Integrated water resource sustainability and vulnerability assessment

Creator	*UNIGE*
Creation date	*1/3/2012*
Date of last revision	*31/3/2012*
Subject	*Integrated Water Resource Management*
Status	*Finalized*
Type	*Word document*
Description	*Describes the methodology adopted by the enviroGRIDS project to assess water resources sustainability and vulnerability in the Black Sea catchment.*
Contributor(s)	*Bär Roger (UNIGE); Lehmann Anthony (UNIGE);*
Rights	*Public*
Identifier	*EnviroGRIDS_D5.3*
Language	*English*
Relation	*EnviroGRIDS_D5.8 Vulnerability and adaptation issues*
Citation	*Baer R and Lehmann A, 2012. Integrated water resource sustainability and vulnerability assessment. EnviroGRIDS_deliverable D5.8, 45p.*

Abstract:

The main objective of this report is to prepare the assessment of water resources sustainability and vulnerability of the Black Sea catchment. It specifically aims at:

- Reviewing existing analytical frameworks (DPSIR, Vulnerability);
- Reviewing existing system of evaluation of water resources (UnWater, GIWA, SOER, WFD, Water footprint,…)
- Proposing a combined indicator system to evaluate water resources sustainability and vulnerability in the Black Sea catchment; and
- Selecting a list of adapted indicators with their reference system and possible data sources.

This report presents an overview on the water resource management and monitoring in Black Sea catchment as well as theoretical aspects of sustainability and vulnerability assessments.

Concerning the vulnerability assessment, emphasis was put on the DPSIR framework and the GIWA Causal-Chain analysis model. It can be concluded that both models seem pertinent in the context of assessments of water resources. However, the DPSIR model seems to be more widely known and used by researcher, decision-makers and international organisations.

This review noted a trend to a more integrated water resources management, thus transgressing national boarders. Important observation systems (e.g. WISE) and river basin based management policies exists in the region (ICPDR), but do not cover the Black Sea catchment completely and in a coordinated manner. Hence, the enviroGRIDS project provides a prime groundwork for sustainability and vulnerability assessments as well as for water management policies in the Black Sea region.

Under the present environmental, political and socio-economical conditions the water resources in the Black Sea catchment can be considered to remain unsustainable in its current state. Analysis in order to more precisely assess the vulnerability of the water resources and to identify key challenges is therefore required.

The Black Sea Commission is collaborating with the Helsinki Commission on the Baltic Sea to develop an implementation plan to set up a modelling tool, linking background pollutants triggering eutrophication in the Black Sea with requirements, set by the Black Sea Commission on reducing input of nutrients, including riverine loads.

The ICPDR developed a Climate Adaptation Strategy for the Danube River catchment. with the University of Munich. The results of the study are currently discussed with the Danube countries. Those include an overview on climate scenarios and expected impacts on the water sector in the Danube catchment. Furthermore, possible climate adaptation measures are currently gathered. The results of those discussions will provide valuable input for the finalisation of the enviroGRIDS study.

The knowledge gained thanks to this literature review has created a useful basis for a vulnerability assessment of water resources in the Black Sea catchment. However, there are still many important knowledge and information gaps that will be filled in the course of the vulnerability assessment process.

Contents

Figures

Annexes

1. Introduction

1.1 Description of WP5

This WP involves the analysis of the impacts of the climate, land use and demographic scenarios on river catchment processes, primarily water quality and quantity. Based on this analysis the impacts of all these changes will be assessed on selected Societal Benefit Areas for the present and the future. The emphasis will be on impacts on ecosystems, biodiversity, agriculture, health and energy sectors.

WP5 methodologies will be grounded in integrated environmental assessment (IEA) and the analysis of impacts in the context of the Driving force-Pressure-State-Impact-Response (DPSIR) framework, as applied in UNEP's GEO-4 report (UNEP 2007) at the global scale and as subsequently translated into sub-global applications. In order to ensure the analysis reflects policy priorities and stakeholder perspectives, participatory methods in the form of stakeholder dialogues will be embedded throughout the process, from the identification of major impact areas to the mapping of impact pathways. Analysis of projected vulnerability will be synthesized based on the relevant results of WP3 and 4, including projected impacts through the analysis of thematic scenarios.

A key goal of WP5 is to build a solid analytic foundation for the identification of adaptation options at multiple scales, which will firmly connect the project to actual users (e.g. Black Sea Commission and International Commission for the Protection of the Danube River) of the information where real life positive impacts can be realized. Adaptation options will be developed at thematic, place-based and at higher region-wide levels. The development of policy and management responses will build on the adaptive management and resilience school of thought. While it will respond to the challenges arising from climate change, it will go beyond that and reflect a more synthetic reality where impacts and adaptive responses emerge in the context of a wider range of interacting forces of local and global change that includes, but that is not limited to climate change (Leichenko and O'Brien 2006).

1.2 Description of Task 5.7

Sustainable development is a high-level policy priority of both the EU as well as most countries in the Black Sea catchment. In order to translate it from a high level goal into an operational concept, the impact of past, current and future activities needs to be analyzed from the point of view of their impact on sustainability outcomes. The analysis requires the identification of sustainability criteria and if possible, specific goals and targets, and a tight set of sustainability indicators. Both the criteria and indicators need to have scientific validity but also reflect stakeholder perspectives. Initially we proposed to use a conceptualization of vulnerability by Turner et al. (2003) as simplified for the GEF Lake Balaton project (Figure 1). The analysis will consider both internal and external processes in the context of functional exposure units, which may range from the entire catchment to sub-ecosystems.

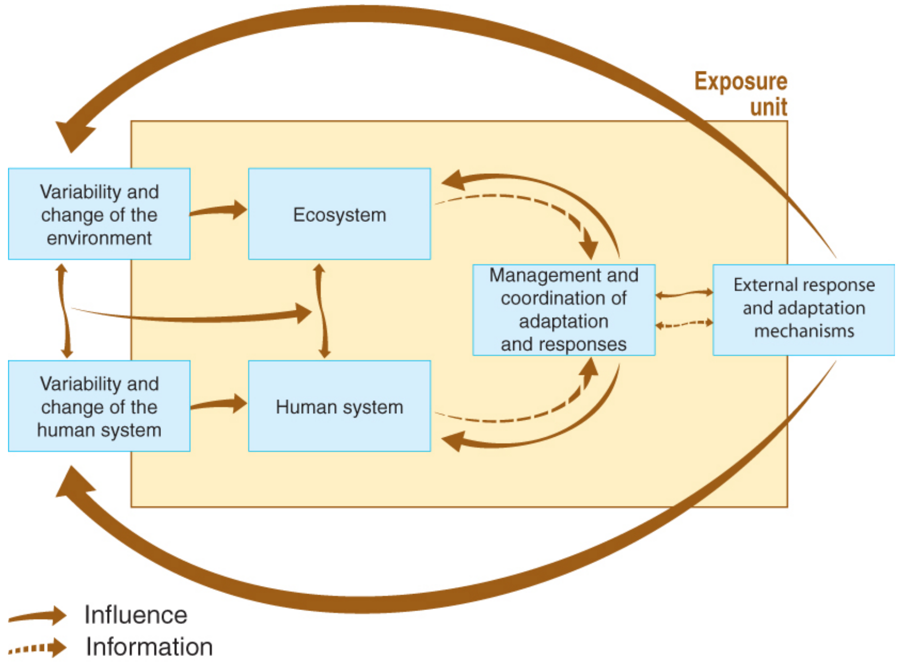

Figure 1: Conceptual framework for integrated vulnerability and sustainability analysis (IISD 2006)

Through channelling data flows from multiple sources into integrated analytic models, EnviroGRIDS will elevate our ability to carry out sustainability assessment on real-life policy issues to a new level. The analytic engine in EnviroGRIDS will satisfy two key requirements for understanding sustainability implications of policies and activities: it will provide improved data at least for some key environmental indicators and through the use of relevant models it will help project impacts into the future. The analysis of sustainability under this Task will also require looking at the thematic, temporal and spatial interlinkages between ecological and social processes to identify potential vulnerabilities and implications for sustainability that emerge at their interface and that may not arise from narrow thematic analyses. Identifying priority sustainability concerns will involve technical analysis of current and projected trends and interactions, but will also involve participatory work with regional stakeholders (e.g. BSC and ICPDR) which are often already aware of key sustainability issues and would have to play a key role in conceptualizing and implementing adaptive responses.

1.3 Document Structure

This report is organized in four chapters. The first chapter presents the general objectives of task 5.7 of the enviroGRIDS project and the specific objectives of this particular deliverable. The second chapter presents two important frameworks on which this deliverable was built: the DPSIR and the Vulnerability frameworks. Then, the third chapter gives an overview of different indicator systems and projects that were recently developed for integrated water resource assessments (IWRM). The last chapter describes the solution chosen for enviroGRIDS to assess the water resource of the Black Sea catchment based essentially on the outputs of the two other work packages (WP3 on scenarios and WP4 on SWAT). Finally, a few conclusions are derived from this review.

1.4 Objectives

The main objective of this report is to prepare the assessment of water resources of the Black Sea catchment. It specifically aims at:

- Reviewing existing analytical frameworks (DPSIR, Vulnerability);
- Reviewing existing system of evaluation of water resources (UnWater, GIWA, SOER, WFD, Water footprint,
- Proposing a combined indicator system to evaluate water resources sustainability and vulnerability in the Black Sea catchment; and
- Selecting a list of adapted indicators with their reference system and possible data sources.

2 Existing Assessment frameworks

Several analytical frameworks for assessing the sustainability and/or the vulnerability of a system can be fund in the literature (Belausteguigoitia 2004; Kirstensen 2004; Chapagain et al. 2011; Ash et al. 2010). Among them, we decided to present two important frameworks: namely the DPSIR and the Vulnerability frameworks that are briefly introduced in the following paragraphs.

2.1 DPSIR Framework

2.1.1 Predecessors and emergence

The DPSIR (Driver, Pressure, State, Impact, Response) model is based on previous environmental frameworks, such as the pressure-state-response (PSR) model that was developed in the 1970s by the Canadian statistician Anthony Fried (Burkhard and Müller, 2008). According to this model, a certain pressure on a system is followed by an appropriate response. The Organisation for Economic Co-operation and Development (OECD) adopted and enhanced the approach in the late 1990s in order to structure and organise indicators for environmental issues. The so-called Pressure-State-Response (PSR) model (OECD, 1993) provided a good explanatory basis for system analyses, but its simplified character can be unsatisfying for complex systems (Burkhard and Müller, 2008). The United Nations Commission for Sustainable Development used another variation called the driving force-state-response (DSP) model. It put emphasis on human demands and activities that affect the natural system (UN, 1996). However, according to Burkhard and Müller (2008) its capacity in regard to more comprehensive human-environmental systems are limited.

An early DPSIR model came into use in the early 1990s when economic activities where included in environmental statistics. The models included human activities, pressures, the state of the environment, impacts on ecosystems, human health and materials, and responses. Since 1995, the model has been used by the European Environment Agency and by EUROSTAT, for the organisation of environmental indicators and statistics, by researcher as a framework for environmental studies as well as a tool in order to support decision-making. In recent years, several vulnerability assessments, at least partially based the DPSIR framework have been conducted or proposed by scientists and transnational as well as international organisations (e.g., Bizikova et al. 2009; UNESCO-IHP 2011a,b; Huang and Cai 2009; Babel and Wahid 2008; Jun et al. 2011; UNEP and WCR 2008; Varis et al. 2012).

2.1.2 Description of the DPSIR model

The DPSIR model is a widely recognised assessment framework used by numerous scientists, professionals and international organisations (e.g., United Nations Environment Program, European Environment Agency) in order to assess the sustainability or vulnerability of environmental and socio-economical systems.

The basic concept of the DPSIR model is the causal relationship between its elements (cf. Figure 2). In short, it can be summarised that Drivers (social, economic, environmental) exert Pressures on the environment, which in turn change the State of the environment. As a consequence the resulting Impacts evoke Responses that can affect Drivers, Pressures, State, or Impacts likewise (Svarstad et al., 2008).

