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Hydrology of the Jordan River Basin: A GIS-Based System to Better Guide Water Resources Management and Decision Making

Georges F. Comair · Daene C. McKinney · David R. Maidment · Gonzalo Espinoza · Harish Sangiredy · Abbas Fayad · Fernando R. Salas

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Abstract A new method of participatory decision support that can be used in transboundary basins is presented. The framework of this method relies first on the creation of a transboundary geographic information system database to store hydrologic data and allow easy access to data from stakeholders. A participatory hydro-political framework is developed to help set up hydrologic models and evaluate joint water management scenarios. Results show that the countries of the Jordan River could benefit from the framework and in the case of southern Lebanon, six climate stations should be replaced or reactivated. Finally, the mechanism of a Lebanese Hydrologic Information System is presented and shows that an observation data model will facilitate science and policy integration.

Keywords Jordan River · Transboundary basins · Database · Decision support system · GIS · Water diplomacy

1 Introduction

The Jordan River Basin is shared between Jordan, Israel, Lebanon, Palestine (West Bank) and Syria. In the Middle East and North Africa (MENA) region, especially in the countries of the Jordan River Basin, data are insufficient or do not exist. Data are often not published in the Middle East for security reasons, e.g., Israel does not publish data on discharge (Klein 1998). Variability of data reporting is another problem. Several authors (Gunkel and Lange 2011; Mithen and Black 2011) mention that the lack of adequate data hinders model performance, and uncertainties increase due to the absence of calibration and validation of hydrological models (Gunkel and Lange 2011). Mithen and Black (2011) developed several rainfall run-off

G. F. Comair (✉) · D. C. McKinney · D. R. Maidment · G. Espinoza · H. Sangiredy · F. R. Salas
Center for Research in Water Resources, University of Texas at Austin, Austin, TX 78712, USA
e-mail: doctorg@utexas.edu

A. Fayad
Department of Civil and Environmental Engineering, American University of Beirut, P.O. Box 11-0236, Riad El-Solh, Beirut 11072020, Lebanon

models for the Jordan River Basin and described the extreme difficulty of modeling in a data poor region.

Remote sensing is often used in the region (Al-Qudah and Abu-Jaber 2009; Gunkel and Lange 2011; Comair et al. 2012a) and data are collected from previous academic studies, government agencies and engineering company studies (e.g. Harza and JRV Group 1998). In addition, with regard to transboundary rivers, the problem of a poor database is often encountered (Barrow 1998). Therefore, flexible and adaptive measures should be implemented when data availability is a problem. Use of a Geographical Information System (GIS) is one potential solution for sharing and processing data (Awad et al. 2009; Holling 1978; Goulter and Forrest 1987). In the Jordan River Basin, only one multi-country water database exists; however, it is static, non-spatially explicit, and not available in electronic form (Hoff 2011).

For transboundary settings, participatory methods have been successful in Europe under the Water Framework Directive (WFD) for interdisciplinary investigations based on an integrated approach (Molina et al. 2011). Participatory integrated assessment (PIA) as defined by Parker et al. (2002) was found to be very helpful for managers in the restoration of extreme aquifer overexploitation in Spain (Molina et al. 2011). A comprehensive review of the application of GIS and remote sensing to groundwater hydrology was also described by Jha et al. (2007). They showed that GIS and remote sensing studies are recommended to be carried out in conjunction with field investigations. PIA has its primary roots in global change impact assessment (Rotmans and Van Asselt 1996; Morgan and Dowlatabadi 1996; Park and Seaton 1996; Risbey et al. 1996; Janssen and Goldworthy 1996; Rothman and Robinson 1997; Geurts and Joldersma 2001; Parker et al. 2002).

In addition, the uses of adaptive decision support systems were successful if combined with stakeholder involvement to address dynamically complex problems in water resources management (Khadra and Lamaddalena 2010; Winz et al. 2009). More adaptive management seemed to be favored by water managers such as the European project NeWater that included environmental, technological, economic, and institutional factors in the management of river basins (Awad et al. 2009; Pahl-Wostl 2007).

The goal of this study is to use a GIS interface to improve data access within governmental institutions and facilitate stakeholder's engagement in basin management, especially for transboundary basins. In the process, we have: (1) Identified gaps to ensure proper data collection and monitoring in the Lebanese part of the Jordan River Basin (the Hasbani Basin); (2) Created a Lebanese Hydrologic Information System (LHIS); (3) Stored the hydrologic data collected in a relational database following an Observation Data Model (ODM); and (4) made the data available for integration with GIS services such as those published through World Water Online (WWO) (Espinoza 2012). The result is a participatory hydro-political framework (PHPF) to implement science and policy integration in transboundary basins. This PHPF was applied in the Jordan River Basin and more specifically in Lebanon. In the future the PHPF can provide unified access to water information and perform hydrologic analysis in any watershed.

2 Methodology

2.1 Participatory Hydro-Political Framework

The PHPF implements the goals of river basin planning and management, summarized by (Barrow 1998), including:

1- Decentralizing planning and management and make it adaptive (Holling 1978);
2- Providing an acceptable planning and management approach that might "side-step" existing stagnant or corrupt arrangements; and
3- Establishing a politically acceptable way of gaining the cooperation of co-riparian states or nations.

The involvement of stakeholders in the early stages of the PHPF is essential for tackling water resources management problems in the Jordan River Basin, within the context of climate uncertainties and fragmented knowledge.

