Information System for Integrated Watershed Management Using Remote Sensing and GIS

P. D. Aher, J. Adinarayana, S. D. Gorantiwar and S. A. Sawant

Abstract Watershed management is an endowed approach to mitigate the gap between demand and supply of water and other natural resources, particularly in the fragile arid and semi-arid tropics (SAT). As this is a complex phenomenon, there is need for a reliable Information System/Decision Support System (DSS). Watershed Management Information System (WATMIS) is a viable and generic toolkit for integrated watershed planning and management of its natural resources using multiple technologies like Geographical Information System (GIS), Remote Sensing (RS), Global Positioning System (GPS), hydrological modelling and soft computing tools. In this system, an attempt has been made to integrate dimensions in Agriculture–Water–Soil–Climate continuum for sustainable management of land and water resources judiciously. The application of WATMIS will be useful to various stakeholders such as agriculturists, rural extension community and water resources managers for better decision making.

Keywords Decision support system · Geographical information systems · Global positioning systems · Hydrological modelling · Remote sensing · Soft computing tools · Watershed management and planning

P. D. Aher (✉) · J. Adinarayana · S. A. Sawant
Centre of Studies in Resources Engineering, Indian Institute of Technology Bombay, Powai 400076, Mumbai, India
e-mail: prajakta_aher@iitb.ac.in

S. D. Gorantiwar
Department of Irrigation and Drainage Engineering, Mahatma Phule Agricultural University, Rahuri 413722, India

P. K. Srivastava et al. (eds.), *Remote Sensing Applications in Environmental Research*, Society of Earth Scientists Series, DOI: 10.1007/978-3-319-05906-8_2,

1 Introduction

Inconsistencies and competition over shared water resources between various sectors such as agriculture, industry and domestic sector make it vital component of arid and semi-arid tropics (SAT). Water is becoming scarcer and every fore-warning alert indicates that it will become even more critical in the future. With socio-economic development, contradiction becomes conspicuous between necessitate for water and its limited resources, and it is a matter of concern to the watershed community, such as water resource researchers, scientists and policy makers. Therefore, sustainable water management is a crucial need of the hour. Hence, it becomes important to apply the emerging tools and technologies for ubiquitous watershed management.

1.1 Why Management of Natural Resources on Watershed Basis?

Soil, water and vegetation are the most vital natural resources for sustainable development and management, and hence should be handled and managed effectively, collectively and simultaneously. Managing the natural resource with sustainable approach is a rational phenomenon in its natural region. In this approach, the natural regions are invented to be in terms of the flow of water, which influences almost all fields of the environment, where the regions are diversified as basin, catchment, sub-catchment, macro watershed (>50,000 ha), sub-watershed (10,000–50,000 ha), milli-watershed (1,000–10,000 ha), micro watershed (100–1,000 ha), mini watershed (1–100 ha) (Nair 2009). However, a particular extent/size of a region is imperative with regard to the aim of its development. Size will also be affected by the possible major components of a development such as afforestation, cultivation practices, etc. Keeping in view the local conditions and completion of the project within a reasonably short time, an average size of 2,000 ha is considered rational for agricultural development with regard to ease of surveys and investigations and effective planning. In the present research work, a watershed has been taken as the smallest planning unit, as it conveniently and efficiently represents continuum of three vital natural resources i.e. soil, water and vegetation.

Watershed management programme has emerged as a sustainable strategy to conserve the natural resources i.e. water, forest and soil in an integrated manner particularly in the rainfed and drought areas (Roy 2005). Planning and management of natural resources at micro level of the watershed where there is a high spatio-temporal variability in Gio-physical and socio-economic variables, particularly in the fragile arid and semi-arid tropics (SATs), is the crucial need of the hour (Aher et al. 2012). The real challenge on water resources planning at a micro level is to assess the quantum of water demand and availability caused due to unavailability of adequate database. Watershed based planning through augmentation of modern techniques such as remote sensing (RS) and Geographic Information System (GIS), for modelling the availability of water resources and sectoral demand is being considered as the most appropriate approach.

1.2 Role of Geographic Information System (GIS) and Remote Sensing (RS) in Watershed Management

A Geographical Information System (GIS) can be defined as a system, which facilitates the storage and intelligent use of geographic data and human activities (Srivastava 2003). The essential features of GIS are the use of sophisticated computer hardware and software to collect, store, manipulate and process for geographic data (Singh 2010). GIS is a tool that allow for the processing of spatial data into information (Samarakoon 2005). GIS has the ability to manipulate spatial data and corresponding attribute information to integrate different types of data in a single analysis at high speed, which is unmatched with manual methods (Rashed et al. 2006).

GIS provides a digital representation of landform which could be used in hydrological modelling. The database available in GIS environment facilitates assimilation of different thematic datasets to understand interrelationships. GIS plays an important role in information management, analysis, and providing solutions to the planning of natural resources. The application of GIS for land use surveys and mapping is gaining importance, largely because of its ability to provide rapid and reliable data within a given time framework (Jain 1996). Many GIS-based watershed applications have been developed since the early 1990s due to advances in desktop GIS capabilities, programming languages, and data availability (Strager et al. 2010). In addition, it facilitates integration of socio-economic information with the resources data to understand the local needs. Once the potential of resources and development needs of the watershed are understood, it is possible to evolve specific action plan for development of land and water resources. It plays a key role in implementing soil and water conservation practices that are essential for sustainable agriculture production.

GIS offers technologically suitable method for land resource assessment, delineating different land use patterns, flood management, irrigation water management, and assessment and monitoring of environmental impact of watershed projects. It is also useful in delineating hydro-morphological units in the area to decide suitable sites for land and water harvesting structures in the problematic sites.