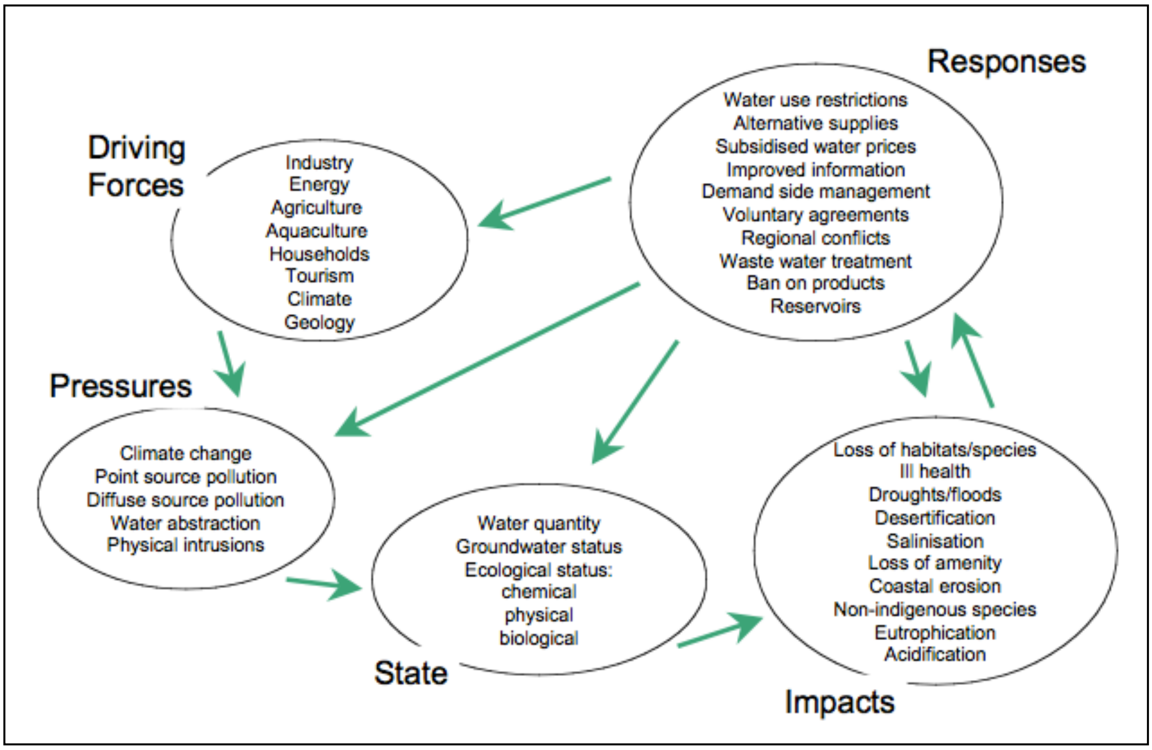

Figure 2: The DPSIR model (Kirstensen, 2004)

The example of water availability in arid regions can be used to illustrate the relationships in the DPSIR model: Increased demand for food (Driving force) can lead to the intensification of agriculture via intensified irrigation and thus to enhanced diversion of water from rivers (Pressure); the declining quantity of water in the river (State) can lead to a shortage of water for drinking and agriculture in the lower reach of the river (Impact); measures to tackle the problem (Response) can undertaken at different stages as for example the introduction of trickle irrigation that would intervene at the Pressure level, whereas the tapping of other water sources (e.g. ground water) would influence the Impact stage.

2.1.3 Applications in water related issues

The DPSIR model has become a popular conceptual framework and is widely used by researcher and policy makers alike (Svarstad et al., 2008). Its application covers a wide range in the field of environmental sciences, including for example the assessment of greenhouse effect (Huang et al., 2011), biodiversity issues (Kohsaka, 2010; Spangenberg et al., 2009) or land use evaluation (Li, 2011). A generic DPSIR framework for water issues has been presented by Kirstensen (2004) (Figure 2). The studies presented below are mostly based on similar water related frameworks.

Bowen and Riley (2003) applied the framework to understand the linkages and interdependencies of socio-economic and coastal environmental dynamics and argued that comprehensive program assessments should incorporate appropriate components revealed through consideration of a DPSIR modelling effort as well as more traditional institutional performance measures.

Karageorgis et al. (2005) assessed the conditions of the Axios River catchment and Thermaikos Gulf under the DPSIR framework. They concluded that the application of the DPSIR framework analysis seems to provide a solid scientific tool useful for tackling environmental issues and that their DPSIR analysis would offer policy makers a list of applicable measures, with sound socio- economic and environmentally friendly background toward an integrated and sustainable watershed-coastal zone management.

Borja et al. (2006) focused in their study on the use of the DPSIR approach, in assessing the pressures and risk of failing the objective of the European Water Framework Directive (WFD), using the Basque (northern Spain) estuarine and coastal waters as a case study. In their conclusion they emphasized the usefulness of the DPSIR especially in combination with certain new methodological approaches.

Jago-on et al. (2009) used the DPSIR model subsurface environments analysing excessive groundwater abstraction, land subsidence and groundwater among selected Asian cities. They concluded that their DPSIR components identified in this article can help anticipate effects of urban development on the subsurface environment which will be helpful in urban planning efforts, but that there is yet a need to develop concrete indicators of urban development for DPSIR analysis in future researches.

Sekovski et al. (2012) implemented the DPSIR framework in order to elaborate the role of coastal megacities in environmental degradation and their contribution to global climate change. They priced the DPSIR as simple, clear and well-organised management tool. However, DPSIR needs some adjustments, such as the establishment of a unique set of indicators, in order to make monitoring of environmental state and impacts in megacities clearer.

2.1.4 Critiques on the DPSIR model

As seen above and in several other studies (Agyemang et al., 2007; Li, 2011; Omann et al., 2009) the DPSIR framework is an analytical framework that recognises the complexity of environmental interactions and provides a means of analysing them. However, this literature review revealed as well critical aspects of the DPSIR framework.

Svarstad et al. (2008) critically examined the theoretical foundations of the DPSIR approach. They argue that the DPSIR framework is not a tool generating neutral knowledge, but reproduces the discursive positions the applicant brings into it. As a consequence they find that the DPSIR framework has shortcomings as a tool for establishing good communication between researchers, on the one hand, and stakeholders and policy makers on the other.

Tscherning et al. (2012) examined whether the application of the DPSIR framework in research can support decision-making. They found that many studies were addressed to political and administrative systems, but only a few studies integrated decision makers into the participative process. Nevertheless, they could conclude that "studies employing DPSIR may provide effective solutions for 'real world problems', by taking into account additional criteria based on knowledge integration, stakeholder involvement and the provision of alternatives. Thus, the DPSIR is a useful tool to support decision making by means of showing solid evidence with alternatives and decision options, rather than presenting predetermined solutions" (Tscherning et al., 2012).

Although some justified critics can be found in the literature, the DPSIR model was mostly judged positively. The framework seems to represent system elements and the theoretical causality-relationship in a pertinent way. Furthermore, the model can be applied in a flexible manner. On the one hand, its structure allows to a certain degree an adaption to different contexts and assessment objectives. On the other hand, examples have shown that this framework can be combined with other conceptual model in order to meet the assessment's specific needs (Bär, 2012).

Overall, it can be concluded that the DPSIR model constitutes an adequate framework for vulnerability assessments of water resources. Though, it is not a universally applicable ready-to-use model, but a pertinent framework that can be adapted to the chosen analytical model, assessment objective and their context.

2.2 Vulnerability framework

2.2.1 Definition

The term "vulnerability" is broad and open to interpretation. According to Varis et al. (2012) the concept of vulnerability remains quite unsettled in the literature. As a result, there are different approaches to determining how it can be measured, which made it difficult to compare studies at a global level (Jun et al., 2011). Thus, it is indispensable to review a few definitions and conceptualisations of the term "vulnerability".

An extensive variety of vulnerability conceptualisations and definitions can be found in the literature, although Varis et al. (2012) state that there seems to be a convergence towards a united definition of the vulnerability concept in recent years. However, while the generalist concept of vulnerability can be applied in a transdisciplinary way, more specific concepts are defined for certain discipline in science (e.g., computer science, psychology or environmental science) in order to meet their specific requirements.

Turner et al. (2003), for example, present a quite general definition of vulnerability in the context of sustainability: "Vulnerability is the degree to which a system, subsystem, or system component is likely to experience harm due to exposure to a hazard, either a perturbation or stress/stressor".

In the context of sustainability, another quite universally applicable definition was given by Bizikova et al. (2009): "Vulnerability refers to the potential of a system to be harmed by an external stress (for instance a threat). It is defined as a function of exposure, sensitivity to impacts and the ability or lack of ability to cope or adapt. The exposure can be due to hazards such as drought, conflict or extreme price fluctuations, and also underlying socio-economic, institutional and environmental conditions. The severity of the impacts not only depends on the exposure, but also on the sensitivity of the specific unit exposed (such as an ecosystem, a watershed, an island, a household, a village, a city or a country) and on the capacity to cope or adapt."

Referring to a water resource management perceptive, Huang and Cai (2009) defined vulnerability as: "the characteristics of water resources system's weakness and flaws that make the system difficult to be functional in the face of socioeconomic and environmental change".

Situated in the context of a transboundary watershed, the notion of "hydropolitical vulnerability" is also interesting. Wolf (2009) defines hydropolitical vulnerability by the risk of political dispute over shared water systems. Concerning the relationship between change, institutions, and hydro-political vulnerability Wolf states that "the likelihood of conflict rises as the rate of change within the basin exceeds the institutional capacity to absorb that change". Thus, dispute settings include the rate of change in the system on the one side, and the institutional capacity on the other side. The general assumption is that "rapid change tends to indicate vulnerability while institutional capacity tends to indicate resilience, and that the two sides must be assessed in conjunction with each other for a more accurate gauge of hydro-political sustainability" (2009).

All these definitions make the allowance to the cognition as stated by Turner et al. (2003) that "vulnerability is not only registered by exposure to hazards (perturbations and stresses) but also resides in the sensitivity and resilience of the system experiencing such hazards".

Turner et al. (2003) developed a framework for vulnerability analysis in sustainability science (Figure 3) including the capacity to treat coupled human–environment systems and their linkages within and outside the systems. Its basic architecture consists of: "(i) linkages to the broader human and biophysical (environmental) conditions and processes operating on the coupled system in question; (ii) perturbations and stressors/stress that emerge from these conditions and processes; and (iii) the coupled human–environment system of concern in which vulnerability resides, including exposure and responses (i.e., coping, impacts, adjustments, and adaptations). These elements are interactive and scale dependent, such that analysis is affected by the way in which the coupled system is conceptualised and bounded for study" (Turner et al., 2003). Some of its main characteristics include that hazards acting on the system arise from influences outside and inside the system, and that the human–environment conditions of the system determine its sensitivity to any set of exposures.

When conducting a vulnerability assessment it has to be beard in mind that the term "vulnerability" is broad and open to interpretation (Hamouda and Moursy, 2009).

Thus, an accurate definition and conceptualisation of the term vulnerability remains indispensable.

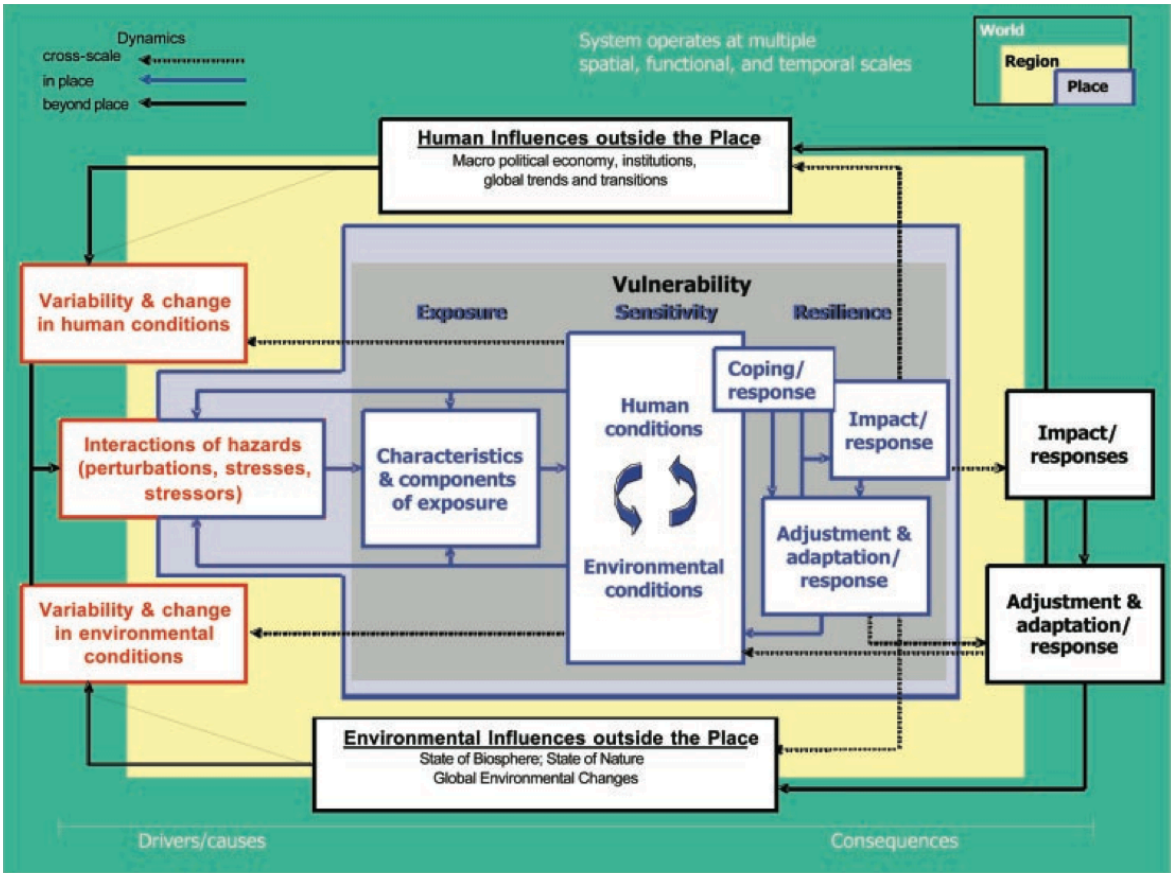

Figure 3: Components of vulnerability identified and linked to factors beyond the system of study and operating at various scales (Turner et al., 2003)

Further conceptual connotations of the term "vulnerability", reviews of past efforts assessing and studying vulnerability and a synthesis of the key insights from the literature on vulnerability analyses, can for example be found in Kok and Jäger (2007), Villagrán De León (2006), Adger (2006) or Füssel (2007).

