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Sustainable water resources management under water-scarce and limited-data conditions

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Abstract

Urbanization and population growth increase the demand for freshwater abstraction, food production, rising thus the agricultural, economic, and productivity expectations. The need for improved water services, sustainable and resilient management under changing climate, are major drivers to set forth the redesigning of water planning. Water scarcity combined with the limited expansion of new infrastructure create competition among water uses and further stress the satisfactory coverage of the increasing needs. Integrated modeling is a way to simulate and address the above challenges, however, poor monitoring, incomplete databases, and complexity make its applications difficult. Questions such as what data to use, how to best exploit the (limited) available databases, what parameters to calculate, and how to satisfy both economic and environmental objectives, occur. This study presents a novel Decision Support System (DSS), combining hydrology, economics, engineering, and social aspects, aimed to participatory management, using simple concepts, and discussing assumptions for working with limited data, and useful parameters to estimate. Water availability and demand, water quality, profits, costs, and management scenario analysis, including nature-based solutions, are explored under climate change scenarios, and alternative policies are evaluated. The combination of the above and the useful modeling insights, under water- and data-scarcity conditions are novel elements, while the aim is to encourage integrated and sustainable water resources management through understandable and user-friendly DSSs.

Keywords: Integrated Water Resources Management, Decision Support System, hydro-economic modelling, nature-based solutions, climate change, MultiCriteria Analysis.

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1. Introduction

Modern water resources management in water scarce areas is called to find the right balance between exploiting the available (often limited and deteriorating) resources and infrastructure to satisfy increasing productive-economic expectations. Limited water resources available, often facing pollution, lack of investments to improve services, and human resources, combined with the expected climatic changes decrease the available and directly exploitable amount of water. On the other hand, increasing water demand, irrational use, non-point pollution, and poor management are making the situation more complex. The above are usually more visible in rural basins.

Several studies have dealt with the need of simulating the above factors and providing sustainable policy recommendations to Decision-Makers (DMs), usually by developing Decision Support Systems (DSS). Alternative ways of water allocation, conjunctive use of surface and groundwater resources, are examined as a basis, on which socio-economic, legislative and climate change aspects are still building on (Peña-Haro et al., 2009; Volk et al., 2008; Esteve et al., 2015). Holistic tools including all the above aspects, providing at the same time dynamic user-interaction systems, involving DMs from the early stages, are still a challenge. The last 20 years several DSSs have been developed: “Mulino” from Giupponi et al. (2000; 2004) for integrating EU’s legislation objectives and environmental impacts, using geo-spatial information and MCA; “MODSIM” (Labadie et al., 2000) introduced a more solid mathematical background for distributing system's flows, while packages such as “Basins” (U.S.E.P.A., 2001), “Ribasim” (Delft Hydraulics, 2006), and “WEAP” (Sieber et al., 2005) focused on watershed characterization and hydrologic behavior and management scenarios comparison. The “DSS for Water Resources Planning Based on Environmental Balance” (Progea S.r.l., 2001) also considered legislation aspects. “Hydro-nomeas” (Koutsoyiannis et al., 2002) was based on integrated system's simulation and optimization, and “MIKE Hydro Basin” (DHI, 2014) included water quantity, quality, demand, and optimization of the system. More specifically oriented packages were also developed depending on the purpose, e.g. “WaterStrategyMan” (WaterStrategyMan Project, 2005) approaches water systems from the economic point-of-view (e.g. cost recovery, pricing policies), or “WARGI” (Sechi and Sulis, 2009) for system's flows simulation under different hydrologic scenarios. However, the applications are limited, remain in the academic cycles, and do not gain any practical acceptance, due to their complexity and data requirements (Badham et al., 2019). Modelers often wonder how to exploit the limited available data, which parameters can be estimated to describe representatively the situation they are facing, and what strategies can satisfy both economic and environmental objectives with low costs.

This study uses simple hydro-economic tools to address the above challenges and answer to these questions, through an Integrated Decision Support System (DSS), that can be flexible in terms of input data and outputs, depending on the case study and its specific characteristics. Water demand, availability and balance, economic aspects, water value, water quality, management strategies, including a coupled GIS- MultiCriteria Analysis (MCA) tool for evaluating nature-based solutions' usefulness, and future climate change scenarios can be considered. The DSS uses MCA, involving experts on water resources management and local decision-makers (DMs). Overall, assumptions for working with limited data are discussed, a number of useful parameters to estimate is justified, and tools-software that one can use are mentioned. The methods have been successfully implemented in South-European, Central-Asian, and North-American basins, but this is the first time that the framework is presented as a whole and single conceptual approach, designed for rural communities facing water scarcity and data limitations. This is considered very topical and crucial issue in Central Asian watersheds (Sehring, 2015; Thalmeinerova, 2015). The ideas and principles that led to the DSS's successful application are also discussed, encouraging the development of more understandable, applicable, user-friendly DSSs, using simple user-familiar terms, and paving the way for a dynamic cooperation between DMs and experts towards sustainable management.

