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Analysis for sustainability in management of water scarce basins: the case of the Gediz River Basin in Turkey

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Abstract

River basins in many Eastern and Southern Mediterranean countries suffer from water scarcity due to rapid demographic and economic development, urbanization, industrialization, tourism, and inefficient agricultural activities, which is often the dominant water user. The Gediz River Basin along the Aegean coast of Turkey demonstrates the entire range of prototypical water management problems and reflects the importance of the institutional and regulatory framework, and the need for direct participation of major actors and stakeholders in the decision making process. The case is studied within the scope of two EU INCO projects: SMART (sustainable management of scarce resources in the coastal zone) and OPTIMA (optimization for sustainable water management), sponsored by EU FP5 and FP6 Programs, respectively. The paper aims to present the results of SMART for the Gediz Basin, where the current situation and possible future changes in domestic, industrial and irrigation water demands and supply are estimated on the basis of prevailing trends. The outputs of OPTIMA, which are basically a continuation of SMART, are not covered herein as the optimization procedure within this project is still in the phase of development.

Keywords: Optimization; Simulation; Sustainability; Water management; Water scarcity

1. Introduction

Water scarcity is a major problem in most river basins of the Eastern and Southern Mediterranean due to rapid demographic and economic development, urbanization, industrialization, tourism, and inefficient agricultural activities, which is often the dominant water user. The situation is aggravated by low availability of renewable water, overexploited groundwater, pollution, inefficient infrastructure, and pronounced seasonality with unfavorable demand

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Fig. 1. The location of the Gediz River Basin in Turkey.

patterns which are very different from the seasonal supply.

The Gediz River Basin along the Aegean coast of Turkey (Fig. 1) is a typical case where two major problems, water scarcity and pollution, need to be addressed for sustainable management of its water resources. The basin covers about 18,000 km^2 and approaches a total population of 2 million. The case demonstrates the entire range of prototypical water management problems in the region, and their potential solutions. The basin is engineered into extensive water resources systems, the major one being irrigation over 110,000 ha of agricultural land (Fig. 2). The existing water resources are under pressure by rapid industrial development, population growth, related increases in agricultural production, and pollution. To provide water for different sectors, to maintain the sustainable development of the region and to assess the long-term impacts of water policies, domestic, industrial, irrigational, and environmental water demands should be evaluated in terms of existing trends and possible future tendencies in water use. The case also reflects the importance of the institutional and regulatory framework, and the need for direct participation of major actors and stakeholders in the planning and decision making processes. A common shared and reliable information basis is a central element of the participatory approach.