2.2.2 Assessing vulnerability

Nowadays, vulnerability assessment is widely used by international and national organisations, where they are mostly used to develop policy recommendations on how to reduce vulnerability and to adapt to change (Kok and Jäger, 2007). In this context the concept of vulnerability has undergone a shift from research-based activities to a stakeholder-driven approach and can thus be anchored in the past and present (vulnerability) and providing responses bearing in mind potential future scenarios (impact) (Bizikova et al., 2009). However, for planning and conducting a vulnerability assessment it is necessary to clarify first some related questions.

One on the primordial questions of vulnerability assessment is usually "Who or what is vulnerable?". First of all, vulnerability assessment is used in different sciences (e.g., computer sciences, economy, psychology, ecology, environmental studies). Second, they can target a wide range of different aspects and different scales within those disciplines (e.g. socio-economic systems, ecosystems, water systems). However, in environmental sciences there is a current trend that vulnerability assessment focus on human vulnerability (Hamouda, Nour El-Din and Moursy, 2009), or socio-economic systems.

Exemplary to that are freshwater resource assessments, since the term "water resources" already implies an anthropocentristic perspective. According to Bridge (2001) the term "resources" refer to "those properties of the physical environment that can be exploited to meet the needs and desires of society". From such a perspective, it seems apparent that in water resources assessments, it is not only the water system itself which is of interest, but the water system's conditions in order to meet societal needs.

This human viewpoint equally concerns the vulnerability definition of Huang and Cai (2009). They define their vulnerability assessment as "an investigation and analytic process to evaluate a system's sensitivity to potential threats, and to identify key challenges to the system in reducing or mitigating the risks associated with the negative consequences from adversarial actions", which does per se implies an anthropocentric viewpoint. However, as they speak of vulnerability of water resources, which can be considered as the most important for all human (and living) beings, their assessment actually concerns the vulnerability of society.

Another issue is addressing the question of "Being vulnerable to what?". Vulnerability assessments can put emphasis on specific factors affecting the vulnerability by anteriorly defining the specific factors affecting the vulnerability. Referring to the vulnerability of water resources, most studies have focused on vulnerability to any kind of environmental change (Babel and Wahid, 2009, 2008; Huang et al., 2008; UNEP and WCR, 2008; Hamouda, 2006; Jun et al., 2011; Strzepek et al., 1996). However, they can equally focus on other issues as for example governance and hydro-political issues (Wolf, 2009; Gooch et al., 2007) or more specific hazards.

In several other studies the emphasis is rather put on the vulnerability itself. By not anteriorly specifying factors affecting the vulnerability, they address rather the question of "How vulnerable is something?". In those cases this delimitation of the factors contributing to the vulnerability is rather a part of the assessment itself. From the reviewed studies several assessments related to water were of this type (Varis et al., 2012; Webster and Roebuck, 2001; Thomson and Abdul-Mehdi, 2009; Hema et al., 2010; Wang et al., 2009).

There are no blueprints for vulnerability assessments, since assessments are mostly embedded in certain context. Thus, in order to clearly define the objectives of the vulnerability assessment the following question should be answered: "Who or what is vulnerable?" and "To what is something or somebody vulnerable?".

2.2.3 Vulnerability indicators

In the context of sustainable development, indicators have already been emphasised by the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro in 1992. Individual countries, as well as international governmental and non-governmental organisations were called to "develop and identify indicators of SD in order to improve the information basis for decision-making at all levels" (UNCED, 1993: Chapter 40). Since then, a multitude of indicator lists has been developed by researchers, non-governmental and governmental organisations.

Indicators are a simplified representation of a much more complex reality. They focus on certain aspects, which are regarded as relevant and on which data are available. Gabrielsen and Peter (2003) defined a list of criteria for indicators communicating the simplified reality in a sound way. Accordingly indicators should:

- match the interest of the target audience;
- be attractive to the eye and accessible;
- be easy to interpret;
- invite action (read further, investigate, ask questions, do something);
- be representative of the issue or area being considered;
- show developments over a relevant time interval;
- go with a reference value for comparing changes over time;
- go with an explanation of causes behind the trends;
- be comparable with other indicators that describe similar areas, sectors or activities;
- be scientifically well-founded; and
- be based on sound statistics.

The threshold of vulnerability has been discussed by Hamouda et al. (2009), defining it as "the value of the indicator which gives the judgment whether on not the indicator contributes significantly to vulnerability". Accordingly, the establishment of thresholds is an important endeavour, since comparison and judgments are essential to indicator evaluation. However, they did not further elaborate on the determination of threshold values. Though, they propose to use "World mean" or "World median" in cases thresholds are not available.

2.2.4 Vulnerability indices

According to Varis et al. (2012) the concept of vulnerability index remains quite unsettled in the literature and experiences of its development in the water and river basin context is limited. However, it seems to attract growing attention (Huang and Cai, 2009; Sullivan, 2011; Jun et al., 2011). The issue of indices aggregation and calculations is a topic widely discussed.

In order to quantify vulnerability, Huang and Cai (2009) state that the indicators for each variable should be determined and quantified. Two of the principles proposed include that 1) indicators should not be too many parameters, but the selected ones must be representative, and 2) that selected parameters are measurable, and easily expressed in formulations with available data support.

Calculation can be done in several different ways. A popular approach is the computation of a composite index, including multivariate analysis and fuzzy logic techniques. Furthermore, factors can be weighted or calculated by simply calculating their average value. According to Huang and Cai (2009) the contribution of each parameter to the vulnerability index should be weighted according to its importance. The procedure of weighting, however, should follow a participative, consultative process including all stakeholders, and adequately incorporating the knowledge and experience available.

In their article, Böhringer and Jochem (2007) criticised the practice of weighting. They found that "normalisation and weighting of indicators – which in general are associated with subjective judgments – reveal a high degree of arbitrariness without mentioning or systematically assessing critical assumptions. As to aggregation, there are scientific rules that guarantee consistency and meaningfulness of composite indices. Yet, these rules are often not taken into account".

As a consequence, several studies (Varis et al., 2012) opt for the method of simply calculating the average values of the index components. Furthermore, this allows comparability of vulnerability index between different river basins, as they are not based on different weightings.

In order to avoid the subjectivity and vagueness rendered by weighting schemes and aggregation mathematical functions, a different approach was chosen by Hamouda et al. (2009). Instead of numerically aggregating their indicators, they opted for a graphical presentation or, more precisely, for radar diagrams. According to them the main advantage of the graphical display of indicators is the simplicity of presenting the results. Moreover, graphical display does not obscure the sources of vulnerability and enables tracking it back to the original data, as it is the case for aggregations.

The issue of weighting is a recurring subject in the literature, representing the variety of approaches for index calculation. The issue of weighting is crucial since the aggregation of indicators always results in some loss. As a result, diverging opinions can be found on how such information loss can be minimise and how it should be handled best.

3 Integrated water resource management (IWRM)

3.1 Principles of integrated water resource management

An increasingly important concept in the water management is the so-called Integrated Water Resources Management (IWRM). The IWRM promotes the management of water and related resources on a watershed basis, thus allowing the IWRM to be a relevant framework for both small catchments and transboundary basins (UNEP and IISD, 2011). It combines land and water management through broad-based stakeholder participation to realise multiple co-benefits in watersheds. However, many countries are applying integrated water resources management at the catchment level, their management is still largely confined to the water sector (World Water Assessment Programme, 2009) ignoring important factors that influence the vulnerabilities and challenges in river basins.

Important decisions affecting water management are made outside the water sector ("water box"). Changes in a water system are not only driven by factors directly related to water management. They are equally driven by external, largely unpredictable drivers, such as demography, climate change, the global economy, changing societal values and norms, technological innovation, laws and customs, and financial markets. As a consequence, leaders in government, the private sector and civil society, thus actors not immediately related to the water sector, should be integrated into the water management. One way to achieve this goal is to make them aware of their role in obtaining IWRM objectives and thus to guarantee a sustainable use of this resource (World Water Assessment Programme, 2009).

According to Gooch et al. (2007) this has already become increasingly the case. Nowadays, water management deals with more issues that affect more people than they did in the past. The increased scope and new demands leads to an increased political character of water management.

Further, water management increasingly focuses on different aspects of vulnerability (Gooch et al. 2007). Changes in water use, the effects of global warming, and increasing populations are central factors affecting the vulnerability of ecological, economic and social systems. Thus, methodologies helping to understand the causal chain of vulnerability should be developed in order to minimise the vulnerability of the affected systems as well as possible.

To sum-up, it can be noted that water management on a watershed approach is quite well established. However, water management and policies does not yet sufficiently integrate elements outside the "water box", thus ignoring crucial driver of change. For further details about water management and governance a remarkable amount of literature is available (e.g. Rogers and Hall 2003; Savenije and Van der Zaag 2008; Carrige 2009; Biswas and Tortajada 2010).

3.2 GIWA Causal-Chain analysis

The UNEP Global International Waters Assessment (GIWA) provides a framework to analyse the root causes of international waters problems. It is based on identifying the factors that shape human behaviour in relation to the direct or indirect use of aquatic resources (Belausteguigoitia, 2004; GIWA, 2002). A range of studies based on the GIWA Causal-Chain model had been conducted between the years 2004 and 2006 (e.g., Wramner (2006); Borysova et al. (2005); Barannik, Borysova and Stolberg (2004); UNEP (2006)).

A precise description of the Causal Chain Analysis can be found in Belausteguigoitia (2004). It can be summarised as a causal chain that is built for a particular site in order to understand the specific characteristics of a problem. The first element of the causal chain analysis is the selection of a site, a problem and its associated environmental and socioeconomic impacts. In the second step, the immediate causes, i.e. physical, biological and chemical factors, producing the problem are identified. The next step consists of the identification of human activities contributing most significantly. In the following steps, the root causes determining those pressures are investigated, explaining how they act and interact to cause the problem. A schema of the causal chain, including potential factors, is given in Figure 4.

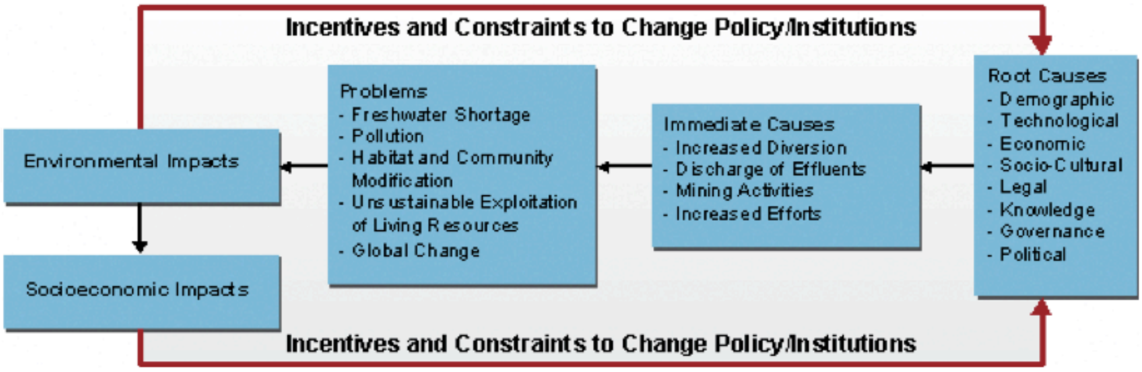

Figure 4: GIWA Causal Chain Analysis (Belausteguigoitia, 2004)

Root causes refer to factors that influence human behaviour. The GIWA approach differentiates between two groups of root causes: causal factors and catalysts. The first one consists of social coordination mechanisms (institutions), which can lead to wasteful use of resources when they are faulty. The second consists of factors that do not cause wasteful use of resources per se (poverty, trade, demographic growth, technology), but expose and magnify the faults of the first group of factors (Belausteguigoitia, 2004).