We propose three levels of participation (Mostert 2003; Henriksen et al. 2009):

1- Stakeholder consultations, which involves interviews and field visits to gather information;
2- Active involvement to engage stakeholders in constructing a final water resources management plan; and
3- Co-decision making to help the stakeholders collaborate to reach a consensus on which simulation model to use and which plan to implement.

Steps 1 and 2 of the PHPF were completed for the Orontes and Hasbani rivers of Lebanon in 2012 (Comair et al. 2012a, b, 2013). The Transboundary Geospatial Database (TGD) of Lebanon can now be incorporated into the PHPF (see Section 3.1 of Comair et al. 2012a). This framework can be adjusted to include additional basin riparians, or future climate change or socio-economic development scenarios.

To apply the PHPF: first, a transboundary geospatial database (TGD) is created using GIS and includes data gathering activities that involve extensive meeting with basin stakeholders, and literature review. This TGD can be then used by the stakeholders and the scientific community. The data obtained for the scientific community can be made available through WWO and the stakeholders can also use WWO or their own internal system to access private data (Fig. 1).

Second, from the obtained data, the stakeholders and the scientific community can simulate the basin hydrology and water management using their own software (Water Evaluation And Planning-WEAP (Yates et al. 2005) and Water Allocation System-WAS (Fisher et al. 2002) are recommended in the Jordan River Basin) to simulate rainfall-runoff responses of rivers and water management scenarios. Finally the best water management alternative can be chosen using a Participatory Decision Support System (PDSS).

This stage of the PHPF is related to studies conducted in Canada and South Africa (Nikolic et al. 2013; Prodanovic and Simonovic 2010; Pollard and Toit 2011; Ahmad and Simonovic 2006). The integration of analytical tools such as GIS and hydrologic simulations were successful under a participatory decision making environment (including the role of governance, policy and regulations). The PHPF is essential to study climate change and implement "what-if" scenarios using WEAP.

Figure 2 shows the hydrologic modeling framework, which is part of the model generation step of the PHPF (step 2). Two scenarios were analyzed and the scenario that showed the best model performance for the Hasbani River Basin (a major tributary of the Jordan River Basin) was recommended to the Lebanese ministry of water. Later publications will present the results of these scenarios.

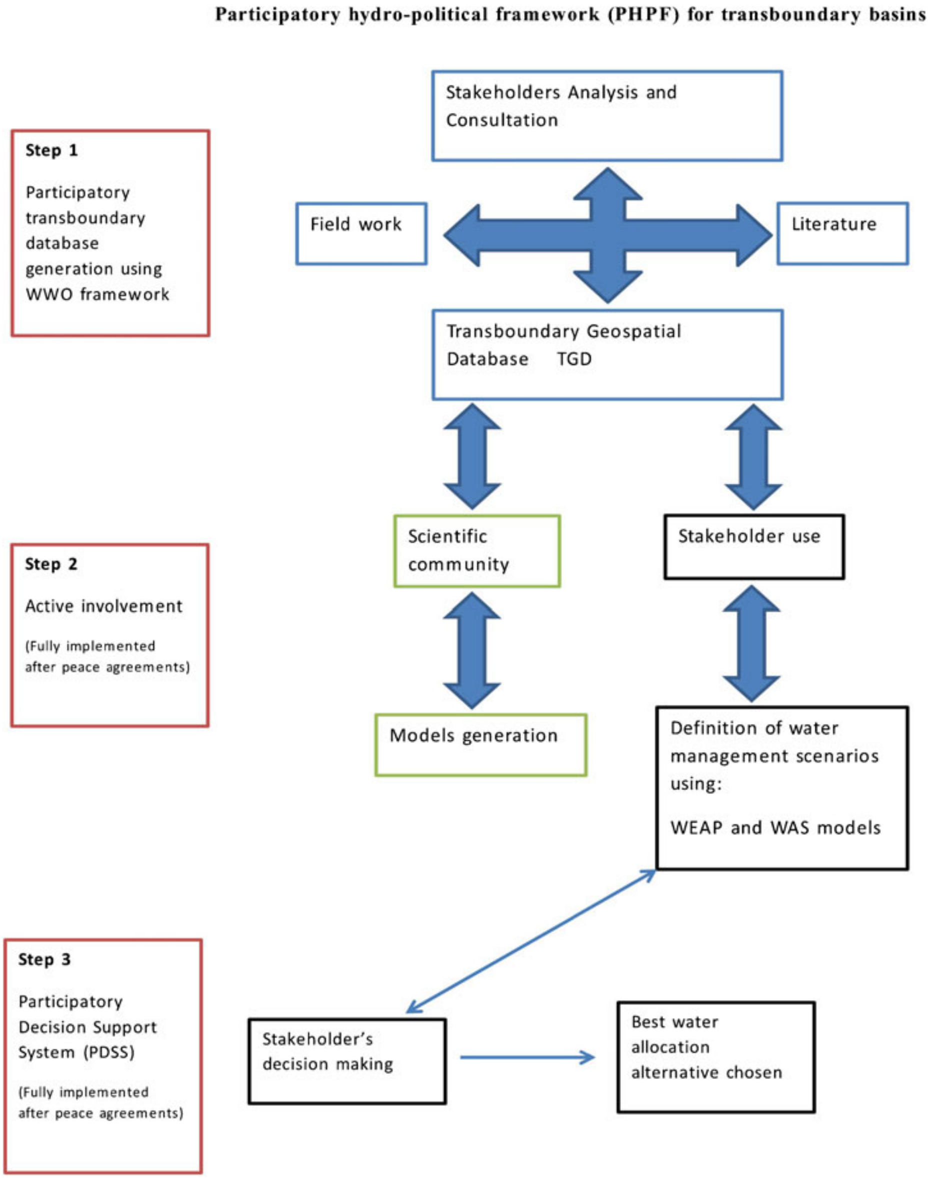

Fig. 1 Participatory Hydro-Political Framework (PHPF)

