Extended abstract

ENVIRONMENTAL IMPACT INDICATORS IN SYSTEMATIC MONITORING OF KARST AQUIFER – DINARIC KARST CASE EXAMPLE

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INTRODUCTION

The project DIKTAS (Protection and Sustainable Use of the Dinaric Karst Transboundary Aquifer System) funded by GEF and implemented by the UN agencies UNDP and UNESCO's IHP is focused on sustainable utilization of classical Dinaric karst aquifer and especially on issues of transboundary concern. One of the main problems identified during project implementation was the lack of systematically monitored data on quantitative and qualitative parameters of karstic aquifers regime. Although shallow aquifers in alluviums of large rivers are systematically monitored by hydrometeorological services of Dinaric countries (former Yugoslavia and Albania) little monitoring data is available on karstic aquifers. Some improvements have resulted from the implementation of the EU Water Framework Directive but in most of the region current monitoring programs which address groundwater (GW) levels and quality cannot provide adequate data for a reliable assessment of the quantitative and chemical status of GW bodies delineated in karstic aquifers (Stritih et al. 2007; Stevanović et al. 2012). Only in Croatia has the characterization of GW bodies been completed and is monitoring occurring mostly in accordance with requirements of the EU Water Framework Directive (WFD).

One of the tasks of the DIKTAS project was to prepare a proposal for the creation of a new Groundwater Monitoring Network in designated areas of transboundary concern which will fully respect specific karst behaviour. GW monitoring delivers information required for the assessment of long-term trends resulting from the alteration of natural conditions and human activity, as well as data needed to evaluate the effectiveness of programs of measures undertaken to improve the status of groundwater and water-dependent eco systems. It is therefore necessary to expand the existing groundwater monitoring network through the inclusion of GW user facilities (water supply systems, industry, agriculture) and to establish new monitoring sites. Monitoring data are to be used to verify risk assessments and complement human impact assessments.

ENVIRONMENTAL IMPACT INDICATORS

General aspects

Indicators are powerful tools for making important dimensions of the environment and society visible and enabling their management (Dahl, 2012). Water dependent ecosystems are essential components of the watersheds which are under increasing pressure from human activities. In karst, dependent ecosystems are exposed to greater potential hazard if they depend on water from aquifer. Although the problem of aquifer over-exploitation is often exaggerated (Custodio, 1992, Burke and Moench, 2000) variable water regime and low water flows during periods of maximal demands (summer months) can cause stress in many aquatic systems. The problem is much more sensitive when it comes to the area of transboundary concern (Chilton, 2002; Puri & Aureli, 2005).

There are many references and projects related to environmental indicators which cover different components of aquatic systems (including springs, streams, rivers, lakes, wetlands, coastal lagoons and estuaries). Some of the more recent, such as Vrba and Lipponen (2007) or UNECE (2007), pointed to a group of indicators helping to evaluate pressures on *water quantity* and on *water quality*.

In the GENESIS project, Preda et al. (2012) classify the following indicator packages:
- indicators of hydrogeomorphological units including groundwater: environmental tracers, water balance components, GW level and pressure, GW vulnerability, GW quality, river flow;
- indicators of physico-chemical components or even physico-chemical parameters as indicators: temperature, electrical conductivity, chlorophyll, concentration of different chemical compounds, dissolved oxygen, NO_3, NO_2, NH_4, PO_4, metals;
- indicators of biological compartments / trophodynamic modules: species richness of phytoplankton, macroinvertebrates, fish, diversity indices, indicator species, multimetric indices.

The main components of a designed indicators package are related to *groundwater state*, its quality, vulnerability and pressures, *dependent ecosystems state* and adjacent pressures within the catchment and their *groundwater dependency*. The GENESIS project introduced the term *Groundwater ecosystem protection area* defined as an administrative unit for ecosystem protection and impact assessment. Within these areas human impacts on groundwater quality and groundwater levels and flow patterns should be minimized or reduced below certain thresholds to protect the integrity of ecosystems (Preda et al. 2012).

The International Sava River Basin Commission (2011) which is also responsible for water management of the Inner Dinarides proposed the *List of monitoring parameters* adjusted to the WFD requirements. Core parameters are: oxygen content, pH value, conductivity, nitrate, ammonium, plus parameters which put GW bodies at risk of failing to achieve good chemical status.

Dinaric karst

By evaluating policy in SE Europe Stritih et al. (2007) highlighted the main issues applicable to Dinaric karst as well:

- How to secure a high level of protection of surface and groundwater, preventing pollution and promoting sustainable water use;
- How to secure funds for needed investments for water infrastructure and protection from pollution;
- What is appropriate institutional structure and division of responsibilities in water management.