Remote sensing is the non-contact recording of information from various electro-magnetic spectrum regions by means of instruments such as cameras, scanners, lasers, linear arrays and/or area arrays located on the ground or arial platforms (Jensen 2007) and the analysis of the acquired information by means of visual and digital image processing (Sabins 1987). Remote sensing, with or without GIS technology, has emerged as an indispensable scientific tool for mapping and planning of natural resources (Vittala et al. 2008; Mahajan and Panwar 2005; Bryan et al. 2011; Burkhard et al. 2012). It plays a hastily escalating role in the field of hydrology and sustainable water resources development and management. These techniques have been extensively applicable in nearly all fields of watershed aspects, like, estimation of evapotranspiration (Bashir et al. 2008; Elhag et al. 2011), soil erosion (Vemu and Pinnamaneni 2011; Esteves et al. 2012; Conoscenti et al. 2013), rainfall runoff modelling (Shrivastava et al. 2004; Rawat et al. 2011; Kim et al. 2012; López-Vicente et al. 2013), flood management (Mason et al. 2003; Park and Hur 2012; Steinfeld et al. 2013) and irrigation water management (Saidi et al. 2009; Georgoussis et al. 2009; Nahry et al. 2011; Liyantonoa et al. 2013).

1.3 Decision Support System in Watershed Management

Decision Support System (DSS) are a model-based set of procedures for processing data and judgments to assist a manager in his/her decision (Little 1970). Adelman (1992) has defined DSS as interactive computer programs that utilize analytical methods, such as decision analysis, optimization algorithms, program scheduling routines, and so on, for developing models to help decision makers to formulate alternatives, analyze their impacts, and interpret and select appropriate options for implementation. DSS is a computer based system of integration of database, models and user interface which are programmed for easily interpretable results to aid the decision makers (Walsh 1993). A DSS can be designed on the basis of user application need as an individual stand-alone or information service based. A stand-alone DSS can be run on a computer dedicated to DSS task where computer acts as desktop microcomputer/high performance workstations or on a multiple-user computer used in a time-sharing mode in which users can share the hardware but with separate stand-alone application (Mallach 2002). DSS can also be developed using web-based services that may be widely used or may be used by multiple units of an organization are beginning to be offered as web-based DSS (Power and Sharda 2007). In addition, the web-based DSS expands the availability of operations and easy accessibility on internet without constraint of time and processing capabilities of the client machine ubiquitously with the additions of hyperlinks and external data/document sources over the stand-alone system (Power 2002).

DSS is a computer-based and is a comprehensive support system than other traditional techniques of decision-making for watershed management community who deal with semi-structured watershed problems such as surface/sub-surface water source long-term availability, hydrological, socio-economic and water quality issues. It is used for development of watershed management plans and operating rules for sustainable environment through policy making. Integration of GIS into spatial DSS system (SDSS) has given the researchers advantage for spatial analysis and visualization (Enache 1994). The ITC Netherlands had developed the first Integrated Land and Water Information System (ILWIS) in 1990s with the integration of GIS which is extremely helpful in spatial modeling. Adinarayana et al. (2006) designed a spatial decision support system for rural land use planning (SDSS/LUP) to support decision making on area selection for different watershed management schemes for conservation planning by providing suggestions and hazard warnings for land use sustainability. Hellweger and Maidment (1999) developed an automated procedure in ARC/INFO and ARC/View to produce the connection of hydrologic elements using the geographic data, which was used to identify the hydrologic elements in Tenkiller reservoir watershed in Oklahoma, USA. In the context of rural development planning, GramyaVikas was developed as a web-based distributed collaboration model to assist the rural extension community in their own decision-making processes in a more interactive, integrated and coordinated manner (Adinarayana et al. 2008). The recent technologies such as Geospatial Information Communication Technology (GeoICT) and Wireless Sensor Network (WSN) were integrated to formulate Geo-Sense, a wed-based DSS to facilitate precision agriculture services (Sudharsan et al. 2012). Many tools for watershed analysis and management are being developed for integrated planning. The modern technology and thinking offered by the advent of the stand-alone or web-based DSS is highly complementary to assure the goals of watershed analysis through solving the complex decision-making process.

1.4 *Need for Advanced and Augmented Techniques for Watershed Management*

In the past, most of the studies consider the watershed management that consists of water resources planning for entire river basin/catchment/sub-catchment scale. The challenge on watershed management at macro/micro level is to make reliable assessment of water demand and availability with the given data. The major gap in the evolving watershed management concept at macro or micro level is due to very limited distribution and exchange of information and datasets caused by different norms, policies, institutional and organizational factors. Hence, it was found that, for studying the detailed aspects of soil and water management as well as to implement hydrological modeling techniques with adequate datasets, it is necessary to understand watershed management at micro level for decentralized planning. Also, land irrigability and capability classification for micro level watershed planning are needed so that the farmer can use better parcels for intensive cultivation with proper conservation measures and soil improving practices.

Technologies are available to solve many watershed problems (irrigation scheduling, water release cycles in canal command area, etc.). However, methods are further needed to effectively demonstrate the benefits of instituting environmentally sound watershed management programmes. Technologies need to be demonstrated in an effective way for easy accomplishment of planes and implementations by the users. These tools and techniques also need to be cost effective. Besides, the physically based hydrological models are very complex and have lots of input parameters and, as previously explained, the major problem is being related to availability of adequate database. Hence, viable methodology must be prevailed over to serve the novice user.

It was found that technologies alone are not producing the expected results to facilitate sustainable development and natural resource management. It is vital to carry out further studies, research and analysis on the concepts and approaches of watershed management. Studies are required on what has been accomplished with existing ones and how these can be made even better.

New concepts and approaches should be developed to reduce the rate of watershed degradation and to improve agriculture development. It is also true that the management and conservation of land and water resources can not be sustainable nor could they be replicated unless all the physico-chemical and biological processes including people's concerns are not taken into account. In addition, participatory approach for water resources conservation and management would be more helpful in reducing the rate of degradation of water resources.