Achieving the third stage is a task for further research. In the future, public participation should include water authorities, local environmental groups and non-governmental organizations, water supply companies, water user associations and farmer unions in order to have full cooperation. A benefit-sharing approach enabled by the law (1997 UN Convention) and science (Integrated Water Resources Management-IWRM) is key to achieving transboundary cooperation; a concrete example of this would be the Orontes River Basin agreement (Comair et al. 2013).

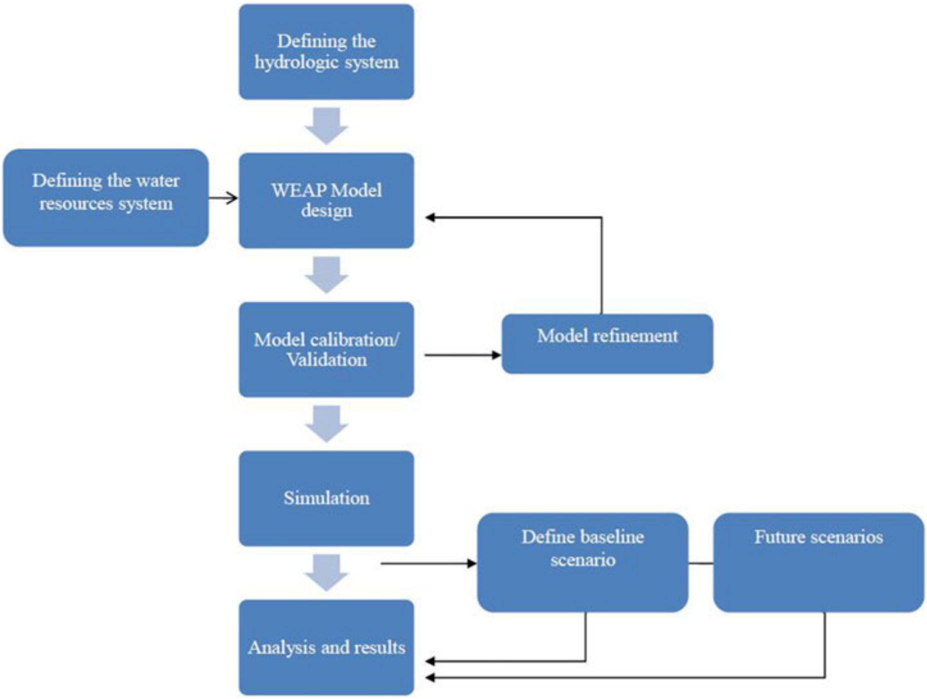

Fig. 2 WEAP model framework for the hydrologic modeling of the Hasbani Basin

2.2 Identification of Gaps to Ensure Data Collection and Monitoring

The method to develop a TGD for Lebanon involved three steps. The first step was performed in Lebanon in summer 2011 and involved inventory building and research and data collection at the basin level. All the data related to water resources in the Hasbani and Orontes Basins were compiled from governmental and academic institutions in Lebanon. In fact, 17 governmental and non-governmental institutions are in charge of collecting and providing water related data. Concerning transboundary basins in the case of the Hasbani and Orontes Rivers, the data mainly came from two institutions: the Ministry of Energy and Water (MEW) and the Litani River Authority (LRA) who provided precipitation, temperature and streamflow data in various formats (Table 1). The second step was to meet and interview several persons working within those institutions, taking their ideas into consideration was essential to developing the water information system of Lebanon. The last step consisted of analyzing the data and identifying any gaps (gages locations, poor instrumentation, etc.) in the two basins in order to understand what needs to be done in Lebanese transboundary rivers to reach the goal of creating a national database that will ensure proper data collection and monitoring.

2.3 Hydrologic Information System

In the case of Lebanon, to improve the coordination between the various organizations in charge of collecting data, we first explained how a Lebanese Hydrologic Information System (LHIS) for Lebanon should be built then how it can be incorporated into WWO to provide unified access to water information for transboundary basins.

Table 1 Streamflow data collected on the two transboundary rivers of Lebanon (Hasbani and Orontes Rivers)

Station name	m	Lat-Long	Drainage area (km^2)	Excel format	Hard copies
Fardis Bridge, Hasbani River	496	33°22′29″ 35°:38′:46″	448	2002 to 2008 daily	1962 to 1966 monthly 1967 to 1972 daily
After Wazani spring, Hasbani River	281	33°:16′:25″3 5°:37′:09″	526	2002 to 2008 daily	1963 to 1966 monthly
Hasbani Spring, Hasbani River	567	33°:24′:29″ 35°:40′:16″	1	2005 to 2008 daily	1963 to 1966 monthly
Hasbani before the spring, Hasbani River	548		340		1963 to 1974 monthly
Orontes River	590	34°:23′:30″ 36°:24′:56″	1241	1967 to 1974 daily 2002 to 2009 daily	

As mentioned earlier, the priority of the MEW is to implement the LHIS for transboundary basins; this has started under the TGD for Lebanon using ArcGIS and the Observations Data Model (ODM) framework. The LHIS is a GIS-based, model-oriented HIS and is presented as a system that integrates GIS data models, GIS processing techniques, and hydrologic models.