The GIWA Causal-Chain model is pertinent to trace back cause-effect relationships. The analysis model allows identifying factors causing changes within a system and therefore contributes essentially to a better understanding of mechanisms leading to vulnerability.

3.3 Water management in the Black Sea catchment

No comprehensive IWRM scheme exists for the Black Sea catchment as a whole. Nonetheless, several transboundary water management programs, mostly following several IWRM principles, can be found. Some important water management projects, organisations and laws concerning the Black Sea catchment area are listed below:

- The EU Water Framework Directive (WFD)[1] is the most important initiative in the field of water for decades (Mostert, 2003). All member states of the EU and all candidate countries have to adapt their water management system to the requirements of the WFD. It is based on the principles of IWRM and aims to achieve at least 'good water status' for all water bodies by 2015. For critics of the European WFD see Rahaman, Varis and Kajander (2004)
- Water Governance in the Western EECCA Countries[2] was a project funded by the EU and involved six countries (Belarus, Moldova and Ukraine, Armenia, Azerbaijan, Georgia). The aim of the project was to support the adoption and implementation of Integrated Water Resource Management in the beneficiary countries.
- The Water Code (WC) is the principle legal document concerning water related issues in the Russian Federation. It has a number of common features with the European WFD, notably the introduction of basin management approaches. Nonetheless, they differ to some degree. A more precise comparison between the European WFD and the Russian Federation WC has been given by Nikitina (2006).
- Information about water management policies in Turkey remains sparse at the current state of the literature review. However, the few documents found (Kibaroglu, 2008) indicate that although integrated water management is applied in Turkey, in practice the IWRM remarkably diverges in their priorities and requirements from the European WFD.
- The Permanent Secretariat of the Commission on the Protection of the Black Sea Against Pollution, or Black Sea Commission (BSC)[3], is an intergovernmental body established in the implementation of the Convention on the Protection of the Black Sea Against Pollution signed in the year 1992. It includes the six coastal Black Sea countries Bulgaria, Georgia, Romania, Russia, Turkey and Ukraine, and is the body responsible for implementing the convention, which has terrestrial waters in its scope.

Furthermore, several national and international commission have been established in recent year in order to implement IWRM schemes:

- The International Commission for the Protection of the Danube River (ICPDR)[4]
- The International Sava River Basin Commission[5]

---

1 http://ec.europa.eu/environment/water/water-framework

2 http://wgw.org.ua

3 http://www.blacksea-commission.org

4 http://www.icpdr.org

- The Azov Center for Watershed Cooperation[6]

Overall, it can be noted that there is a clear pursuit of the implementation of IWRM schemes. Furthermore, the European WFD appears to be particularly important. Not only because a good portion of the Western Black Sea catchment territory belongs to European Union member states, but equally because the European Union is funding and technically supporting the implementation of IWRM schemes in non-member countries.

3.4 Global assessments and monitoring

A growing number of water system assessments and monitoring programs have been conducted and implemented in recent years (for a more comprehensive overview of programs on a worldwide and European scale (EAA 2011)).

On a global scale, most notably the Unites Nations' Water Program play a key role in implementing, coordinating and supporting monitoring and assessment programs. However, a range of different initiatives of a global scale can be found. The following list presents a few of the most important programs at a global scale:

- The UNEP's Global Environmental Outlook (e.g. GEO-4)[7] providing a chapter assessing the state of water (UNEP, 2007).
- The World Water Assessment Programme (WWAP)[8] of the UNESCO has produces the World Water Development Report (WWDR) every three years since 2003 and provides a comprehensive assessment of the state of the world's freshwater resources (World Water Assessment Programme, 2003, 2006, 2009).
- The International Hydrological Programme (IHE) of the UNESCO[9] is an intergovernmental programme of the UN system devoted to water research, water resources management, and education and capacity building.

- The WHO/UNICEF Joint Monitoring Programme on Water Supply and Sanitation Reports[10] reports assess the progress being made toward reaching the Millennium Development Goals water and sanitation targets.
- The Global Annual Assessment of Sanitation and Drinking-Water[11] (GLAAS) is a UN-Water initiative implemented by WHO. The objective of UN-Water GLAAS is to provide policymakers at all levels with a reliable, easily accessible, compre-

5 http://www.savacommission.org
6 http://azovcenter.ru
7 http://www.unep.org/geo
8 http://www.unesco.org/new/en/natural-sciences/environment/water/wwap
9 http://www.unesco.org/new/en/natural-sciences/environment/water/ihp
10 http://www.wssinfo.org
11 http://www.who.int/water_sanitation_health/glaas/en

hensive and global analysis of the evidence to make informed decisions in sanitation and drinking-water.

- The Global Runoff Data Centre (GRDC)[12] compiled a global database of stream flow data. Its database is continually updated and contains daily and monthly discharge data information for over 2,900 hydrologic stations in river basins located in 143 countries.
- The United Nations' GEMS/Water Programme[13] provides data and information on the state and trends of global inland water quality.
- The Global International Water Assessment (GIWA)[14] of the UNEP was a comprehensive and integrated global assessment of international waters, the ecological status of and the causes of environmental problems in 66 water areas in the world, and focus on the key issues and problems facing the aquatic environment in transboundary waters.
- The Global Water Partnership (GWP)[15] is a global action network producing many publications related to IWRM, policy planning and other advice for water resources management.

The above-mentioned programs present an overview of the state of water resources primarily on the global scale. They are inappropriate for practical water management programs as they do not consider the regional contexts and aim rather on interregional comparisons than detailed cause-chain analyses. However, they frequently serve as a framework for assessments on a lower geographical scale and thus often provide crucial information for water management programs on a regional scale.

3.5 Water Footprint

"The water footprint is an indicator of freshwater use that looks at both direct and indirect water use of a consumer or producer[16]. The water footprint of an individual, community or business is defined as the total volume of freshwater used to produce the goods and services consumed by the individual or community or produced by the business. Water use is measured in terms of water volumes consumed (evaporated or incorporated into a product) and/or polluted per unit of time. A water footprint can be calculated for a particular product, for any well-defined group of consumers (for example, an individual, family, village, city, province, state or nation) (Figure 5) or producers (for example, a public organization, private enterprise or economic sector). The water footprint is a geographically explicit indicator, showing not only volumes of water use and pollution, but also the locations." (Hoekstra et al. 2011).

[12] http://www.gewex.org/grdc.html

[13] http://www.gemswater.org

[14] http://www.unep.org/dewa/giwa

[15] http://www.gwp.org

[16] http://www.waterfootprint.org

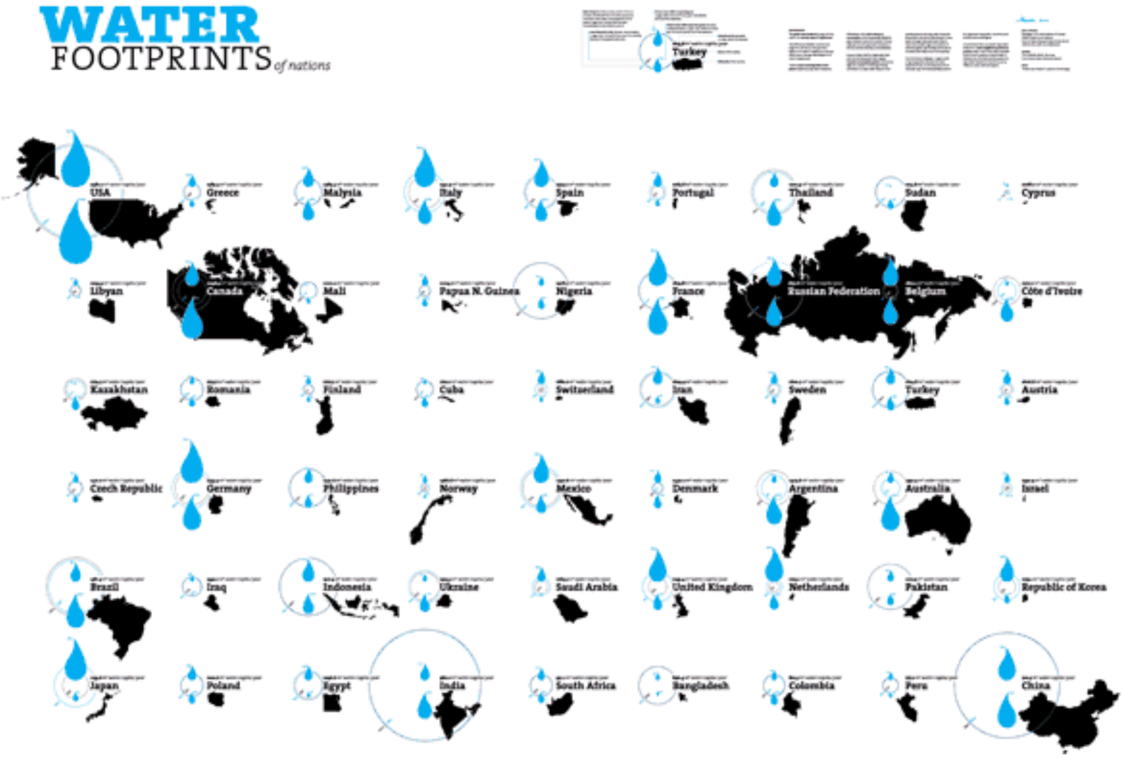

Figure 5: Water footprints of Nations

3.6 Regional information systems

On a regional scale primarily two comprehensive water information systems concern the Black Sea catchment: The Water Information System for Europe (WISE)[17] and the enviroGRIDS[18] project.

The Water Information System for Europe (WISE) is a partnership between the European Commission (DG Environment, Joint Research Centre and Eurostat) and the European Environment Agency. Its a web-portal offering water related information ranging from inland waters to marine and covering directives, implementation reports, supporting activities, reported datasets, interactive maps, statistics, indicators, forecasting services, an inventory for water related projects and research activities. By facilitating access to this information to administrations, working professionals, scientist and the great public WISE offers an information fundament for assessments and decision-making processes.

17 http://water.europa.eu

18 http://www.envirogrids.net

The enviroGRIDS project is an observation system covering the Black Sea catchment. It helps bridging the gap between science and policy by building the capacity of scientist to assemble a data-driven observation system, the capacity of decision-makers to use it, and the capacity of the general public to understand the important environmental, social and economic issues at stake. The datasets will be compatible with the GEOSS and European INSPIRE Directive on spatial data thus allowing easy data sharing and communication. For these reasons, project should provide a prime groundwork for sustainability and vulnerability assessments as well as for water management policies (Figure 6).

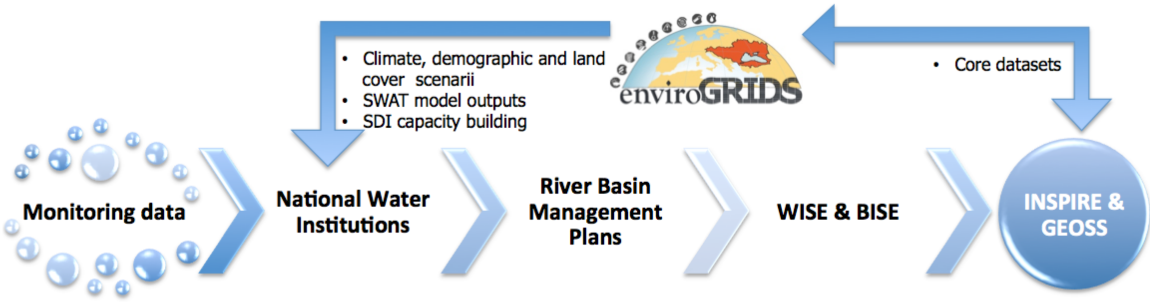

Figure 6: enviroGRIDS contribution in the IWRM of the Black Sea catchment

3.7 Black Sea Commission and Climate Change

The Causal Chain Analyses in the 2007 Black Sea Transboundary Diagnostic Analysis found climate change to be a contributory factor to all four transboundary problems, but not an immediate or underlying cause. Moreover, the causes of climate change are global, so need to be addressed primarily at a global, rather than a regional level, albeit with national targets set to tackle the issue. For this reason, climate change is included only in Management Target 13 of the Strategic Action Plan for the Environmental Protection and Rehabilitation of the Black Sea "Assess impacts of climate change on Black Sea ecosystem and sustainable development of the coastal population", with the intention only to investigate the impacts of this phenomenon.

The Black Sea Commission is however collaborating with the Helsinki Commission on the Baltic Sea to develop an implementation plan to set up a modelling tool, linking background pollutants triggering eutrophication in the Black Sea with requirements, set by the Black Sea Commission on reducing input of nutrients, including riverine loads. Such modeling tool is needed to elaborate a catchment-based and target-oriented strategy to reduce the pollution originated from the land based sources and activities in the Black Sea catchment. The outputs of the enviroGRIDS scenarios will be very helpful to build strategy, while outputs of SWAT model are expected to provide assessment of pollution loads to the Black Sea.

