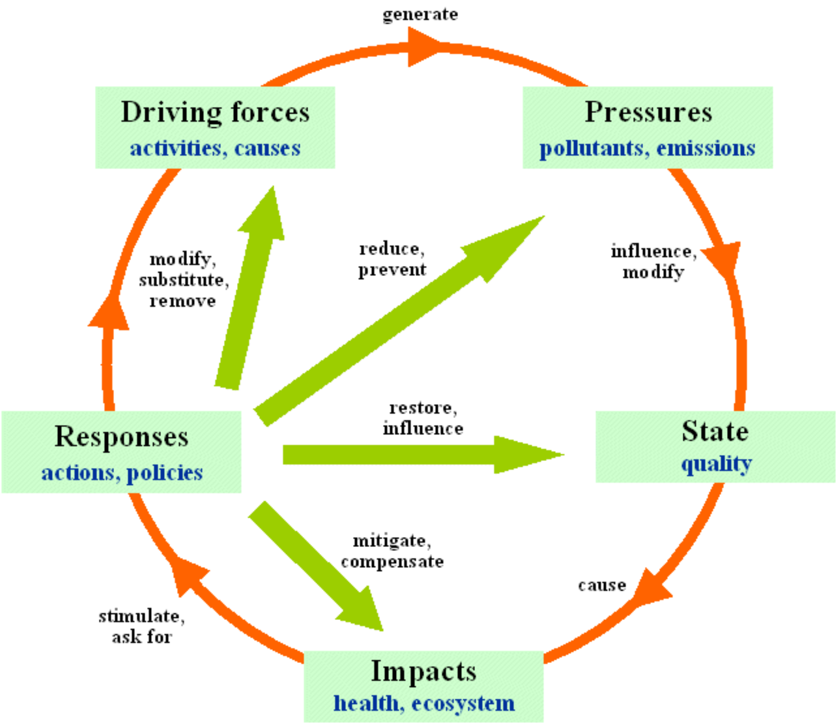


Figure 2: basic structure and interconnections of the DPSIR framework

The PSR and extended DPSIR frameworks work well in the environmental dimension of sustainable development indicators, where there are often clear definitions of cause-effect linkages between each stage in the DPSIR scheme. However, as noted by many authors (e.g., /5/), the framework is lacking in its ability to capture the full complexity of the less obvious cause-effect chains as seen in social and economic dimensions of sustainability, where many indicators are difficult to be classified in this framework and the environmental effects are often out-weighed by social and economic issues.

2.3 Characteristics of indicators

An indicator is more than simply a piece of data. Indicators are useful every time the performance of a system, the evolution of a process or the results of a particular action on a complex system, such as the environment, needs to be evaluated. In all these events, an instrument is needed able to extract comprehensible and reliable informative content from a potential huge amount of data and information.

Indicators are thus instruments that extract synthetic pieces of information by means of a multidimensional representation of a complex and wide phenomenon, thereby trying to make clear a situation or a characteristic that is not directly perceivable. They represent an *empirical model of the reality*, implicitly assuming that a complex phenomenon could be represented by a limited number of variables /6/.

Indicators have two major functions /1/, /7/:

- simplification of measurements. «They reduce the number of measurements and parameters, which normally would be required to give an 'exact' representation of a process or a situation.

As a consequence, the dimension of a set of indicators and the amount of detail contained in the set need to be limited. A set with a large number of indicators will tend to clutter the overview it is meant to provide. Too few or even a single dimension, on the other hand, may be insufficient to provide all the necessary relevant information. In addition, methodological problems related to weighting tend to become greater with an increasing level of aggregation»;

- simplification of communication. «They simplify the communication process by which the information of results of measurement is provided to the end-users. Due to this simplification and adaptation to user needs, indicators may not always meet strict scientific demands to demonstrate causal chains. Indicators should therefore be regarded as an expression of 'the best knowledge available'».

An indicator offers therefore a monitoring capability, that is defined not only in temporal terms, but also through the intrinsic potentiality to compare and ranking different locations, regions or countries (in a kind of benchmarking exercise).

Last but not least, indicators are generally thought to have a 'didactic function', in other words they are involved in teaching, learning and awareness-raising (see Section 2.4). Community support and media-appeal should not be compromised. These have been proven to be most critical to keeping sustainable development issues alive and at the forefront of discussions. The balance between 'scientific soundness' and 'didactic function' of indicators will be analyzed in the next Section.

2.4 'Top down' and 'bottom up' approaches

As seen in the previous Sections, the 'traditional' view is that indicators summarise complex technical issues, allowing the key conclusions and implications to be summarised and then communicated and understood by policy makers, practitioners and lay persons. This could perhaps be described as the expert-to-generalist or 'top down' approach. An in-depth technical and 'holistic' understanding of environmental, social or economic processes is a pre-requisite for the formulation of such indicators. In the field of the sustainability of 'extremely complex' environmental systems the overall feasibility of such a 'top down' approach is, at least, questionable and, even if implemented, the number as well as the characteristics of the proposed set of indicators will generally vary from expert group to expert group.

This report mainly refers to a complementary or alternative use of indicators. Recently, especially at local level (i.e., when the local community can be involved directly), it has become increasingly popular to make use of the so-called 'bottom-up' approach. In this framework, indicators play also a didactic function and their identification and selection tends to focus more on the *collective perception* of the local community rather than on the *technical knowledge* of experts (as in the 'top down' approach). The origin of the 'bottom-up' approach seems to be in the work of the Sustainable Seattle Project (http://www.sustainableseattle.org/), but it has become a developed worldwide phenomenon, probably due to its association with Local Agenda 21 initiatives.

In this approach, the construction of a set of indicators becomes a process by which local Stakeholders find expression for their subjective experience of local (un)sustainable development. Indicators can therefore help Stakeholders to understand the breadth of sustainable development Issues and the (non necessarily obvious) relationships among them. If successful, the resulting indicators provide a mean of communicating the *perceived* local collective assessment of sustainability to a wider public and to policy makers. Those using indicators have found that they are invaluable not just as a means of measuring progress, but also as a tool to raise awareness of the key issues and to help people understand what they themselves need to do. From this point of view, the success of such initiatives should not be judged on the benchmarks and indicators themselves, but increased community activity (local projects and strategies, committees and meetings, etc…). The concept is based on the philosophy that the more broad-based and participatory the process, the greater are the chances of public buy-in and exposure for the programme /3/. One has also to notice that modern technology offers a major support, as it provides inexpensive means of getting and sharing information and it allows the construction of a 'virtual forum' for building community visions and goals .

Many share the belief that the exchange of information that occurs through a 'bottom up' indicator programme far outweighs the long-term benefits offered by the actual indicators themselves. In this context it is worth recalling an important result of the Environmental Sustainability Indicators Programme (/7/, p. 163): «*…finally, a clear priority emerges, that may be of interest to recent European policies on governance: the level of satisfaction with the opportunities to participate in local planning and decision making records a very low score (31%) and, above all, a very high number of 'no answer', suggesting low awareness among citizens as to their rights to participation*».

2.5 Indicator Aggregation and Weighting

In considering all the many and various individual indicators of sustainability, it is easy to forget that the ultimate objective is to assess whether the system is (overall) developing in a sustainable manner. The UN Commission on Sustainable Development pointed out that: «*the process of measuring sustainable development calls for simple, elegant and effective measures that do not compromise the underlying complexity. High-level decision makers (government ministers, foundation executives and heads of corporations) routinely ask for a small number of indices that are easy to understand and use in decision making*» /8/.

Some writers suggest aggregation to form a limited number of broad thematic composite indices (e.g., the Ecological Footprint, an index of social justice or a competitiveness index). Other writers describe the same process in terms of an 'information pyramid', with raw data at the base, overlain successively by statistics, indicators and composite (aggregated) indices. Others perceive a need for a single summary sustainability index, emphasising that the goal of an overall 'index of sustainability' can only be achieved after much 'invisible' development work on raw data, processed data, statistics and indicators. The obvious advantage of an overall 'index of sustainability' is that it prioritises issues and is appealing to the public for its straightforward message. One can notice that such an effort has been successfully implemented, since decades, in the field of economics. A composite index, 'annual percentage changes in Gross Domestic Product - GDP', although extremely complex to be evaluated (i.e., it requires much 'invisible' development work on raw data) and although it has given origin to strong criticisms from a theoretical/conceptual point of view (it makes no distinction between economic transactions that add to - or diminish - well-being), has, as a matter of facts become a primary index used as a 'transparent' measure, with great resonance in the media, of the 'economical success' of a national government.

In the environmental field, the process of aggregation is made more difficult by the complexity of the sustainability concept. A number of composite indices have been developed at the international level. These are reviewed by the UN Commission on Sustainable Development /8/. They include, e.g., the Genuine Progress Index, the UNDP Human Development Index, the World Conservation Union's Well-Being Assessment, the WWF Living Planet Index, Wackernagel's Ecological Footprint, the Water Poverty Index and the EU Commission's Policy Performance Index. However, all of these aggregated indices are thematic and partial in one way or another, addressing aspects of sustainability.

In addition to these ‘statistical exercises’ there has been a number of attempts to represent overall sustainability assessments by combining individual indicators or indices in graphical formats. Perhaps the most sophisticated of these is the International Institute for Sustainable Development (IISD) ‘Dashboard’, which uses position to indicate theme, size to convey relative importance, and colour to indicate how critical the level of the indicator is.

However, neither statistical aggregation nor graphical presentation obviate the need to address the difficult theoretical issues relating to the relative weights assigned to individual indicators within the overall assessment (*assigning weights is not an exact science*). The danger indeed is that the majority of users could ignore these assumptions in their enthusiasm for apparently simple and conclusive assessments /5/.

3 A QUESTIONNAIRE-BASED APPROACH

As reported in the previous Chapter, two main alternative approaches can be implemented in order to generate a multidimensional set of indicators.
The standard and classical ‘top down’ approach tends to postulate it ‘a priori’, making use of panels of experts. As an alternative, especially in sustainability related initiatives at local level, a ‘bottom up’ approach can be used, where the set of indicators is not ‘imposed’, but is let to emerge from the involved Stakeholders. Even in this ‘community empowerment’ approach, however, the common praxis is that of having a ‘facilitator’ so that the dynamic of the group, and in end effect the emerging set of indicators, is not necessarily an unbiased, spontaneous and shared process, but could be (intentionally or unintentionally) influenced by the people ‘in charge’ of leading it. On the other side, supervision from ‘facilitators’ and ‘experts in the field’ is desirable, in order to guarantee a comprehensive and scientifically sound base to the discussions.