The development of a dynamic hydrologic system for data handling, watershed modeling and water resources assessment in Lebanon is the main aim of the proposed LHIS. The central hypothesis of the LHIS is that advancements in hydrologic modeling and the sound understating of water resources depend on the amalgamation of reliable hydrologic models with spatial and long-term time series records. This hypothesis is formulated from existing literature in the fields of hydrologic models, GIS for water resources, and the integration of data models and simulation models in water resources, more specifically the integration of watershed hydrologic models, GIS data models, and GIS processing tools in a single system framework (Maidment 2002).

The rational for undertaking the LHIS is that, once a complete hydrologic data model is implemented at the watershed scale, and the connection between the data model and simulation models (i.e., hydrologic models) is established, it is possible to enhance hydrologic and water resources analysis while reducing time spent on basic data harvesting and model calibration. The originality of the LHIS is its attempt to implement the concept of watershed modeling using a HIS framework (Maidment 2004; Goodall and Maidment 2005; Maidment 2005). Creating the LHIS involved the development of a hydrologic data management system, under ArcHydro (Maidment 2002), for the first time in Lebanon. It makes use of the advanced capabilities of GIS to develop models that support data integration for the hydrologic simulation models. The concept of the LHIS allows running hydrologic models in an efficient and flexible manner and automates the processes for the management, communication, and exchange of information between the different LHIS components. The development of the LHIS ensures data sharing, allowing for future update of the hydrologic model, and steady analysis of water resources. These outcomes positively add to the existing knowledge and contribute to the development of water resources plans and decisions making. Figure 3 shows the LHIS framework.

The geodatabase under the Data Model component focuses on defining the watershed physical environment using spatial and temporal data. This includes: (1) climate (precipitation, temperature, and humidity); (2) hydrology; (3) water bodies (river and lakes); (4) physiographic features such as topography, soil maps, land use, geology and hydrogeology; (5) water resources data; and (6) social and economic data.

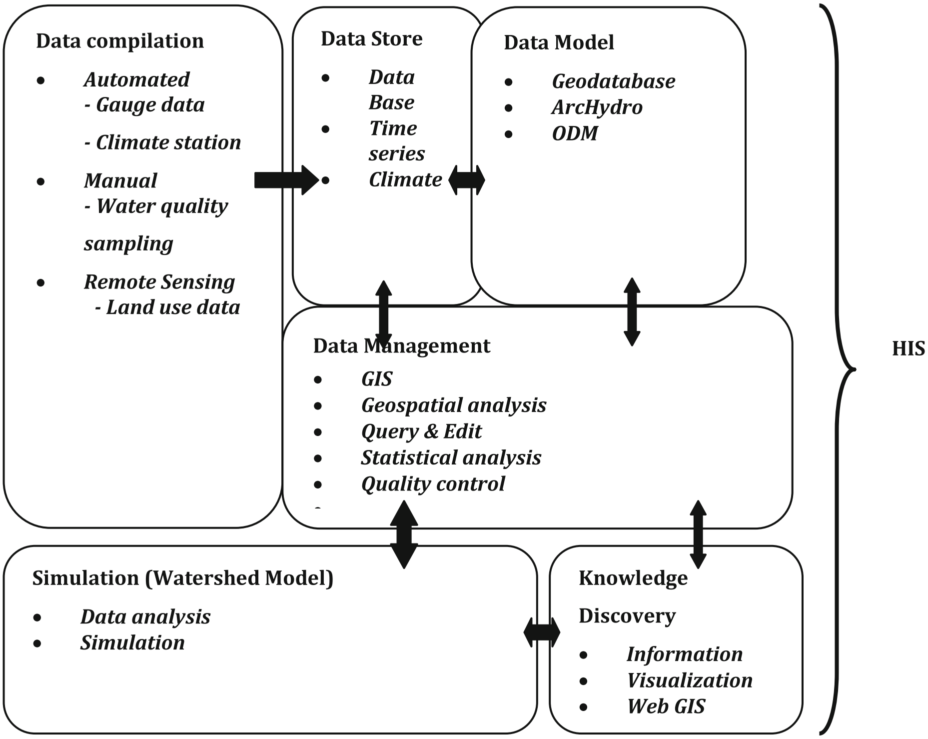

Fig. 3 Prototype of the proposed HIS, modified after (Maidment 2005)

2.4 Observation Data Model and World Water Online

The CUAHSI ODM was used in the Hasbani and Orontes basins. (Horsburgh et al. 2008; Tarboton et al. 2011; CUAHSI 2013). This framework provides an efficient platform to store, query and share hydrologic time series data across multiple investigators and stakeholders. Point observations such as precipitation and stream discharge have two primary attributes, location and time, and the ODM provides an optimal framework to store both of these attributes of these variables. The ODM schema classifies the attributes of the observations into facts and descriptive dimensional attributes that give the facts a context.