In water resources management, previously specified case studies related to DSS and Information Systems are site/problem precise having focused only on specific hydrological processes such as runoff/erosion, etc. (Palmer and Holmes 1988; Reitsma 1996; Ito et al. 2001; Shim et al. 2002; Koutsoyiannis et al. 2003; Zhang et al. 2004; Mysiak et al. 2005; Calder et al. 2008; Tian-en et al. 2009; Alminana et al. 2010). Furthermore, a few watershed DSSs are merely related to environmental problems e.g. water quality assessment (Poch et al. 2004; Rao et al. 2007; Mullinix et al. 2009; Weng et al. 2010). As watershed management process not only include data related to spatial and temporal attributes but also includes data related with surface water storage, ground water recharge and ground water management, hydrology climatology, agriculture, topography, environmental and socio-economic aspects. The challenging task for natural resources researcher is to combine all the concepts and to prepare entire spatial and non-spatial attribute database by amalgamating the leading edge technologies to form decision making analysis technique. Thus, development of entire watershed management decision support and information system is needed to integrate the Agriculture–Water–Soil–Climate constituents to accomplish the natural resources management and, in turn, sustainable development. Also, the complexities of hydrological models cause many problems for the novice user, particularly in SAT region where spatio-temporal variability of environmental factors is high.

There is a need of appropriate modelling and application of modern techniques to integrate Agriculture–Water–Soil–Climate environments to optimize and allocate the land and water resources properly. Suitable measures, data, and modern techniques such as GIS, Remote Sensing and soft computing tools that could be utilized to manage watersheds imply appropriate technologies at the farmer level and provide watershed services for upstream and downstream areas.

Keeping the above points in view, an attempt has been made to develop a viable, full-fledged, user friendly and holistic toolkit for integrated watershed planning and management of its natural resources, christened “WATMIS: Watershed Management Information System”. WATMIS is a web-based information/decision support system (DSS) that integrates soil-vegetation-climate-environment dynamics in formulation of hydrological systems water balance model through the multi-cropping agricultural practices with distinct irrigation practices.

2 Study Area

The WATMIS was demonstrated over a watershed located at Pimpalgaon Ujjaini in Ahmednagar District of Maharashtra state, India (Fig. 1). Maharashtra, has only 13 % of the cropped area under irrigated water, and the remaining area is dependent on rainfall only. In this state larger flow irrigation projects are working but it can not satisfy irrigation water need for all, particularly at rural community level. Therefore, planning these units; using recent tools and techniques, and in situ methods of soil and water conservation at micro watershed and/village level is necessary. The watershed is located between 74°45′00″E to 74°51′00″E longitude and 19°08′43″N to 19°11′31″N latitude.

The study area falls in transition zone between mountainous and water scarcity region of central plateau region and characterized by very shallow to very deep black, moderately permeable soils, and shows sandy loam to clay texture over nearly level (<1 %) to very steep sloping land (>35 %). Agriculture is practiced mainly with single agricultural season (*kharif*: June–October or *rabi*: November–March) with exception under double crop cultivation (Aher et al. 2012). The limiting soil moisture is the major threat influencing crop yield. The watershed represents water scarcity, acute drought prone and rain shadow conditions and falls under semi-arid tropical climatic conditions with the mean minimum and maximum temperatures of about 11 and 35 °C in winter and summer seasons, respectively, with an average rainfall of about 650 mm. Thereby, all these characteristics suggest water scarcity and land degradation are major environmental intimidation.

3 Conceptual Design

In a sound watershed management framework, various complex decision making processes are involved with structural and non-structural practices that can be undertaken to optimize of land and water resources, prevent soil erosion, stabilize water demand, and to increase productivity through efficient land use planning. The WATMIS attempt illustrate the development of a viable and generic toolkit for integrated watershed planning and management of its natural resources. The system is conglomeration of multiple technologies like Geographical Information System (GIS), Remote Sensing (RS), Global Positioning System (GPS), hydrological modelling, soft-computing tools, etc.

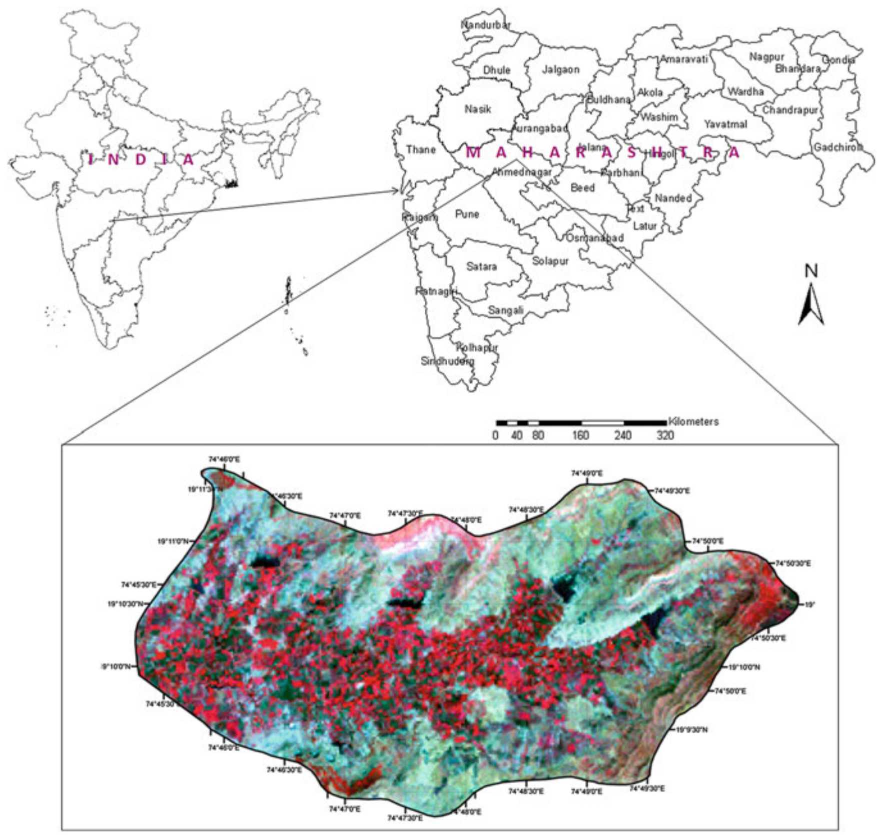

Fig. 1 Study area location map of Pimpalgaon Ujjaini watershed, Ahmednagar (MH), India

3.1 Data Used

Various spatial, non-spatial, temporal, attribute, and thematic datasets were used in WATMIS. Satellite Data of Landsat 7 Enhanced Thematic Matter (ETM/ETM+), particularly in the growing phases of crops (September–December), were used for obtaining land use distributions as well as irrigation water necessitate. The meteorological (Julian day of year, mean relative humidity, solar radiation, open pan evaporation, wind speed, and daily minimum and maximum air temperature), cropping system, soil (field capacity, soil type, permanent wilting point) and watershed datasets were used for dynamic hydrological modeling to obtain maximum crop yield through optimal allocation of watershed resources.