In the present report, a guided ‘bottom up’ procedure is presented, finalized to the development of a methodology to ‘extract’ the underlying multidimensional structure of the system object of study, as perceived by the Stakeholders (the so-called ‘conceptual map’), as well as to support the ‘discovery’ of a ‘consistent’ set of synthetic indicators (e.g., weighted sums of basic indicators).

3.1 Methodology

The methodology is based on interviewing Stakeholders (i.e., compilation of a Questionnaire), an approach more typical of the ‘soft’ social sciences than of the ‘hard’ physical/mathematical sciences. Schematically, the applied procedure is as follows:

- Step 1: Generate, test and submit the Questionnaire. The generation of the questionnaire is essentially a creative process where the ‘people in charge’ make up an ‘exhaustive’, ‘holistic’ list of Issues that are supposed to cover the multifaceted aspects inherent to the system under investigation and its sustainability. Representative Stakeholders are then asked to score the relevance of each Issue (e.g., by making use of a 7-point symmetric semantic differential scale, anchored to: ‘Extremely Unimportant’ and ‘Extremely Important’). As common praxis in any Survey, the respondents should be able to easily understand precisely what information has been asked, with little or no error and should be able to easily provide this information. This means the Items should be written down in a way that facilitates rather than interferes with the respondents’ ability to understand the question and report the answer to the best of their ability. The perception, understanding and comprehensiveness of the Questionnaire have therefore to be initially tested before being submitted to local

Stakeholders. Many references exist in literature on how to formulate. develop, test and use Questionnaires, see e.g. /9/.

- Step 2: Analyze the Questionnaires. The main aim of the statistical analysis (explorative factor analysis, multidimensional scaling or confirmatory factor analysis in case a model for the 'conceptual map' is already available) is to untangle the overlapping information provided by correlated Issues and to peer beneath the surface to check the existence and consequently 'discover' any latent multidimensional 'underlying structure'. The statistical procedures allow the extraction of an 'optimal' number of orthogonal (i.e., independent) dimensions (typically, expressed as weighted sums of subgroups of Issues).
- Step 3: Interpret the multidimensional 'underlying structure'. Once the single dimensions extracted in previous step have been interpreted, a consistent set of 'synthetic indicators' could possibly be introduced (making use of the linear combinations that make up the extracted factors). This allows a synthetic representation of how the 'complex system' under study tends to be perceived and allows to express 'what is going on' in terms of a reduced set of new dimensions.

A further step in the methodology allows, by making use of the previous results, to gain additional insights into the systems under study:

- Multigroup analysis. Analyze, compare and rank the complex environmental systems and/or the classes of Stakeholders in the framework of the extracted factors.

In the present Chapter, methodological aspects related to the statistical analysis of the Questionnaires will be introduced and critically discussed. Chapter 4, is instead dedicated to a specific application in the field of 'Sustainable Water Management'.

3.2 Multivariate analysis

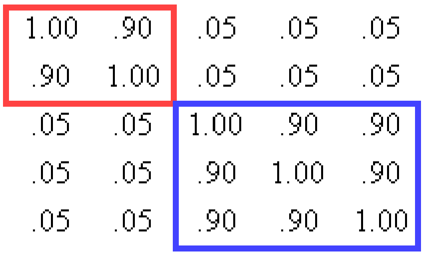
Multivariate analysis proposes a collection of approaches that can be applied when several variables are measured, on each individual, in one or more sample units. Typically, these variables happen to be correlated (if this were not so, one could stop at the univariate level and it would be of no advantage to use a multivariate approach). The main aim of (explorative) multivariate analysis is to untangle the overlapping information provided by the correlated variables and peer beneath the surface to check the existence and consequently 'discover' any 'underlying structure'. Thus the main goal of most explorative multivariate techniques becomes just a simplification of the set of the original data, by seeking to express what is going on in terms of a reduced set of new dimensions (whose meaning can be possibly interpreted).

3.2.1 Exploratory Factor Analysis

In factor analysis one basically tries to represent a large amount of originally measured variables ($y_1, y_2, \ldots, y_N$) as linear combinations of a much smaller set of new 'basic' variables, called *factors* ($f_1, f_2, \ldots, f_m$ with $m < N$). The basic idea is that if the original variables $y_1, y_2, \ldots, y_N$ are at least moderately correlated, they must be somewhat 'redundant' (i.e., they must share some common piece of information), and therefore the actual, true dimensionality of the measurements is in reality less than N. The goal of factor analysis is therefore to reduce the redundancy intrinsic to correlated variables, by introducing a 'minimum' number of basic factors. These factors can be thought as '*underlying constructs*' or '*latent variables*' that 'generate' the ys. Like the original variables, the factors vary from measurement to measurement but, unlike the variables, the factors cannot be directly measured or observed. The existence of these hypothetical variables is therefore open to question.

Suppose the pattern of the high and low correlations in the correlation matrix allows the identification of a particular subset of variables that are highly correlated among themselves but only negligibly correlated with all the other variables. Then these variables might have found origin from a single underlying factor. If other variables can be analogously grouped into specific subsets, then each of these groups of variables could just be the reflection of an underlying factor. In this case the pattern in the correlation matrix corresponds directly to the factors.

For example, suppose, in an ‘ideal’ case, that the correlation matrix looks like the one reported in Figure 3. Then the 1st and 2nd variables correspond to a factor; the 3rd, 4th and 5th variables correspond to another independent factor. In most cases the correlation matrix does not have such a simple pattern, however, factor analysis will still be able to partition the variables into clusters. The goal of factor analysis is to achieve a ‘simple structure’ in which each variable loads highly on only one factor, with small loadings on all other factors. In practice, one would often fail to achieve this goal, but hopefully could come closer to the desired simple structure.



1.00	.90	.05	.05	.05
.90	1.00	.05	.05	.05
.05	.05	1.00	.90	.90
.05	.05	.90	1.00	.90
.05	.05	.90	.90	1.00

Figure 3: correlation matrix, where the 5 original variables let them ‘ideally’ split into 2 factors

In contrast with the ‘ideal’ case of Figure 3, Rencher portrays the following most ‘critical’ scenario: «*A researcher designs a long questionnaire, with answers to be given in, say, a five-point semantic differential scale or Likert scale. The respondents, who vary in attitude from uninterested to resentful, hurriedly mark answers that in many cases are not even good subjective responses to the questions. Then the researcher submits the results to a handy factor analysis program. Being disappointed in the results, he or she appeals to a statistician for help. They attempt to improve the results by trying different methods of extraction, different rotations, different values of m, and so on. But it is all to no avail. The scree plot looks more like the foothills than a steep cliff with gently sloping debris at the bottom. There is no clear value of m. They have to extract 10 or 12 factors to account for, say, 60% of the variance, and interpretation of this large number of factors is hopeless. If a few underlying dimensions exist, they are totally obscured by both systematic and random errors in marking the questionnaire. A factor analysis model simply does not fit such a data set, unless a large value of m is used, which gives useless results. It is not necessarily the ‘discreteness’ of the data that causes the problem, but the ‘noisiness’ of the data. The specified variables are not measured accurately. In some cases, discrete variables yield satisfactory results. On the other hand, continuous variables do not guarantee good results*» /10/.

Reality usually lies in between these two extreme examples!

3.2.2 Multidimensional scaling

Multidimensional scaling (MDS) can be considered to be a flexible alternative to factor analysis. In factor analysis, the similarities between objects (e.g., variables) are reflected by the correlation/covariance matrix. With MDS, matrices of any kind of distances or similarities can be analyzed. The 'beauty' of MDS lies in its capability to analyze any kind of distance or similarity matrix.

Even though there are similarities in the type of research questions to which these two procedures can be applied, multidimensional scaling and factor analysis are fundamentally different methods. Standard factor analysis requires that the underlying data are distributed as multivariate normal, and that the relationships are linear. MDS imposes no such restrictions. As long as the rank-ordering of distances (or similarities) in the matrix is meaningful, MDS can be used.

MDS is not so much an exact procedure, but rather a way to 'rearrange' multidimensional objects in an efficient manner. Starting, e.g., by a distance matrix, MDS attempts to arrange 'objects' in a space with a specified number of dimensions so as to reproduce the observed distances as good as possible. As a result, the distances can be 'explained' in terms of underlying dimensions.

4 AN APPLICATION: SUSTAINABLE WATER MANAGEMENT

The present Chapter is dedicated to a specific application of the proposed approach to a 'complex environmental system', using the sustainable management of water resource as a test-bench. The application was carried out in the framework of OPTIMA (Optimisation for Sustainable Water Management) a Project using both a participative approach as well as detailed numerical modelling. OPTIMA is financed by the European Union in the INCO-MPC - 6th Framework Programme. Detailed information about the project can be found in Internet, at http://www.ess.co.at/OPTIMA.

The (sustainable) water management at basin scale represents an extremely complex system where social, economic and environmental aspects are particularly interconnected (see Figure 4). In particular, the 'optimization' of water management is not only linked to the identification of the 'best possible' sharing and rate of use (in social, economic and environmental terms) of the natural resources (mainly, surface and groundwater) among different Stakeholders (e.g., Households, Tourism, Agriculture, Industry – in competition among them in cases of water scarcity), but should also include quality aspects in a self-consistent way. This is a consequence of the fact that the demand is water quality as well as activity-specific (e.g., in domestic use, the quality requirements for drinking water are of course much more stringent than those applied to water to be used for flushing toilets). Therefore, instead of a single 'flux of water' throughout the system, as a matter of facts, one should better introduce a 'set of fluxes' characterized by different levels of water quality. Each activity would therefore be characterized by a minimum threshold for acceptable water quality and while 'polluting activity' will cause some transfer from 'higher' to 'lower quality' water, the opposite would occur if water treatment plants are implemented. It is this interconnection between quantity and quality that tends to make the area of application particularly attractive.

