GFIS (GEOGRAPHIC FORECASTING INFORMATION SYSTEM): A CASE STUDY IN WATER RESOURCES MANAGEMENT

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ABSTRACT

The current study presents the development of a Forecasting Information System for geographic data (cross-sectional time-series for different geographic regions). GFIS, Geographic Forecasting Information System, was developed with MS Visual Basic (User Interface), ArcView (GIS) and MS Access (DBMS) during the MSc thesis of one of the authors in 2000.

GFIS is suitable for the management and forecasting for all time-series that present a geographic dimension and can be illustrated in a Geographical Information System (GIS). The forecasting capabilities of the system extend from classical time-series extrapolation methods (exponential smoothing, regression) (Assimakopoulos, 1994) to more complex methods (Theta model).

The applicability of the system was tested with a case study in Water Resources Management. GFIS was used in order to create rainfall forecasts for the watersheds in Lakonia, a region in southern Greece. The estimation, forecasting, planning and management of hydrological resources are of great importance and prerequisite for sustainable development.

KEYWORDS: Time-series, forecasting, Theta model, GIS, rainfall, hydrological resource.

INTRODUCTION

Human nature will face new millennium with many serious environmental unsolved problems that will put in great danger the survival and existence of all the species in the entire planet. As a result of development in agriculture, industry, shipping, transportation, tourism, etc, many problems created because of the uncontrollably use of natural resources and the pollution of the air, water and soils, in that degree, is beyond the ability of self - purification and defence of the ecosystem.

As long as the economic development does not adapt the principles of sustainable the pressure in the environment will increase because the production and the consuming will demand more

natural resources than it can recreate and it will create more pollution than ever before.

The estimation, forecasting, planning and management of hydrological resources are some of the more critical requirements for the sustainable development (Ogilire, 1995; Redclift, 1993; Turner and Kerry (ed.), 1993).

The selection and processing of hydrological data plays a key role in the management and monitoring of hydrological resources (Andrieu *et al.,* 1996). The Observed fall of level and shrinkage of resources during the last years (due to important rainfalls reduction), made imperative the need of hydrology research of watersheds (basins). This will facilitate the decision-making, which will contribute in successful phenomenon treatment (Bindlish and Barros, 2000).

Principal information on hydrologic parameters estimation could be found in various services that assemble climatic data from local meteorological stations. Data collection and processing for various hydrologic parameters calculation constitute a time-consuming work.

The proposed methodology is about data processing and storage that depend on GIS theory and forecasting methods. The methodology succeeds direct and fast data access, processing and forecasting in a GIS platform. This is the first step of the hydrological study of watersheds.

The paper' s scope is to create a Geographic Forecasting Information System GFIS and to test it in the management of available hydrological data.

The case study under consideration aims at the use of GFIS in order to create rainfall forecasts for the watersheds in Lakonia, a region in southern Greece for water management.

The project was completed in three phases:

1. Implementation of geographical model that includes spatial data of region (digital elevation terrain, coast line, hydrological grid, watershed, meteorological gauges).
2. GIS topology of spatial data and appending new attributes in those data.
3. GFIS design and implementation that include data processing in GIS and forecasting rainfalls for the watersheds in Lakonia. GFIS construction involved: user interface, processing model and forecasting model.

GFIS provides an easy way to restore, append and edit hydrological data. Also defines average rainfall in any time (hydrological year) and in any gauge (meteorological station) in research region. The most important issue is that Geographic Forecasting Information System G.F.I.S. can give excellent results that could be used in watersheds balance researches and in resource management.

SYSTEM DESCRIPTION

GFIS is suitable for the management and forecasting for all time-series that present a geographic dimension and can be illustrated in a GIS System. The forecasting capabilities of the system extend from classical time-series extrapolation methods (exponential smoothing, regression) to more complex methods (Theta model).

Main operation of GFIS is data processing and time-series forecasting. The applicability of the system was tested with a case study in Water Resources Management. GFIS was used in order to create rainfall forecasts for the watersheds in Lakonia, a region in southern Greece. The estimation, forecasting, planning and management of hydrological resources are of great importance and prerequisite for sustainable development.

The project including three phases: a) Geographical data development by digitisation, b) topology creation and data editing, and c) system and interface implementation

The G.F.I.S. developed in ARCVIEW version 3.1 and the user interface made in VISUAL BASIC 6. The database made in ACCESS.