2. Materials and Methods

The experience shows that custom-made DSSs are more likely to be applied rather than the developed packages (examples mentioned above) because case-specific factors and data availability often define and guide the modeling process (Hajkowicz and Collins, 2007; Raseman et al., 2016). Each model's driver must be its purpose-output. Starting from what the model needs to inform us, leads to the main parameters that can be used as outputs, which can then be estimated to the degree that data availability allows. At this point the flexibility is necessary, as sometimes assumptions need to be made for the estimations or alternative outputs must be considered for the same purpose. Based on the main common features of Central Asian rural basins regarding hydrological and management (and data) practices, while having in mind their specific characteristics, the basic and usually useful outputs are set (Fig.1): Estimating water requirements, water value and quality, and stakeholders' profits are essential, and their knowledge facilitates evaluating the effect of different options for balancing environmental and economic objectives. They are also 'versatile' parameters, since they can be easily estimated for other water uses. Including costs (e.g. direct, implementation and opportunity costs) has proved to be of great interest and influence to DMs' plans. The first two costs can be estimated in detail depending on the data, but also a proxy can be used based on past experience and experts' judgement, in case of no data. Opportunity costs need more detail, however, their added value when comparing management options is significant. Since these are estimated, they can be used as criteria for the evaluation of the alternative management options based on their performances (MCA model).

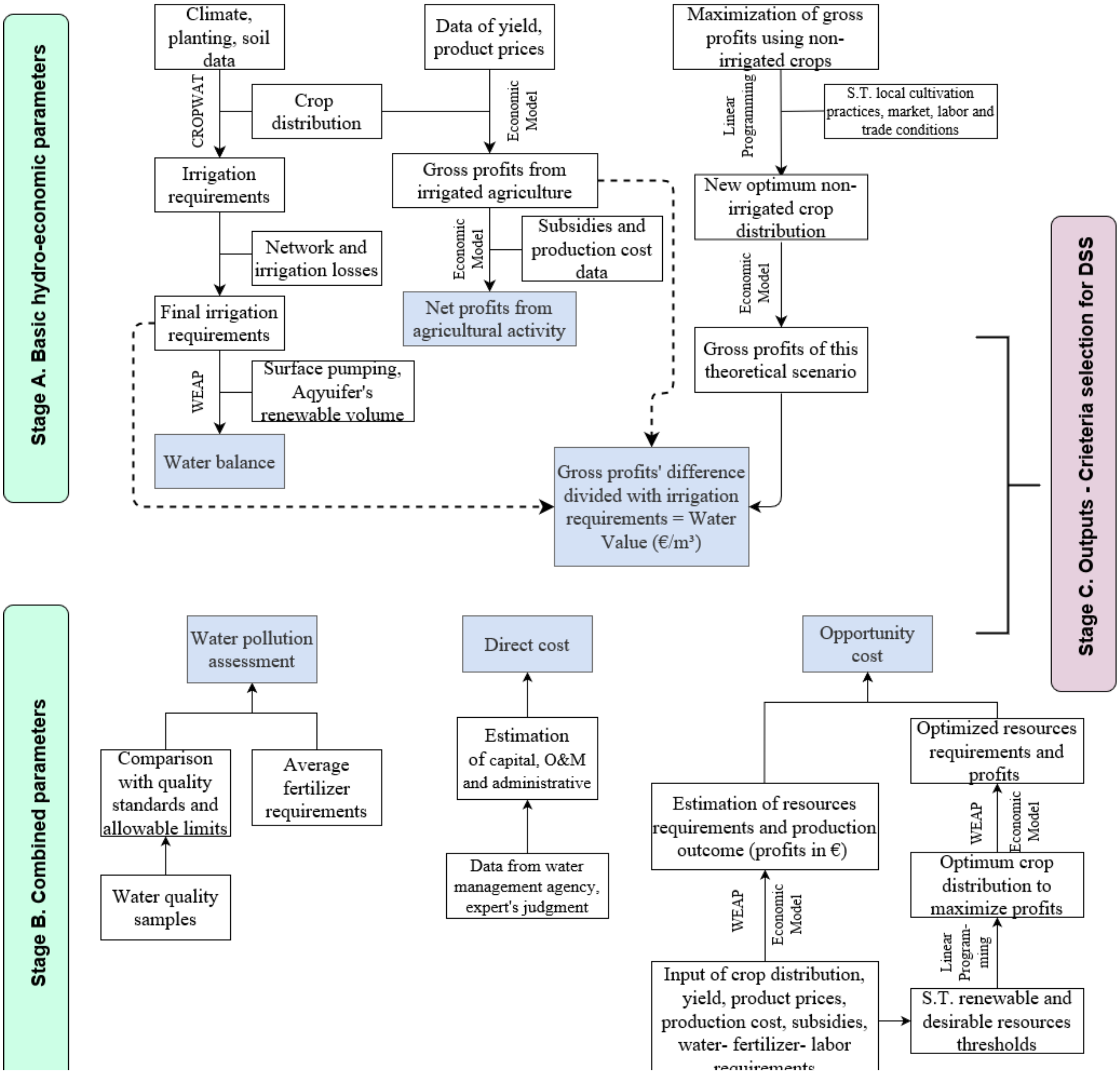

Figure 1. Extended conceptual framework (S.T.="subject to" for stating optimization constraints). The example refers to irrigated basins (as complex and data-hungry cases), and the tools (software) are indicative.

