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Geographical Information System (GIS) in Water Resources Engineering

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Abstract : The world is getting populated day by day & the population explosion is creating pressure on all the natural resources & the necessity of spending the same in a judicious fashion is the cry of the day. The primal item of man use is water which is scarce as ever & the judicious spending of the same is necessary using a GIS monitored system, coupled with minimal use of fertiliser to maximise the crop growth at the minimal use of irrigation. GIS applications are tools that allow users to create interactive queries (user-created searches), analyze spatial information, edit data in maps & present the results of all these operations. In more generic sense GIS is a tool that allows users to create interactive queries analyze the spatial information & edit data. The later part of the paper discusses the scope of GIS, its uncertanities, raster to vector translation, data representation, GIS in irrigation management, GIS for predicting the future irrigation demand growth, GIS based irrigation water demand estimation, etc. The paper further discusses GISAREG program in irrigation simulation with a special reference to GIS user-interface techniques in precision farming of rice leading to the GIS model in estimating the regionally distributed drought water demand. In a nutshell the paper discusses all the facets of application of GIS in mankind including GIS model in estimating the regionally distributed drought water demand.

Keywords—GISAREG, GIS in irrigation management, GIS in drought water estimation, DSS, ArcView GIS's application in Italy.

I. Introduction : With the world's population touching the six billion mark & with expectations to increase by another three billion over the next five decades, the world's food scenario is thinning fast. Irrigation produces 30 to 40% of the world's food crops on 17% of the total arable land (Seckler et al., 1998). To meet future demands for food with an increasingly scarcity of water supply, it is a must to manage our water resources better. When water supplies are abundant & environmental pollution & degradation is no issue, water managers can afford to be lax in its management with population growth & the effects of cyclic droughts on irrigated agriculture have put pressure on the available water resources. Such prevailing conditions have the effect of creating an imbalance between the increasing water demand & limited available water supply. Under this perspective, effective planning & management can only be obtained on the basis of reliable information on spatial & temporal patterns of farmers' water demand on framing irrigation practices & on physical & operational features of large-scale irrigation systems, is the cry of the day. Chowdary et al. (2008) showed that satellite remote sensing coupled with GIS, offers an excellent alternative to conventional mapping techniques in monitoring & mapping of surface & sub-surface waterlogged areas. El Nahry et al. (2011) found that for central pivot irrigation under precision farming, remote sensing & GIS techniques have played a vital role in the variable rate of water applications that were defined due to management zone requirements.

Fertilizers were added at variable rates. Crop water requirements were determined, according to the actual plant requirements using SEBAL model with the aid of FAO CROPWAT model. On that basis water was supplied at variable rates. Hatzios & Kriton (2000) used the soils information, recompiled from an uncorrected aerial photographic base to a USGS topographic base map. Soil data were added to numerous other data layers & images. Utset & Borroto (2001) used the GIS to create raster layers with electrical conductivity of soil & topographical altitudes to determine the border of saline effect zones. Szalai et al. (2004) analysed several applications of the GIS in climatology, meteorology & regional evapotranspiration, as well as, to determine irrigation requirements. Xiaopveng et al. (2011) developed an irrigation scheduling method by integrating the 'check-book irrigation method' into a GIS-coupled soil, water & nitrogen management model. The soil, water & crop information required by the check-book method previously collected from field observations was estimated by the soil, water & nitrogen management model. A geographical information system (GIS) is a system designed to capture, store, manipulate, analyze, manage & present all types of geographical data. GIS applications are tools that allow users to create interactive queries (user-created searches), analyze spatial information, edit data in maps & present the results of all these operations. In more generic sense GIS is a tool that allows users to create interactive queries analyze the spatial information & edit data. It allows users to bring all types of information based on the geographic & locational component of the data. GIS lets one model scenarios to test various hypotheses & observes the outcomes visually to find/identify the outcome, that meets the needs of the stakeholders. Now days GIS & related technologies are increasingly being recognized as useful tools for studying natural resources, inventory studies & management because of their capability to bring together geographically referenced data from a variety of subject matters to aid in processing interpretation & analysis of such data.

Benefits of GIS over other Information Systems :

GIS is fundamentally used to answer questions & make decisions. GIS has many benefits, which include :

- Analysis of spatial data in a complex environment
- Ability to integrate different databases into one environment

- Ability to display & manage spatial data in a spatial context
- Rapid production of specialized maps & graphic products
- Performs complex spatial analysis
- Cost savings resulting from greater efficiency.
- Improved communication
- Better geographic information & record-keeping.
- Managing information & results geographically.