3.2 Tools and Technologies Used

- *PostgreSQL*: PostgreSQL (9.0) is an open source, standards compliant and highly customizable Object Relational Database Management System (ORDBMS) based on Relational Database Management Systems (RDBMS), developed by PostgreSQL Global Development Group. It provides support for foreign keys, joins, views, triggers, and stored procedures (in multiple languages) and includes most of the data types such as integer, numeric, boolean, char, variable character, date, interval, and timestamp (PostgreSQL, 9.0). GiST (Generalized Search Tree) with PostGIS public project supports geographic objects in PostgreSQL by allowing it to be used as a spatial database for GIS. ORDBMS has been used as back end for retrieval of attribute/non-spatial and spatial datasets for further analysis and modeling.
- *Apache server*: Apache server (2.2) developed by Apache Software Foundation, provides open-source web server platform for online distribution of website services (Apache 2013). In WATMIS, the server processes the requests received from user and sent back the generated information through the web browser.
- *Hyper Text Markup Language* (*HTML*): WATMIS uses Hyper Text Markup Language (HTML), an extended version of Standard Generalized Markup Language (SGML), for development of documents on the World Wide Web (WWW) (World Wide Web Consortium 2013). HTML expresses data input/ display and environmental modelling results through user.
- *Hypertext Preprocessor* (*PHP*): Open source Hypertext Preprocessor (PHP), a server-side scripting language, in combination with HTML was used for WATMIS development. As it provides server-side scripting, command line scripting and desktop applications with a graphical user interface (GUI), which widely supports in executing dynamic, interactive database-server enabled web pages (The PHP Group 2012) on client/user action.
- *Map Server*: WATMIS uses Map Server Open Source geographic data rendering engine, developed by the University of Minnesota. Map Server WWW-GIS technology is built up on numerous Open Geospatial Consortium (OGC) standards and provides access to DBMS and also provides a user friendly interface for data input, query, analysis and display of various vector and raster datasets (MapServer 2013).
- *Java Script*: It is a programming language which can be combined into HTML pages for providing high level of interactivity to web pages than simple HTML (Oracle 2013). This language is used for dynamic visualization of data on internet.
- *pMapper*: *pMapper* framework was used for querying and visualization of spatial information on web. It has extensive functionality as well as multiple configurations to provide the setup of a MapServer application based on PHP/ MapScript (pMapper 2013).

3.3 System Architecture

WATMIS is a user friendly-interactive-web based decision support system that consists of different hydrological processes and their modelling for sustainable development and management of natural resources on a watershed basis. The fundamental processes of hydrological cycle such as rainfall, surface runoff, ET, etc. along with various components of watershed management techniques were integrated and modeled for developing the WATMIS that can integrate and handle various models and GIS data sets. Besides, an integrated hydrological simulation model was developed and assimilated with user interfaces to form a holistic structure for watershed management decision making processes.

A schematic representation of the integrated WATMIS is depicted in Fig. 2. The system is implemented as a layered structure, with every layer corresponding to a different functionality. The design of WATMIS consists of following three layers:

- Database Management System (DBMS)
- Application layer (AL)
- User-Database-Model Interface (UDMI)

The Database Management System (DBMS) includes various spatial as well as non-spatial multi source (satellite, GPS, ground and map-based data and reports) datasets of the watershed such as soil, hydrologic, meteorological, geologic, land and vegetation. Server Side Application Layer (AL) is implemented using Apache server-2.2 (Apache 2013) which is a powerful and flexible technology for hosting dynamic web pages. This provides user-friendly and robust platform for various modelling environments through data assimilation-integration-analysis. The User-Database-Model Interface (UDMI) consists of different forms for receiving the information from the user by using HTML (Hyper Text Markup Language) and PHP (Hypertext Preprocessor) languages. UDMI presents robust mechanism for transfer/access of the data for user community. It also provides platform for data analysis and modelling of the hydrologic components for efficient watershed management.

4 Online Generation and Implementation of WATMIS

In SAT regions, the available water can be either surface water or sub-surface water (ground water) or both as a result of rainfall. Agricultural water requirement is a major component of water demand in a watershed. Also, the water demands can be domestic needs of human population as well as of animals. Particularly in semi-arid tropics, to get the desired benefits of watershed management approach, adoption of certain soil and water conservation measures in the watershed is essential. Hence, an attempt has been made for natural resources planning and management on a watershed basis. The watershed based natural resources planning