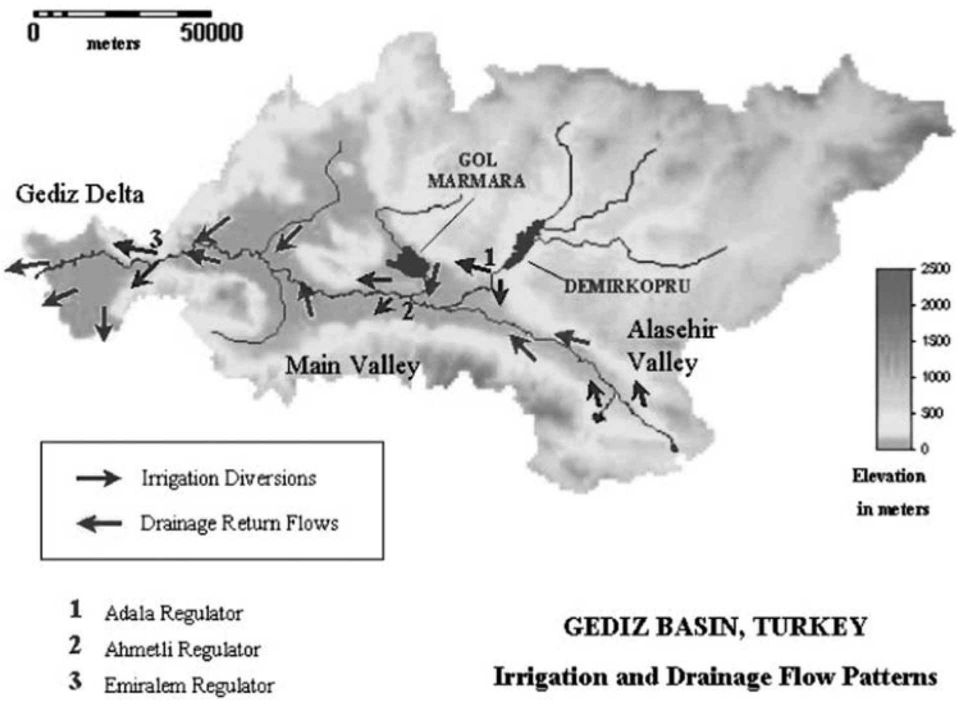

Fig. 2. The layout of the Gediz River Basin in Turkey.

The case is studied within the scope of two EU INCO projects: SMART project supported by European Union FP5 Program and OPTIMA sponsored by EU FP6 Programme. The paper aims to present the methods and the obtained results of the SMART project for the Gediz Basin, where the current situation and possible future changes in domestic, industrial and irrigation water demands and supply are estimated on the basis of prevailing trends. An annual water budget simulation model called WaterWare (provided by Environmental Software Systems-ESS, Austria) is used to determine the performance of the existing river network system in terms of the available water. The analysis is mainly based on comparison of alternative water management scenarios.

The studies on water management in the Gediz are continued within the OPTIMA project, where a simulation based water resources planning and optimization system is being developed and applied to address quantity and quality, water demand and supply, surface and groundwater, water technologies and efficiency of use, allocation strategies, costs and benefits. A web based client-server implementation supports distributed use and easy access, and a participatory approach involving local stakeholders for multi-criteria optimization and decision support. The underlying dynamic (daily) simulation model, i.e. WaterWare, describes the water resources systems at a basin scale including the groundwater system for conjunctive use. The model not only covers the physiographic and hydrological elements, but also aims to represent the institutional and regulatory framework, and the socioeconomic driving forces. As the optimization studies within the OPTIMA project are still being developed, it has not been possible to cover OPTIMA Gediz case study within the scope of this paper.

SMART and OPTIMA projects support EU Water Framework Directive (2000/60/EC) so that the case study presented is essentially one of the initial studies where implementation of the Directive is demonstrated on a Turkish river basin. In that regard, the current work is expected to contribute significantly to activities in the Turkish environmental sector which is still in the adaptation phase of European policies.

2. Studies covered by the SMART project

The SMART project, which was implemented between 2002 and 2005 with the support of EU FP5 Programme, served to explore methods and tools for long-term policy analysis and strategic decision support for integrated coastal development with special emphasis on water resources and land use, and the resource balance between the coastal region and inland areas [1]. The SMART approach is based on a multi-sectoral integration of quantitative and qualitative analysis, combining advanced tools of quantitative systems engineering based on numerical simulation models, with methods of environmental, socioeconomic and policy impact assessment using rule-based expert systems technology and interactive decision support methods. Water resources modeling, including both quantitative and qualitative aspects has provided the framework for policy scenarios, exploring different development strategies, the consequences and implications of demographic, socioeconomic, and technological development, and the interaction of these driving forces towards long-term sustainability of the coastal regions and their hinterland.

The SMART project has provided the smooth integration of advanced quantitative tools based on applied systems analysis and information technology, such as the state-of-the-art simulation and optimisation models and expert systems technology, into the sociopolitical and economic framework of regional development planning and public policy with its uncertainties, qualitative criteria, and conflicting objectives.

The central model of SMART is a dynamic, basin wide water resources model within the WaterWare system [2]. The main elements of WaterWare, which are operational in a web environment accessible with a standard web browser, and the associated online manual pages include the Land Use Change Model (LUC), the Rainfall-Runoff Model (RRM) and its automatic calibration tool (RRMCAL), and the water resources model (WRM). The water resources model of WaterWare uses a topological network representation of a river basin, consisting of various node types and the river reaches and canals connecting them. Nodes represent objects such as sub-catchments, reservoirs, wells, diversions and confluences and areas of water demand such as cities, tourist resorts, irrigation districts, and large industries. The surface water network can be coupled to one or more aquifers to represent conjunctive use scenarios. Control nodes keep track of flows versus targets or constraints and can represent both minimum flow requirements, environmental water demands such as for the nourishment of wetlands, as well as flooding conditions with arbitrary penalty functions.

