Groundwater for Sustainable Development 2-3 (2016) 7–15

Contents lists available at ScienceDirect

Groundwater for Sustainable Development

journal homepage: www.elsevier.com/locate/gsd

Research paper

Data integration as the key to building a decision support system for groundwater management: Case of Saiss aquifers, Morocco

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ARTICLE INFO

Article history:
Received 3 December 2015
Received in revised form
21 March 2016
Accepted 13 April 2016
Available online 20 April 2016

Keywords:
Decision support system
Groundwater
Heterogeneous data
Data integration
Spatiotemporal data warehouse
Saiss aquifers

ABSTRACT

The widespread of Information Technology tools and the increasing of data production in groundwater management allowed the development of different information systems. Even if this field requires various disciplines, organizations and authorities in charge of groundwater have often worked with operational and specific information systems focusing on a single discipline. Driven by the need to integrate all available data from distributed sources to get relevant information at different levels of the decision-making process, many researches try to deal with this issue. This paper aims to show the role of data integration in building spatiotemporal data warehouse for supporting decision making in groundwater governance and management. The paper presents the approach adopted in this work which consider the geographical unit 'water point' as the model heart and the axis of groundwater data analysis. In order to illustrate this approach, Saiss aquifers have been chosen as a study area. Actually, Saiss aquifer system comprises two superimposed and connected aquifers. These aquifers play a significant role in the socio-economic development of Fez–Meknes region through the supply of drinking water and the satisfaction of irrigation water demand. From the 80s, with decreasing precipitation and increasing groundwater use, Saiss aquifers have known strong overexploitation. Spatiotemporal data warehouse of Saiss aquifers constitutes a platform for developing decision support systems, geo-analytical tools, and intelligent mobile applications, able to quick response to multidimensional queries of groundwater managers and users.

1. Introduction

Even though the debate on the importance of information systems for supporting decision making just started in recent years, the evolution and proliferation of Decision Support Systems (DSS) continue to mark different areas. Significant efforts have been made over the last two decades for the development of geospatial DSS to produce geo-decisional information (Bauzer-Medeiros et al., 2006; Jost, 2001).

The effectiveness of the decision making is based on the provision of relevant information and adapted analysis tools. In the field of groundwater resources management, the amount of available digital data sets is increasing, especially for geospatial data, produced in the framework of numerous studies and researches. Organizations and authorities in charge of groundwater, like Basin Authorities, are actually used to work with operational and specific information systems. This solution, especially if data is variable in time and space, currently turns out an obsolete and outdated solution in the decision making efficiency. This is because of their disparity and the lack of interoperability of these information systems that often become underused or containing outdated and insignificant data in the absence of other complementary data.

Driven by the need to integrate all available data from distributed sources, many researches were focused on data integration process. Thus, data integration is the combination of heterogeneous data residing at different sources, and providing the user an integrated and reconciled view of data in order to extract explicit information at different levels of the decision-making

Abbreviations: ABHS, River basin agency of Sebou; CPU, Central processing unit; DSS, Decision support system; DW, Data warehouse; ETL Process, Export, transfer and load Process; GIS, Geographic information system; ICT, Information and communication technologies; MDA, Multi-dimensional analytical; MPIWRD, Master plan of integrated water resources development; OLAP, On-line analytical processing; SOLAP, Spatial on-line analytical processing; STDW, Spatiotemporal data warehouse; WP_ID, Water point identifier.

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http://dx.doi.org/10.1016/j.gsd.2016.04.003
2352-801X/

process (Cali et al., 2004).

Moreover, data integration gives also users the opportunity to make an integrated analysis of prior information, a single geographical referencing of spatial data, a specialization of data through relationships with geo-referenced geometric entities, and mutual enrichment with semantic and geometric properties (Butenuth et al., 2007). Objectively, a real integration of geographic data is much more than a simple overlay data in a geographic information system (GIS). It is rather towards exchange between individual objects in various information systems (Butenuth et al., 2007).

Data warehouse is considered one of the effective solutions for data integration from different sources. Several definitions have been used to describe what a data warehouse is. Inmon (1996) defined the data warehouse, as “a subject-oriented, integrated, time-variant, non-volatile collection of data in support of management's decision making process”.

The purpose of data warehouse is to provide from integrated data the basis for management reports, decision making support, data mining and sophisticated on-line analytical processing (OLAP) through quick answering to multi-dimensional analytical (MDA) queries (Nilakanta et al., 2008).