The approach selected in OPTIMA in order to prepare the 'holistic' Questionnaire, was based on a relatively pragmatic framework that tends to reflect directly the 'Water Budget' at 'River Basin Scale' (see Figure 4). The Water Issues Questionnaire was structured in three main Sections:

- Water Management. This section addressed issues related to management, policy/institutional, and regulatory/legal aspects, dealing with the existence of clearly established competences of water institutions, efficient mechanisms of water regulation (standards, quotas, water rights), socially and economically acceptable forms of allocation and tariff structures, effective stakeholder participation (including gender equity), adequate management resources for investments in infrastructures maintenance, technologies and research;

- Water Demand. This section dealt with the economic sectors and spheres of human activity which, through their demand for water, exert a pressure on the resources eventually causing scarcity problems (both quantity and quality): household (demographic and urbanisation trends, access to safe, sufficient water supply and impacts on health), tourism (tourism and recent trends), agriculture (land use and land use change), industry (industrialization and water demand from industry) and other functions (e.g., water for navigation or ecological purposes)
- Water Supply. This section assessed the state of water resources in terms of quantity and quality, and some of the impacts on the surface and groundwater compartments, also describing the efficiency of the allocation systems and other infrastructures (e.g., artificial basins and water treatment plants efficiency and capacity) and their impact on biodiversity. This section also considered the limits to economic development and to the ‘quality of life’ of the population reelated to water scarcity, requiring new solutions (e.g., land use change, or low consumption technologies) for a better management of such scarce resources, also preserving the ecological status of aquatic ecosystems.

The three sections included 58 Issues. A brief introductory Section dedicated to the evaluation of the basic ‘Physical Characteristics’ of the Basin of concern (Water scarcity, Floods, Droughts, Groundwater availability, Watershed degradation, Coastal interaction), was also included in the Questionnaire, thus bringing the total number of Issues from 58 to 64.

A Glossary included those terms needed to guarantee univocal definitions and interpretations. The Questionnaire and the Glossary are publicly available at http://www.ess.co.at/OPTIMA.

Stakeholders were invited to score the significance (in reference to the Watershed of concern) of each Issue making use of a 7-point symmetric semantic differential scale, anchored to: ‘Extremely Unimportant’ and ‘Extremely Important’ (the intermediate levels had been labelled, respectively, as ‘Very Unimportant’, ‘Unimportant’, ‘Neutral’, ‘Important’, ‘Very Important’). Alternatively, the answer ‘don’t know’ could be selected (e.g., when the question - or its formulation - was not found sufficiently understandable/unambiguous or when the interviewed perceived himself/herself ‘too incompetent’ on that specific Item).

The compilation of the Questionnaires was carried out by means of Interviews with trained Interviewers. The Stakeholders were also invited to provide additional free-text comments further explaining their choice and assessment, at least for those Issues that were found particularly relevant.

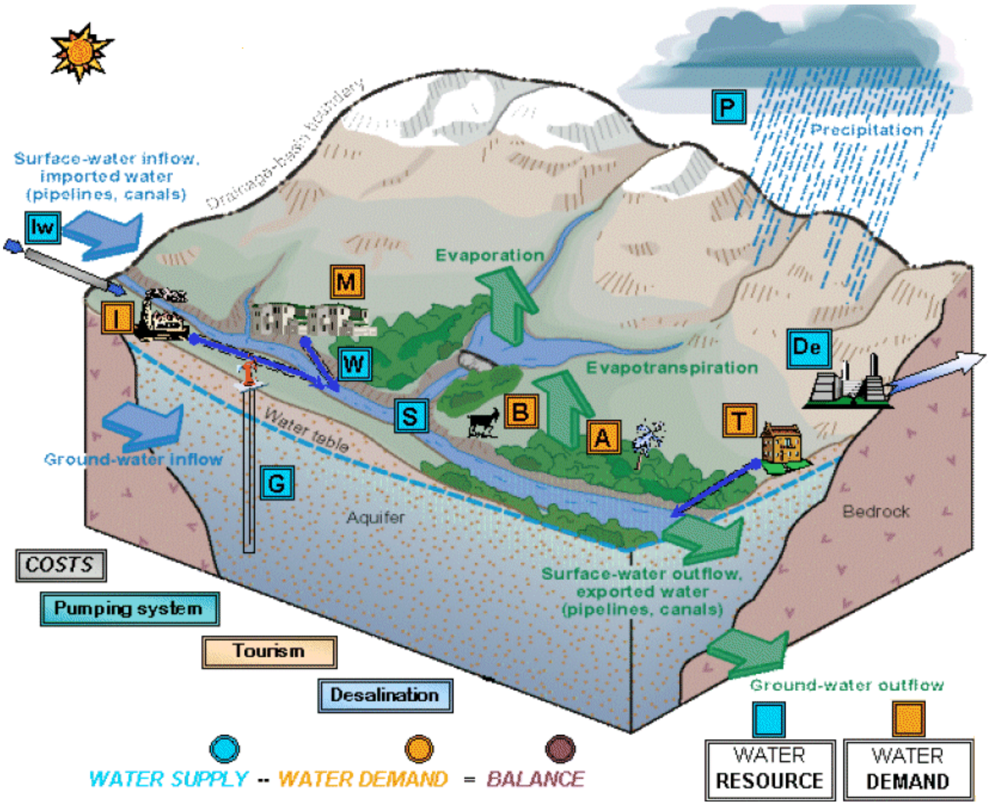


Figure 4: Schematic representation of the 'complex environmental system' related to Water Management at Basin level. The figure is taken from Ref. /13/, where the following abbreviations are used to represent 'water resources': De – desalination; G – groundwater; IW – imported water; P – precipitation, S – surface water and W –wastewater. The 'driving forces' (water demand) are, on the other side, represented by: A – agriculture; B – breeding; I – industry; M – municipal and T – tourism.

4.1 Data Collection

The dataset collected in the frame of the OPTIMA application consisted of 75 questionnaires, representing the 7 OPTIMA Case Studies: Dhiarzos River (Cyprus), Gediz River (Turkey), Litani River (Lebanon), Martil River (Morocco), Melian River (Tunisia), Wadi Zeimar/Alexander River (two branches of the same river, flowing in Palestine and Israel, respectively) and Zarqa River (Jordan). The aforementioned basins offer an heterogeneous selection of typical Mediterranean Watersheds ranging from minor (e.g., Dhiarzos River basin, characterized by a size of 260 km^2 and a population of 3,550 inhabitants) to major Basins (e.g., Gediz River with a size of 17,600 km^2 and nearly 2 millions residents).

The distribution of the responses on the 7-point ordinal scale, as well as on two classes of 'missing values' (one refers to the selection of the 'don't know' option, the other sums up those cases where no answer was assigned, for any other reason, to the Item), for all 64 variables contained in the Questionnaire, is shown in Figure 5.

One can notice that the respondents tend prevalently to select the 'important', 'very important' and 'extremely important' scores of the ordinal scale. Fewer people answered on the 'unimportant' branch of the scale.

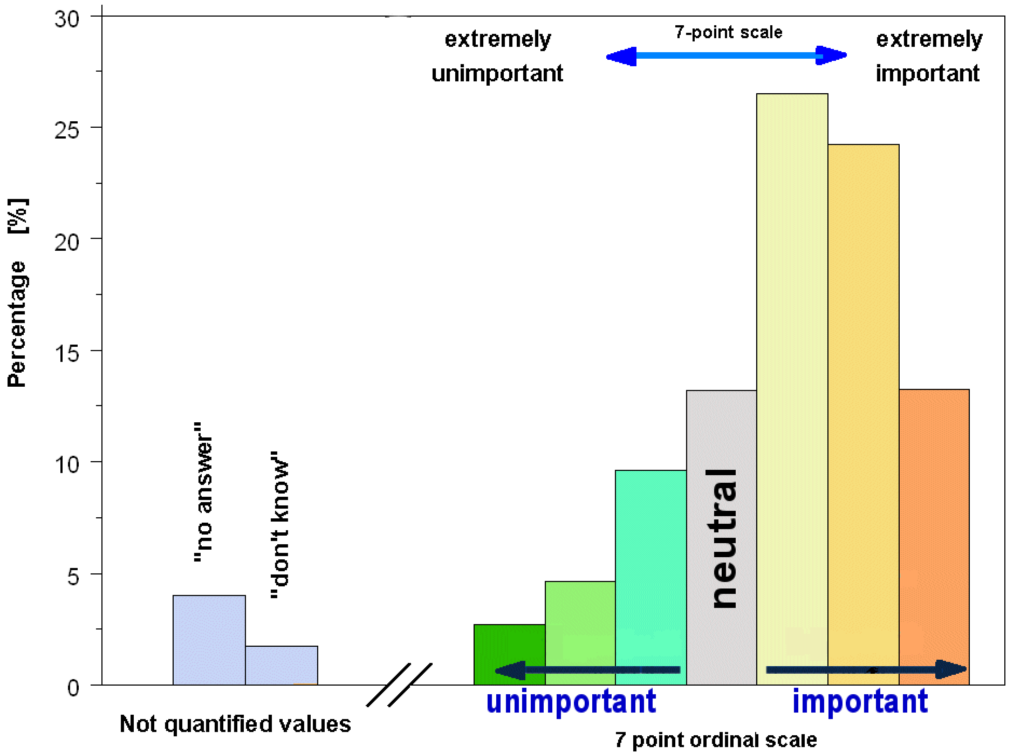


Figure 5: Percentage distribution of the responses to the 75 compiled questionnaires for the 7 OPTIMA case studies

4.2 Technical Issues

Before applying factor analysis, two technical problems should still be solved: how 'missing values' and how ordinal variables should be treated. It is a rather normal praxis to have to approach this kind of problems when analyzing survey data. The procedure, implemented in this report, is described in details in the OPTIMA deliverable D02, related to the statistical analysis /14/.

For 'missing values', an 'imputation procedure' was chosen (due to the relatively small percentage of 'missing values', see Figure 5, the results of interest appear to be sufficiently 'robust' with respect to alternative treatments of 'missing values').