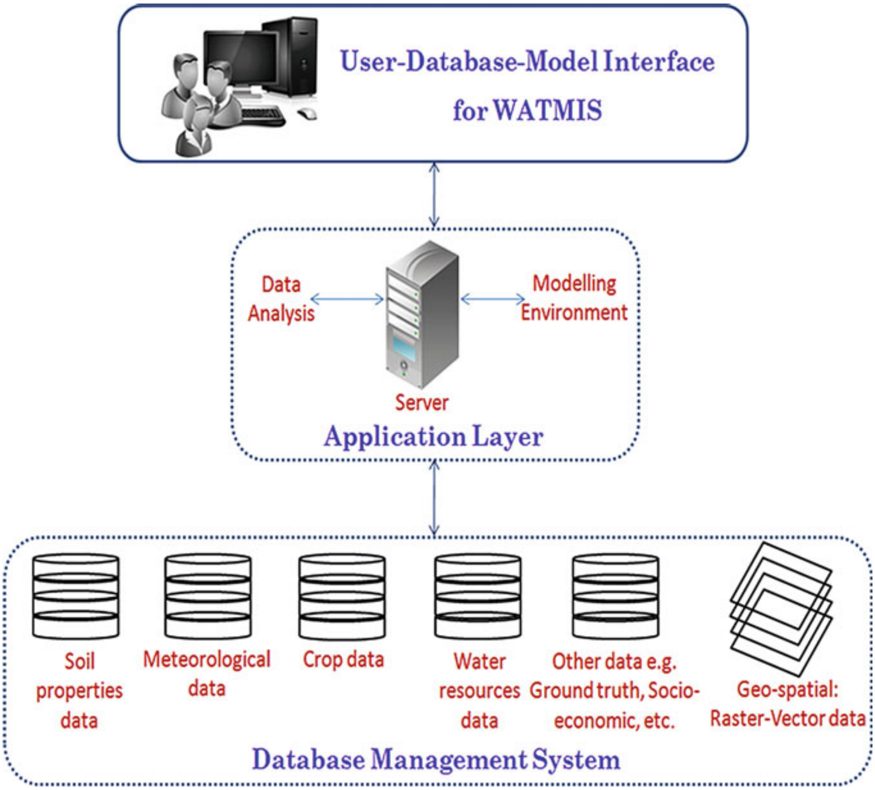

Fig. 2 System architecture of watershed management information system (WATMIS)

approach will basically consists of water availability assessment, modelling of major water availability-demand components, and operational planning of water resources by considering all the processes in hydrological cycle of a watershed. Ahmednagar district in Maharashtra, an inland and drought-prone district, falling under SAT region has been chosen in order to verify the management approaches and suggest the best management practices (BMPs) by demonstrating and developing a user friendly and widely supported open-source software based watershed management information system for better decision making.

WATMIS is designed and developed by using modern scientific developments and technologies to achieve holistic, sustainable watershed management aspects on the basis of architecture shown in Fig. 2. The system consists of various types of databases such as agricultural, meteorological, irrigation and soil as well as hydrological models and spatial/non-spatial user database model interface. The homepage of WATMIS (Fig. 3) depicts various information repository services about natural resources management information system with which the user communicates to the system by furnishing the login details. The user communication plays a significant role in endowing the BMPs. Therefore, the module

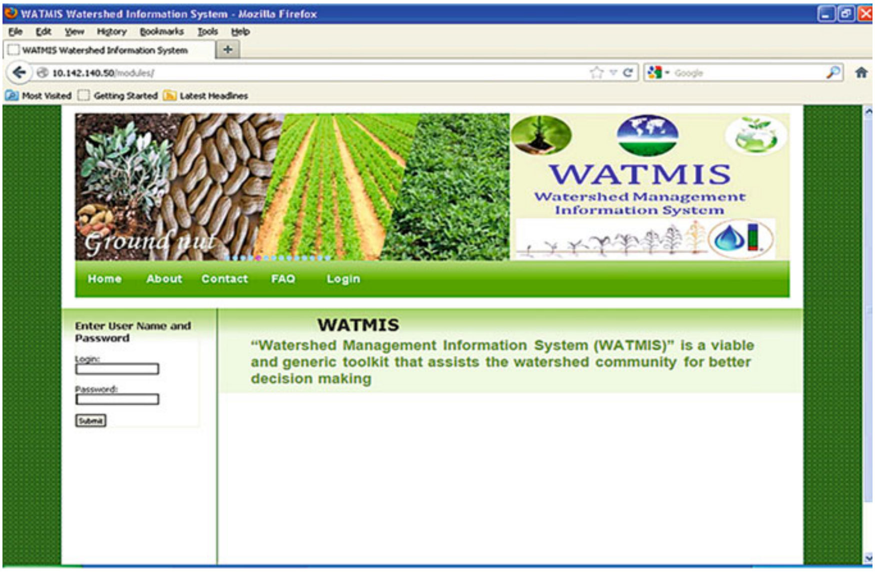

Fig. 3 Homepage of WATMIS

consists of learning repository services that provides introduction and basic information about the watershed modelling environment, Frequently-Asked-Questions (FAQ) and expertise contact details. Furthermore, through the login, user is navigated to simulation and modelling environment.

To increase the robustness and applicability of land and water resources management system, an integrated object-oriented relational approach based database is designed for development of various interfaces or modules. The data necessitated to be handled consists of multi scale spatial and non-spatial data from various reports, ancillary data sources, satellite, geographical, hydrological and environmental data sets such as, topographic maps, soil types, cropping system, meteorological data, etc. The DBMS layer is implemented using Apache server and is used for efficiently designing the tables, relationships, referential integrity rules and queries. All the datasets in DBMS have ability to data input, accessibility, update, visualization, and analysis through proper interaction among themselves via primary key and foreign key relationship.

WATMIS provides spatial database interaction system which is immense helpful in visualization of watershed framework layers such as land use patterns, soil types/texture, availability of nutrients, land capability and irrigability patterns, etc. The spatial dataset interface was designed by using open source GIS application, 'Map Server', in conjuction with front-end application 'p.mapper', which is implemented through incorporating Java Script, Map Script and PHP scripts. This facilitates for visualization and database query of the spatial location of interest directly for decision making and implementing the planning strategies. Furthermore, these