The aim is the minimum data requirements and the higher accuracy based on modeling experiences. There can be many and different paths for the above, but since there is no commercial DSS including all of them, we present a combining approach using an indicative set of tools. Both the paths and the tools of Fig.1 are indicative and must be flexible. In this section the methodological framework and theory is briefly explained, and in the next section application examples are following:

i) Water balance

For the surface and groundwater availability, and also renewable volumes (i.e. rainfall and infiltration) simple hydrological models, more complex aquifer models, or simply the design study of each area's supply source (pumping stations, reservoirs, etc.) can be used. Regarding water demand, the irrigation requirements from the crops' areas can be considered from average relevant tables, or modeling can be used. A simple case as recommended here, was used to develop a single CROPWAT (FAO, 2015) and MS Excel model of the method Blanney-Criddle (Blaney and Criddle, 1962). Irrigation requirements were increased by the respective losses' coefficients for the network and the irrigation methods efficiency, as they were found from field surveys. Very basic meteorological, soil, cropping, network and irrigation data are required, while CROPWAT provides default values to try, while always comparing the results to previous estimates, can result in more accurate estimations. Other water uses' demand can be calculated from respective average consumption tables and specific consumption data. Given water supply and demand, the water balance can be easily calculated, as their difference.

ii) Profits from agricultural activities

A straightforward logistic model is demonstrated for the estimation of Net Profits (NP) (Eq.1):

$$NP = GP - TPC \tag{1}$$

Where GP stands for Gross Profit and TPC for Total Production Cost. GP are the sum of gross revenue (selling a unit of product at the current product prices) plus subsidies. TPC of each crop is considered as the sum of expenditures incurred for producing one unit of product (e.g. costs of lubrication, herbicides, seeds, sprays, defoliants, harvesting cost, pumping costs, electricity, oil, labor, planting cost, mechanical operations, and agricultural deductions). For both GP and TPC, other proxies can be used in case of lack of data, such as older estimations, field surveys (crispy data) or statistical values.

iii) Water value

The literature of Environmental Economics has examined the water value estimation through several methods. This literature is a starting point to be reviewed before application, in order to choose the most appropriate each time. "Net Income Change" method is a way to indirectly estimate the irrigation's value in agricultural income in this example, because it can be performed with very few data, while avoiding time-consuming questionnaire surveys, and exploits parts of the two previous outputs. It compares NPs between a baseline (BAU) Scenario and a non-irrigated scenario, with all other factors remaining constant. The only difference between the two scenarios is solely due to the irrigation water (Gibbons, 1986). The non-irrigated scenario used the corresponding non-irrigated crops to the existing ones, as they occurred from linear programming maximizing profits, subject to cultivation, labor, and market constraints (Latinopoulos, 2006).

iv) Water quality

This step includes collecting and editing data from sampling stations (surface or groundwater, or both depending on the area). The detected pollutants concentrations are compared with their allowed limits (thresholds), identifying thus which actions should be restricted. The actions will be guided by the current fertilizers and pesticides application levels. This procedure requires sampling data, which often are difficult to get and may include uncertainties. The estimation of the total fertilizing demand can be achieved (as in Fig.1) concerning crop distribution and their average fertilizing requirements (i.e. fertilizer's kg per area units, times the examined area) while in case of more detailed data, agronomic modeling is recommended. The latter is way more informative as it informs us also about the water quality itself.

v) Direct costs for the water supplier

This parameter is the sum of capital cost, cost of maintenance and operation, and administrative cost (at their present values), as obtained and estimated from annual balance sheets of the local water management agency. Many decisions are based on this estimate and/or the policy's implementation costs. In case of incomplete data, experts' judgment based on previous similar estimations and data can be used. In case of not accessible data or absence of water management agency, there must be considered whether it is better to follow solutions (e.g. value transfer approaches) or omit this output.