Water is a major resource in Dinaric karst and is managed by different sectors and authorities in all concerned countries. Harmonization of national legislatives, legal and institutional reforms, creation of a common or unique *Water Information System* and protocol for data exchange are some of the proposals prepared in the Strategic Action Plan (SAP) of the DIKTAS project.

When it comes to concrete water and environmental impact assessment several efforts have been undertaken to develop meaningful indicators. DIKTAS diagnostic analysis has prepared an initial list comprising 23 different parameters for assessing pressures on GW quantity and quality and resulting pressures on dependent ecosystems in selected aquifers of transboundary concern. Their knowledge and observation should support sustainable water use and the protection of nature and ecosystems.

Table 1 – Environmental status indicators for selected Dinaric karst transboundary aquifers (TBAs)

No	Group	Indicator	Expressed as	Unit
1	**Water Resources Availability (Pressures on Water Quantity)**	Renewable freshwater resources	ratio: Total flow of surface and groundwater in the study area vs. Total rainwater in study area (TBA catchment)	mM^3/year : mM^3/year or %
1a		Renewable freshwater resources in recession (drought) periods	Sub-indicator: As above but in critical drought periods (summer-autumn)	mM^3/4 critical months : mM^3/4 critical months or %
2		"Domicile" (and "External") freshwater resources	ratio: Total flow of surface and groundwater generated in the part of TBA inside each country vs. Total flow of surface and groundwater in the entire TBA catchment	mM^3/year : mM^3/year or %
3		Renewable GW resources (Dynamic reserves)	ratio: Total flow of groundwater in the studied TBA catchment vs. Total rainwater in the studied TBA catchment	mM^3/year : mM^3/year or %
3a		Renewable GW resources (Dynamic reserves) in critical periods	Sub-indicator: the same as above but in critical drought periods (summer-autumn)	mM^3/4 critical months : mM^3/4 critical months or %
4		Water exploitation index	ratio: Total water amount utilized for different purposes[1] vs. Total renewable freshwater resources	mM^3/year : mM^3/year or %
5		Groundwater exploitation index	ratio: Total groundwater utilized for different purposes[2] vs. Total flow of groundwater in the study area	mM^3/year : mM^3/year or %
6		Water demands (availability)	ratio: Total water demands for different purposes[3] vs. Total renewable freshwater resources	mM^3/year : mM^3/year or %
7		Drinking water demands	ratio: Total water demands for drinking purpose vs. (1) Total renewable freshwater resources and vs. (2) Total flow of groundwater in the study area	mM^3/year : mM^3/year or %
8		Water available per capita	Water available (household water access) calculated per capita per year	m^3/cap/ year
9		Irrigation water demands and use	ratio: Total water used for irrigation purpose vs. Total	mM^3/year : mM^3/year

[1] Includes different end-users: Drinking water purpose; Irrigation; Industry; Hydropower; Water dependent eco-systems. The Indicator should be calculated for each consumer separately, but also expressed as (1+2+3) vs. (5)
[2] The same as above
[3] Demands to be calculated for each specific end-user as in the case of items 4 and 5.

			renewable freshwater resources	or %
10		Hydropower water use	ratio: Total water used for HP vs. Total renewable surface water resources	mM^3/year : mM^3/year or %
11		Groundwater depletion	Annual depletion of groundwater table (av. value) due to over abstraction. Punctually measured at selected points	m/year
12		Losses	ratio: Total water losses (non-utilized)[4] from the systems constructed for different purposes vs. Total tapped renewable freshwater resources	%
13	**Pressures on Water Quality**	Drinking water quality	ratio: Number of samples of raw drinking water (from the sources) with inappropriate quality[5] vs. Total number of the controlled samples	no : no or %
14		Industry waste water index	ratio: Flow of untreated industrial (incl. mining) waste water (returned to recipients) vs. Total flow of waste water generated in study area	mM^3/year : mM^3/year or %
15		Household waste water index	ratio: Flow of untreated domestic waste water (returned to recipients) vs. Total flow of domestic waste water in study area	mM^3/year : mM^3/year or %
16		Specific pollutants index	ratio: Concentration (average) of selected component (pollutant) vs. maximal permitted level of the same component (pollutant) [6] in drinking water	expressed in mg/l : mg/l (permitted level) or µg/l : µg/l (permitted level) or % of samples of inappropriate quality of cpec. comp. vs. total samples
17		Fertilizer index	ratio: Amount of mineral or organic fertilizers used per unit of arable land	kg/ha or tones /ha
18		Pesticide index	ratio: Amount of pesticide used per unit of arable land	kg/ha
19		Landfill status	ratio: Number of inhabitants in study area without sanitary proper solid waste dumps vs. Total population in study area	.000 : .000 or %
20		Water reuse	ratio: Reused or recycled water vs. Total flow of waste water in study area	mM^3/year : mM^3/year or %
21		Salt water intrusion (in coastal aquifers)	ratio: Total water flow - already salty, brackish or under direct threat of intrusion	mM^3/year : mM^3/year or %