The general format for data input to the ODM is a single file containing a table with a header whose names are same as the columns in the tables of the ODM. Rules regarding input file creation, and the required and optional columns for each table to be loaded can be found in the software manual (CUAHSI 2013).

The ODM helps remove the problem of publishing and using observational data, due to heterogeneity in the vocabulary of the variable names used to describe the data by using an extensive control vocabulary. It also stores metadata about the collected data, e.g., source, methods used for collecting the data, and the quality of the data. The relational database management system enables users to apply a wide variety of data extraction, integration and analysis tools. The ODM framework also makes it easy to share observations, and use the data in mapping services like WWO.

The WWO framework for transboundary basins such as the Jordan River Basin will improve the following:

1- Sharing, data accessibility and transparency;
2- Cooperation between organizations, stakeholders and public engagement in basin management; and
3- Scientific knowledge.

The mechanism of World Water Online is presented in Figure 4. Users will be able to access various types of data such as climate, geospatial and water data.

Water agencies in various countries have created extensive databases that can be accessed remotely through their own web sites. The CUAHSI Hydrologic Information System has developed a standard mechanism of querying such data using web services, and a standard language called WaterML in which responses to queries are returned (CUAHSI 2013). If such web sites and services are indexed in a common way, e.g., in WWO they can provide unified access to water information for the globe.

A test case of WWO was developed for Mexico that integrates hydrographic, meteorological, discharge, elevation and precipitation data (Espinoza 2012). The integration of the Mexican HIS within WWO is made through the integration of the three networks of the Mexican National Water Commission (CONAGUA): EMA, EPPREPMEX and BANDAS. The first two systems are dynamic systems, because data is being ingested continuously and the latter is a static system, due to the lack of automatic and continuous updates.

3 Results and Discussion

3.1 Lebanon's Current Situation

The main conclusions that can be drawn after meeting the stakeholders in Lebanon are:

1- Each institution uses different methods, making coordination difficult;
2- Lack of experience of personnel and financial resources;

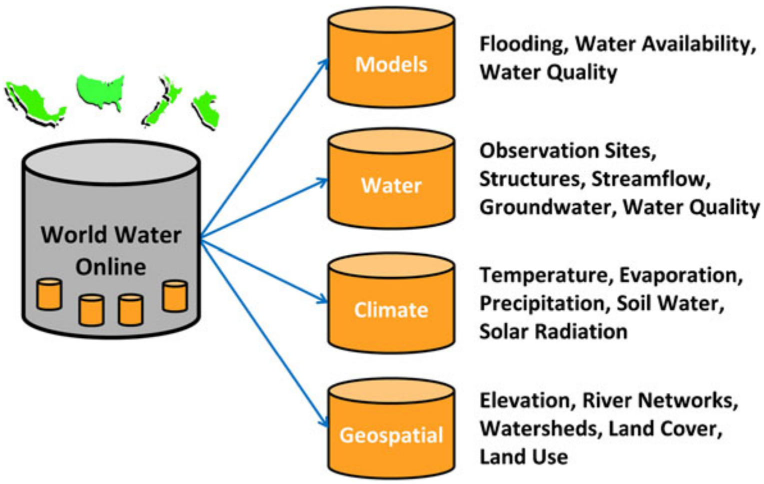

Fig. 4 Prototype of the proposed world water online

3- Poor coordination between institutions concerning:

   a) Collection of water quality data which are divided between the MEW, Lebanese Army and others; and
   b) Different methods of measurement between the MEW (spring flows) and LRA (streamflows);

4- Procedures for collecting and exchanging water related data are very tedious since obtaining water data needs the approval of a higher authority in the administration and this delays the data processing; and
5- Lack of an automatic or web-based data sharing system and 90 % of the data are obtained in hard copy rather than electronic form.

The issues described above are related to institutional problems faced by the Lebanese water sector, i.e., the system is fragmented and communication between the water organizations is poor. To clarify this point, we need to realize that in Lebanon two organizations are responsible for collecting data in transboundary rivers: the MEW and the LRA. The MEW has the mission to plan, study and execute large hydraulic projects in the entire Lebanese territory. In addition, it includes a hydrology division that is responsible to measure all the natural spring flow in Lebanon. This division lacks personnel and proper measuring equipment. However, in October 2011 the MEW started the implementation of a Water Information System with the help of the European Union to assist the government in updating the national 10-year Strategic Plan for the water sector. This plan includes, among other things, the analysis of the water resources situation in the country and the establishment of a GIS database that includes hydrologic and meteorological data. The building of such a geodatabase for Hasbani and Orontes rivers is a critical part of this plan.

Created in 1954, the LRA collects streamflow and climate data from the Litani basin only. However, due to political problems since 1967, especially after the civil war in Lebanon (1975–1991), the LRA was in charge of collecting data for all Lebanese rivers and is currently managing 62 streamflow gage stations. Recently, in 2010, the LRA created an internal GIS data management system and updated its hydrological equipment including some wireless transmission of data to a database. The problem still facing the MEW and the LRA is the lack of coordination; information is not easily shared between the two institutions and only available upon official request.

For successful implementation of the LHIS, the following need to be updated or generated:

1- Data related to hydrology and water resources (climate, streamflow, hydrogeology, etc.);
2- Data related to water demand (urban, potable, irrigation, industrial, etc.);
3- Data related to water quality (springs, treatment plant inflow/outflow, sea water outflow, etc.);
4- Data related to water infrastructure (dams, lakes, canals, sewers/storm water and irrigation networks, etc.); and
5- Institutional data (legislative texts, administration institutions, roles and actions, authorities, construction permits, etc.).