vi) Opportunity cost

In water scarcity conditions, the most efficient option is an essential objective. Often water managers follow options without having considered a range of possible choices and selecting the overall most profitable. To control for this, opportunity cost as foregone benefits (of the optimum uses) to the current water uses is a good measure (Tietenberg & Lewis, 2011). Many approaches can be found in Environmental Valuation studies to estimate it. In this example, linear programming is used, to compute the optimum crop distribution (maximizing NPs), subject to water use, fertilizer use, labour and land constraints. The difference of the NPs of the BAU's situation from the ones of the optimized situation is considered as the opportunity cost. This comparison can sensitize DMs to consider crop replacements as an effective management tool. The data availability can define the detail of the optimization problem, while many tools can be used for the solution (e.g. GAMS, LINGO, MS Excel solver, MATLAB, etc.).

vii) Management Scenarios (alternative policies)

As mentioned, the system can be tested under various alternative policies aiming to different goals (evaluated and ranked in Stage C of Fig.1). Poor infrastructure is a usual issue for most areas, so starting from the improvements of the system regarding water use efficiency is recommended. For example:

- Open irrigation canals are often used, despite the great losses. The water transfer efficiency for such networks can be estimated from field surveys. A scenario suggesting proper cleaning and maintenance of the canals/networks, or even replacement with pressurized network can be developed and simulated by increasing the water transfer efficiency coefficient (losses reduction in water balance step).
- Similarly, the irrigation methods can be updated in a scenario that replaces canal irrigation and sprinklers with drip irrigation to achieve higher irrigation efficiency coefficients (i.e., reduced water demand in water balance step).
- Water reuse and sustainable drainage options can often act as additional supply.
- Agricultural Policy and Practices around the world are highlighting the need of adopting less water–consuming cropping patterns. A crop-replacement scenario according to such recommendations will result in reduced irrigation water demand. Simple replacements (e.g. percentages of crops' areas) or more complex problems (e.g. optimization to find a crop distribution that will maximize or minimize an objective function using water demand in the constraints) can be used, depending on the data availability.
- Enhancing the system's performance will ensure that any additional water supply will be treated with the best possible efficiency, and thus will not be 'wasted'. At this point, additional supply scenarios (which are also more costly) can be introduced (new dams/reservoirs, different supply paths, smaller locally placed reservoirs, water re-use etc.) and combination of scenarios can be explored based on the case study.

viii) The role of wetlands as nature-based solutions

A special category of alternative policies concerns wetland management, which becomes more and more topical. Their management can be included in the set of alternative policies, aiming mainly to the protection from disasters, and improvement of ecosystem and environmental functionalities, which in turn can boost economic activities. Wetlands provide multiple Ecosystem Services (ES) (e.g., stormwater retention, nutrient filtering, climate stability, flora and fauna, soil improvement, etc.) (Jaramillo et al.,2019). The difficulty to estimate (and valuate) all these ES leads to their conversion into (more profitable) farmland, causing environmental problems (Davidson, 2014). Each study area has its own specialities and needs, so a certain ES is more likely to be of interest (e.g. stormwater retention). A simple tool combining Geographic Information Systems (GIS) and MCA (the Analytic Hierarchy Process – AHP) is suggested for a preliminary, low cost, and no data-hungry estimation of the wetland's potential to achieve a certain goal (ES standard performance). Alamanos and Papaioannou (2020) presented such a tool for evaluating wetland's effectiveness for nutrient filtering in a Canadian basin. The method first selects all the factors that affect the ES of interest (nutrient filtering ability) and checks their correlation. After removing the correlated factors (for simpler calculations and avoiding double-estimations), the remaining ones are used as criteria (spatial data – raster files). For example, land-use, soil, vegetation, climatic, and landscape/topography parameters affecting its functions, inflows, outflows, and speed of processes. The maps of the criteria are normalized in a high-low scale (depending on which values are affecting positively or negatively the ES of interest). AHP is then used to weight the importance of each criterion to the final ES performance, according to the literature and modeler's judgement. The final weights of each criterion are used to synthesize the initial maps into the final result-map. The result is a map of high-low potential of wetlands' effectiveness for the examined ES. This map can be produced with an easy, holistic, and low-cost method without many data requirements, and it can also be validated from previous studies, e.g. on the stormwater or pollution behaviour of the study area (Alamanos, 2021).

ix) Climate change scenarios

The above framework, including the alternative management policies, can be examined under climate change scenarios. Arid areas' planning must be adapted on the drier climate (precipitation (P) and temperature (T) changes), as predicted from the latest results of the program CORDEX (cordex.org) of the Representative Concentration Pathways (RCPs), as proposed by the IPCC in its 5th Assessment Report (AR5) in 2014 (IPCC, 2014; Moss et al., 2008). These projections can be used either for a direct (one climatic model) sensitivity analysis to the alternative options (using different-future temperature and rainfall values), for developing custom scenarios-situations based on ensemble means of more Regional Circulation Model (RCM) simulations, based different Global Circulation Models (GCMs). It is worth noting that using an ensemble (many simulations, instead of one climatic model) is a more realistic approach and a novel element, as it includes all possible forecasting ranges, allowing the analyst to also examine uncertainties, if desired. In the applications section, an ensemble mean is used (Example 1) to develop three climatic scenarios to test the system's performance. In any case, the projected T and P must be statistically adjusted (corrected) on the case study's ones, and several statistical downscaling methods have been developed for that purpose (Trzaska and Schnarr, 2014). The impacts of the climate change scenarios (T and P changes) can be simulated mainly on the water balance (availability and demand), and sometimes on the NPs (i.e. repeating the water balance – step i and the economic model of the NPs – step ii).