METHODOLOGY

The methodology's philosophy in watershed simulation is:

- The basic components - objects of watersheds are points, lines and polygons that based on GIS topology.
- Attributes of those components are elevation, length, slope, soil, vegetation etc.
- Types of functions, like: infiltration, surface flow, etc.
- Linkage between objects - coverage and watershed organic parts like: running of water, hydrological grid (primary steams and sud - streams), lakes (natural - technical), swamps, nodes (points of primary and secondary streams intersection), area, canopy, elevation - slope, etc.

GFIS is an integrated system that includes sub - systems, as shown in Figure 1.
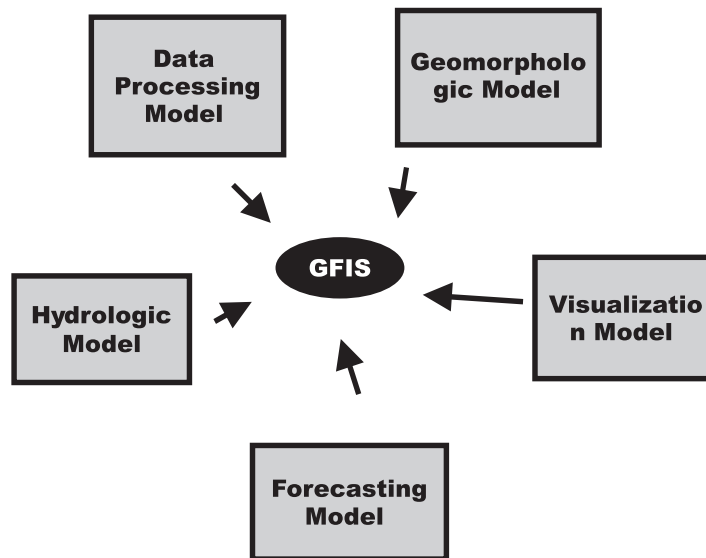
Figure 1. GFIS sub - systems

FORECASTING METHODS

GFIS forecasting capabilities extend from classical time-series extrapolation methods (exponential smoothing, regression) to more complex methods (Theta model). There is a brief presentation of forecasting methods that are used by the system.

Exponential Smoothing Models

The single exponential smoothing model is one of the common forecasting techniques used in the private sector. The model is a moving average of forecasts that have been corrected for the error observed in preceding forecasts. In the first smoothing model, there is assumed no trend or seasonal pattern.

$$F_t = F_{t-1} + \alpha(A_{t-1} - F_{t-1}) \qquad (1)$$

where F_t is the forecast at time t, A_{t-i} is the actual value at time t-i, and N is the number of time periods averaged.

The parameter α is the smoothing coefficient and has an estimated value between zero and one. It is referred to as an exponential smoothing model because the value of tends to affect past values exponentially. As α approaches one, the forecast resembles a short-term moving average, while an α closer to zero tends to resemble long-term moving averages. Regardless of the value of α, however, exponential smoothing tends to give more recent values higher implicit weights. Again, α is typically estimated using trial and error to secure the best fitting model, but software today can rapidly find the model that minimizes forecast error (Assimakopoulos, 1994).

Simple Regression

The simple linear regression model may be defined precisely as follows.

$$Y_i = \alpha + \beta X_i + \varepsilon_i \qquad (2)$$

where Y_i and X_i represent the ith observations of the variables Y and X respectively, α and β are fixed (but unknown) parameters and ε_i is a random variable that is normally distributed with mean zero and having a variance σ_ε^2.

Note the formalities in a model of this type. The expression $\alpha + \beta X_i$ is the regression relationship - in this case a straight line - and α and β are called parameters (which are unknown, but if they were known they would be fixed numbers). There are several assumptions made about X_i and ε_i which are important:

1. The explanatory variable X_i takes values which are assumed to be either fixed numbers (measured without error), or they are random but uncorrelated with the error terms ε_i. In either case, the values of X_i must not be all the same.
2. The error terms ε_i are uncorrelated with one another.

3. The error terms ε_i all have mean zero and variance σ_ε^2, and have a normal distribution (Maktridakis, Wheelwright and Hyndman, 1998).