3.8 ICPDR and the Water Framework Directive

The ICPDR is a transnational body established by the Danube River Protection Convention, comprising as contracting parties 14 Danube countries and the European Union. The ICPDR is charged with coordinating the trans-boundary aspects for the implementation of the EU Water Framework Directive (WFD) as well as the EU Floods Directive (EFD) in the Danube River catchment. At the Ministerial Meeting in February 2010, the Ministers of the Danube countries asked the ICPDR to develop until the end of 2012 a Climate Adaptation Strategy for the Danube River catchment. This activity is also supported by the EU Strategy for the Danube Region.

A Danube Climate Adaptation Study was developed by the University of Munich. The main outcomes of the study include the following:

- Summary of ongoing and finalised research and development projects on the adaptation of the water sector to climate change (climate scenarios, impact studies, risk analyses)
- Identification of required adaptation actions on local, regional, national and international level
- Development of integrative concept for transboundary actions for the development of the Climate Adaptation Strategy during 2012.

The results of the study are currently discussed with the Danube countries. Those include an overview on climate scenarios and expected impacts on the water sector in the Danube catchment. Furthermore, possible climate adaptation measures are currently gathered. The results of those discussions will provide valuable input for the finalisation of the enviroGRIDS study.

4 Proposed sustainability and vulnerability assessment

4.1 Combined conceptual framework

The proposed conceptual framework for the sustainability and vulnerability assessment of the Black Sea catchment is based on a combination of the DPSIR model and the concept of vulnerability. Using the example of biophysical vulnerability, Maxim and Spangenberg (2006) presented a way to reconcile these two well-established frameworks. They identified synonymous terms by systematically structuring sustainability problems based on the distinction of four "spheres of sustainability" (environmental, economic, social/human, political/societal).

The DPSIR elements (Driver, Pressure, State, Impact, Response) were linked to the components of the vulnerability concept (Stressor, Adaptation, etc.). Thereby, the linkage of the DPSIR elements and vulnerability components as presented by Maxim and Spangenberg (2006) can be summarised as following:

- The "**Driver**" category includes "**Stressors**" reflecting the latent potential of social, economic or institutional features to develop "Pressures".

- The "**Pressure**" category includes "**Stressors**" reflecting the consequences of economic activity for the environmental sphere.
- The "**State**" is reflecting the "Inherent Vulnerability" (i.e., the biophysical structures and life support functions, which have not a direct meaning for the social system but whose changes may indirectly lead to Impacts on humans).
- The concept of "**Impact**" has mainly the same meaning in the DPSIR and in the vulnerability vocabulary. Thus, "Impact" is a function of "Sensitivity", "Adaptation", and "Exposure".
- The "**Response**" is linked to "**Adaptation**". However, it is admitted that Responses target the only political level, while "Adaptation" (one element of vulnerability) includes more than political responses, dealing with all levels of the social, economic and institutional changes which aim at diminishing vulnerability.

However, the framework as presented above is not adequately adapted to our needs. On the one hand, the framework should specifically tailor to the goals of the vulnerability assessment. However, this is so far not the case. On the other hand, it is argued here that the aspect of "sensitivity" is not adequately incorporated. Although, "Sensitivity" is often considered a key element of vulnerability (Turner et al., 2003; Adger, 2006; Miller et al., 2010) this component was not linked to any of the DPSIR elements. As a consequence, an ameliorated concept adapted to the context of a water vulnerability assessment is proposed.

As in the example of Maxim and Spangenberg (2006), the DPSIR framework and the concept of vulnerability analysis are coupled. This enables the vulnerability assessment to regard to the society-environment interactions in a perspective of the widely used DPSIR model. Each element of the DPSIR framework (Driver, Pressure, State, Impact, Resource) is linked to one of the main components of the vulnerability concept (Stressor, Exposure, Sensibility, Potential impact, Adaptive capacity, Vulnerability) as defined by the IPCC (2007) (Figure 7).

- "**Drivers**" reflect latent changes in social and economic (e.g. population growth, land use changes) features that can cause "Pressures". Though, they can include equally environmental features (e.g. climate change).
- "**Pressure**" is mostly defined as human activities (negatively) affecting the environment (water). However, in the following it is defined as any human activities (e.g. waste water discharge) or natural phenomena (e.g. decline in precipitation) that are induced by the driving forces and affect the environment (water quality and quantity). Both, "Pressures" as well as its underlying "Drivers" are considered as "**Stressors**".
- The "**State**" can refer to natural systems alone or to both, natural and socio-economic systems (Maxim et al., 2009). In the proposed approach the "State" refers on the one hand to the state of the water as a resource, and on the other hand, to the state of the environmental, socio-economic, governmental conditions. In the former case the state corresponds to the "**Exposure**" of water resources to stresses

(e.g. high ratio between water demand and available water). The latter implies the "**Sensitivity**" of the water resource system, or in other words, to the capacity environmental, socio-economic, governmental system to cope with stresses without being significantly negative impacted by stresses.

- In the proposed framework "**Impacts**" links to the "**Potential Impacts**". However, an "Impacts" in the DPSIR model is usually an empirically measurable variable, while a "Potential Impact" in the vulnerability conceptualisation remains merely a potential, resulting as a function of exposure to stress and the sensibility of the affected systems.
- "**Responses**" are societal (decision-making) measures to correct the problem of the previous phases (Ness et al., 2010). Following the DPSIR logic, responses are the result of undesired impacts that already occurred. In other words, they are uniquely reactive. The "**Adaptive Capacity**", however, is wider in its interpretation. It represents not the actual response, but the capacity to respond. Thus, adaptive measures can be taken before an undesired impact occurs. In other words, they can be preventive. Furthermore, potential responses can directly target the stressors, the systems sensibility or both.

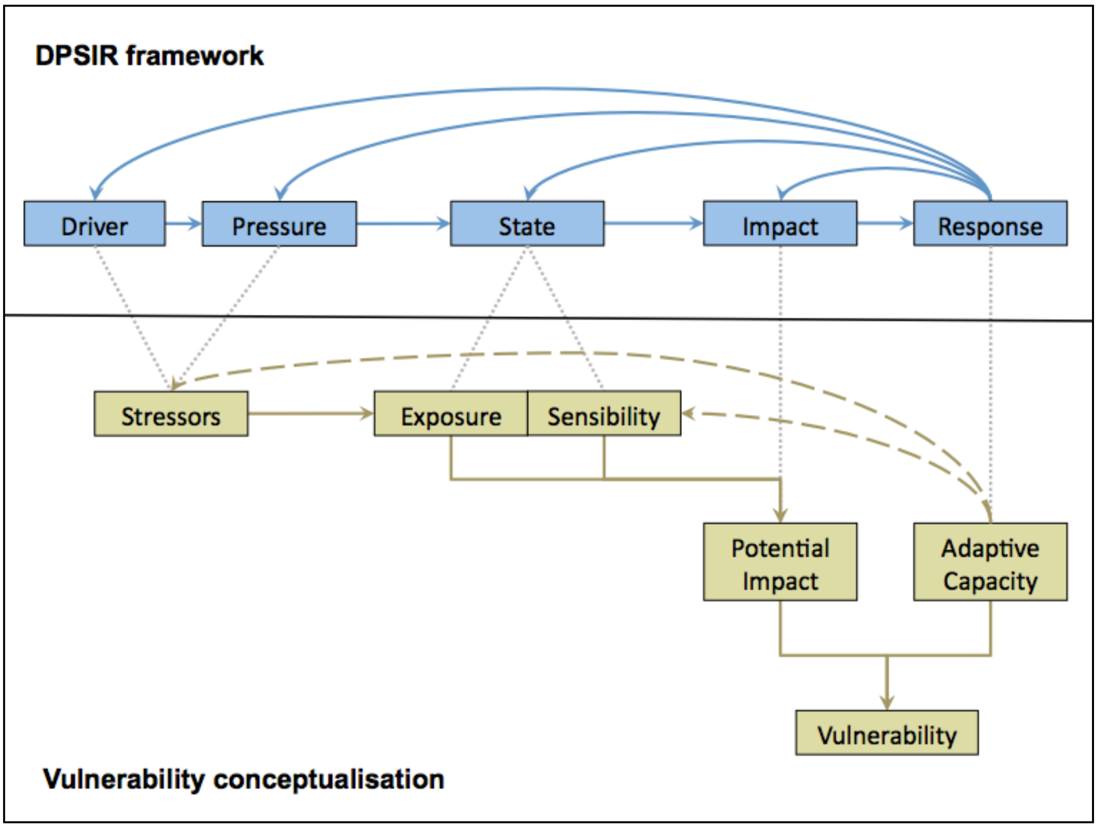

Figure 7: Proposed links between the DPSIR and Vulnerability frameworks

4.2 List of proposed indicators

A preliminary set of indicators was chosen (Figure 8). Most of the selected indicators are currently used and accepted by trans- and international organisations (EU, UN-Water, UNEP, OECD, FAO, etc.) or have been used by researchers in vulnerability assessment studies (e.g., Huang and Cai, 2009; Sullivan, 2011; Hamouda et al., 2009).

The criteria and indicators need to have scientific validity but also reflect stakeholder perspectives. On the one hand, local stakeholders are often aware of key vulnerability issues. On the other hand, the indicators play a key role in the conceptualisation and the implementation of adaptive measures. Thus, revising the indicator selection with support of stakeholder parties will be of great importance. At this stage, some of the selected indicators have certainly little interest in the Black Sea regional context (e.g. pourcentage of undernourished people) but they were kept sofar in order to propose an indicator system that could be used in other regional contexts.

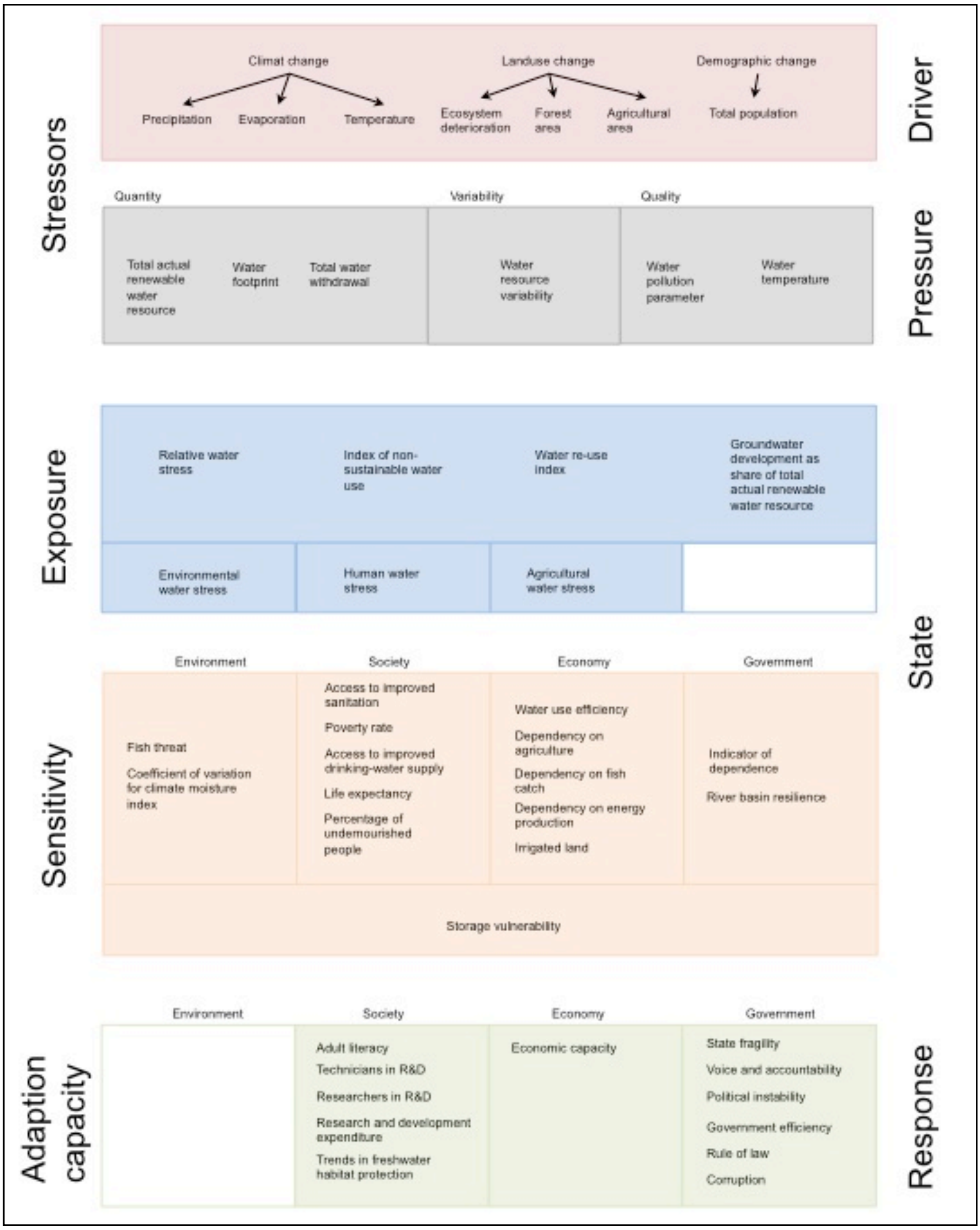

Figure 8: Proposed indicators are grouped by DPSIR categories and vulnerability components

The proposed indicators are grouped by DPSIR categories and vulnerability components, which allows situating them in the conceptual framework. The "Pressure" category is subdivided in three further categories. This allows to identity whether the stressors affect the water quality, the quantity or the variability of availability. "State" and "Response" are subdivided into five different categories. "Environment", "Society", "Economy" and "Governance" corresponding to the "four spheres of sustainability" as proposed by O'Connor (2006). This permits to better understand complex interrelations within the system. The fifth category "All" is used when an indicator concerns all spheres (Annex 2).