II. Material & Methodology : GIS techniques & technology

Modern GIS technologies use digital information, for which various digitized data creation methods are used. The most common method of data creation is digitization, where a hard copy of the map or survey plan is transferred into a digital medium through the use of a CAD program & geo-referencing capabilities. With the wide availability of ortho-rectified imagery (from satellites, aircraft, Helikites & UAVs), heads-up digitizing is becoming the main avenue through which geographic data is extracted. Heads-up digitizing involves the tracing of geographic data directly on top of the aerial imagery, instead of by the traditional method of tracing the geographic form on a separate digitizing tablet (i.e. heads-down digitizing).

Relating information from different sources :

GIS uses spatio-temporal (space-time) location as the key index variable for all other information. Just as a relational database containing text or numbers can relate many different tables using common key index variables, GIS can relate otherwise unrelated information by using location as the key index variable. The key is the location &/or extent in space-time.

GIS uncertainties:

GIS accuracy depends upon source data & how it is encoded to be data referenced. Land surveyors have been able to provide a high level of positional accuracy utilizing the GPS-derived positions. High-resolution digital terrain & aerial imagery powerful computers & web technology are changing the quality, utility & expectations of GIS to serve society on a grand scale, but never the less there are other source data that have an impact on overall GIS accuracy, like paper maps, though these may be of limited use in achieving the desired accuracy since the aging of maps affects their dimensional stability.

In developing a digital topographic database for a GIS, topographical maps are the main source & aerial photography & satellite imagery are extra sources for collecting data & identifying attributes which can be mapped in layers over a location facsimile of scale. The scale of a map & geographical rendering area representation type are very important aspects since the information content depends mainly on the scale set resulting locability of the map's representations. In order to digitize a map, the map has to be checked within theoretical dimensions, then scanned into a raster format & resulting raster data has to be given a theoretical dimension by a rubber sheeting / warping technology process.

Data representation :

GIS data represents real objects (such as roads, land use, elevation, trees, waterways, etc.) with digital data, determining the mix. Real objects can be divided into two abstractions : discrete objects (e.g. a house) & continuous fields (such as rainfall amount or elevations). Traditionally, there are two broad methods used to store data in a GIS for both kinds of abstractions mapping references : raster images & vector. Points, lines & polygons are the stuff of mapped location attribute references. A new hybrid method of storing data is that of identifying point clouds, which combine three-dimensional points with RGB information at each point, returning a "3D color image". GIS thematic maps then are becoming more & more realistically, visually descriptive of what they set out to show or determine.

Data capture:

The current trend for geographical information system (GIS) is that accurate mapping & data analysis are completed while in the field. Depicted hardware (field-map technology) is used mainly for forest inventories, monitoring & mapping.

Data capture — entering information into the system — consumes much of the time of GIS practitioners. There are a variety of methods used to enter data into a GIS where it is stored in a digital format.

Raster-to-vector translation :

Data restructuring can be performed by a GIS to convert data into different formats. For example, a GIS may be used to convert a satellite image map to a vector structure by generating lines around all cells with the same classification, while determining the cell spatial relationships, such as adjacency or inclusion. More advanced data processing can occur with image processing, a technique developed in the late 1960s by NASA & the private sector to provide contrast enhancement, false color rendering & a variety of other techniques including use of two dimensional Fourier transforms. Since digital data is collected & stored in various ways, the two data sources may not be entirely compatible. So a GIS must be able to convert geographic data from one structure to another. In so doing, the implicit assumptions behind different ontologies & classifications require analysis. Object ontologies have gained increasing prominence as a consequence of object-oriented programming & sustained work by Barry Smith & co-workers.

Projections coordinate systems & registration :

The earth can be represented by various models, each of which may provide a different set of coordinates (e.g. latitude, longitude, elevation, etc.) for any given point on the Earth's surface. The simplest model is to assume the earth to be a perfect sphere. As more measurements of the earth have accumulated, the models of the earth have become more sophisticated & more accurate.

GIS in Irrigation Management :

GIS is a familiar & popular tool for management & decision making in water resources for agricultural & conservation purposes. A spatial approach such GIS is particularly appropriate for the handling the spatial data in irrigation management. GIS technology such as ARC/INFO software was efficiently & effectively used in many water resources planning & management worldwide. It can help to establish agricultural water rights, support the application for drilling permits for irrigation purposes & track water rights information. It can also be used to evaluate the loss of water from soil drainage & unlined canals, as well as help to determine the suitability, cost-effectiveness & prioritization of canal projects in planning stages.