3. Gediz case study

3.1. Socioeconomic analysis

Water demand projections required by SMART are based on an integrated analysis including social, economic, and institutional perspectives. Accordingly, socioeconomic data for the Gediz Basin are compiled to contribute to both the socioeconomic analysis and the development of basin management scenarios.

Four tasks are identified in the socioeconomic analysis:

(1) Population, demographic and migration policy analysis.
(2) Political and economic options adopted for the study area.
(3) Competing water uses.
(4) Economic analysis of water resources.

For each task, socioeconomic data are compiled and processed to derive various indicators representing the tasks. In Task 1, population dynamics are identified on the basis of demographic parameters and projections, such as those related to birth, death, migration, and their trends in the past. In particular, migration policies are analyzed, and it is observed that a limiting migration policy has different effects on population growth from those imposed by a free migration policy. The purpose of Task 2 has been to analyze the institutional structure of water quantity and quality management in the basin; thus, planning and management policies, instruments and their levels in the region are studied to include also the level and pattern of economic growth. It is therefore intended in Task 2 to analyze the basic policies and options for economic growth that lie at the origin of competing uses of water. The consequences in terms of labor demand are also important issues to understand the changes in regional dynamics and expected developments. Analysis of basin stakeholders and their interests, along with the identification of water demands, are performed within the scope of Task 3. The economic and demographic structures of the rural/urban interface are investigated in terms of their consequences for multi-sectoral current and projected water demand, and the implied conflicts. In Task 4, costs of water supply are included in the analyses, considering the possible differences between costs of domestic water, irrigation water, industrial and other needs (e.g., aquaculture) [3].

It must be noted that data needs of the above tasks are extensive, and difficulties have been experienced in compiling some of the required data for the analyses due to the scattered, incomplete and unreliable nature of available data sets for the Gediz Basin. For example, no data are available on industrial income distribution and growth of Gross Domestic Product (GDP) at regional or municipal scales. Along the same line, domestic water consumption is different in each of the 36 municipalities in the Gediz Basin due to varying life-styles. Another problem encountered is the lack of sufficient information on groundwater use; in general, data on groundwater use are not recorded but roughly estimated. Similarly, water consumption in commercial and industrial units is not known; hence, it is estimated roughly on the basis of per capita values, regarding the total water budget along the basin. On the other hand, costs of agricultural water consumption are not fixed; irrigation water is allocated by State Hydraulic Works (DSI) for free, but Irrigation User Associations decide upon the fees, regarding maintenance, operation and management costs in the irrigation schemes. Industrial units receiving water from municipal water distribution schemes pay approximately 0.90 €/m^3, but no cost is defined for groundwater use. In Gediz, new investments on reservoir storage are not planned except for the two reservoirs which are currently under construction. Furthermore, no data are available on investments for treatment and water distribution schemes [3].

3.2. Scenario development

In SMART, three dimensions, namely economic, social and environmental, are considered as pillars of sustainability, and it is emphasized that sustainability lies in the cross-section of these three dimensions. Accordingly, a significant part of efforts identified for SMART is devoted to the development and comparison of management scenarios for the selected case study area, regarding sustainability criteria. Three types of scenarios are considered after determining the current status of the basin as: (a) business as usual (BAU); (b) optimistic (OPT), and (c) pessimistic (PESS).

The business as usual scenario assumes the continuation of existing trends and depends on the current dynamics of the study area. The optimistic scenario foresees improvement in the existing policies and trends and focuses on the environment. On the other hand, in the pessimistic scenario, it is assumed that population trends may increase the pressure over water use and that there is an aggravation of existing policies and trends that may have harmful effects over water. Each scenario is designed on the basis of the "Water Demand Framework" as shown in Fig. 3. For each scenario, sustainability indicators are determined, and then all scenarios are compared to each other.