In order to assess the vulnerability of the water resources, the indicators will be aggregated into indexes in two steps. On the one hand, sub-indices will be created in order to assemble thematically close indicators. Thereby, it could be interesting to create indexes for each of the sustainability spheres (environment, society, economy, and governance). This allowed identifying which spheres were mostly exposed to possibly negative impacts, which spheres were the most sensitive or which spheres had the biggest capacity to reduce vulnerability.

On the other hand, indicators will be aggregated to the vulnerability components. The distinction between exposure, sensitivity and adaptive capacity allows describing vulnerability with a more specific vocabulary. Following the concept presented in NERI (2002), the classification will permit to distinguish vulnerable systems, adaptive systems, robust/inflexible systems and resilient systems (Figure 9), instead of only identifying a degree of vulnerability.

Vulnerable systems/resources		
Sensitivity	Capacity to respond	
	Low	High
High	Vulnerable system	Adaptive system
Low	Robust, inflexible system	Resilient system

Figure 9: Vulnerability as contingent on sensitivity and adaptive capacity, in areas of high risk of exposure (NERI, 2002).

The vulnerability assessment will include the calculation of a vulnerability index, as well as the graphical representation by means of radar diagrams. However, the precise method for both, the index computation and graphical representation, have yet to be defined.

4.3 Main sources of data

The vulnerability assessment will be conducted not on a national but on a sub-national scale. Thus, the data needs to be on a sufficiently fine scale. While some data is or will be available on a sufficiently fine scale, other data will need to be downscaled.

The vulnerability analysis will be based on several different data sources. They are mainly provided by national or international organisations or by the enviroGRIDS project.

- Demographic, land use change and climate change scenarios and the modelled spatial distribution of water quantity and water quality will be provided by the enviroGRIDS project (WP3, WP4).

- All other information (i.e. economy, health, education, government, etc.) will be provided by national and international organisations (EU, OECD, FAO, WHO etc.).

A more detailed overview of the proposed data sources can be found in the Annex 2.

5 Conclusions

This literature review presented an overview on the water resource management and monitoring in Black Sea catchment as well as theoretical aspects of sustainability and vulnerability assessments. Its main objective was to gain knowledge helpful for conducting a vulnerability assessment of water resources in the Black Sea catchment.

Concerning the vulnerability assessment, emphasis was put on the DPSIR framework and the GIWA Causal-Chain analysis model. It can be concluded that that both models seem pertinent in the context of assessments of water resources. However, the DPSIR model seems to be more widely known and used by researcher, decision-makers and international organisations.

Reviewing the concept of vulnerability it could be concluded that issue of vulnerability assessments is broad and varying. Thus, the conduction of a vulnerability assessment includes necessarily an accurate definition of the term and how it will be used in the context of an assessment.

This review noted a trend to a more integrated water resources management, thus transgressing national boarders. Important observation systems (e.g. WISE) and river basin based management policies exists in the region (ICPDR), but do not cover the Black Sea catchment completely and in a coordinated manner. Hence, the enviroGRIDS project provides a prime groundwork for sustainability and vulnerability assessments as well as for water management policies in the Black Sea region.

The review on indicators showed that indicators are essential to vulnerability assessments. Nonetheless, issues as, for example, establishing threshold are vaguely defined and thus remain delicate.

The aggregation of indicators in order to obtain vulnerability indexes follows varying approaches. Once more, there is no best method, hence, in order to obtain the best possible result the method should be accurately defined and be adapted to the assessment objectives.

Under the present environmental, political and socio-economical conditions the water resources in the Black Sea catchment can be considered to remain unsustainable in its current state. Analysis in order to more precisely assess the vulnerability of the water resources and to identify key challenges is therefore required.

The Black Sea Commission is collaborating with the Helsinki Commission on the Baltic Sea to develop an implementation plan to set up a modelling tool, linking background pollutants triggering eutrophication in the Black Sea with requirements, set by the Black Sea Commission on reducing input of nutrients, including riverine loads.

The ICPDR developed a Climate Adaptation Strategy for the Danube River catchment. with the University of Munich. The results of the study are currently discussed with the Danube countries. Those include an overview on climate scenarios and expected impacts on the water sector in the Danube catchment. Furthermore, possible climate adaptation measures are currently gathered. The results of those discussions will provide valuable input for the finalisation of the enviroGRIDS study

The knowledge gained thanks to this literature review has created a useful basis for a vulnerability assessment of water resources in the Black Sea catchment. However, there are still many important knowledge and information gaps that will be filled in the course of the vulnerability assessment process.

References

Adger WN, 2006. "Vulnerability." Global Environmental Change 16(3): 268 – 281.

Ash N, Blanco H and Garcia K, eds. 2010. Ecosystems and Human Well-Being: A Manual for Assessment Practitioners. Washington, DC: Island Press.

Babel MS and Wahid SM, 2008. Freshwater under Tread: South Asia. In Vulnerability Assessment of Freshwater Resources to Environmental Change. Nairobi: United Nations Environment Programme.

Babel MS and Wahid SM, 2009. Freshwater under Tread: South East Asia. In Vulnerability Assessment of Freshwater Resources to Environmental Change. Nairobi: United Nations Environment Programme.

Bär R, 2012. "The Driver - Pressure - State - Impact - Response (DPSIR) Model: Literature Review." Unpublished.

Barannik V, Borysova O and Stolberg F, 2004. "The Caspian Sea region: environmental change." Ambio 33: 45–51.

Belausteguigoitia, JC, 2004. "Causal chain analysis and root causes: the GIWA approach." Ambio 33:7 –12.

Biswas AK and Tortajada C, 2010. "Future Water Governance: Problems and Perspectives." International Journal of Water Resources Development 26: 129–139.

Bizikova L, Bellali J, Habtezion Z, Diakhite M and Pinter L, 2009. IEA Training Manual (Volume Two): Vulnerability and Impact Assessment for Adaptation to Climate Change. Nairobi: United Nations Environment Programme.

Böhringer C and Jochem P, 2007. "Measuring the immeasurable — A survey of sustainability indices." Ecological Economics 63.

Borja A, Galparsoro I, Solaun O, Muxika I, Tello EM, Uriarte A and Valencia V, 2006. "The European Water Framework Directive and the DPSIR, a methodological approach to assess the risk of failing to achieve good ecological status." Estuarine, Coastal and Shelf Science 66: 84 – 96.

Borysova, Olena, Andrey Kondakov, Susanna Paleari, Elina Rautalahti- Miettinen, Felix Stolberg and Dag Daler. 2005. Eutrophication in the Black Sea region: Impact assessment and Causal chain analysis. Kalmar: University of Kalmar.

Bowen RE and Riley C, 2003. "Socio-economic indicators and integrated coastal management." Ocean and Coastal Management 46: 299 – 312.

Bridge G, 2001. Resource Geography. In International Encyclopedia of the Social and Behavioral Sciences, ed. Editors in Chief: Neil J. Smelser and Paul B. Baltes. Oxford: Pergamon pp. 13266 – 13269.

Burkhard B. and Müller F, 2008. Driver-Pressure-State-Impact-Response. In Encyclopedia of Ecology, ed. Sven Erik Jorgensen and Brian Fath. Oxford: Academic Press pp. 967 – 970.

Carrige S, 2009. “Triggering change in water policies.” Global Water Parnership Policy Brief (8).

Chapagain AK, Hoekstra AY, Aldaya MM and Mekonnen MM, 2011. The Water Footprint Assessment Manual: Setting the Global Standard. London: Earthscan.

EAA, 2011. Europe’s Environment: An Assessement of Assessments. Copenhagen: European Environment Agency.

Füssel HM, 2007. “Vulnerability: A generally applicable conceptual framework for climate change research.” Global Environmental Change 17: 155 – 167.

Gabrielsen P. and Bosch P, 2003. Environmental Indicators: Typology and Use in Reporting. In EEA internal working paper. Europen Environmental Agency.

GIWA, 2002. GIWA Methodology: Detailes Assessement - Causal Chain Analysis - Policy Options. Global International Water Assessment.

Gooch GD, Rieu-Clarke AS and Nhung DK, 2007. “A Multi-disciplinary Approach to Vulnerability Assessment and Transboundary Water Governance: The Case of the Sesan Basin.” presented at the International Forum on Water Environmental Governance in Asia on 14 - 15 March 2007, Bangkok, Thailand.

Hamouda MAA, 2006. Vulnerability Assessement of Water Resources Systems in the Eastern Nile Basin to Environmental Facors. Master’s thesis Cairo University, Institute of African Research and Studies, Department of Natural Resource.

Hamouda MAA, El-Din MN and Moursy F, 2009. “Vulnerability Assessment of Water Resources Systems in the Eastern Nile Basin.” Water Resources Management 23: 2697–2725.

Hema S, Subramani T and Elango L, 2010. “GIS Study on Vulnerability Assessment of Water Quality in a Part of Cauvery River.” International Journal of Environmental Sciences: 1–17.

Hoekstra AY, Chapagain AK, Aldaya MM and Mekonnen MM, 2011. The water footprint assessment manual: Setting the global standard, Earthscan, London, UK.

Huang Y and Cai M, 2009. Methodologies Guidelines. In Vulnerability Assessment of Freshwater Resources to Environmental Change. United Nations Environment Programme.

Huang Y, Cai M, Zhang J, Chandmani D and Cai J, 2008. Freshwater under tread: Northeast Asia. In Vulnerability Assessment of Freshwater Resources to Environmental Change. Nairobi: United Nations Environment Programme.

IPCC, 2007. Fourth Assessment Report (AR4) of the Internatinoal Panel on Climate Change. Cambridge University Press, Cambridge.

Jago-on KAB, KanekoS, Fujikura R, Fujiwara A, Imai T, Matsumoto T, Zhang J, Tanikawa H, Tanaka K, Lee B and Taniguchi M, 2009. "Urbanization and subsurface environmental issues: An attempt at DPSIR model application in Asian cities." Science of The Total Environment 407: 3089 – 3104.

Jun KS, Chung ES, Sung JY and Lee KS, 2011. "Development of spatial water resources vulnerability index considering climate change impacts." Science of The Total Environment 409: 5228 – 5242.

Karageorgis AP, Skourtos MS, Kapsimalis V, Kontogianni AD, Skoulikidis NT, Pagou K, Nikolaidis NP, Drakopoulou P, Zanou B, Karamanos H, Levkov Z and Anagnostou C, 2005. "An integrated approach to watershed management within the DPSIR framework: Axios River catchment and Thermaikos Gulf." Regional Environmental Change 5:1 38–160.

Kibaroglu A, 2008. Analysis of the Integrated Water Resources Management Approach: Turkey-EU Water Relations as A Case-study. Technical report Water Observation and Information System for Balkan Countries.

Kirstensen P, 2004. "The DPSIR framework." Environmental Research p. 10.

Kohsaka R, 2010. "Developing biodiversity indicators for cities: applying the DPSIR model to Nagoya and integrating social and ecological aspects." Ecological Research 25:925–936.

Kok MTJ and Jäger J, eds. 2007. Vulnerability of People and the Environment – Challenges and Opportunities (Background Report on Chapter 7 of the Fourth Global Environment Outlook). United Nations Environment Programme.

Li J, 2011. The spatial-temporal differences of regional urban land intensive use based on DPSIR framework. In 2nd International Conference on Artificial Intelligence, Management Science and Electronic Commerce (AIMSEC). pp. 835 –838.

Maxim L and Spangenberg JH, 2006. Bridging the gap between two analytical frameworks. Proceedings of the Ninth Biennial Conference of the Internatig". December 15-18. New Delhi, India. 20pp.

Maxim L, Spangenberg JH and O'Connor M, 2009. An analysis of risks for biodiversity under the dpsir framework. Ecological Economics, 69: 12 – 23.