The THETA model

The model is based on the concept of modifying the local curvatures of the time series. This change is obtained from a coefficient, called Theta-coefficient (as a symbol is used the Greek letter Theta), which is applied directly to the second differences of the time series (Assimakopoulos and Nikolopoulos, 2000):

$$X''_{new}(\theta) = \theta X''_{data}, \qquad (3)$$

$$\text{where } X''_{data} = X_t - 2X_{t-1} + X_{t-2} \qquad (4)$$

at time t.

DATA
Geographical data

For geographical model was used digitising methodology in order to create coverage of the case study region. This process included the following four steps:

*   Use of maps of 1:50.000 scales. The topological maps were got in Greek Geographic Army Department.
*   Topological maps was scanned and exported in files with tiff format (raster data).
*   Raster data was stretched in four maps edges and transferred in Hellenic Geodetic Reference System (EGSA 87).
*   Vector data creation by digitising raster data in ARCINFO.

The above-digitised data constitute the project's geographical data. Geographical data are the following:

*   Contour coverage. Digitising was done with 100-meter step for high elevation areas and with 20-meter step for flat areas. In flat areas was chosen smaller digitising step, preparative to not exist large areas without information of the elevation. Null information about the elevation hinder interpolation processing for Digital Elevation Model (DEM). Contour coverage was used to develop Digital Elevation Model and Digital Elevation Model was used to develop the watersheds.
*   Streams - rivers coverage. Primary and secondary streams grid was digitised. Streams

coverage used for map visualization and for outfall node location. Outfall node location is very important for watershed specification.
*   Coastline - inlands coverage. This coverage was digitised for map visualization reasons.
*   Meteorological gauges/stations coverage. Stations coverage includes 20 meteorological gauges and used for rainfalls map visualization.

Rainfall data was gathered from the following Government's services.
*   Hellenic National Meteorological Service
*   Hellenic Ministry for the Environment Physical Planning and Public Works
*   Hellenic Ministry of Agriculture
*   Hellenic Institute of Forestal Research

Hydrological data

The hydrological data are monthly. They begin in 1952 and end in 1993. The Table 1 refers in meteorological stations information and includes name, coordinates (latitude and longitude in degrees) and elevation (in meters) of each station.

RESULTS

System includes monthly hydrological data (rainfalls) for each station (20 stations) in Lakonia region. Time series begin at 1952 and end at 1993. Forecasting Horizon is set to 10 years. System produces monthly rainfall forecasts for 1994 until 2004.

User can choose monthly data for any year from GFIS basic menu and create forecasting or show respective map layout. In table 2 selective data from system are shown.

CONCLUSIONS

Geographic Forecasts Information System has the advantage to connect and process between descriptive / qualitative attributes and their spatial position (geographical data which declare the position and the form). Each digital map is constituted by geographical data and qualitative attributes, maintaining the spatial relations between their characteristics.

G.F.I.S. main capabilities are:
*   Data production from raw data and data classification in different layers
*   Data use in framework of decision making
*   Data management for large databases

Table 1. Information for meteorological stations

Name	Latitude	Longitude	Elevation	Time- series	Organization
Sparta	37° 04'	22° 26'	205	1956-57, 1664-65	Hellenic National Meteorological Service
Githio	36° 46'	22° 34'	10	1979-80, 1991-92	Hellenic National Meteorological Service
Arna	36° 53'	22° 25'	760	1954-55, 1991-92	Hellenic Ministry for the Environment Physical Planning and Public Works
Karies	37° 18'	22° 30'	880	1954-55, 1963-64	Hellenic Ministry for the Environment Physical Planning and Public Works
Vrodamas	36° 58'	22° 39'	150	1952-53, 1992-93	Hellenic Ministry for the Environment Physical Planning and Public Works
Petrina	36° 51'	22° 30'	205	1954-55, 1992-93	Hellenic Ministry for the Environment Physical Planning and Public Works
Elos	36° 50'	22° 42'	10	1972-73, 1991-92	Hellenic Ministry of Agriculture
Sellasia	37° 10'	22° 25'	560	1963-64, 1966-67	Hellenic Ministry of Agriculture
Bassaras	37° 10'	22° 30'	650	1971-72, 1992-93	Hellenic Ministry of Agriculture
Foinikio	36° 44'	22° 54'	180	1978-79, 1985-86	Hellenic Ministry of Agriculture
Papadianika	36° 43'	22° 51'	60	1978-79, 1985-86	Hellenic Ministry of Agriculture
Kremasti	36° 59'	22° 52'	800	1979-80, 1985-86	Hellenic Ministry of Agriculture
Sikia	36° 46'	22° 56'	160	1978-79, 1985-86	Hellenic Ministry of Agriculture
Metamorfosi	36° 49'	22° 55'	120	1978-79, 1985-86	Hellenic Ministry of Agriculture
Koupia	36° 52'	22° 54'	540	1978-79, 1985-86	Hellenic Ministry of Agriculture
Saint Dimitrios	36° 56'	22° 49'	385	1978-79, 1992-93	Hellenic Ministry of Agriculture
Kastoreio	37° 10'	22° 18'	480	1963-64, 1966-67	Hellenic Ministry of Agriculture
Asopos	36° 44'	22° 51'	55	1976-77, 1992-93	Hellenic Ministry of Agriculture
Molaoi	36° 48'	22° 51'	200	1971-72, 1992-93	Hellenic Ministry of Agriculture
Vamvakou	37° 15'	22° 34'	1000	1962-63, 1982-83	Hellenic Institute of Forestal Research