The application of GIS has become popular in water resources management due to its dynamic process to incorporate data & display results.
GIS techniques are more time & cost efficient than the conventional field techniques & can be used to formulate a management plan much more efficiently & link land cover data to topographic data & to other information concerning processes & properties related to geographic location.

GIS based irrigation water demand estimation :

Enormous amount of effort has been made on the estimation of crop evapotranspiration (ET), mostly focused on finding water requirements for different crops under various local conditions, i.e. soil, climate, etc. Far less work has been done on a region-wide scale. Similar to the farm level scenario, variations in elements such as soil play an important role. The spatial analysis & management capabilities of GIS have rendered, it a powerful tool for expanding the previous work from farm scale to a regional level.
The basic data for irrigation water demand estimation are collected with a spatial resolution. These data (soil, climate, crops, etc.) subsequently form a spatial database. Regional irrigation water demand estimations are normally based on cropping patterns or land use. An example would be the estimation in a command area with several river basins where a vector based data model is applied. Compared to other relevant studies, this model not only maps irrigation demand, but also captures spatial variations & reflects, any changes in irrigation water demand once cropping pattern is altered.
A 'Decision Support System' (DSS) is also used to aid decision making. Once all relevant data are captured, DSS would act as an effective tool in terms of improving demand planning by creating different scenarios & visualizing the impacts under these scenarios. Another attractive feature is the fact that GIS can easily categorize the results of irrigation water demands.
For example, data classified by different canal systems can lead to a much more effective & accurate estimation. An overview of the process is illustrated in Figure 1

GISAREG in irrigation simulation :

GISAREG irrigation simulation model has been in use in many parts of the world, aiming at selecting the most proper irrigation model for crops. Several applications have provided evidence for the suitability of this model in irrigation management, e.g. Mediterranean [8], North China [9]. However, the fact that this model normally works at crop field scale renders it heavy & slow, when it comes to regional scale where a significant number of combinations of field & crop characteristics are required. This drawback has been overcome by the integration of GIS. This approach is even more attractive when remote sensed crop data becomes available & characteristics are detected for individual cropped field.

The GIS integrated model enables easily handled simulation of water management & allows visualization of the spatial distribution of water demand in the designated region. The latter, in particular, facilitates the localization of any discrepancies in water management, providing an indication of whether interventions are required. Moreover, easy analysis of crop water & irrigation requirement can be achieved & therefore, data obtained could be compared with target values. Further improvement on the model would be the inclusion of groundwater table depth & soil raster GIS layers, allowing groundwater contribution & impacts of salinity on evapotranspiration & crop yields are to be taken into account.

GIS for predicting the future irrigation demand growth :

In countries where water demand is increasing & resource depleting, it is crucial to estimate the water demand growth rate so that strategic planning can be implemented. The introduction of GIS technique generates maps which illustrate the predicted change in the spatial distribution of irrigation demand within a certain time frame.
All predictions are referred to a design dry year which is defined as a year with a probability of exceeding the irrigation need by 20%. The methodology adopted is a three-stage process. First of all, the existing dry year baseline & underlying growth rate are reviewed. This is followed by estimating the impact of future agro-economic & technical conditions on growth rates. The last step involves combining the above two results to produce predictions. This method takes into account, local variability in soil, climate & cropping, producing an irrigation demand map. Results derived from this approach can be useful in water resource planning by individuals or regulatory authorities.

GIS for groundwater assessment in large irrigation projects

In large irrigation project areas, groundwater played an important role as the water source before canal irrigation was introduced. Integrated management of groundwater & surface water resources has been achieved in recent years, aiming to improve the productivity as well as preventing groundwater depletion & soil salinity. Therefore, groundwater resource assessment is essential for the development of the integrated management. Sondhi *et al.* reported in 1989 that based on the mechanism of the groundwater flow, groundwater basin simulation models were applied to integrated management.