Legal documents and laws need to be amended and updated to: (1) clearly assign the task of collecting the data to each institution; and (2) ensure coordination between all 17 institutions that gather water related data. This will eliminate duplicate work in water information studies in Lebanon funded by foreign organizations (EU, USAID, Italian cooperation, etc.).

3.2 Observation Data Model and World Water Online

Three different variables: streamflow, springflow and precipitation were available for the Hasbani and Orontes streams in paper documents from the Government of Lebanon. The paper documents were scanned and the scanned documents were converted into spreadsheet documents that were then checked against the original paper documents for errors. Upon confirming the quality of the spreadsheet files, the data were transformed into templates for the ODM tables (Fig. 5).

Initial analysis of the scanned records showed that precipitation was measured at 10 sites and flow was measured at 7 sites on the Hasbani and Orontes Rivers. Moreover the stream flow data were available for daily and monthly time periods, whereas only monthly precipitation data were available at the sites. The initial inventory of the data also showed gaps in time series for some sites.

The problem with the Hasbani Basin data was that the climate data are not compatible in terms of time frame with the streamflow data. Since southern Lebanon is a very dangerous and military sensitive area, no continuous measurements existed before 2002. The 13 climate stations available there only recorded precipitation from 1943 to 1971. Today, only the Kfar Qouq station contains time series from 2002 to 2010 (Fig. 6). The climate stations located in or near the Hasbani watershed need to be updated. Of the 13 climate stations (Fig. 6) located in southern Lebanon, seven are working but data are not often collected (shown in green) and six should be replaced or reactivated (shown in red). There is no need to add more flow gages because the two locations, Fardiss and after Wazzani Spring, are placed properly on the river (Fig. 5).

SiteID	SiteCode	SiteName	Latitude	Longitude
1	11	Yanta	33.603475	35.944597
2	12	Deir-el-Aachayer	33.561094	36.010583
3	13	Kfar Qouq	33.53668333	35.89143333
4	14	Rachaya	33.501878	35.839831
5	15	Kfar ez zeit	33.430022	35.739669
6	16	hasbaya	33.397911	35.68515
7	17	marjaayoun	33.359694	35.588931
8	18	Fardis	33.371911	35.668025

ValueID	DataValue	LocalDateTime	UTCOffset	DateTimeUTC	SiteID	VariableID
9	0	1961-09-01 02:00:00.000	2	1961-09-01 00:00:00.000	1	17
10	25	1961-10-01 02:00:00.000	2	1961-10-01 00:00:00.000	1	17
11	50	1961-11-01 02:00:00.000	2	1961-11-01 00:00:00.000	1	17
12	19	1961-12-01 02:00:00.000	2	1961-12-01 00:00:00.000	1	17
13	12	1962-01-01 02:00:00.000	2	1962-01-01 00:00:00.000	1	17
14	10	1962-02-01 02:00:00.000	2	1962-02-01 00:00:00.000	1	17
15	3	1962-03-01 02:00:00.000	2	1962-03-01 00:00:00.000	1	17

VariableID	VariableCode	VariableName	Speciation	VariableUnitsID	SampleMedium
17	P-Precipitation	Precipitation	Not Applicable	54	Precipitation
18	SF-FlowRate	Streamflow	Not Applicable	36	Surface Water
19	SF-Volume	Streamflow	Not Applicable	126	Surface Water

UnitsID	UnitsName	UnitsType	UnitsAbbreviation
36	cubic meters per second	Flow	m3/s
54	millimeter	Length	mm
126	cubic meter	Volume	m3

Fig. 5 The relational model of ODM for data values observed on the Hasbani Stream