x) The DSS

The final step uses the above outputs to evaluate the different examined alternative policies, integrating them into a DSS through MCA. In previous research (Alamanos et al., 2018) more MCA methods were tested (MAUT, MAVT, SMART, SAW, AHP, ELECTRE I, STEM, PROMETHEE, MAPPAC, TOPSIS) in order to identify the best-fitting technique for similar problems. That was found to be MAUT (additive utility function) (Neumann and Morgenstern, 1953; Churchman et al., 1957) using a value-weight system (utility functions), similar to a decision maker's logic (Keeney and Raiffa, 1976), where the alternative with highest utility according to the evaluation criteria is considered to be the most appropriate. Of course, any other method can be used if it suits better to the problem's structure (probably the results will be the same regarding the alternatives' ranking). The evaluation of the alternatives can be an opportunity for starting cooperation among different stakeholder groups, by inviting them to assign their weights of importance. Thus, a ranking of the alternative options can be finally obtained from different sample-groups and comparing them to identify gaps and build bridges of communication and information.

3. Applications and Discussion

This section presents example cases that successfully combined some of the above methods, mentions other similar user-developed DSS developments, and discusses the common principles. Three main examples are described to practically showcase the methodology as analyzed in the previous section (example 1), its modifications when there are not enough data, and the coupling with other models – integration with classic socio-economic tools (example 2). The third example describes a practical analysis for spatial planning of nature-based solutions, as part of the methods mentioned in the previous section. Finally, more examples are reviewed, to highlight the importance of flexible modelling settings and modifications of the aforementioned routines. These examples have been and are extensively applied in various case studies, so the reader can find more information on methodological alternative paths, depending on the case.

Example 1

The biggest part of the methodology described in the previous section has been applied in the Lake Karla watershed and in Almyros watershed in Central Greece, both agricultural areas of 1173 km^2 and 850 km^2 respectively, facing water scarcity (Alamanos et al., 2019; 2021): They are characterized by dry climate with dry and hot summers and cold and humid winters, limited available water resources, and high production and economic expectations because the majority of the population rely on agriculture for their income and both areas are the most important agricultural ‘producers’ for the country. Both areas have overexploited their groundwater (Almyros also faces salinization issues), and water infrastructure of very poor condition (networks and irrigation methods) leading to great losses and inefficiency. The local management is in primitive stage, there is no systematical management, poor or no data available, no water pricing, and no cooperation between stakeholders and authorities, leading to numerous illegal private wells (Alamanos et al., 2019). In Lake Karla watershed, the Lake was drained in 1962 for expanding the farmland, but the environmental problems caused led to the restoration of the former lake in 1981. By 2012 the works were completed and the refilling of the lake with surface water from River Pinios (North border of the watershed) started. The operation of the new lake-reservoir would enable the surrounding areas to be irrigated from its surface waters, limiting thus the aquifer’s overexploitation. Still in 2021, the lake has not been refilled because farmers are using the water that is supposed to refill the lake, before it reaches there. At the same time, crop distribution is based on the subsidies in both areas, resulting in water-demanding choices that further degrade the ecosystem. Non-point pollution is a significant pressure, resulted from the intensification of agriculture the last decades. The only irrigation water management service in both areas is a small agency running the surface network of Pinios River in the North of Lake Karla watershed (Alamanos et al., 2019). It faces funding problems, limited personnel, farmers' debts, difficulties in monitoring and keeping any kind of data records, and is unable to implement any economic/managerial policy.

The above description aimed to show the seriousness of the situation, the limited access to data (which was the main challenge), and the need to provide integrated modeling solutions. The methodology of the previous section was applied, proved that the situation can be reversed and become prosperous for the population and the environment. For detailed description of the application, see Alamanos et al. (2019), as here only some points-assumptions are discussed in the context of the approach used:

- Crop data were not available, so land uses were classified using satellite remote sensing imaging (Spiliotopoulos et al., 2015) for classifying the crops and estimating irrigation water demand.
- Data from the design studies of the river's pumping stations and older studies on the aquifers renewable volume were used to estimate water availability, since modeling was not possible due to data limitations.
- Agri-economic estimations were made by using statistical data from local/regional agencies (i.e. data concerning crops' yields, production costs, product prices, etc).

The methodology of the previous section is further tailored to data-scarce conditions, as explained, and it was then followed to estimate the water balance, net profits from agricultural activities, water value, direct costs, and opportunity costs.