The necessity of a treatment of ordinal variables derives from the fact that the use of a 7-point ordinal scale offers only a limited measure of the relevancy of a specific Item (i.e., a rank ordering of observations rather than precise measurements), contrary to continuous interval or ratio measurement scales. E.g., it cannot be said that a 'Very Important' Issue is twice as important as an 'Important' one or that the difference between 'Extremely Important' and 'Very Important' is comparable to the difference between 'Neutral' and 'Unimportant'. Nevertheless a straightforward and often implemented approach consists in converting the ordinal scale into integer scores (e.g., 1,2,3,…), treating the ordinal variables as if they had metric properties. It has been empirically observed that, especially when the number of categories is large, the failure to address the ordinality of the data is likely negligible (e.g., many multivariate techniques give reliable results even when the ordinal scale is treated as an integer scale /10/). Indeed, Bentler & Chou have argued that, given normally distributed ordinal variables, «*continuous methods can be used with little worry when a variable has four or more categories*» (/15/, p. 88).

In analyzing the data, two alternative approaches have been implemented: the first one using the straightforward replacement of ordinal categories with integer numbers (e.g., from 1 to 7) and applying traditional statistical methods as if the variables were continuous, the second one aimed at a more consistent treatment of the lack of precise measurements (as a consequence of the ordinality of the variables). This kind of analysis is described in details by Jöreskog (e.g., /16/) and makes use of the so-called *polychoric* correlation matrix and MINRES (MINimum RESiduals, based on unweighted least squares) factoring method. Details about its implementation in the present study are reported in the OPTIMA deliverable D02 /14/.

It is however important to underline that, results obtained through MINRES factoring of the *polychoric* correlation matrix are found to be, at least for our aims, substantially ‘equivalent’ to the ‘much straightforward’ standard solution obtained by simply substituting the ordinal variable by an integer scale and treating it as a continuous variable, though its lack of consistency from a formal point of view /14/.

4.3 Multivariate Statistical Analysis

The analyzed dataset consists of 75 cases (respondents) on 57 Items. Out of the original 64 Items of the Questionnaires, one (related to shipping and considered ‘ambiguous’, as most of the rivers were not navigable) was eliminated and the 6 related to the ‘Physical Characteristics’ were kept apart, for ‘post analysis’.

In Figure 6, the results of a Principal Components Analysis of the covariance matrix, are reported.

Many criteria have been suggested to decide how many principal components to retain (and select the number of factors to be extracted, in case of Factor Analysis), see, e.g. /11/. In our framework of investigation of a complex system, the ‘correct’ number of components reflects the latent dimensionality of the system and is therefore a basic information. The main three criteria for selecting the number of components are:

- Cattell’s scree test criterion – the plot of the eigenvalues against their rank often provides a convenient visual method of separating the important components from the less-important components (looking for a natural break between the ‘large’ eigenvalues and the ‘small’ eigenvalues). It should be noted that, even in case of Factor Analysis, the scree test must be performed on principal components /11/;
- Kaiser’s criterion – exclude those principal components with eigenvalues below the average;
- in case of Factor Analysis use of a significance test in the framework of ‘maximum likehood’ factor analysis (this approach, however, is only applicable to sufficiently large samples).

The scree plot, shown in Figure 6, supports a solution with 4-5 components. Alternatively, a secondary break could be identified after the 10th component, a result compatible with the Kaiser criterion (that indicates 10-14 components). The analyzed data set is too small to allow the use of techniques based on significance tests.

We will use this result to guide the choice of the number of factors to be extracted (by factor analysis). After having tried different solutions (in terms of applied rotation and number of extracted factors) and having checked their robustness and interpretability, two solutions have been selected. The first one is related to the extraction of only ‘essential’ factors (4 factors), the second one will push the number of factors towards a higher number (11 factors).

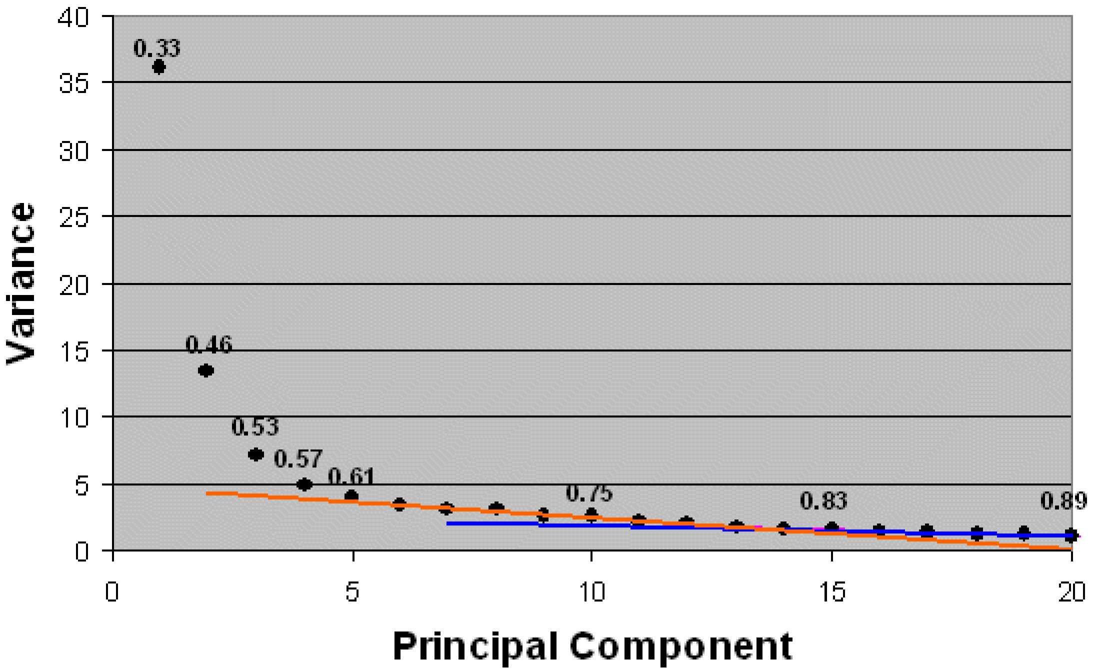


Figure 6: Scree plot of the Principal Component Analysis. The labels on top of representative points corresponds to the cumulative proportion of the explained variance

The extraction of a too small number of factors (*underfactoring*) would tend to ‘telescope’ factors together, and to produce second-order factors (i.e., in case of an oblique rotation, the extracted factors tend to show relatively high correlations, that could be themselves factor analyzed, finding a second-order structure). On the other side, in particular with reference to the present Questionnaire, we expect that the extraction of too many factors would *overfactoring*, allowing a subset of ‘bloated specific’ factors to emerge /11/.

4.3.1 Factor Analysis

By trying different numbers of factors, different extraction and rotation algorithms, we came to the conclusion that the first few factors are sufficiently ‘robust’ and reproducible independently of the implemented procedure (including the technique used to impute ‘missing values’).

The principal factor method of factor analysis is ‘identical’ to that of principal components except that instead of unity in the diagonals (in case of analysis of the regression matrix) some other estimate of *communality* is inserted. This means that while the principal component method explains all variance in a matrix, the principal factor method does not. This, at least from a theoretical point of view, is an advantage, because it is unlikely that factors could explain all the variance in any given matrix, and, since all correlations contain errors, the full account of principal components must be contaminated by error.

The solution obtained by extracting four (*varimax* rotated) orthogonal factors by principal factor estimate, explains about 50% of the variation in the 57 variables of the original data. Even with the seven-point scale, the variability of the scores assigned to the Questionnaire Items is limited, consequently Pearson correlations are far from ideal coefficients (a non-parametric analogous, such as the rank-based Spearman ρ, could be a better choice). Generally speaking, factors derived from Item correlations, partly as a consequence of this problem of the correlation coefficients, tend to account for relatively small proportions of the variance in the matrix /11/.

The solution obtained by treating the ordinal variables as continuous one and the more consistent (and complex) treatment of ordinal variables (estimation of the *polychoric* correlation and MINRES factoring method) bring to practically identical results /14/. Indeed, this tends to confirm the statement of Bentler & Chou reported in Section 4.1.

The 'meaning' of these factors can be interpreted on the base of the factor loadings, eventually with the auxiliary help of the correlation with other possibly available 'markers' (i.e., measurements that have not been used in the process of extracting the factor themselves, as, e.g., the 'Physical Characteristics' that have also been included in the Questionnaire). The factor loadings are correlations of the original variables with the factors. It is usual to regard factor loadings as high if they are greater than 0.6 (the positive or negative sign is irrelevant) and moderately high if they are above 0.3 /11/. A factor loading of 0.3 indicates that 9% of the variance of the variable is accounted by the factor. It is common practice to take it as large enough to indicate the loading is salient. Other loadings (with absolute value smaller than 0.3) are generally ignored.

However, in reality, the usefulness of a loading (or a correlation) is determined by its statistical significance (i.e., the probability that it could not have arisen just 'by chance'). This depends, e.g., on the number of variables in the analysis and the number of extracted (and *varimax* rotated) factors. We have therefore tried an estimation of the probability that loadings could arise 'by chance' through an 'ad hoc' simulation. A 'random sampling' from the original survey data was used in order to generate a battery of 'artificial survey matrices' (75 rows – 57 columns). These random matrices were then submitted to factor analysis (4 *varimax* rotated factors). It was found that, in these 'random surveys', the probability of obtaining, by chance, factor loadings higher (in absolute value) than 0.3 was about 13%, higher than 0.5 was 1.6% and only in 0.3% of the cases factor loadings higher than 0.8 would arise 'casually'. Taking into account that in our analysis of the Survey data 228 factor loadings were extracted (57 variables x 4 factors) from the results of the simulations one could roughly expect about 30, 4 and 1 of them to be greater than, respectively, 0.3, 0.5, 0.8, just 'by chance'. In the original Survey data, these numbers were significantly higher, respectively: 60, 43 and 7, suggesting that, while factor loadings around 0.3 should still be taken with some care (i.e., they could have just found origin 'by chance'), loadings higher than 0.4-0.5 are highly probably significant and could therefore be interpreted. However, correlations between items (especially if evaluated from ordinal variables) remain rather unreliable. The only way to overcome this uncertainty would be to use larger samples.