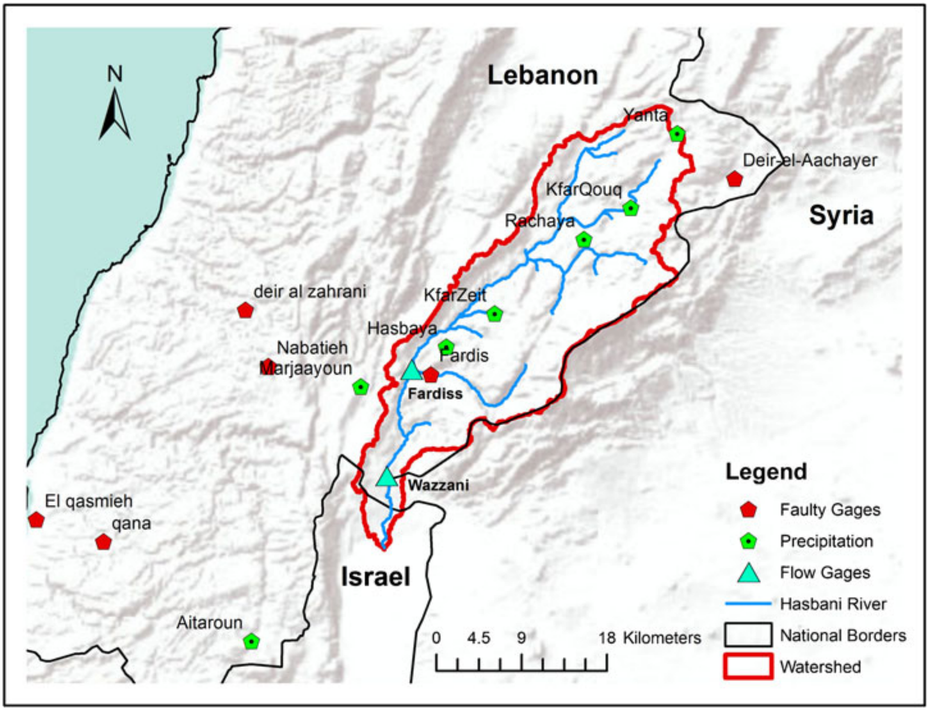

Fig. 6 Proposed rain gage locations

So far (2013), some Lebanese transboundary data have been included in WWO. The Mexico test case has been implemented and proved to practical for the Mexican academic and water agencies, and it has improved the accessibility of water data (Espinoza 2012).

WWO is not only a source of data; it is also a place where a user can find geoprocessing tools. Analysis can be performed in the cloud, e.g., using the 'Precipitation-Discharge analyses' tool where the precipitation and discharge data for a given area and time period are related and maps of geographically distributed runoff can be created (Espinoza 2012).

Since the INBO Portugal conference in October 2011, and the World Water Forum in Marseille, Lebanon, Jordan and Palestine have expressed interests in joining the WWO data sharing effort and providing data pertaining to the Jordan River Basin. WWO can provide unified access to water information through a dynamic map in an online system. Water agencies and research institutions in the Jordan River Basin, will be able to access the geospatial database remotely through the World Wide Web, and perform hydrologic analysis of any watershed included in WWO.

With the LHIS, countries sharing the Jordan River Basin can benefit by using the GEOSS Water Services (GEOSS 2013). Such a web-based HIS can be federated between countries using a global framework for synthesizing water observations within countries as well as between countries. This concept may be easier to work with than trying to get one created locally (say for the Middle East alone).

4 Conclusion

This paper has addressed the development of a transboundary geospatial database (TGD) through an active participatory approach involving all water system stakeholders. The TGD was developed and used to store hydrologic data, allow easy access to data and to set up hydrologic models. The TGD can be linked to a participatory hydro-political framework (PHPF) to assist stakeholders and the scientific community to participate in a decision support system and evaluate water management scenarios. The Helsinki Rules (ILA - International Law Association 1966), the Helsinki Convention (United Nations Economic Commission for Europe UNECE 1992), and the United Nations Watercourse Convention (UNWC), stress that co-riparian states should exchange data and information related to hydrological, meteorological, as well as water quality (Article 8, 11 &12 of UNWC). This data sharing is essential at the earliest stage of cooperation even if a joint river basin organization is not established as it is in the Jordan River Basin. Data sharing mechanisms explained in this paper: ODM and GIS web interface such as World Water Online (WWO) are needed to standardize the data and make it accessible by all riparian states. As Article 9 of the UNWC says that states should “facilitate its utilisation by the other watercourse state”. This concept of data sharing and analysis was among the solutions presented at the World Water Forum of 2012 (Comair et al. 2012a).

The PHPF and the LHIS can be a useful tool to facilitate water diplomacy and improve sectoral communication in Lebanon by providing usable science and improved knowledge, and the GIS methods are compatible with existing practices in riparian countries such as Lebanon and Jordan. Accessibility to policy makers has been proven by various interactions and meetings conducted with the stakeholders. The successful implementation of the PHPF relies on the motivation of each country in a transboundary basin.

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References

Ahmad S, Simonovic S (2006) An intelligent decision support system for management of floods. Water Resour Manag 20:391–410

Al-Qudah K, Abu-Jaber N (2009) A GIS database for sustainable management of shallow water resources in the Tulul al Ashaqif Region, NE Jordan. Water Resour Manag 23:603–615

Awad M, Khawlie M, Darwich T (2009) Web based meta-database and its role in improving water resources management in the Mediterranean basin. Water Resour Manag 23:2669–2680

Barrow C (1998) River basin development planning and management: A critical review. World Dev 26(1):171–186

Comair G, McKinney D, Scoullos M, Flinker R, Espinoza G (2013) Transboundary cooperation in international basins: Clarification and experiences from the Orontes river basin agreement, part 1. Environmental Science and Policy 31:133–140

Comair G, McKinney D, Siegel D (2012a) Hydrology of the Jordan River basin: Watershed delineation, precipitation and evapotranspiration. Water Resour Manag 26(14):4281–4293

Comair G, Gupta P, Ingenloff C, Shin G, McKinney D (2012b) Water resources management in the Jordan River basin. Water and Envir Journal 27:495–504

CUAHSI (2013) Consortium of Universities for the Advancement of Hydrologic Science, Inc. http://www.cuahsi.org/Accessed July 15 2013