[4] Note: Mostly referring to water transport. If water leaked from reservoir and is utilized downstream for another purpose this is not a loss.
[5] No compliance with drinking water standards for whatever reasons (microbiology, chemistry, specific comp.)
[6] Pollutant or specific component in concentration higher than permitted, such as NO_3, P or $PO_{3(4)}$, pesticides, PCB, turbidity, biology indicators, etc. List to be specified in accordance to actual situation within TBAs and in compliance with EU Water Frame Directive for surveillance and operational monitoring

			vs. Total renewable freshwater resources	
22		Protected habitat	ratio: Total surface of protected area vs. Total surface of study area	km^2 : km^2 or %
23		Water demands of dependent eco system	ratio: Total water demands for downstream dependent eco system vs. Total renewable freshwater resources-dynamic, or Total water demands for (WDES) vs. Minimal discharge	mM^3/year : mM^3/year or %
23a		Specific species Sub-indicators: Specific endemic and endangered species (list)	Specific water demands (flow) for endangered species throughout the year (e.g. trout)	Presence of protected endemic species – List

Not all the mentioned indicators have to be determined and followed; selection has to be made in accordance with local conditions. Some indicators are proposed to be observed on an annual basis such as: Renewable groundwater resources; Groundwater exploitation index; Groundwater depletion; while some others need frequent monitoring such as Specific pollutants index; Drinking water quality (by observing selected critical parameters); while others should be observed continously in an established GW Monitoring Network due to the specific intensive and variable regime of karstic aquifer systems. The number of monitoring stations and sampling frequency should be in accordance with EU WFD and European experiences (Jousma and Willems, 1996), proportional to the complexity of status assessment of the groundwater body and presence of pollution trends. In the case of Dinaric karst most of the monitoring sites should be located in drainage areas i.e. along basic levels of erosion and near recharge (ponors) and extraction sites (well fields, intakes).

GENERAL SETUP FOR MONITORING NETWORK IN SELECTED TBAs

The general setup for a Monitoring Network in designated areas of transboundary aquifers should primarily include the following "hydro" parameters:

1. *Rainfall* and other climate elements (air temperature, humidity, wind, evaporation) observed on a daily basis.
2. *Riverflow* observed on a daily basis – limnigraphs for automatic recording or classical gauging stations installed on major rivers and streams in each country sharing TBA (entrance / exit stations).
3. *Springflow* observed on a daily basis – as above, the limnigraphs for automatic recording or classical gauging stations installed on major springs within TBA.
4. *Groundwater table* observed on a daily basis – automatic data logger ("diver") for groundwater table recording installed in piezometers properly selected to represent aquifer system in recharge/discharge areas in both countries sharing TBA. In addition, a classical manual recording of the groundwater table on a daily/weekly basis (depending on wet/dry seasons) should also take place on the piezometers of the 2nd rank.
5. *Water quality* control is to be organized in compliance with EU WFD requirements for surveillance and operational monitoring. Sampling frequency and the number of observed parameters (salinity, chemistry, turbidity, biology, specific components and pollutants) are to be adapted to local circumstances and pollution risks. As a minimum in the initial stage (surveillance) a set of the complete analyses is to be organized on major springs, streams and piezometers twice a year (high and low water periods).

To be able to define other environmental impact indicators in addition to the above "hydro" parameters, relevant information on surface waters and groundwater regime (quantity and quality) should be collected and provided on a regular basis to the responsible authorities and local water management institutions such as water agencies, hydrometeorological surveys, health and sanitary control centres, and municipalities. Groundwater monitoring and data collection must be the task of all those using groundwater for drinking and process water purposes.

Some demonstration sites in Dinaric karst are already identified and proposed for the installation of a modern monitoring network for observation of karstic groundwater and for climate elements and surface waters regime. Establishment of similar national water information systems, data exchange protocol, synchronization of legislation in the water sector, harmonization of criteria for GW protection and definition of ecological flow, and an experts working group are some of the proposed activities to take place beyond this stage of DIKTAS project.

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