Miller F, Osbahr H, Boyd E, Thomalla F, Bharwani S, Ziervogel G, Walker B, Birkmann JJ, Van Der Leeuw S, Rockström J, Hinkel J, Downing T, Folke C and Nelson D, 2010. Resilience and vulnerability: complementary or conflicting concepts? Ecology And Society, 15.

Mostert E, 2003. "The European Water Framework Directive and water management research." Physics and Chemistry of the Earth, Parts A/B/C 28: 523 – 527.

Ness B, Anderberg S and Olsson L, 2010. Structuring problems in sustainability science: The multi-level dpsir framework. Geoforum, 41: 479 – 488.

Nikitina E, ed. 2006. Russian Federation Water Code and Eu Water Framework Directive.

O'Connor M, 2006. "The "Four Spheres" framework for sustainability." Ecological Complexity 3: 285 – 292.

OECD, 1993. OECD core set of indicators for environmental performance reviews. OECD Environmental Directorate Monographs No.83. Paris: Organisation for Economic Co-operation and Development.

Rahaman MM, Varis O and Kajander T, 2004. "EU Water Framework Directive vs. Integrated Water Resources Management: The Seven Mismatches." International Journal of Water Resources Development 20: 565–575.

Rogers P and Hall AW, 2003. TEC Background Papers: Effective Water Governance. Stockholm: Global Water Partnership.

Savenije HHG and Van der Zaag P, 2008. "Integrated water resources management: Concepts and issues." Physics and Chemistry of the Earth, Parts A/B/C 33: 290 – 297.

Sekovski I, Newton A and Dennison WC, 2012. "Megacities in the coastal zone: Using a driver-pressure-state-impact-response framework to address complex environmental problems." Estuarine, Coastal and Shelf Science 96: 48 – 59.

Spangenberg JH, Martinez-Alier J, Omann I, Monterroso I and Binimelis R, 2009. "The DPSIR scheme for analysing biodiversity loss and developing preservation strategies." Ecological Economics 69: 9 – 11.

Strzepek KM, Yates DN and El Quosy DED, 1996. "Vulnerability assessment of water resources in Egypt to climatic change in the Nile Basin." Climate Research 6: 89–95.

Sullivan CA, 2011. "Quantifying water vulnerability: a multidimensional approach." Stochastic Environmental Research and Risk Assessmet 25: 627–640.

Svarstad H, Petersen LK, Rothman D, Siepel H and Wätzold F, 2008. "Discursive biases of the environmental research framework DPSIR." Land Use Policy 25:116 – 125.

Thomson B and Abdul-Mehdi A, eds. 2009. Water Resource Assessment of the Mora River. New Mexico: Water Resource Program.

Turner BL., Kasperson RE, Matson PA, McCarthy JJ, Corell RW, Christensen L, Eckley N, Kasperson JX, Luers A, Martello ML, Polsky C, Pulsipher A and Schiller A, 2003. "A framework for vulnerability analysis in sustainability science." Proceedings of the National Academy of Sciences 100: 8074–8079.

UN, 1996. Indicators of sustainable development. Framework and Methodologies. Technical report United Nations.

UNCED, ed. 1993. Agenda 21: Earth Summit - The United Nations Programme of Action from Rio. New York: United Nations.

UNEP and IISD, ed. 2011. Ecosystem Approaches in Integrated Water Resources Management (IWRM): A Review of Transboundary River Basins. Nairobi: United

Nations Environment Programme and the International Institute for Sustainable Development.

UNEP and WCR, ed. 2008. Vulnerability assessment of freshwater resources to environmental change - Africa. Nairobi: United Nations Environment Programme.

UNEP, 2006. Global International Waters Assessment: Challenges to International Waters – Regional Assessments in a Global Perspective. Nairobi: United Nations Environment Programme.

UNEP, ed. 2007. Global Environment Outlook: Environment for Development (Geo 4). Nairobi: United Nations Environment Programme.

UNESCO-IHP, 2011a. Methodology for the GEF Transboundary Waters Assessment Programme. Volume 2: Methodology for the Assessment of Transboundary Aquifers. Nairobi: United Nations Environment Programme.

UNESCO-IHP, 2011b. Methodology for the GEF Transboundary Waters Assessment Programme. Volume 4: Methodology for the Assessment of Transboundary River Basins. Nairobi: United Nations Environment Programme.

Varis O, Kummu M and Salmivaara A, 2012. "Ten major rivers in monsoon Asia-Pacific: An assessment of vulnerability." Applied Geography 32(2):441 – 454.

Villagrán DL and Carlos J, 2006. Vulnerability: A Conceptual and Methodological Review. In Publication series of United Nations University Institute for Environment and Human Security. Number 4 Bonn: UNU Institute for Environment and Human Security p.66.

Wang X, Li J, Shan S and Li C, 2009. Quantitative Assessment of Water Resources Vulnerability in Zhangjiakou region of Guanting Reservoir Basin, North China. In 3rd International Conference on Bioinformatics and Biomedical Engineering.

Webster TC and Roebuck L, 2001. Water Resource Assessment of Suriname. Technical report US Army Corps of Engineers, Mobile District and Topographic Engineering Center.

Wolf AT, 2003. "Water and Human Security."

Wolf AT, 2009. Hydropolitical Resilience and Vulnerability along International Waters: Europe. Nairobi: United Nations Environment Programme pp. 1–14.

World Water Assessment Programme. 2003. The United Nations World Water Development Report 1: Water for People, Water for Life. Paris: The United Nations Educational, Scientific and Cultural Organization.

World Water Assessment Programme. 2006. The United Nations World Water Development Report 2: Water a shared responsibility. Paris: The United Nations Educational, Scientific and Cultural Organization.

World Water Assessment Programme. 2009. The United Nations World Water Development Report 3: Water in a Changing World. Paris: The United Nations Educational, Scientific and Cultural Organization.

Wramner P, 2006. Global International Waters Assessment GIWA. Kalmar: Kalmar University.

WWAP, 2012. The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk, The United Nations Educational, Scientific and Cultural Organization, Paris.

Abbreviations and Acronyms

- AOS Atmosphere-Ocean System
- ATEAM Advanced Terrestrial Ecosystem Analysis and Modelling
- BSB Black Sea Basin
- BSC Commission on the Protection of the Black Sea Against Pollution
- CA Cellular Automata
- DDNI Danube Delta' National Institute
- DEM Digital Elevation Model
- DPSIR Driver - Pressure - State - Impact - Response
- EIS Energy-Industry System
- ESA European Space Agency
- ESRIN European Space Research Institute
- EU European Union
- FAO Food and Agriculture Organization of the United Nations
- GDP Gross Domestic Product
- GHG Greenhouse Gases
- GIWA Global International Waters Assessment - UNEP
- ICPDR International Commission for the Protection of the Danube River
- IMAGE Integrated Model to Assess the Global Environment
- IPCC-SRES Intergovernmental Panel on Climate Change - Special Report Emission Scenarios
- MCK Map Comparison Kit
- MODIS Moderate Resolution Imaging Spectroradiometer
- NUTS Nomenclature of Units for Territorial Statistics
- OECD Organization for Economic Co-operation and Development
- PRELUDE PRospective Environmental analysis of Land Use Development in Europe
- RCM Random Constraint Match
- REF EE Easter countries undergoing Economic Reform
- RIKS Research Institute for Knowledge Systems
- RIVM National Institute for Public Health and the Environment
- SOER European State of the Environment Report
- SRES Special Report Emission Scenarios
- TES Terrestrial–Environmental System
- UMA University of Malaga
- UNEP United Nations Environment Programme
- UNEP-GRID United Nations Environment Programme DEWA/GRID-Europe
- UNIGE University of Geneva
- UnWater United Nations World Water
- USS User Support Unit
- Water footprint An indicator of freshwater use
- WFA World Fire Atlas
- WFD Water Framework Directive
- WISE Water Information System for Europe
- WWDR4 United Nations World Water Development Report 4

Annexes

Annex 1: Cross-cuttings between DPSIR model and tetrahedral framework for sustainability analysis

	SOCIAL	ECONOMIC	ENVIRONMENTAL	POLITICAL
SOCIAL	*The Social Sphere* *Ideologies and Lifestyles* DRIVING FORCE Socio-economic "STRESSOR" (Social Vulnerability)			
ECONOMIC	Management Practices *Sustaining what and for whom? Employment, Work conditions, Distributional issues related to "environmental justice" conflicts* DRIVING FORCE Socio-economic "STRESSOR" (Social Vulnerability)	*The Economic Sphere* *Performance, Products and Output* DRIVING FORCE Socio-economic "STRESSOR" (Social Vulnerability)		
ENVIRONMENTAL	Living with(in) Nature *Role of environmental values in the social fabric* IMPACTS *on the Environmental Function "Scenery"* "IMPACTS" (Biophysical vulnerability)	PRESSURES on biodiversity Physical, chemical or biological "STRESSOR" IMPACTS *on Environmental Functions "Source", "Sinks", "Site" and "Scenery"* "IMPACTS" (Biophysical vulnerability)	*The Environmental Sphere* STATE CHANGES OF STATE *[of the Environmental Function "Life Support"]* "INHERENT VULNERABILITY"	
POLITICAL	Social Policy: Public awareness and participation, Policies for an ageing society RESPONSE "ADAPTATION"	Economic Policy: Shaping the rules and limits of markets RESPONSE "ADAPTATION"	Environmental Policy: Definition of risks in the environmental regulation RESPONSE "ADAPTATION"	*The Political Sphere* *Integration of biodiversity in policies, Efficiency in the implementation of policies for biodiversity protection* DRIVING FORCE Socio-economic "STRESSOR" (Social Vulnerability)

(Maxim and Spangenberg, 2006)

Annex 2: Proposed indicators for vulnerability assessment of water resources

Indicator	Application example	Description	Rational	Interpretation	Category	Data sources
Climate change		Change in precipitation and evaporation (both quantiy and variability)				enviroGRIDS Output WP3 (Scenarios of change)
Demography		Change in total population and population density				enviroGRIDS Output WP3 (Scenarios of change)
Land use change		Change in land cover pattern (Forest area, agriculture, vegetation cover)				enviroGRIDS Output WP3 (Scenarios of change)
Total actual renewable water resources	WWAP (2012)	The annualized total actual renewable water resource is the theoretical maximum annual volume of water resources available in a country.	The more water is available, the less it is likely that there is a shortage of water.	The less the higher the pressure	Quantity	enviroGRIDS Output WP4 (Hydrological models)
Waterfootprint	Mekonnen and Hoekstra (2011)	The total amount of fresh water that is used to produce the goods and services consumed by the inhabitants of the nation.	The likelyhood of water shortag increases as more water is evaporated, incoporated into a product,or diverted (Blue water footprint); evapotransaporated or incorportated into plants (Green water footprint); or required to assimilate the load of pollutants based on natural background concentrations and existing ambient water quality standards (Grey water footprint).	The higher the higher the pressure	Quantity	enviroGRIDS Output WP4; AQUASTAT
Total water withdrawal (sum of sectors)	WWAP (2012)	Annual quantity of water withdrawn for agricultural, industrial and municipal purposes. It includes renewable freshwater resources as well as potential over-abstraction of renewable groundwater or withdrawal of fossil groundwater and potential use of desalinated water or treated wastewater.	The higher the water withdrawal, the less water remains available	The higher the higher the pressure	Quantity	AQUASTAT
Sources of contemporary nitrogen loading	WWAP (2012)	Total and inorganic nitrogen loads as deposition, fixation, fertilizer, livestock loads, human loads and total distributed nitrogen to the land and aquatic system	This indicator provides a measure of potential water pollution by explicitly mapping out the extent of both natural and anthropogenic nitrogen loading to the land and aquatic systems.	The higher the higher the pressure	Quality	All data for this indicator is available from the Water Systems Analysis Group at University of New Hampshire (http://wwdrii.sr.unh.edu/download.html)
Water Pollution Parameter	Huang and Cai (2009)	Ratio between the total untreated wastewater discharge and the total water resources of a river basin	A higher ratio of untreated waste water discharge leasd to the degradation of freshwater quality.	The higher the higher the pressure	Quality	AQUASTAT; enviroGRIDS Output WP4 (Hydrological models)
Water resource variation	Huang and Cai (2009)	Coefficient of variation of precipitation over the last 50 years.	A higher variability of freshwater leads to a higher probability of temporary shortage of water.	The higher the higher the pressure	Variability	IPCC; AQUASTAT
Change inf forest area	Hamouda et al. (2009)	Change in forest area is the total percent change in both natural forests and plantations	Deforestation causes an increase in rainfall variability, soil erosion, and river sedimentation, thus an increase in vulnerability	The higher the higher the pressure	Variability	enviroGRIDS Output WP3
Ecosystem deterioration	Huang and Cai (2009)	The land ratio without vegetation coverage can be used to represent the contribution of ecosystem deterioration to the vulnerability of water resources	Vegetations cover prevents rainwater from immediet evaportion and run-off and enhances the infiltration into the soil and aquifiers. Thus, vegetation diminished water variability.	The higher the higher the pressure	Variability	enviroGRIDS Output WP3