Table 2. Rainfall Data

Meteorological Stations				
Year	Month	ARNA	GYTHIO	SPARTA
Rainfall observations (mm)				
1992_1993	SEP	7,60	14,00	7,00
1992_1993	OCT	62,80	125,49	29,30
1992_1993	NOV	122,40	230,60	99,95
1992_1993	DEC	233,30	198,50	86,20
1992_1993	JAN	64,60	153,04	58,25
1992_1993	FEB	249,90	98,89	52,30
1992_1993	MAR	80,70	92,24	52,65
1992_1993	APR	6,10	70,15	47,15
1992_1993	MAY	103,60	15,14	64,95
1992_1993	JUN	0,00	8,55	16,23
1992_1993	JUL	28,10	13,96	15,75
1992_1993	AUG	42,70	14,59	54,20
1993_1994	SEP	45,80	14,20	26,13
1993_1994	OCT	123,43	127,25	82,59
1993_1994	NOV	206,82	233,81	109,04
1993_1994	DEC	280,67	201,25	129,25
1993_1994	JAN	253,18	155,15	119,71
1993_1994	FEB	196,40	100,24	99,35
1993_1994	MAR	142,27	93,50	83,53
1993_1994	APR	80,55	71,10	47,87
1993_1994	MAY	52,36	15,35	31,17
1993_1994	JUN	20,69	8,66	14,54
1993_1994	JUL	12,87	14,14	23,29
1993_1994	AUG	12,15	14,78	20,53

- Data process and analysis. G.F.I.S. includes different model procedures: Data Processing Model, Hydrologic Model, Geomorphologic Model, Visualization Model, Forecasting Model
- Use of GIS modules and potentials like: overlay, buffering, DTM, DEM, etc.
- Development and assessment of alternatives decision scenarios.
- Variety of forecasting methods
- Forecasting procedures for any time-series and spatial data.
- Data saving in different formats like: .txt, .xls etc
- Printing / plotting reports, charts, and layout maps

G.F.I.S. is a useful tool for data analysis, forecasting and geographic representation. It was developed with MS Visual Basic 6.0 (User Interface), ArcView 3.1 (GIS) and MS Access (DBMS) during the MSc thesis of one of the authors in 2000.

The specific project allocates rainfall and temperature data. For that reason gives the user the opportunity to analyse the case study region and deduce information from the results. With this case study, the user can:

- *Take information for the number, characteristics and time-series of each meteorological station*
- *Hydrological time-series forecast*
- *Station classification depend on rainfall (annual rainfall or average rainfall)*
- *Printing / plotting reports, charts, and layout maps for specific region that*

The specific project is a very important research because it concerns:

- Forecasting hydrological resources
- Water resource management for environment and sustainable natural resource development (De Vries, 1989).
- Forecasting the effect of the surface flow, inundation, and dryness.

- Integrated approach of environmental management and development
- The G.F.I.S. is a module of decision supporting in management of hydrological resources
- The effect of management of sustainable natural resource development
- Quality protection of water and soils.
- The Geographic Forecasting Information System is suitable for all geographic data.

System prospective is:

- The system can be used in many applications and spatial data (social economic data, demographic data, etc) (Martin 1996).
- Many other forecasting methods can be included in the future: econometric methods, neural networks.

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