On the basis of factor loadings, the following interpretation of the four factor solution is proposed. One has to notice that being orthogonal (*varimax* rotated), the four factors are uncorrelated (i.e., 'independent'):

1st factor	**'Pressure' and 'impact' on water demand and quality, mainly related to non-agricultural 'driving forces'** (tourism, household, industry). Agriculture, the main source of stress in Mediterranean countries, loads only partially on this factor. Agriculture seems possibly to be perceived as an 'unavoidable background' present in every basin and tends therefore to emerge only in connection with other more 'agriculture specific' Issues, as those included in the 2nd and 4th factors. The increasing demand for water resources, forecasted to be driven by the intensification of human activities (growths of 'driving forces', agriculture and water import included), loads on this factor - showing a trend towards further increasing pressures. Further contributions to the pressure on water quantity and quality (both surface and groundwater) come from an unsatisfactory infrastructure (mainly in relation to the

	distribution network, sewer system, irrigation efficiency and deficiencies in the use of alternative water resources). The critical ‘status’ of the basin is also reflected by the loading of ‘impact of the infrastructures on biodiversity and loss of habitat’, on the factor. Criticalities in the regulatory and institutional framework tend not to be put in direct relation with this factor. Relatively high loadings are found only for ‘social Issues’, as ‘deficiencies in access to information’ and one of the two ‘gender issues’; on the contrary, institutional responsibilities and lack of participation appears as anti-correlated to the 1st factor.
2nd factor	**Deficiencies in the regulatory and institutional ‘response’** (DPSIR Framework), **mainly in relation with Agriculture** This is the first factor where the impact of agriculture on water quantity and water quality loads directly (the other is the 4th). However, what the factor seems to suggest is, more than the impact of agriculture itself (that appears to be considered as ‘unavoidable’, see discussion for the first factor), an unsatisfying Institutional ‘response’ to the criticalities. This is reflected by overlap, conflict and fragmentation of competences between institutions; lack of participation; problems with private sector participation in the provision of water and sanitation; deficiencies in the management and enforcement of water quality standards and water rights. Such ‘unsatisfactory’ circumstances seem to be related to a situation of conflict (arising from the limitation of surface and groundwater supply, also dictated by the too poor quality of the available resources that limits further their use). Deficiencies in tariff structure also load on this factors (although the 4th factor seems to better isolate ‘unfair’ water pricing policy), as well as deficiencies in the infrastructure (abstraction, distribution network, sanitation and sewer system).
3rd factor	**Techno-economical barriers and (industrial) impact on water quality** (limiting its further use due to ‘too low’ quality) Although the loadings of the two explicit quality indicators (surface water and groundwater) are not very significant, this factor seems to reflect the limits to the water use dictated by too low quality (in particularly connected with the presence of industrial activities), obsolete technologies, maintenance and techno-economical barriers. Also one of the two ‘gender Issues’ as well as ‘lack of education/awareness programmes and campaigns’ happen to load on this factor.
4th factor	**‘Subventioned’ water price (agriculture and household)** This factor extracts the ‘too low’ water price, with respect to the implementation of a ‘full cost recovery’ (and, consistently, is anti-correlated with the Issue ‘too high water price with respect to basic social needs or economic competitiveness of agricultural and industrial firms’). Among the ‘driving forces’ (household, tourism, agriculture and industry), household and agriculture are found, as could be expected, to be correlated with the main deviations from the ‘full cost recovery’. Among the four extracted factors, the 4th is the one where technological and infrastructural limits tend to play the minor role.

The analysis of the scree plot in Figure 6 suggests the possibility of an extended solution related to a higher number of factors (i.e., an increase in the number of dimensions of the underlying ‘latent structure'). This possibility has been investigated, also with the aim of testing the stability of the previously presented and interpreted 4-factor solution and of analyzing how the factors tend to split when multidimensional structures of higher order are allowed for.

The *varimax* rotated solution, when 11 factors are extracted, is reported in the OPTIMA deliverable D02 /14/. The 1st extracted factor is practically 'identical' to that of the 4-factor solution. This confirms the robustness of the relationship inherent to the available data, even when the number of extracted factors is let to increase. The same can be said, though to a lesser degree, for the 2nd and 3rd factors of the 4-factor solution that 're-emerge' in the 11-factor solution as, respectively, the 3rd and 2nd factors. On the other side, the 4th factor can only be partly identified with the 7th factor in the 11-factor solution /14/.

The other novel factors, in the 11th factor solutions, tend mainly to highlight:

- subclasses of correlated issues that could have a 'physical meaning' (e.g., the 4th factor that isolates insufficient infrastructures and obsolete technology - particularly critical in basins with conflicts for the limited available water resources);
- 'clusters' of Issues whose high correlations are probably due to the fact that they are perceived, by most respondents, as re-formulation of the same concept (e.g., 6th factor that mainly collects all issues related to household water quality) - such kind of 'clusters' are known as '*bloated-specific*' factors /11/;
- issues that presumably happen to be correlated just 'by chance' (i.e., due to the relatively small sample of available data - even a set of random numbers would generate some 'high' correlations). No 'physical meaning' can be associated to them (e.g., 11th factor that highlights a connection between uncontrolled solid waste disposal, flood control and dependency on water imports) /14/. They are therefore not expected to be reproduced by larger samples or by other, independently collected, datasets.

It is interesting that even increasing the number of extracted factors (i.e., from 4 to 11), the main factor still condenses the contributions from all the 3 'non agricultural' driving forces (i.e., household, tourism and industry appear together). Only allowing more freedom in selecting the position of factors in factor space, by means of an oblique rotation (i.e., releasing the constraint of orthogonality), it is possible to find solutions where the driving forces tend to load on different (but in this case correlated) factors.

4.3.2 Multidimensional Scaling

The analysis of the Questionnaire through multidimensional scaling (MDS), in spite of its elasticity and flexibility in the definition of distances, does not bring to 'simpler' alternative interpretations. On the opposite, it tends to further support the factor analysis solution emerged in the previous Section, as the number and interpretation of the extracted dimensions is similar to that already presented in Section 4.3.1 /14/.

The flexibility of MDS can however be used to represents the 'relative positioning' of the seven analyzed Case Studies. There are two basic approaches to defining these inter-group proximities. Firstly, the proximity between two groups might be defined by a suitable summary of the proximities between respondents from either group. Secondly, each group might be 'condensed' into a single 'representative observation' (e.g., the group mean value) and the inter-group proximity defined as the proximity between these 'representative observations' /21/.

This second approach has been implemented. One obvious method for constructing inter-group dissimilarity measures would be to treat the variables as continuous and evaluate the average values scored, on each single Issue, by each single group. Euclidean distance could then be evaluated from these mean values. More appropriate, however, might be a measure that incorporates, in one way or another, knowledge of within-group variation. One possibility is to use *Mahalanobis distance*, based on the *pooled* within-group covariance matrix /21/. When correlations between variables within groups are slight, the *Mahalanobis distance* will be similar to the Euclidean distance calculated on variables standardized through a division by their within-group standard deviation. Thus, the *Mahalanobis distance* increases with increasing distance between the group centres and with decreasing within-group variation. By also employing within-group correlations the *Mahalanobis distance* takes account of the (possibly non-spherical) shape of the groups (see, e.g., Figure 9, in Section 4.4). The use of the *Mahalanobis distance* implies that willingness to assume that the covariance matrices are at least approximately the same in the groups under investigation (several alternatives have also been proposed for cases in which this assumption is inappropriate /21/).

To compare the different case studies, the previous approach has been implemented by first estimating the average values and the pooled within-group covariance matrix[1] and successively the *Mahalanobis distances* between each pair of Case Studies. Classical multidimensional scaling was then applied to the obtained matrix of *Mahalanobis distances*. The analysis of the '*scree plot*' suggests a mainly one-dimensional solution (i.e., along the x-axis of the 2-D plot reported in Figure 7).

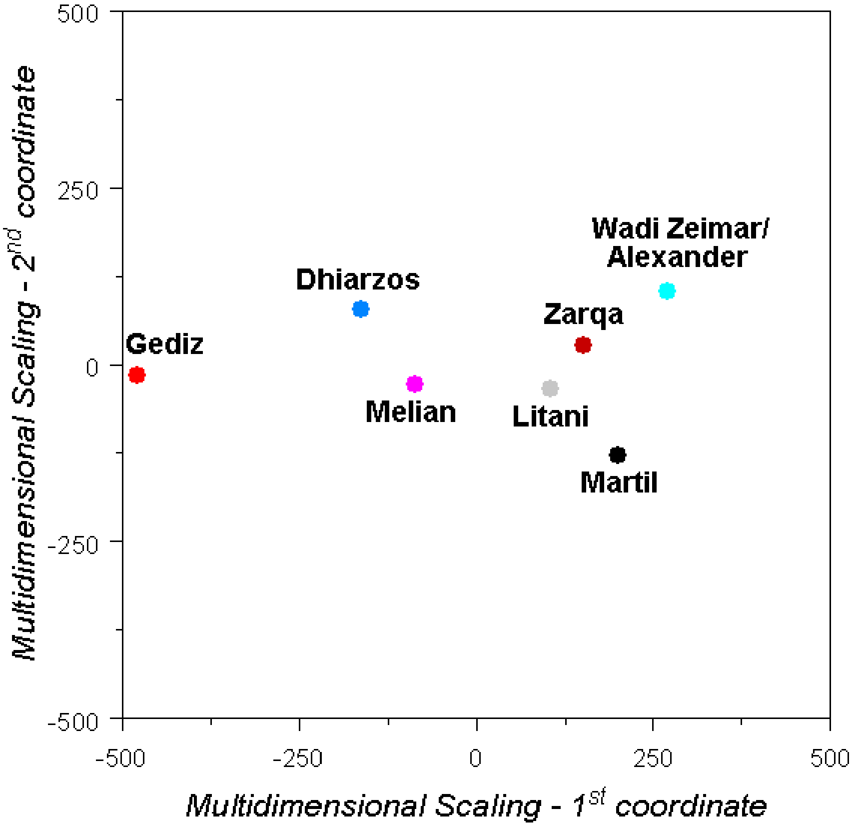


Figure 7: positioning of the seven analyzed Case Studies, obtained through a multidimensional scaling of the matrix of Mahalanobis distances.