In the Gediz Basin, domestic, agricultural and industrial water demands constitute the main types of water consumption along the entire basin. Nearly 100% of available water is consumed by these three sectors. While domestic and industrial water demands are met by groundwater resources, almost 75% of surface waters is utilized by irrigation schemes [4].

Domestic water demand has increased within the past years because of high immigration rates from rural to urban areas. Immigration has also resulted in rapid development in urban areas so that most of the infrastructural investments have become insufficient. Increases in industrial water demand depend mainly on the accelerated growth in industrial areas, especially in Manisa Province and Kemalpasa districts. Water needs of the industry are met by groundwater, but no records of consumption are available. The increase in agricultural water demand is caused by high losses in the existing irrigation schemes and to a certain degree, by changes in crop patterns. The driving forces considered for increases in these three main types of water consumption are summarized in Fig. 4 [4].

The baseline variables/driving forces are considered for development of three scenarios: business as usual (BAU), optimistic and pessimistic

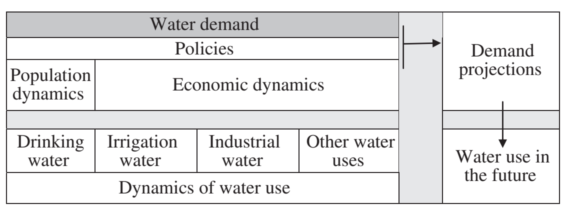

Fig. 3. Framework for water demand projections.

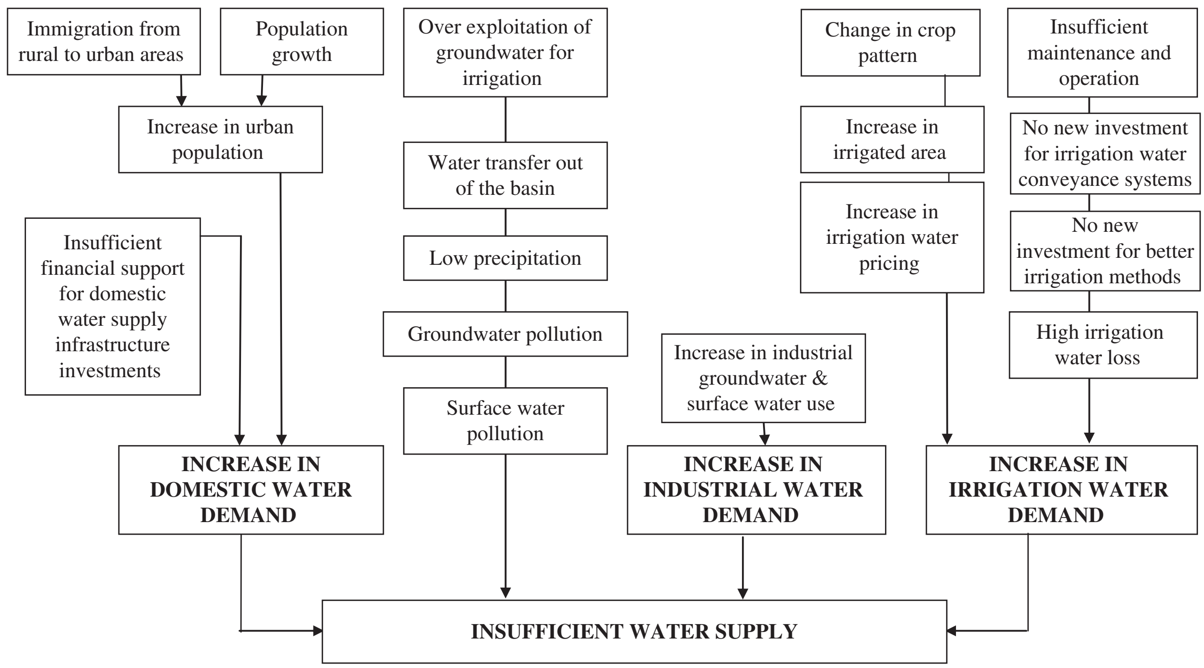

Fig. 4. Driving forces leading to insufficient water supply.

for the Gediz Basin as in Table 1, for which the following assumptions are made [4]:

- There is an existing and successful birth control policy in Turkey. In scenario development, birth control is taken into consideration for BAU and optimistic scenarios. In rural areas of eastern Turkey, birth control is not fully successful; hence, such a situation is also developed in the pessimistic scenario although Gediz Basin is not in the eastern but in the western part of Turkey.
- The high immigration rate from rural to urban areas is reflected in the pessimistic scenario as an increased urban population growth rate. For the optimistic scenario, birth and death rates are balanced in urban areas where only immigration is considered since there has been a descending trend in the rural population over the last 10 years.
- Decreases in the average precipitation rate are considered only in the pessimistic scenario, regarding the historical drought periods that lasted more than 6 years with a decrease of 40% in precipitation.
- Both the groundwater and the surface water supplies are considered in the pessimistic scenario as they both decrease when precipitation decreases.
- Water is transferred out of basin to meet Izmir municipality's domestic water needs; furthermore, there is an on-going project (Gordes Reservoir), which will also supply domestic water to the city of Izmir.
- Increases in domestic water use are foreseen for both the optimistic and the pessimistic scenarios due to expected increases in immigration and improving life standards.
- Irrigation water use is expected to decrease with a possible adoption of better irrigation methods in the optimistic scenario; in the pessimistic scenario, an increase is foreseen due to worse management policies, crop pattern changes, and insufficient public awareness.

Table 1
Scenarios developed for the Gediz Basin

Variables/driving forces	Baseline	BAU	Optimistic	Pessimistic
Birth control	Existing	Existing (partially successful)	Existing (successful)	Existing (unsuccessful)
Urban growth rate	1.5%/y	1.5%/y	1%/y	3%/y
Rural growth rate	–1%/y	–1%/y	–1%/y	–2%/y
Precipitation rate	700 mm/y	0%	0%	–10%
Groundwater supply	9 mm/y	0%	0%	–10%
Surface water supply	59 mm/y	0%	0%	–10%
Groundwater pollution	Class IV	Class IV	Class III	Class IV
Basin-out water supply (surface & ground)	0.2 mm/y	0.2 mm/y	0.4 mm/y	0.5 mm/y
Domestic water use (surface & ground)	7.4 mm/y	0%	0.5%/y	2.5%/y
Industrial water use (groundwater)	3 mm/y	0%	4%/y	8%/y
Irrigation water use	39 mm/y	0%/y	–40%	15%
Domestic water supply investments	Sufficient	Sufficient	Sufficient	Insufficient
Change in crop pattern	Cotton, grape, maize	Cotton, grape, maize	Grape, vegetable, maize	Cotton, grape
Irrigation m/o investments	Insufficient	Insufficient	Sufficient	Insufficient
Loss rate in irrigation system	30%	30%	10%	30%
Irrigated area	1070 km^2	0%	0%	0%
Industrial water use (surface)	0 mm	0 mm	4 mm	4 mm
Surface water quality	Class IV	Class IV	Class III	Class IV
Water exploitation awareness	Insufficient awareness	Insufficient awareness	Comprehensive awareness	Insufficient awareness

- In the optimistic scenario, irrigation water loss rate decreases due to development of better conveyance systems and sufficient maintenance.
- No change in irrigated area is expected, as urban areas are growing.
- There is a dam under construction, which will supply industrial water; hence surface water is also expected to meet increasing industrial water demand.

4. Conclusions

Considering the current water-consuming activities in Gediz Basin, the results of SMART scenarios have shown that irrigation demand is affected and it will be the most affected one in the future by water scarcity. Furthermore, when water scarcity occurs due to natural drought conditions, industrial water demand cannot be met due to low groundwater levels. Changes in crop patterns do not significantly affect the irrigation demand. On the other hand, improvement of the irrigation schemes, either in conveyance systems or in the method of field irrigation, is positively reflected in the water budget of the basin. This is due to the fact that 75% of the surface waters are consumed by irrigation. The current efficiency of the irrigation schemes is in the order of 60–70%; but this figure may be increased to 90% if improvements in the irrigation systems can be realized. Following from the above point, system reliability in scenarios with no irrigation system improvements (pessimistic scenarios) remains below 80%; whereas it increases to above 90% for BAU and optimistic scenarios.

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