Relative water stress index	WWAP (2012)	Domestic, Industrial and Agricultural water demand per available water supply per grid cell along river network. This indicator is also known as Relative Water Demand (RWD)	This indicator provides a measure of the water demand pressures from the domestic, industrial and agricultural sectors relative to the local and upstream water supplies. Areas experiencing water stress and water scarcity can be identified by relative water demand ratios exceeding 0.2 and 0.4, respectively.	The higher the more exposed	All	AQUASTAT; enviroGRIDS Output WP4
Index of non-sustainable water use	WWAP (2012)	Comparison of total and agricultural water demands to renewable water supply, indicating areas where non-sustainable practices may be occurring. [Renewable freshwater resources (streamflow) minus geospatially distributed human water demand]	This indicator provides a measure of the human water demand in excess of natural water supply (local runoff plus river flow).	The higher the more exposed	All	AQUASTAT; enviroGRIDS Output WP4
Water reuse index	WWAP (2012)	Aggregate upstream water demand/use per available water supply per grid cell along river network	With high values for this Index, we can expect increasing competition for water between users, both nature and society, as well as pollution and potential public health problems. The Water Reuse Index can vary greatly in response to climate variations. The reuse index reflects the aggregate impact of water competition throughout the basin. With such increased water scarcity and pressure of the resource based there is an increased propensity for: polluted water, governance problems, conflict, human health problems, downstream ecosystem stress, curtailment of economic activities (i.e. abandoning irrigation).	The higher the more exposed	All	AQUASTAT; enviroGRIDS Output WP4
Groundwater development as share of total actual renewable water resources	WWAP (2012)	Groundwater abstraction as a percent of the groundwater recharge component of the Total Actual Renewable Water Resources	This indicator can be used to evaluate whether there is potential for further development of groundwater resources or whether groundwater resources are overexploited. As a limitation, it has to be understood that volumes of renewed water resources cannot be directly related to volumes of water theoretically available on a sustainable basis.	The higher the more exposed	All	AQUASTAT; enviroGRIDS Output WP4
Environmental water stress	UNEP (2011)	Mean annual runoff minus environmental water requirement, divided by total withdrawals	This indicator considers the Environmental Water Requirement (EWR), or the water quantity aspect, including both low-flow and high-flow components. The indicator can be compared to the human and agricultural water stress indicators to see which issue is likely to be of greatest importance to the basin in terms of quantity.	The less the more exposed	Environment	International Water Managment Institute; enviroGRIDS Output WP4 (Hydrological models)
Human water stress (UNEP 2011)	UNEP (2011)	Water availability per person per year	This indicator deals with the quantity of water available per person per year, on the premise that the less water available per person, the greater the impact on human development and well-being, and the less water there is available for other sectors.	The less the more exposed	Society	AQUASTAT; enviroGRIDS Output WP3 and WP4
Agricultural water stress (UNEP 2011)	UNEP (2011)	Available water in the basin (accounting for water abstracted for domestic and industrial uses, and irrigation), divided by area of cropland	This indicator covers both rain-fed (implicitly) and irrigated (explicitly) agriculture. The proportion of irrigation indicates the dependency of agriculture in the basin on irrigation. Higher levels of irrigation will generally indicate higher levels of water withdrawal, less available water for other sectors, and potential vulnerability to decreases in rainfall as a result of climate change.	The less the more exposed	Economy	AQUASTAT; enviroGRIDS Output WP3
Storage vulnerability	Sullian (2011)	Water amount stored in dams per capita	Allows regulatin the water availability (Variability).	The lower the more sensitive	All	Global Reservoir and Dam (GRanD) database
Fish thread	UNEP (2011)	Total estimated fish harvest relative to expected fish productivity and the proportion of non-			Environment	FishBase database

		native species				
Coefficient of variation for climate moisture index	WWAP (2012)	The Coefficient of Variation (CV) Index for the climate moisture index (CMI) is a statistical measure of variability in the ratio of plant water demand to precipitation.	It is useful for identifying regions with highly variable climates as potentially vulnerable to periodic water stress and/or scarcity. Increased climate variability indicates larger year-to-year fluctuations, and hence, less predictability in the climate.	The higher the more sensitive	Environment	Water Systems Analysis Group (University of New Hampshire)
Access to improved sanitation	UNEP (2011) / WWAP (2012)	Proportion of population using an improved drinking-water source. Improved drinking-water sources include; piped water into dwellings, piped water to yards/plots, public taps or standpipes, tubewells or boreholes, protected dug wells, protected springs, rainwater.	Access to improved sanitation will be an indication of population health as the lack of improved sanitation often lead to an increase in water-related diseases, such as cholera and diarrhoea.1 There are also economic aspects to consider as the diseases related to poor sanitation prevent people from working.	The lower the more sensitive	Society	World Health Organization and United Nations Children's Fund, Joint Measurement Programme (JMP)
Access to improved drinking-water supply	UNEP (2011) / WWAP (2012)	Proportion of population using improved sanitation facilities. Improved sanitation includes flush toilets, piped sewer systems, septic tanks, flush/pour flush to pit latrines, ventilated improved pit latrines, pit latrines with slab, composting toilets.	Access to improved drinking-water supply will indicate the efficiency of the basin's water governance structure. It will also be an indication of the population health as the lack of improved drinking-water often lead to an increase in water-related diseases, such as cholera and diarrhoea.1 Access to improved drinking-water can also provide economic benefits if less time is spent on securing household water supply.	The lower the more sensitive	Society	World Health Organization and United Nations Children's Fund, Joint Measurement Programme (JMP)
Life expectancy	UNEP (2011)	Number of years a child is expected to live at the time of birth.	Life expectancy is an indication of the level of several functions and patterns in society. A higher life expectancy is an indication of a society where the population has access to nutritious food and healthcare.	The lower the more sensitive	Society	WHO
Percentage of undernourished people	WWAP (2012)	Percentage of people not having access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life.	The proportion of undernourished people provides a measure of the extent of the hunger problem for the region/country and thus may be considered a measure of food insecurity.	The higher the more sensitive	Society	FAO
Poverty rate	Hamouda et al. (2009)	Population below $2 a day is the percentage of the population living on less than $2.00 a day at 2005 international prices.	Poore people are more likely the suffer from fresh water related deseases. Equally they possess fewer possibilities to take measures concrete in case of water scarcity or pollution.	The higher the more sensitive	Society	World Bank
Water use efficiancy	UNEP (2011)	The indicator combines Gross Domestic Product (GDP)/capita/total withdrawals	A relationship between GDP and freshwater withdrawal where GDP values are high and withdrawal rates are low points towards efficient water use that is less likely to impact negatively on human and natural systems alike while still providing a basis for strong economic developmen. The most at-risk basins would have a low GDP and high water withdrawal.	The lower the more sensitive	Economy	CIESIN; World Bank
Dependency on agriculture	UNEP (2011) / WWAP (2012)	The proportion of agricultural GDP to total GDP for a basin.	Agriculture is globally the sector that consumes by far the most freshwater. Water is of key importance to sustain irrigation schemes that in many cases provide substantial contributions to national or basin economies.	The higher the more sensitive	Economy	World Bank; OECD
Dependency on fish catches	UNEP (2011)	Fish catch GDP / total GDP	The fishery sector is in many cases a substantial contributor to national and basin economies.	The higher the more sensitive	Economy	World Bank, FAO, and WorldFish Centre
Dependency on energy production	UNEP (2011)	Energy-related GDP divided by total GDP for the basin, based on per capita averages.	Energy production is crucial to development, and energy production generally requires significant amounts of reliable water supply. Thus basins highly reliant on water- related energy production may be more vulnerable to pressures.	The higher the more sensitive	Economy	US Energy Information Administration (EIA); World Bank

Irrigated land	WWAP (2012)	Area under irrigation as a proportion of total cultivated land	As a measure of the dependence of a country's or region's agriculture on irrigation, this indicator shows the vulnerability of that sector to water stress, which has implications for national food security depending on production and trade patterns.	The higher the more sensitive	Economy	World Bank
Indicator of dependence	Hamouda et al. (2009)	Inflow as ratio of total water availability	Dependence of country's water resources on inflow from neighbouring countries	The higher the more sensitive	Governance	enviroGRIDS Output WP4
River basin resilience	UNEP (2011)	Combination of type of treaty and membership of river basin organizations for each country basin unit, aggregated to the basin level based on population, area, irrigation area, and discharge	The level of institutional and regulatory capacity of a basin is critical to defining its resilience or vulnerability to climate change-induced water variability. This indicator assesses this capacity against the risk of variability. The results also indicate the potential for transboundary conflict within the basin, with low scores indicating greater potential for conflict.	The lower the more sensitive	Governance	Oregon State University (De Stefano, et al., 2010);
Adult literacy	(UNEP 2011)	Proportion of population aged 15 or above that can both read and write a short simple statement on their everyday life. The definition is taken from the HDR indicator on adult literacy.	Adult literacy will indicate the level of education in the basin and provide an indication of the knowledge capacity to deal with issues in the basin. An educated population can more easily take on the development challenges it faces, such as ensuring environmental sustainability, increasing productivity and empowering women and creating gender equality.	The higher the higher the adaption capacity	Society	UNESCO
Technicians in R&D		Technicians in R&D and equivalent staff are people whose main tasks require technical knowledge and experience in engineering, physical and life sciences (technicians), or social sciences and humanities (equivalent staff). They participate in R&D by performing scientific and technical tasks involving the application of concepts and operational methods, normally under the supervision of researchers.		The higher the higher the adaption capacity	Society	UNESCO
Researchers in R&D		Researchers in R&D are professionals engaged in the conception or creation of new knowledge, products, processes, methods, or systems and in the management of the projects concerned.		The higher the higher the adaption capacity	Society	UNESCO
Research and development expenditure		Expenditures for research and development are current and capital expenditures (both public and private) on creative work undertaken systematically to increase knowledge, including knowledge of humanity, culture, and society, and the use of knowledge for new applications. R&D covers basic research, applied research, and experimental development.		The higher the higher the adaption capacity	Society	UNESCO
Economic disparity	UNEP (2011)	The Gini index is an estimate of inequality. It measures the extent to which the distribution of income (or, in some cases, consumption expenditure) among individuals or households within an economy deviates from a perfectly equal distribution.	The level of inequality in a basin is an important dimension of welfare, and indicates likely levels of participation in governance, representation in public authorities, and capacity for sound environmental management where conflict may occur between welfare needs and environmental concerns. Gross inequality may lead to social or political unrest, which puts at risk efforts to create healthy, educated societies resilient to pressures on their water resources	The lower the higher the adaption capacity	Society	World Bank

Trends in freshwater habitat protection	WWAP (2012)	The percentage of area of different types of freshwater habitat set aside for protection over time, preferably from 1990 or befor	Protection of wetlands and aquatic ecosystems illustrates society's recognition of the importance of these ecosystems and their willingness to take concrete steps to protect these valuable resources.	The higher the higher the adaption capacity	Society	UNEP-WCMC
Economic capacity		GDP per capita	The financial resources determine wheter cost-intensive adaptive measures can be conducted or not.	The higher the higher capacity	Economy	World Bank; OECD
State Fragility		State Fragility Index	Indicator for the policy effectiveness.	The lower the higher the adaption capacity	Gouvernance	Country indicators for foreign policy. CIFP, Carleton University (Toronto)
Voice and Accountability		Captures perceptions of the extent to which a country's citizens are able to participate in selecting their government, as well as freedom of expression, freedom of association, and a free media	Indicator for the policy effectiveness.	The higher the higher the adaption capacity	Gouvernance	World Bank
Political instability		Political instability Index	Indicator for the policy effectiveness.	The lower the higher the adaption capacity	Gouvernance	Country indicators for foreign policy. CIFP, Carleton University (Toronto)
Political Stability and Absence of Violence		Measures the perceptions of the likelihood that the government will be destabilized or overthrown by unconstitutional or violent means, including domestic violence and terrorism	Indicator for the policy effectiveness.	The higher the higher the adaption capacity	Gouvernance	World Bank
Government Effectiveness		Captures perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies	Indicator for the policy effectiveness.	The higher the higher the adaption capacity	Gouvernance	World Bank
Rule of Law		Captures perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence	Indicator for the policy effectiveness.	The higher the higher the adaption capacity	Gouvernance	World Bank
Corruption		Corruption Perception Index	Indicator for the policy effectiveness.	The lower the higher the adaption capacity	Gouvernance	Corruption perception index. Transparency International (Bonn)
Control of Corruption		Captures perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as "capture" of the state by elites and privat interests	Indicator for the policy effectiveness.	The higher the higher the adaption capacity	Gouvernance	World Bank