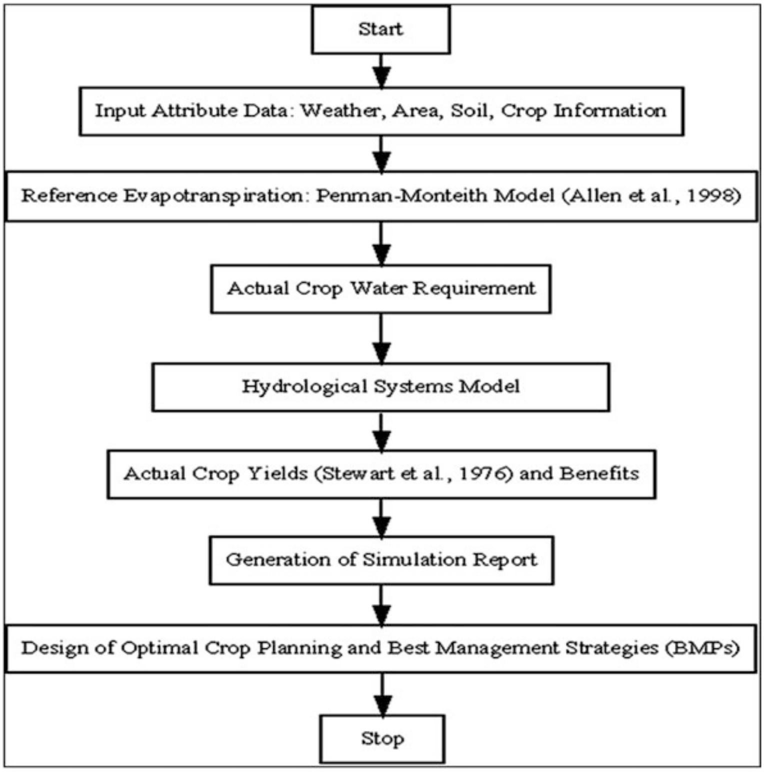

Fig. 4 Flow design for optimum allocation of available land and water resources

query modules provides the information about the topography, soils, crops and management zones of the sub-watersheds/parcel units on which soil and water resources conservation measures can be implemented through watershed prioritization.

The simulation UIL consists of various forms for accepting information from the user/client and validating those forms using PHP script. Privilege has been provided to user to select the number of crops, the soil system on which the crop is grown and the temporal variation of cropping season for which meteorological data such as relative humidity, rainfall, sun shine hours, daily maximum and minimum temperatures, wind speed, etc. was taken to run the hydrological model. The modelling approach adopted through integration of soil–vegetation–climate–environment dynamics in formulation of hydrological model for the multi-cropping agricultural systems (Fig. 4).

In data analysis and modelling environment, the basic input data can be retrieved through DBMS to calculate the crop water requirement (Fig. 5) and actual crop water demand, which further provided as an input for analyzing the hydrological model to obtain the actual crop yields and benefits with distinct

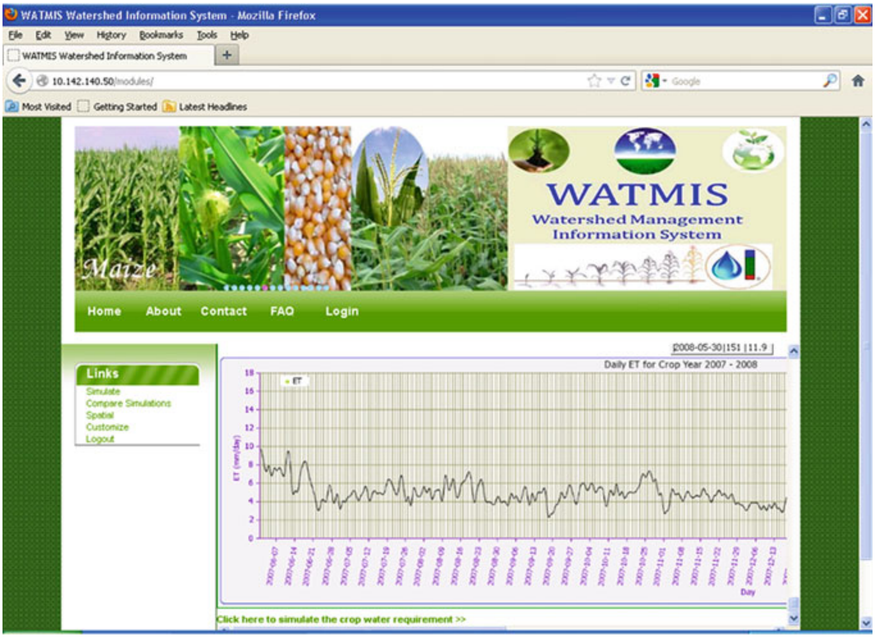

Fig. 5 Simulation of hydrological model

irrigation practices. Furthermore, simulation report generation service was also provided to the client that facilitates in comparative analysis among different possible planning strategies to accomplish the optimal solution. If the given irrigation strategy is not appropriate, the information service was provided to farmer about when to irrigate and how much to irrigate. Thus, the simulation emphasizes on factors influencing crop yields such as irrigation strategies, soil types, etc. to facilitate judicious planning and management of natural resources through optimization of available land and water properly.

During the course of operation of WATMIS, expert advices in the form of help menu or FAQ's provide sound basis for taking appropriate decisions. The 'Customize' operation facilitates user to modify, add, delete the input data for modelling the WATMIS for a given area of interest. Currently, web-enabled WATMIS is operational at local host and the system will be deployed at various user organizations with their broadband lines to make it online.

5 Conclusion

A viable, cost-effective, object-oriented and generic toolkit, called "WATMIS: Watershed Management Information System" using emerging tools and technologies such as, soft computing, GIS, RS, GPS, hydrological modelling, etc. was developed for online integrated watershed planning and management of its natural resources. The effective development of the WATMIS illustrates successful formulation of the framework for supported web-based sustainability.

WATMIS successfully assimilates Agriculture–Water–Soil–Climate continuum for attaining the suitable irrigation level for multiple cropping systems. In addition, it assesses crop yield, demarcating prioritization zones for soil and water conservation management and implementing knowledge repository services during information-decision support with spatial/non-spatial database management, visualization, analysis, query and user individualized customization utilities for optimization and management of land and water resources properly. With augmentation of the frequent temporal variation in satellite data, the system can be improved towards real to near-real time evaluation. The application of WATMIS will be useful to various stakeholders such as agriculturists, rural extension community, and water resources managers for better decisions making.