- Regarding water quality, data were collected from surface and groundwater sampling stations, and were used to identify which pollutants' concentrations are above the maximum allowed limits (as established by World Health Organization and European Union). The source-uses of those substances led to the development of the appropriate management actions.
- All the above outputs were simulated for management scenarios aiming to a reduced water demand, as described above: increasing network and irrigation methods efficiency, ensuring the immediate operation of the Karla reservoir and the new reservoir's network, and crop replacements were considered as management scenarios (alternative policies). The implementation cost of these scenarios was also calculated from Pinios agency's past data and experts' estimations. These management scenarios also will contribute to the improvement of water quality through the quantitative replenishment of the water bodies.
- For the climate change scenarios, the results of RCP2.6, RCP4.5 and RCP8.5 were used based on the ensemble mean of the 10 simulations of the RCMs based on five different GCMs (divided to 30year-periods until 2100). For the data's statistical adjustment (correction) on the existing ones, a simple D-test is implemented. The downscaled T and P were used to develop three new scenarios: a mild, an intermediate and a worst-case climate change scenario. Their impacts were simulated on the water balance and the net profits (hydrologic and economic model), considering effects on water availability (aquifer's renewable water), irrigation requirements (due to higher evapotranspiration losses), crops' yield (estimated by regression models of T,P and yield).

- At this stage, considering the performances of the management scenarios under each output (criterion), the DSS model was applied using four different MCA methods (MAUT, AHP, ELECTRE I, and TOPSIS). The samples that assigned weights were the region's DMs (all local authorities involved), and experts on the field (scholars and academics), setting the bases for a collaborative planning and a cooperation, which is considered essential. The experts' group considered 'environmental' criteria more important than the 'economic' ones, slightly in contrast with the DMs' group, but the bases for informing each group and communicating their ideas and expectations are set, and still in progress. For further description of this analysis, see Alamanos et al. (2018).

Example 2

Another part of this methodology was applied in Urumqi River Basin of Xinjiang Province, China. Xinjiang is in the arid and inland region of northwest China, characterized by limited rainfall, large evaporation, and severe water shortage. The climate is dry, with hot summers and cold winters. Urumqi River sustains life in the area: both upstream (rural region), and downstream (urban region). The upstream agriculture is characterized by poor infrastructure and management, contributing to water inefficient use, i.e. high irrigation losses because of methods such as open channel irrigation, and limited crop choices because of the climatic and soil conditions (Y.Li et al., 2020; Yang et al., 2019). The exponentially increasing population of the urban downstream area requires more and more freshwater, and that causes conflicts. In order to balance upstream and downstream uses, cover the increased urban water demand, and also preserve agriculture, the local government applied the scheme "reduce grain and save water" in 2012 (i.e. obligatory fallowing for certain areas in return of a compensation amount). The long-term fallow gradually caused soil desertification, soils lost their fertility, deteriorating also the surrounding ecological environment. Considering these consequences, the fallow area was decided to be slightly reduced in 2017. From 2018, the water-saving goal from fallowing is 20 hm^3/year. However, the way that this policy was implemented lacked equity and does not fully consider the willingness of farmers to fallow, or to continue fallowing, or for how long they wish to do it. In the work of Alamanos and Zeng (2021), these factors were analyzed, and was found that a significant portion of farmers need to cultivate because they highly rely on agriculture for their income. Moreover, the potential of a wiser water resources management (using part of the presented DSS) was also examined:

- There were no available data regarding water supply, reservoirs characteristics (there were no available supply data to estimate a water balance, however, the coverage of the same needs without deficits, is an important insight supporting the aforementioned finding. Regarding the reservoirs, no data were available, hence we could not include their volume components to compare their performances (e.g. water levels, storage, pumping capacities, evaporation, spills, releases). So only the inflows (per source) and the outflows (to sites) were simulated for each reservoir, based on water demand estimations.

- Water demand was estimated for each use (urban, industrial, agricultural, livestock), following the methods and tools presented in the previous section.
- The simulation refers to the baseline scenario and to a Demand Management Scenario (DM Sc.), considering: maintenance of surface network (cleaning, pipelines, etc.), more efficient irrigation methods (e.g. drip irrigation), increasing thus the irrigation networks and methods performance coefficients, and an alternative usage of one reservoir (using it for industrial water supply, instead of using Urumqi River, in order to increase the river's ecological flows). The water conservation from the DM Sc. was hoped to provide enough irrigation water to the farmers that need to cultivate, without requiring additional supply.

Indeed, the DM Sc. increased water use efficiency, provided significant water savings and reduced river's pumping, contributing to the environmental sustainability. In fact, water demand was reduced by 70.8 hm^3/year (highly effective compared to the current policy's annual water-saving goal of 20 hm^3/year), allowing agriculture to use this amount, or just the remaining 50 hm^3/year, enhancing thus the local socio-economic growth and satisfaction. For the detailed process see Alamanos and Zeng (2021), however, here the approach is discussed to highlight that even in the case of very limited data, simple calculations provide significant information and impact. In this particular example, economic-agricultural needs can be covered, meeting also environmental objectives, and socially acceptable policy. So, integrated modeling efforts are encouraged, even with initial assumptions, allowing refining in the future.