Espinoza G (2012) A Mexican Case Study for World Water Online. CRWR Online Report 2012–01. http://www.crwr.utexas.edu/reports/2012/rpt12-1.shtml. Accessed July 15 2013
Fisher FM, Arlosoroff S, Eckstein Z, Haddadin M, Hamati SG, Huber-Lee A, Jarrar A, Jayyousi A, Shamir U, Wesseling H (2002) Optimal water management and conflict resolution: The Middle East water project. Water Resour Res 38(11):1243
GEOSS (2013) Group On Earth Observations GEOSS Water Services for Societal Benefit.http://www.ogcnetwork.net/system/files/AIP6_GEOSS_Water_Services_Proposal_final.pdf Accessed July 15 2013
Geurts J, Joldersma C (2001) Methodology for participatory policy analysis. Eur J Oper Res 128:300–310
Goodall J, Maidment D (2005) A Geotemporal Framework for Hydrologic Analysis. CRWR Online Report 05–8. http://www.crwr.utexas.edu/reports/pdf/2005/rtp05-08.pdf. Accessed July 15 2013
Goulter I, Forrest D (1987) Use of geographical information-systems (GIS) in river basin management. Water Science and Technology 19(9):81–86
Gunkel A, Lange L (2011) New insights into the natural variability of water resources in the lower Jordan River Basin. Water Resour Manag 25:1–18
Harza, JRV Group (1998) Jordan Rift valley integrated development study. Red-Sea-Dead Sea canal project. Prefeasibility Report. Volume 1-Main Report.
Henriksen HJ, Refsgaard JC, Holberg AL, Ferr N, Gigsbeer P, Scholten H (2009) Harmonised principles for public participation in quality assurance of integrated water resources modelling. Water Resour Manag 23: 2539–2554
Hoff H (2011) A water resources planning tool for the Jordan River Basin. Water 3:718–736
Holling C (1978) Adaptive environmental planning and management. Wiley, Chichester
Horsburgh JS, Tarboton DG, Maidment DR, Zaslavsky I (2008) A relational model for environmental and water resources data. Water Resour Res 44(W05406)
ILA - International Law Association (1966) The Helsinki rules on the uses of the waters of international rivers. Adopted by the International Law Association at the 52nd Conf, Helsinki
Janssen W, Goldworthy P (1996) Multidisciplinary research for natural resource management: Conceptual practical implications. Agric syst 51:259–279
Jha M, Chowdhury A, Chowdary VM, Peiffer S (2007) Groundwater management and development by integrated remote sensing and geographic information systems: Prospects and constraints. Water Resour Manage 21:427–467
Khadra R, Lamaddalena N (2010) Development of a decision support system for irrigation systems analysis. Water Resour Manage 24:3279–3297
Klein M (1998) Water balance of the upper Jordan River basin. Water Int 23(4):244–248
Maidment DR (2002) Arc hydro: GIS for water resources. ESRI Press, Redlands
Maidment DR (2004) Creating hydrologic information systems. www.utexas.edu/. Accessed January 15, 2004.
Maidment DR (2005) A data model for hydrologic observations. CUAHSI Hydrologic Information System Symposium, Austin, p 23
Mithen SJ, Black E (2011) Water, life and civilisation: Climate, environment and society in the Jordan Valley. Cambridge UP, Cambridge
Molina JL, García-Aróstegui JL, Bromley J, Benavente J (2011) Integrated assessment of the EuropeanWFD implementation in extremely overexploited aquifers through participatory modelling. Water Resour Manag 23:2737–2760
Morgan MG, Dowlatabadi H (1996) Learning from integrated assessment of climate change. Clim Chang 34: 337–368
Mostert E (2003) The challenge of public participation. Water Policy 5(2):179–197
Nikolic V, Imonovic S, Milicevic D (2013) Analytical support for integrated water resources management: A New method for addressing spatial and temporal variability. Water Resour Manag 27:401–417
Pahl-Wostl C (2007) Transitions towards adaptive management of water facing climate and global change. Water Resour Manag 21:49–62
Park J, Seaton RAF (1996) Integrative research sustainable agriculture. Agric Syst 50:81–100
Parker P, Letcher R, Jakeman AJ (2002) Progress in integrated assessment modelling. Environ Modell Softw 17: 209–217
Pollard S, Toit D (2011) Towards adaptive integrated water resources management in southern africa: The role of self-organisation and multi-scale feedbacks for learning and responsiveness in the letaba and crocodile catchments. Water Resour Manag 25:4019–4035
Prodanovic P, Simonovic S (2010) An operational model for support of integrated watershed management. Water Resour Manag 24:1161–1194
Risbey J, Klikar MA, Patwardhan A (1996) Assessing integrated assessments. Clim Change 34:369–395
Rothman DS, Robinson JB (1997) Growing pains: A conceptual framework for considering integrated assessments. Environ Monit Assess 46:23–43

Rotmans J, Van Asselt M (1996) Integrated assessment: Growing child on its way to maturity. An editorial essay. Clim Chang 34:327–336

Tarboton D, Maidment D, Zaslavsky I, Ames D, Goodall J, Hooper P, Horsburgh J, Valentine D, Whiteaker T, Schreuders K (2011) Data Interoperability in the Hydrologic Sciences, The CUAHSI Hydrologic Information System. Proceedings of the Environmental Information Management Conference 2011, 132–137, http://eim.ecoinformatics.org/eim2011/eim-proceedings-2011/view. Accessed July 15 2013

United Nations Economic Commission for Europe (UNECE). 1992. http://rod.eionet.europa.eu/instruments/184. Accessed July 15 2013

Winz I, Brierley G, Trowsdale S (2009) The use of system dynamics simulation in water resources management. Water Resour Manag 23:1301–1323

Yates D, Sieber J, Purkey DR, Huber-Lee A (2005) WEAP21-A demand, priority, and preference driven water planning model: Part 1, model characteristics. Water International 30:487–500