References

Adelman L (1992) Evaluating decision support and expert systems. John Wiley and Sons, New York

Adinarayana J, Laurenson M, Ninomiya S (2006) Web-based decision support system for rural land use planning-WebLUP-a prototype. Agric Eng Int CIGR E-J 8 (Manuscript IT 05 005)

Adinarayana J, Tewari G, Azmi S, Sudharsan D (2008) GramyaVikas—a distributed collaboration model for rural development planning. J Comput Electron Agric 62(2):128–140

Aher PD, Adinarayana J, Gorantiwar SD (2012) Use of morphological characteristics for multi-criteria evaluation through fuzzy analytical hierarchy process for prioritization of watersheds. In: 21st century watershed technology: improving water quality and the environment conference proceedings, Bari, Italy, pp 12–13639, 27 May–1 June 2012

Alminana M, Escudero LF, Landete M, Monge JF, Rabasa A, Soriano J (2010) WISCHE: a DSS for water irrigation scheduling. Omega 38(6):492–500

Apache (2013) Apache HTTP server project. http://httpd.apache.org/. Accessed on: 30 Jan 2013

Bashir MA, Hata T, Tanakamaru H, Abdelhadi AW, Tada A (2008) Satellite-based energy balance model to estimate seasonal evapotranspiration for irrigated sorghum: a case study from the Gezira scheme, Sudan. Hydrol Earth Syst Sci 12(4):1129–1139

Bryan BA, King D, Ward JR (2011) Modelling and mapping agricultural opportunity costs to guide landscape planning for natural resource management. Ecol Ind 11(1):199–208

Burkhard B, Kroll F, Nedkov S, Müller F (2012) Mapping ecosystem service supply, demand and budgets. Ecol Ind 21:17–29

Calder I, Gosain A, Rao MSRM, Batchelor C, Garratt J, Bishop E (2008) Watershed development in India. 2. New approaches for managing externalities and meeting sustainability requirements. Environ Dev Sustain 10(4):427–440

Conoscenti C, Agnesi V, Angileri S, Cappadonia C, Rotigliano E, Märker M (2013) A GIS-based approach for gully erosion susceptibility modelling: a test in Sicily, Italy. Environ Earth Sci 1–17. DOI: 10.1007/s12665-012-2205-y

Elhag M, Psilovikos A, Manakos I, Perakis K (2011) Application of the SEBS water balance model in estimating daily evapotranspiration and evaporative fraction from remote sensing data over the Nile delta. Water Resour Manage 25:2731–2742

Enache M (1994) Integrating GIS with DSS: a research agenda. In: Proceedings of Urban and Regional Information Association (URISA), Milwaukee, Wisconsin, pp 154–166, 12–15 Aug

Esteves TCJ, Kirkby MJ, Shakesby RA, Ferreira AJD, Soares JAA, Irvine BJ, Ferreira CSS, Coelho COA, Bento CPM, Carreiras MA (2012) Mitigating land degradation caused by wildfire: application of the PESERA model to fire-affected sites in central Portugal. Geoderma 191:40–50

Georgoussis H, Babajimopoulos C, Panoras A, Arampatzis G, Hatzigiannakis E, Ilias A, Papamichail D (2009) Regional scale irrigation scheduling using a mathematical model and GIS. Desalination 237(2):108–116

Hellweger FL, Maidment DR (1999) Definition and connection of hydrologic elements using geographic data. J Hydrol Eng 4(1):10–18

Ito K, Xu ZX, Jinno K, Kojiri T, Kawamura A (2001) Decision support system for surface water planning in river basin. J Water Resour Plann Manag 127(4):272–276

Jain MK (1996) Geomorphologic and land use planning for Danda watershed. National Institute of Hydrology, Roorkee

Jensen JR (2007) Remote sensing of the environment: an earth resource perspective, 2nd edn. Prentice Hall, New Jersey

Kim J, Noh J, Son K, Kim I (2012) Impacts of GIS data quality on determination of runoff and suspended sediments in the Imha watershed in Korea. Geosci J 16(2):181–192

Koutsoyiannis D, Karavokiros G, Efstratiadis A, Mamassis N, Koukouvinos A, Christofides A (2003) A decision support system for the management of the water resource system of Athens. Phys Chem Earth 25(14–15):599–609

Little JDC (1970) Models and managers: the concept of a decision calculus. Manage Sci 16(8-B):466–485

Liyantonoa Kato Tb, Kuroda Hc, Yoshida K (2013) GIS analysis of conjunctive water resource use in Nganjuk district, east Java, Indonesia. Paddy Water Environ 11(1–4):193–205

López-Vicente M, Poesen J, Navas A, Gaspar L (2013) Predicting runoff and sediment connectivity and soil erosion by water for different land use scenarios in the Spanish Pre-Pyrenees. Catena 102:62–73

Mahajan S, Panwar P (2005) Land use changes in Ashwani Khad watershed using GIS techniques. J Indian Soc Remote Sens 33(2):227–232

Mallach EG (2002) Decision support and data warehouse systems. Tata Mcgraw Hill, New Delhi

MapServer (2013) MapServer 6.2.0 documentation. http://mapserver.org . Accessed on: 02 Jan 2013

Mason DC, Cobby DM, Horritt MS, Bates PD (2003) Floodplain friction parameterization in two-dimensional river flood models using vegetation heights derived from airborne scanning laser altimetry. Hydrol Process 17:1711–1732

Mullinix C, Hearn P, Huajun Z, Aguinaldo J (2009) Web-based decision support and visualization tools for water quality management in the Chesapeake Bay watershed. In: The 17th international conference on geoinformatics, Fairfax, Virginia, USA, pp 1–6, 12–14 Aug 2009

Mysiak J, Giupponi C, Rosato P (2005) Towards the development of a decision support system for water resource management. Environ Model Softw 20(2):203–214

Nair ASK (2009) A new scientific management approach to water related natural disasters. In: Proceedings of Kerala environment congress, Thiruvanthapuram, pp 143–154, 19–21 Aug