Example 3

The last part of the methods described above that will be very briefly discussed is an approach for evaluating wetland's role in the management options. The use of nature-based solutions for achieving or preserving different ES is well-known and also are the difficulties of quantifying these factors. For example, water quality improvement from wetlands is much more uncertain to estimate, compared to treatment plants with known efficiency. A wetland's performance for nutrient filtering depends on various factors (physical, geomorphological, hydrological, climatological, vegetation, soil, surrounding land uses, inflows, initial concentrations, connectivity with other water bodies, groundwater recharge, etc.). Quantifications of their performance are often challenging and very limited, because of the amount of required data and specialized knowledge. That is one significant cause of the great wetland loss being observed in Southern Canada. The framework proposed by Alamanos and Papaioannou (2020) to estimate the wetlands' (or other areas of interest) performance on nutrient filtering (or other ES) was included in the methodology of the previous section because it introduces a more justified way to address the above challenges, and the field was poorly explored from that point of view. The combination of GIS-MCA tools makes the concept of experts' judgement more scientifically justified and as a tool is easy to use, does not require extended eco-hydrological knowledge, and data. The basic steps of the procedure were:

- Define the ES of interest: nutrient filtering in this example,

- Criteria selection: all the factors that affect this ES (except of those that are correlated – see previous section),
- Criteria Normalization and mapping in high-low scale (depending on which values are affecting positively or negatively the ES performance),
- AHP: experts weight the importance (degree of impact) of each criterion on the ES performance – AHP assigns the final weights to each criterion,
- GIS (raster calculator): applies the final AHP weights to each criterion and synthesizes them into the final result-map,
- Result-map: a high-low map with the effectiveness of the areas of wetlands for nutrient filtering.
- Validation: comparison with previous results of water quality or nutrient exports.
- Management actions: having this preliminary evaluation of wetlands performance, actions can be targeted: preserve certain wetland areas, convert others into farmlands, or restore important areas that need to provide that ES.

The following Figure is indicative of the process, with the analytical results-map.