Figure 7, highlights the 'proximity' among the different Case Studies, after that each case Study has been 'condensed' into a single 'representative observation'. Complementary and more detailed analyses can be undertaken starting from the raw measurements associated to the single respondents

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[1] The *pooled* within-group covariance matrix is evaluated as $\mathbf{S}_{pl} = \Sigma\,[(n_i-1)\cdot \mathbf{S}_i] / \Sigma(n_i-1)$, where the sums extend over the groups, and n_i and S_i represent, respectively, the number of respondents and the correlation matrix associated with the ith group.

and using different hierarchical aggregations (e.g., on the base of the ‘Case Study’ or ‘Stakeholder Class’). This kind of analysis will be presented in the next Section, using the 4-factor solution as frame of reference. The analysis emphasizes how an extremely complex environmental system, as that related to sustainable water management, is essentially perceived through a ‘conceptual map’ based on a limited number of synthetic aggregated variables.

4.4 Multigroup Analysis

In the procedure for extracting the factors, no use is done of the fact that the available compiled Questionnaires refer to seven different (and independent) Case Studies. The set of compiled Questionnaires is treated as a single (even though heterogeneous, see Section 5.2) input dataset, with no indications of which questionnaires belong to each one of the seven Case Studies. It is therefore interesting to analyze ‘post hoc’ if the different Case Studies tend to present, with respect to the extracted Factors, significantly different behaviours.

This is also of primary importance with respect to the objective of using the ‘conceptual map’ extracted by factor analysis to support the construction of consistent aggregated indicators. It is, as a matter of facts, crucial that a ‘good indicator’ should have the power to discriminate between different entities.

The result of such a kind of analysis, in relation to the 1st factor, is represented graphically in Figure 8.

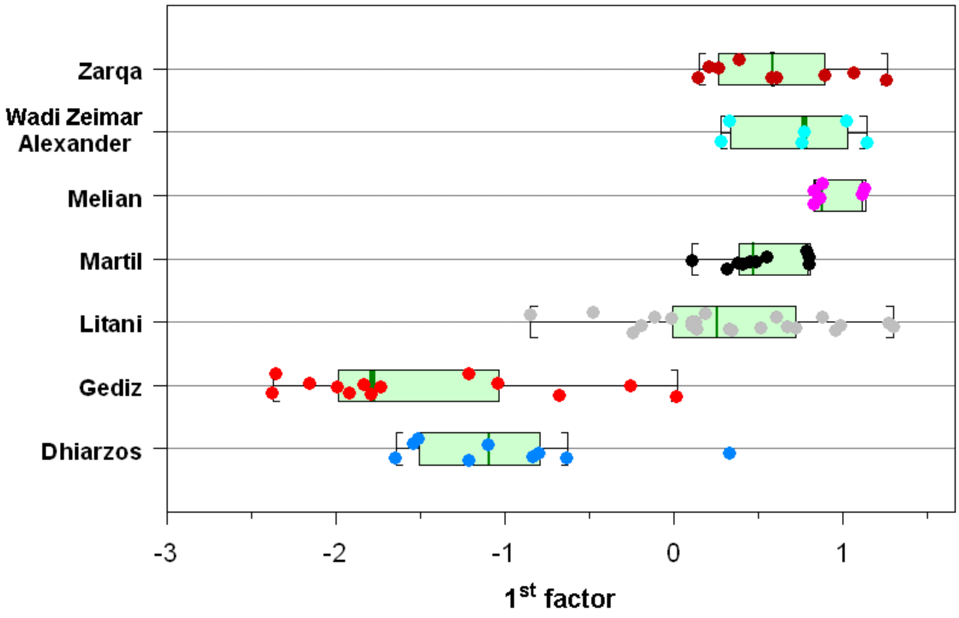

Figure 8: Factor scoring on the 1st factor (of the 4 factor solution), with the several respondents aggregated by Case Study. In the plot, the points are randomly ‘jittered’ on the y-axis in order to obtain a clearer visualization.

The 1st factor, shown in Figure 8, offers a rather clear discrimination among the different Case Studies. The Gediz (Turkey) and the Dhiarzos (Cyprus) basins tend to show systematically lower scorings. On the opposite, the most critical situation appears to be related with the Melian (Tunisia), the Wadi Zeimar/Alexander (Palestine/Israel) and the Zarqa (Jordan) rivers. One has to remember that this factor has been interpreted as mainly reflecting the Pressure (prevalently related to non-agricultural ‘driving forces’) on water quantity and quality (see Section 4.3.1).

The scorings on the first two factors are graphically shown in Figure 9. To highlight the distributional properties of the data (as well as the possible presence of 'outliers'), the scatterplot is enhanced by representing the *bivariate boxplots* (i.e., the 'two dimensional analogue' of the familiar boxplots for univariate data, see, e.g., /17/) associated to each Case Study. The *bivariate boxplots*, based on the calculation of 'robust' measures, consist essentially of a pair of tilted concentric ellipses, one of which (full line) includes 50% of the data and the other (dotted line) which should delineate potential troublesome outliers.

It is evident from Figure 9 that, even if only the 'global dataset' of compiled Questionnaires has been given as input to factor analysis (i.e., without specifying to which Case Study a single Questionnaire belongs), the results on the first two factors can discriminate relatively well among most of the Case Studies under investigation. The 'between-Case Study' variation tends generally to overcome the 'within-Case Study' variation (related to the discrepancy in the point of view of different respondents) reflecting therefore some 'specific characters' of the different Case Studies.

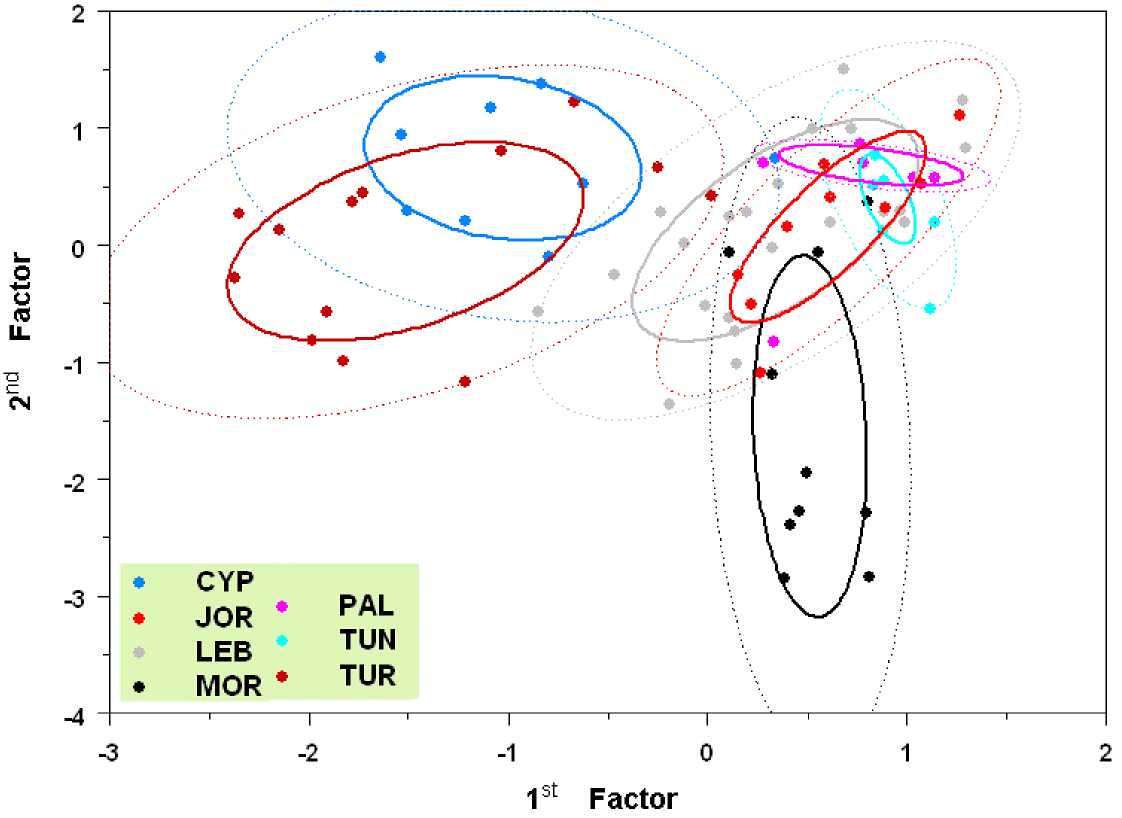

Figure 9: representation of the scores on the first two factors

Not surprisingly, the results of factor analysis (Figure 9) tend to resemble those obtained by the application of multidimensional scaling (Figure 7), only the positioning associated to the Melian river is unexpected. One has however to notice that for the Melian (and the Wadi Zeimar/Alexander) only six compiled Questionnaires were available at the time of writing. One can therefore expect, for these Case Studies, the results not to be 'particularly robust', especially if based on evaluations of distributional properties as means and standard deviations.

A last analysis of the 4-factor solution was dedicated to investigate whether distinct classes of respondents (Stakeholders) tended to score the extracted factors in a significantly different way. In order to *demean* the data from the systematic differences observed in the different Case Studies, the analysis was not done on the original scorings but on their deviations from the average value observed in the corresponding Case Study.

Four different aggregations of the Stakeholders (by 'scope', by 'size', by 'category' and by 'type' – see Ref. /14/, for definitions) were analyzed, in order to test if the (demeaned) average scorings assigned by different classes of Stakeholders to each of the four factors differed in a significant way. The analysis was done by means of the method of analysis of variance (ANOVA) and of its alternative non-parametric equivalent: Kruskal-Wallis rank sum test.

The two methods agreed in selecting as '*highly significantly*' different (p-value < 0.01) the scoring on the 1st factor, when the responses were aggregated by 'category', by 'type' and by 'scope'. A further '*highly significantly*' difference was found for the 4th factor, aggregating the Stakeholders by 'scope'. No significantly different scorings (even at the p-value < 0.05 level) were instead observed for the 2nd and 3rd factors (for the 4 types of aggregation being tested).

- As an example, the results on the 1st factor for the aggregation by 'scope' are shown in Figure 10. Multiple comparisons identify the following pairwise combinations as significant sources of the discrepancies: 'local' vs. 'national' and 'local' vs. 'international' ('local' tends to assign lower scorings). The 1st factor ('pressure and impact on water demand and quality - mainly related to non-agricultural driving forces') seems to be perceived as 'less critical' by locally based Stakeholders than by national/international ones.