OLAP tools are not robust to analyze spatial and temporal data. GIS tools are helpful in spatial data analysis but still are not good enough to make full use of spatiotemporal datasets. Therefore, the new approach is to couple OLAP and GIS functions. The huge potential of this alliance allows the use of data warehouses techniques simultaneously with OLAP analysis and reporting tools, dashboards and data mining and maps visualization. This alliance is called Spatial OLAP systems, or SOLAP (Maceachren and Kraak, 2001). Several researches have been oriented towards the study of possible combinations of different OLAP and GIS technologies.

The field of Spatial Data Warehouses (SDW) has been emerging since the past decade due to the need to analyze large volumes of spatial data. The research in this field has been especially on conceptual models, materialization of spatial indexes, aggregation operations and SOLAP.

Spatial data warehouses aim at effective and efficient querying of spatial data. Decision-makers in water resources management and groundwater especially, often need to get the global picture, but when they see unexpected trends or variations, they need to drill down to get more details to discover the reason for these variations. For example, varying flow at a source that could be due to several reasons like drought, pumping, etc.

The most critical components in data warehouse design are the process of Extract, Transform and Load data (ETL), and data warehouse modeling (Franconi and Sattler, 1999). Data warehouse design has distinguished characteristics compared to traditional database design. This is, in part, because data warehouse design depends upon already existing database systems from which data are extracted, transformed, and aggregated (Nilakanta et al., 2008). The multidimensional conceptual data model can be physically achieved either by using a relational database approach or making use of a specialized multidimensional database.

In the literature, several researchers understood the importance of data integration into a spatiotemporal data warehouse in different fields such as forest inventory (Van Damme, 2010), agriculture (Vidal et al., 1997), and road traffic (Bauzer-Medeiros et al., 2006) and also in water management (Jost, 2001; Vidal et al., 1997). Driven by the need of groundwater data mastering and management some researchers started investing in building information systems and spatiotemporal data warehouses for groundwater (Refsgaard et al., 2010). Convinced of the importance of a unified set for storing and managing groundwater data, some organizations like the Australian Water Commission, launched a project to implement a National Groundwater Information System (NGIS) in 2009 (El Sawah et al., 2011). Despite these efforts, the approach remains unknown and at least not well mastered by groundwater managers and needs to be further strengthened.

The contribution of this paper consists to demonstrate that data integration is an important and an efficient solution to face data distribution and heterogeneity and to build DSS related to groundwater management. To deal with these issues, this paper presents the complexity of data integration process, and the approach adopted to construct DW model. In order to illustrate this approach, Saiss aquifers have been chosen as a study area. The paper will also explain the operating possibilities of this DW as a platform for a DSS development.

2. Materials and methods

2.1. Data integration in a spatiotemporal data warehouse

Data integration in a spatiotemporal data warehouse is recognized in the scientific community specialized in information and communication technologies (ICT), by its complexity in its different stages. This work would mainly focus on the process of DW design and development adapted to groundwater.

Few studies have been carried out on this topic in the field of groundwater resources management. Thus, the approach taken in this work is the result of a reflection on the most appropriate way to store, organize and explore variable data in time and space in order to give managers an interactive platform of data. This platform should initially allow viewing and understanding the phenomena occurring in the study area, and then to help make more suitable decisions regarding integrated water resources management. This approach is adapted to the type of collected data and deals with different constraints faced during data treatment.

The approach proposed in this work consists of 9 steps as explained in Fig. 1:

1. Identification and knowledge of what information is needed for decision making purposes of groundwater managers: This information might be qualitative and quantitative on groundwater supply and current and future water demand and eventually their evolution in time and space. *Example of query*: *What could be the evolution of the groundwater level in the south of the aquifer since the 80s?*
2. Choosing the appropriate solution: Thinking on possible methods to meet the diagnosed needs and expectations, and the choice of the most suitable solution for the DSS building;
3. Data collection: Collection of data relating to groundwater resources from entities responsible for data and information production in various forms and from various sources. Any data type is welcome initially;
4. Data analysis: The analysis of collected data is a very important step in deciding the adequacy with the need for information and the consistency of the DW, and the degree of its success;
5. Metadata definition: Due to the importance of data on data (metadata), this step is considered as a key step in DW building. Metadata are used to store and inquire about information on data in the DW like its origins, sources, how were calculated … etc. Metadata can not only enable the data warehouses design, but also the user interface of the DW (Mattison, 1996; Wu et al., 2001);
6. DW design: DW design and conception is an important step because of its importance in defining the consistence and the