Nahry AHE, Ali RR, Baroudy AAE (2011) An approach for precision farming under pivot irrigation system using remote sensing and GIS techniques. Agric Water Manag 98(4):517–531

Oracle (2013) Java scripting programmer's guide. http://docs.oracle.com . Accessed on: 27 Jan 2013

Palmer RN, Holmes KJ (1988) Operational guidance during droughts: expert system approach. J Water Resour Plann Manag 114(6):647–666

Park JH, Hur YT (2012) Development and application of GIS based K-DRUM for flood runoff simulation using radar rainfall. J Hydro-Environ Res 6(3):209–219

pMapper (2013) pMapper documentation. http://www.pmapper.net/ . Accessed on: 09 Jan 2013

Poch M, Comas J, Rodrý I, Sa M, Corte U (2004) Designing and building real environmental decision support systems. Environ Model Softw 19(9):857–873
Power DJ (2002) Decision support systems: concepts and resources for managers. Greenwood/ Quorum, Westport
Power DJ, Sharda R (2007) Model-driven decision support systems: concepts and research directions. Decis Support Syst 43:1044–1061
Rao M, Fan G, Thomas J, Cherian G, Chudiwale V, Awawdeh M (2007) A web-based GIS decision support system for managing and planning USDA's conservation reserve program (CRP). Environ Model Softw 22(9):1270–1280
Rashed M, Idris Y, Shaban M (2006) Integrative approach of GIS and remote sensing to represent the hydrogeological and hydrochemical conditions of Wadi Qena—Egypt. In: The 2nd international conference on water resources and arid environment, Saudi Arabia, pp 26–29, Nov 2006
Rawat PK, Tiwari PC, Pant CC, Sharama AK, Pant PD (2011) Modelling of stream run-off and sediment output for erosion hazard assessment in Lesser Himalaya: need for sustainable land use plan using remote sensing and GIS: a case study. Nat Hazards 59(3):1277–1297
Reitsma RF (1996) Structure and support of water-resources management and decision-making. J Hydrol 177(3–4):253–268
Roy UN (2005) Participatory RS and GIS for micro level watershed planning and management. In: 31st international symposium on remote sensing of environment, Saint Petersberg, 20–24 June 2005
Sabins FF Jr (1987) Remote sensing: principles and interpretation. W. H. Freeman and Co., New York
Saidi S, Bouri B, Dhia HB, Anselme B (2009) A GIS-based susceptibility indexing method for irrigation and drinking water management planning: application to Chebba-Mellouleche Aquifer, Tunisia. Agric Water Manag 96(12):1683–1690
Samarakoon L (2005) Basic geographic information system (GIS) vector/raster model. ISPRS workshop on remote sensing and GIS for watershed management, Laos, 2–5 Dec
Shim KC, Fontane DG, Labadie JW (2002) Spatial decision support system for integrated river basin flood control. J Water Resour Plann Manag 128(3):190–201
Shrivastava PK, Tripathi MP, Das SN (2004) Hydrological modeling of a small watershed using satellite data and GIS technique. J Indian Soc Remote Sens 32(2):145–157
Singh S (2010) Geography for UPSC prelims, 3rd edn. Tata McGraw-Hill Education, New Delhi
Srivastava VK (2003) Role of GIS in natural resources management. In: Thakur B (ed) Perspectives in resource management in developing countries. Concept Publishing Company, New Delhi, pp 479–484
Steinfeld CMM, Kingsford RT, Laffan SW (2013) Semi-automated GIS techniques for detecting floodplain earthworks. Hydrol Process 27:579–591
Strager MP, Fletcher JJ, Strager JM, Yuill CB, Eli RN, Todd PJ, Lamont SJ (2010) Watershed analysis with GIS: the watershed characterization and modeling system software application. Comput Geosci 36(7):970–976
Sudharsan D, Adinarayana J, Tripathy AK, Ninomiya S, Hirafuji M, Kiura T, Desai UB, Merchant SN, Reddy DR, Sreenivas G (2012) GeoSense: a multimode information and communication system. ISRN Sensor Networks, 2012, Article ID 215103, 13 p, doi: 10.5402/2012/215103
The PHP Group (2012) PHP manual. http://php.net/ . Accessed on: 14 Sept 2012
Tian-en C, Li-ping C, Yunbin G, Yanji W (2009) Spatial decision support system for precision farming based on GIS web service. In: Proceedings of information technology and applications, 2009 (IFITA '09), China, pp 372–376, 15–17 May
Vemu S, Pinnamaneni UB (2011) Estimation of spatial patterns of soil erosion using remote sensing and GIS: a case study of Indravati catchment. Nat Hazards 59(3):1299–1315
Vittala SS, Govindaiah S, Gowda HH (2008) Prioritization of sub-watersheds for sustainable development and management of natural resources: an integrated approach using remote sensing, GIS and socio-economic data. Curr Sci 95(3):345–354

Walsh MR (1993) Toward spatial decision support systems in water resources. J Water Resour Plann Manag 119(2):158–169

Weng SQ, Huang GH, Li YP (2010) An integrated scenario-based multi-criteria decision support system for water resources management and planning—a case study in the Haihe River Basin. Expert Syst Appl 37(12):8242–8254

World Wide Web Consortium (2013) World Wide Web Consortium (W3C). http://www.w3.org/ . Accessed on: 12 Jan 2013

Zhang J, Li J, Zhu Y (2004) Integrating crop simulation models with WebGIS for remote crop production management. In: Proceedings of international geoscience and remote sensing symposium, Anchorage, Alaska, pp 2598–2600, 20–24 Sept

Springer

http://www.springer.com/978-3-319-05905-1

Remote Sensing Applications in Environmental Research

Srivastava, P.K.; Mukherjee, S.; Gupta, M.; Islam, T. (Eds.)

2014, XVI, 212 p. 80 illus., 66 illus. in color., Hardcover
ISBN: 978-3-319-05905-1