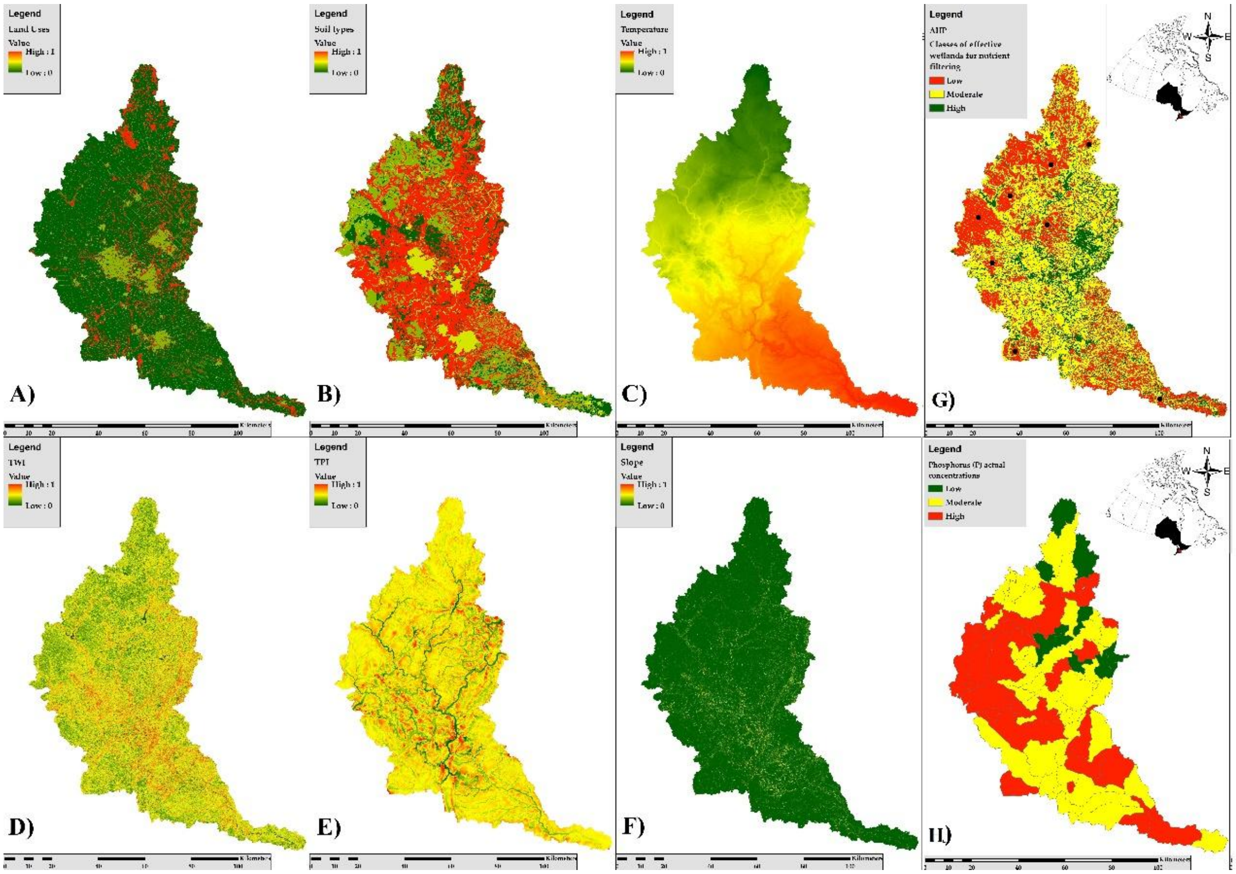

Figure 2. Indicative maps combining the normalized criteria (high-low scale) used for a Canadian watershed (A-F), with the results (G) and validation map (H).

The tool can be used for identifying any type of area of interest that depends on certain factors and can be used with very few data (Alamanos, 2021).

More Examples

Emphasis was given on the framework of Fig.1, thus the first three examples referred to those specific applications. However, the international experience includes numerous similar custom-made DSSs. Indicatively: in Syria coupling WEAP with MODFLOW (Droubi et al., 2008), in China combining MCA and multi-objective optimization (Weng et al., 2010), and in Greece using SWAT and genetic algorithms to minimize diffuse surface water pollution (Panagopoulos et al., 2012). Integrated models have the advantage of connecting environmental and socio-economic processes in a way tailored to each case study, compared to predefined functions (e.g. Nikolic and Simonovic, 2015). Recent applications in Asia use more sophisticated approaches to connect traditional hydrology to socio-economic aspects, and DSS practices (e.g. Safavi et al., 2016; Al-Jawad et al., 2019).

The first three examples were analyzed under the prism of the data-scarcity conditions and their respective design to tackle them, which is not a deeply-explored aspect of the literature so far. Considering them with the examples of this section, the lesson is that data limitations can be balanced by cross-checking the data that include assumptions with statistical databases for similar cases, or of greater scale (provincial, country), or default-recommended values of software. The use of many scenarios (management and climatic) acts very well as ‘sensitivity’ testing and optimizing model’s parameters.

Common features of all the above examples are the definition of the processes based on a problem that requires specific insights. This guides the output parameters, and the tools follow: Custom-made DSSs include data that the developers trust, are based on their own assumptions, sense of how the system works, and perform desirable uncertainty or sensitivity analyses. Commercial packages are then used as tools that will serve complementary the users’ purposes. Usually the least-cost approach (single-criterion planning) is actually considered in the areas examined. The practical impact of each effort is significant, both in terms of modeling and as study-area applications.

4. Conclusion

There are limited studies on how to implement integrated water resources management to provide solid guidance to modelers. The information provided in relevant books is often too general, while Badham et al. (2019) provided a high-level guide to contextual approaches. However, when it comes to practice, data restrictions often concern analysts’ decisions. This study attempted to contribute by presenting an indicative DSS, including real experiences from integrated modeling with limited data, in order to provide insights for similar Asian cases. The ideas and principles that led to the successful application of the tools discussed are based on flexibility of ways and tools to perform the desirable analyses: Data limitations can be tackled by using simple primary data from field surveys, remote sensing, other official-national statistical databases, older design studies, or reasonable assumptions. Taking into account as many factors as possible, including parameters that combine hydrological and economic aspects greatly helps the modeler understand deeper the system, but also improves the model's capabilities itself. Integrated modeling is not restricted to the context of multidisciplinary outputs, but also requires integrated groups of stakeholders; including both experts and DMs in the MCA application creates cooperation bridges. Moreover, DMs were familiarized with the modeling results and capabilities.

A limitation of this study is that all examined factors, models and examples cannot be presented in detail in a paper's length, but the focus is to support modelers when facing tough and complex decisions, encourage any integrated modeling attempt even in difficult circumstances, and to provide insights from different case-studies experiences that were facing similar water issues (rather than presenting the modeling aspect). There is no lack of modeling tools or methodological applications – in fact there are many high-quality approaches using complex and advanced techniques (and this often restrains their practical applicability).

Integrated modeling needs integrated data, but any attempt can be an important step since every model is a trade-off between accuracy, usefulness, complexity, time, and data requirements. Even though an area is in early-primitive management stages, obtaining proxies of hydro-economic results, makes DMs to pay more attention to these issues. Any effort can bring an outcome, and especially in areas facing serious water and management problems, the impact of such studies is significant. This indicates that the most important is the mindset that accompanies and structures the models, not the opposite.

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