Chowdary *et al*. reported an example in India where the project area is divided into a set of 'basic simulation units' (BSU) that are homogenous with respect to the conditions that influence the recharge processes. The spatial distribution of recharge could be mapped via the transfer of the model output to GIS by running the models for the BSUs. The input data obtained from the recharge map could then be used to predict the groundwater levels. This approach allows independent development of GIS & the existing model. It can be used as a decision support tool to identify a strategy which is most suited to local conditions.

applying the most appropriate amount of water is very difficult due to the fact that a large number of spatially distributed data need to be taken into account. Therefore, collecting data from all interacting factors is essential.
Although many tools have been in use to improve water management, it is estimated that the overall irrigation efficiency is less than 50%. In order to increase rice production, it is crucial to effectively apply the most appropriate amount of water & conduct suitable water allocation management.

Given the advanced characteristics of GIS techniques, GIS user-interface techniques linked with water management model has been introduced to improve rice production. This technique provides information systems to aid decision making in the daily operation & management of precision farming & a scheduling & a monitoring program has to be developed. The former controls the right amount of water deliveries according to crop water requirements, whereas the latter gives an indication of whether water is distributed evenly& detects any excess or shortage. Data obtained are summarized & presented by maps, tables & graphs which give comprehensive representation of the situation & facilitate decision making.

GIS model in estimating the regionally distributed drought water demand :

With the development of GIS, Water Resources & Agricultural Permitting & Planning System (GWRAPPS) by integrating Agricultural Field Scale Irrigation Requirements Simulation (AFSIRS) & a database management system within an ArcGIS framework has been achieved. GWRAPPS successfully extends the AFSIRS application, from a farm scale to a regional scale & uses spatially distributed data to estimate irrigation requirements. One of the most attractive features is to provide a comprehensive overview of water demand which is not readily accessible before. Thus the regional crop water requirements under different drought scenarios can be estimated. Many examples have proved that GWRAPPS is capable of considering spatial variability of climate & soils at farm & regional scales under both normal & drought conditions.

GIS-integrated irrigation water management in Apulia, Italy

Another GIS based tool was developed & used in Apulia, Italy for handling spatial & non-spatial irrigation data for evaluation of the irrigation scenarios under different soil, climatic & management conditions (Todorovic & Steduto, 2003).The aim of

Cropping pattern can also be adjusted to optimal so that water table can be maintained at a suitable level.

GIS user-interface techniques in precision farming of rice :

Precision farming is defined as using the optimum amount of resources to achieve maximum yield. In the irrigation of rice
the system was to provide support for irrigation authorities on evaluating irrigation scenario & identifying the areas with water deficit. ArcView GIS was customized with Avenue programming language to design & develop, the irrigation water

Methodology development: The use of GIS to design & plan irrigation system requires a procedure for adequate analysis as is shown in the flow-chart (Figure 1).
The methodology developed & applied to this study consists of the following steps: distribution system. As ArcGIS database is used as an input in this system & integrated for the irrigation computation; outputs can be shown in the form of maps. The system has wide area of application, farm scale to region scale.

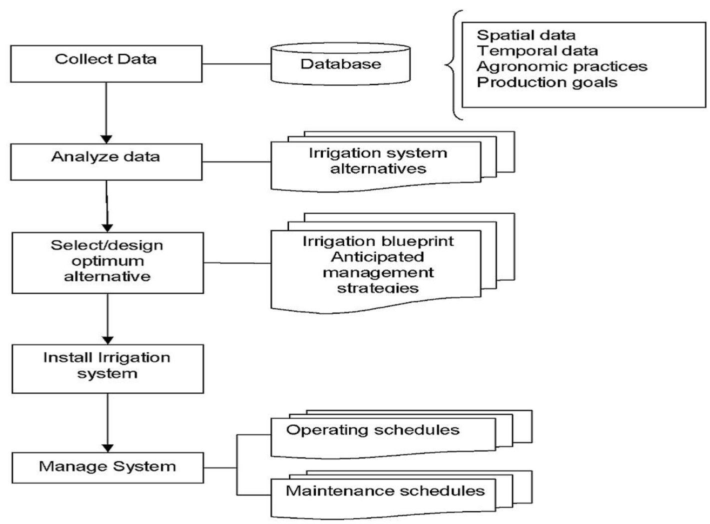

Figure 1

Methodology implemented in this work :

1. Data collection :

In this step the soil data as texture, water holding capacity, infiltration rate, bulk density, etc. must be collected. In addition, topography, actual plots, constructions, irrigation network, drainage network geo-referenced basic information requiring the coordinates of each sampling point for the different information, developing the thematic layers for each parameter must be obtained.