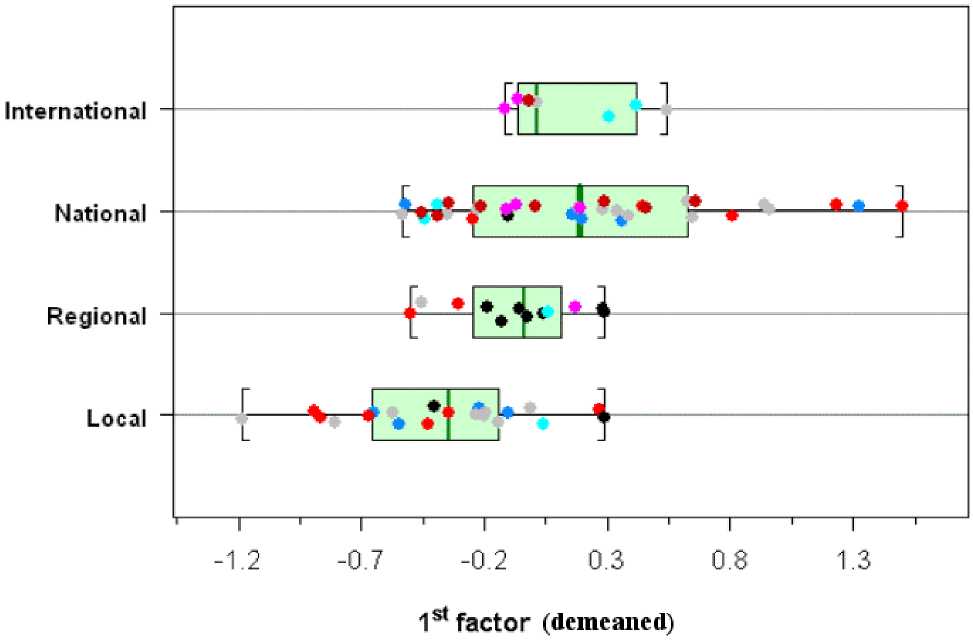

Figure 10: same as Figure 8 but discriminating for 'Scope of Stakeholder' instead that for 'Case Study'. Local Stakeholders tend, on average, to assign lower scoring to the 1st factor (i.e., to perceive it as 'less critical').

5 CRITICAL DISCUSSION

There is an extreme wealth of rapidly evolving and developing literature in the area of sustainable indicators. However, most authors mainly tend to refer just to those they wish to agree with and to ignore the rest (well…, we must admit that this was basically the approach used in Section 2!). In this Chapter we try to incorporate some self-reflections and balance the pros and cons, by letting few crucial and in our opinion still unsolved topics to emerge and by critically discussing the contributions, the methodology proposed in this report, could actually give.

5.1 Qualitative vs. Quantitative Indicators

As mentioned in Chapter 2.1, indicators represent an empirical model of reality, implicitly assuming that complex systems could indeed be reduced to a set of numbers (but, for instance, without being able to know how many indicators are needed to 'adequately represent reality'). It should always be kept in mind, as a constant warning for the possibility of misinterpreting indicators, that the applicability of an indicator set strongly relies on this (unproved) basic assumption. As noticed in /18/, «*essentially all science is the study of either very small bits of reality or simplified surrogates for complex whole systems. How we simplify can be critical. Careless simplification leads to misleading simplistic conclusions*». The indicators may not be linked to a full understanding of the Issues that influence a particular variable, providing only partial and in some ways ineffective information.

There is a wide spectrum of complexity in the quantification of indicators: this goes from the 'easy to define and easy to quantify' to the more complex ones ('difficult to define and difficult to quantify' and/or 'qualitative issue in search of some kind of measurable effect') /2/. It has been noticed that this wide spectrum of complexity can bring to a distortion of priorities, directing efforts towards the easily measurable, and away from the other (perhaps equally or even more important) difficult to quantify or even unquantifiable issues. Sustainability indicators are meant to offer society a way to counteract scientific, political and social uncertainty by providing what appear to be cold and rational calculations that are not affected by political and social bias. However, the reality of indicators is that they too are created and measured inside a society and a system and that these contextual factors often colours the way in which indicators are used.

Following OECD definition, see Section 2.1, an indicator is a parameter or a value derived from parameters. As such it is normally a quantitative measure. This may seem too obvious to mention – and yet there are many examples of documents purporting to propose or recommend indicators but which instead cite issues (e.g., 'quality of life') without specifying variables, which may be used to quantify them. The approach presented in this report could, at a first sight, look to share such limits. As a matter of facts, the dimensions extracted by the factor analysis of the questionnaire are weighted sums of Issues, not weighted sums of quantitatively measurable parameters and therefore no recipe is explicitly given on how these aggregated indicators could be quantified.

Our claim is that the procedure, at least in principle, allows a 'self-consistent' disaggregation of primary composite indices in terms of 'elementary indicators'. E.g., if the meaning of 'quality of life' is associated, a posteriori, to one of the extracted factors, the procedure brings automatically to a definition, in terms of elementary Issues, of the more abstract, but nevertheless basic concept of 'quality of life'. The fact that an intangible composite Quality (as, e.g., 'quality of life') appears decomposed in a weighted sum of elementary Issues is certainly a major step towards any quantitative definition of such an 'abstract entity'.

5.2 Issues related to sampling

In the procedure presented in Chapter 3, the factors emerging from factor analysis are obviously affected by the samples (i.e., measurements) from whom they are extracted. As described in /11/, there two basic approaches, which leads to different formulation in practice.

One line of reasoning indicates that the samples should be homogeneous. For instance, if we analyze basins with scarce industrial development, it is likely that an Issue related to 'pollution by industrial discharges' would not appear correlated with the quality of 'surface water' to any great extent. This is because this sample is homogeneous for 'scarce industrial development'. However, if we were to carry out a similar study using the whole range of industrial development, industrial discharges would possibly load highly on a 'water pollution factor'. From this point of view, it might be concluded that heterogeneous samples should always be used. Homogeneous samples, by definition, lower variance and thus lower factor loadings. In exploratory factor analysis, therefore, generally it seems a better strategy to use heterogeneous samples, in order to increase the variance.

There is however a danger when using heterogeneous samples. As a matter of facts, it can be argued that scores from different groups should not be added together. For example, if we studied two basins one with extreme and the other with no industrial development, to add them together and factor their scores would appear 'nonsensical' since the 'average industrial development' reflected by the factors would not reflect any member of the group. From this, a conclusion opposite to the previous one might be concluded, i.e., that only homogeneous groups should be factored. This is however a consequence of the fact that an unrepresentative sample has been used.

Samples must not only be representative but must be of sufficient size to produce reliable factors. In data with a clear factor structure, samples of around hundred members are considered to be of sufficient size to produce reliable factors (if factor analysis is carried out with smaller samples than the results should need replication with other samples) /11/. The general rule is obviously '*the more subjects the better*'. However, a main role is played by the variable to subject ratio. There have been various claims made concerning the ratio of subjects to variables running from as large as 10:1 as the necessary minimum, down to 2:1 (again the rule is 'the bigger the ratio the better'). On the other side, it has also been claimed that the variable to subject ratio could be less important than the ratio of subject to factors (this last should be more than 20:1) /12/.

Even in cases where factors provide a satisfactory fit to the data, one should still be tentative in interpretation until the existence of the factors can be independently established. If the same factors emerge in repeated sampling from the same (or a similar) population, then one can have confidence that application of the model has uncovered some real underlying structure. Thus, it is good practice to repeat the experiment to check the stability of the factors. If the data set is large enough, it could be split in half and a factor analysis performed on each half (cross-validation). The two solutions could be compared with each other and with the solution for the complete set, in order to check if they could just be an artefact of the present sample and would not reappear in another sample from the same population.

Only the analysis of a heterogeneous sample of sufficient size can bring to the discovery of 'universal' factors, which could, at least in principle, be interpreted and translated in quantitative aggregated indices.

5.3 Recursive procedures

Recursive procedures can be implemented in order to optimize the Issues Questionnaire at the base of the proposed methodology. Generally speaking, variance is made up of three components: common factor variance, specific factor variance and error variance /11/. The last two are referred to as unique variance. Ideally the common factor variance of any variable should be as large as possible and unitary (accounted for by one factor alone). It follows from this factor analytic model of test variance that factor analysis is the ideal method for test construction. Thus by administering items and subjecting their intecorrelations to factor analysis it is possible to select items which load on only one factor. This ensures that the test is unifactorial.

Alternatively, the following steps can be implemented in order to design a reliable scale /19/:

- Step 1: Generating items. This is the usual creative process where the researcher makes up as many items as possible that seem to relate to the system to be investigated.
- Step 2: Choosing items of 'optimum difficulty'. In the first draft of the questionnaire, are included 'as many items as possible'. The questionnaire is then administered to an initial sample of typical respondents, and the results examined for each item. First, one would look at various characteristics of the items, for example, in order to identify 'floor' or 'ceiling' effects. If all respondents agree or disagree with an item, then it obviously does not help us to discriminate between respondents, and thus, it is useless for the design of a reliable scale. In test construction, the proportion of respondents who agree or disagree with an item, or who answer a test item correctly, is often referred to as the item difficulty. In essence, we would look at the item means and standard deviations and eliminate those items that show extreme means, and zero or nearly zero variances.
- Step 3: Choosing internally consistent items. A reliable scale is made up of items that proportionately measure mostly true score. To do so, we would make a '*reliability analysis*'. The quantities of most interest are, e.g.: the correlation between the respective item and the total sum score (without the respective item), the squared multiple correlation between the respective item and all others, and the internal consistency of the scale (Cronbach's Alpha coefficient) if the respective item would be deleted. Clearly, few items can 'stick out', in that they are not consistent with the rest of the scale. These items will be eliminated in Step 4.
- Step 4: Returning to Step 1. After deleting all items that are not consistent with the scale, we may not be left with enough items to make up an overall reliable scale (remember that, the fewer items, the less reliable the scale). In practice, one often goes through several rounds of generating items and eliminating items, until one arrives at a final set that makes up a reliable scale.

A reliable scale, designed following the 4 previous steps, will tend to load on a common factor. The higher the loading the better the test. However, if we write items which are (or are perceived as) essentially paraphrases of each other they will correlate highly and end up loading on a common factor but would not bring a proportional added value. Redundancies of this kind generate 'bloated specific' factors, a term used by Cattell (e.g., /20/). 'Bloated specific' factors look like 'normal' factors but are really only specific variance. They can only be discriminated from common factors by the fact that they correlate with no other factors or external criteria /11/.

For example, in the Water Issues Questionnaire several 'too strongly' correlated Items were identified. This is probably due to the fact that the respondents failed to discriminate between the 'subtle differences' implicit in the Item formulations and tended therefore to perceive the Items as 'paraphrases of the same general Issue'. For example, all Issues related to 'Tourism' appear extremely correlated (see Figure 11). Due to the variety of questions (covering water quantity, quality, technology and future projections, all referred to Tourism), it is considered 'highly improbable' for such high correlations to be 'real' (this is, of course, a subjective opinion!). What is supposed to have happened is that the respondents, due to the relatively limited knowledge of the 'details' of the impact of Tourism (a secondary driving force), tended to give very similar ratings to all Tourism related Items (i.e., unimportant if tourism itself is considered un unimportant driving force, important if tourism is considered to be important). Furthermore, in the Questionnaire, all Tourism related Items were presented in a row (i.e., one after the other), facilitating a compilation using identical, or only slightly different, scoring. One has also to notice that the same effect doesn't happen, e.g., in case of Agriculture, where the impacts are clearer and the respondents seem now able to discriminate among the different Agricultural related Issues (see Figure 12). A similar effect is also observed for all the couples of Items where the same Question was proposed twice, the first time referring to surface water the second to groundwater (this can be observed even in Figure 11, where the demand of surface water and groundwater, as well as the pollution of surface water and groundwater, appear to be extremely correlated). All this surface water/groundwater doublets are 'anomalously' correlated, suggesting the difficulty, for most respondents, to discriminate between impact on surface water and groundwater (i.e., the two water compartments tend to be perceived as mainly equivalent).

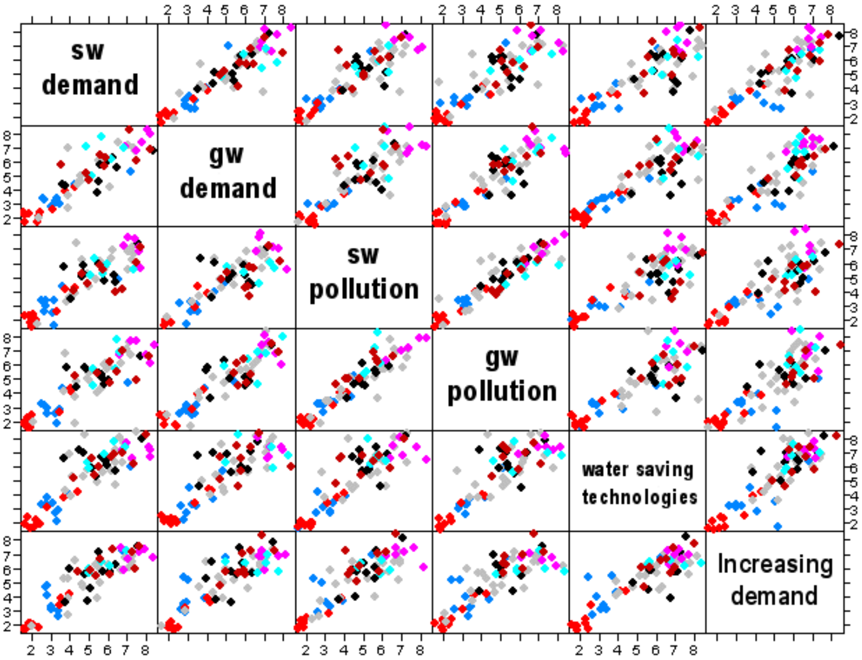

Figure 11: Scatter plot matrix showing the correlations between the ratings of tourism related Items (sw is an abbreviation for surface water, gw for groundwater). The points are 'randomly jittered' in both the x- and y-directions to avoid overlapping, as all Items are rated on the 7-points ordinal scale (here represented as an integer scale from 2 ➔ Extremely unimportant to 8 ➔ Extremely important). Different colours are assigned to the seven different OPTIMA Case Studies.

Under this point of view, one can suppose the present form of the 'Water Issues Questionnaire' to be somewhat 'redundant'. As a matter of facts, some Items tend to be perceived by the 'average respondent' as 'paraphrases of the same questions'. It is this intrinsic redundancy that can give origin to 'bloated specific' factors, with little general value. The effect could be attenuated by eliminating few of the redundant Issues or (as a better choice) by creating 'sum scales' (i.e., forming new variables made up of the sums or averages of the 'clusters' of multiple 'redundant' scores) before the data are submitted to the statistical analysis.

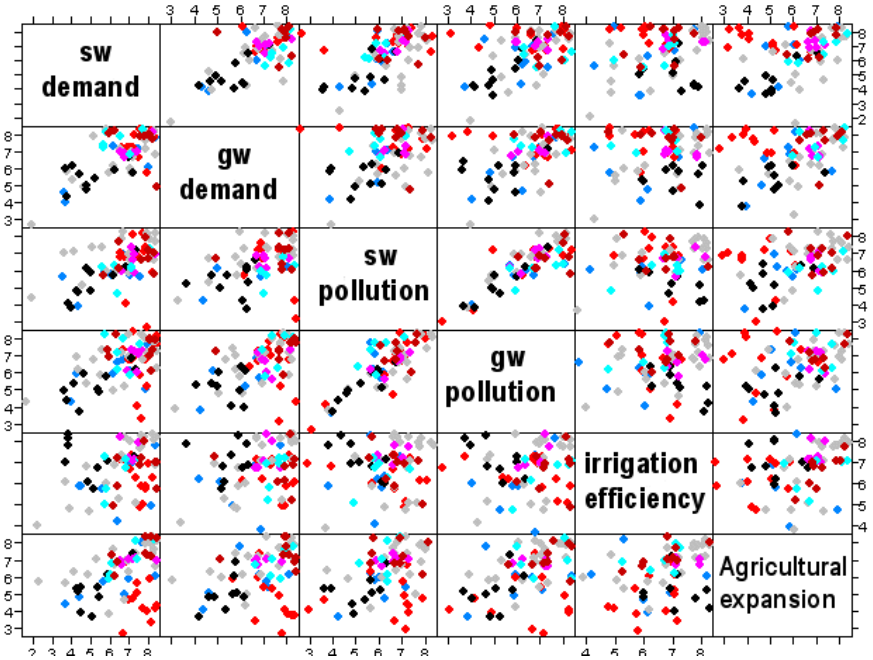

Figure 12: same as Figure 11, but now in relation to Agriculture related Items

CONCLUSIONS

Indicators represent an empirical model of reality, implicitly assuming that complex systems can be adequately represented through limited sets of variables and indeed condensed in multidimensional measurements (i.e., finite numbers of coefficients). As noticed in /18/, «*essentially all science is the study of either very small bits of reality or simplified surrogates for complex whole systems. How we simplify can be critical. Careless simplification leads to misleading simplistic conclusions*».

In the framework of ‘sustainability’, the ‘discovery’ of adequate multidimensional sets of indicators is alternatively based on: *technical knowledge* of experts (the traditional ‘top down’ approach), or *collective perception* of the local communities (the more recent ‘bottom-up’ approach). In the ‘bottom up’ approach, indicators are also seen as a tool to raise awareness, by helping Stakeholders to discover the breadth of sustainable development Issues and the (non necessarily obvious) relationships among them and what they themselves need to do. The main idea is that the more broad-based and participatory the process, the greater are the chances of public buy-in and exposure for the programme /3/. It is awareness that brings the participants one step closer to identifying and taking the necessary actions.

Aiming at the discovery of the *collective perception*, we have presented a procedure, routinely employed in ‘soft’ psychological/social sciences, but barely used in ‘hard’ physical/mathematical sciences (as environmental sciences). The approach assumes that the perception of complex environmental systems is based on a ‘conceptual map’, with a limited number of dimensions. Aim of the procedure is to discover and ‘bring to the surface’ the multidimensional nature of this ‘latent structure’, by means of an ‘ad hoc’ Questionnaire.

The Questionnaire aims to present an ‘exhaustive’, ‘holistic’ list of Issues that are supposed to cover the multifaceted system under investigation and its sustainability. Representative Stakeholders are asked to score the perceived relevance of each Issue and the set of compiled Questionnaires is factor analyzed. Explorative factor analysis is an ideal technique when data are complex and it is uncertain what the most important variables are. In this case, it has the capability of disaggregating the Issues in a set of independent clusters, where Issues included in the same cluster are perceived as strongly correlated (i.e., they should share some ‘common origin’). In geometrical terms, the procedure allows to project the complex system in a multidimensional space (whose dimension is estimated in a consistent way). The extracted factors correspond to an ideal set of orthogonal coordinates in this space. As an end effect, this allows a synthetic representation of how the ‘complex system’ under study tends to be perceived and allows to express ‘what is going on’ in terms of a reduced set of independent dimensions. This coordinate system, revealed by factor analyzing the Questionnaires and previously unknown, satisfies several ‘desiderata’ for the deduction of a proper set of indicators (aggregated indices).

An application of the methodology to Sustainable Management of Water Resources in seven Mediterranean Basins, has, discovered the following four-dimensional orthogonal ‘latent structure’:

1st factor: ‘Pressure’ and ‘impact’ on water demand and quality, mainly related to non-agricultural ‘driving forces’ (tourism, household, industry)

2nd factor: Deficiencies in the regulatory and institutional ‘response’ (DPSIR Framework), mainly in relation with Agriculture

3rd factor: Techno-economical barriers and (industrial) impact on water quality

4th factor: ‘Subventioned’ water price (agriculture and household)

indicating, for each dimension, a set of correlated Issues. However, due to the relatively small sample size of the available data, the generality of the result cannot be ‘guaranteed’ (i.e., it could be, at least partially, ‘data specific’ and not emerge in other ‘equivalent samples’).

The major future steps in the ‘Water Management’ application are therefore:

- a validation of the results on an independent dataset (or a further increase in the number of compiled questionnaires);
- the improvement of the Questionnaire (decreasing ‘redundancies’ through the creation of ‘sum scales’);
- the ‘translation’ of the perceived factors in quantitative composite indices (using the linear combinations defining the factors in terms of basic Issues).

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