2. Analysis :

On the basis of the data, the spatial distribution for each parameter, considering the most restrictive areas & their weight in the total study area must be evaluated, for the design & management of the irrigation systems & the pipe distribution network. A thematic layer with the established irrigation system is incorporated.

The design system is done taking into account the procedure given by Holzapfel et al. (1984) for surface irrigation & for pressurized irrigation on the basis of Holzapfel et al. (1990) & Abarca(2002). For the optimal design of surface irrigation the length, time of cutoff & discharge must be considered (Holzapfel et al., 1985; Walker & Skogerboe, 1987, Holzapfel et al., 2010). The optimal design of pressurized irrigation system takes into account, the selection of emitters (Holzapfel et al, 2007), optimal design of subunits & optimal pipe diameter (Pizarro, 1996; Stuardo, 2006).

It is important to mention that all the thematic layers are dynamic & can improve as a greater quantity of new information is incorporated. This dynamic nature permits adaptation of irrigation system management to real-time conditions & even system design modification is permitted. The use of this tool is also of great use in farm management & planning since it can also help in other activities necessary for the production process, such as crop rotation, changes in farm structures or their location, implementation of new crops with new irrigation systems.

III. Results & Tables:

Table 1: Details of tools/systems with their features & locations

l. No.	ame	esearcher/ rganization	ocation	oals (Aims)	IS integration	Key Features
1	AREG	Teixeira & Pereira, 1992	ifferent parts the World	Simulate irrigation schedule for soil climate crop combination, evaluation of selected irrigation schedule	No	Decision support selection of suitable irrigation schedule, applies to field scale & suitable for large area
2	ISAREG	Fortes et al., 2005	yr Darya basin, zbekistan	Simulate schedule for project, help management	Yes	Simulate irrigation schedule in different water management scenarios for region/project scale, can be visualize spatial distribution of water demand
3	cheme irrigation manageme formation system (SIMIS)	Mateos etal., 2002	ifferent parts the World	Facilitate water& day to day management, manage irrigation water delivery schedule, and help in integrate management of Irrigation project.	Yes	Simulate different crop & irrigation scenario for water delivery schedule, compare existing situation for improvement irrigation, can be visualized input/output.
4	Web based GIS	Dhakal, 2010	lentejo gion, Portugal	Share weather & Evapotranspiration information to farmers through internet to support irrigation management.	Yes	Publishes weather & Evapotranspiration map from interpolation of automatic weather data through web.
5	GIS based interactive tool r irrigation management	Pervez & Hoque; 2008	angladesh	Help managers in Irrigation planning & management at project level, facilitate the operation & management processes of command area.	Yes	User friendly graphical user interface, decision support in design stage, real time analysis of irrigation components.

IV Conclusion:

Still a lot of work needs to be done in this field in shaping the future requirements of the society. GIS can be utilised as a tool for astrological foresight to weather, rainfall, storm & other natural calamities & hence can be utilised as a means to forecast the occurance of rainfall & other weather changes. Hence on that basis the necessity of irrigation for crops can be planned/manipulated towards a minimum. Proper utilisation of water resources conserves the resources of Mother Nature & works towards a sustainable growth.

References:

i. *Geographic Information System, Wikipedia*
ii. *Arup K. Sarma, GIS & Remote Sensing Application in Water Resources.*
iii. *Nagraj S. Patil & A. K. Gosain, Geographical Information System (GIS) for Water Resources Management.*
iv. *Saroj Acharya, Ashish Pandey & U.C. Chaube, Use Of Geographic Information Systems In Irrigation Management : A Review.*
v. *John P Wilson, Helena Mitasova, & Dawn Wright, Water Resource Applications of GIS.*
vi. *D. Nagesh Kumar, Remote Sensing & GIS Applications for Water Resources Assessment.*
vii. *Eduardo Antonio Holzapfel Hoces, José Luis Arumí, Antonieta Rodríguez & Vital Pedro da Silva Paz, Geographic information system supported farm irrigation system design & planning.*
viii. *Mladen Todorovic & Pasquale Steduto, A GIS for irrigation management.*
ix. *Abdelmonem M.A. & Kamal H.A., Surface Irrigation Management in Relation to Water Infiltration & Distribution in Soils.*
x. *Eduardo Antonio Holzapfel Hoces, José Luis Arumí, Antonieta Rodríguez, Vital Pedro da Silva Paz, Geographic Information System supported farm irrigation system design & planning.*