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Real-time monitoring and management of point and areal hydrometeorological data in the Athens metropolitan area

MARIA MIMIKOU & ANDREAS GRAMMATIKOGIANNIS
Department of Water Resources, Hydraulics and Maritime Engineering, School of Civil Engineering, National Technical University of Athens, 5 Heroon Polytechniou, 15780 Zographou, Athens, Greece
mimikou@chi.civil.ntua.gr

Abstract This paper focuses on the implementation of a fully automated telemetric network (METEONET) of 11 hydrometeorological stations which was installed for the integrated analysis and management of the meteorological information concerning the Athens metropolitan area in the Attica district of Greece. Various dynamic software applications are linked to the central database of the project supporting the analysis and synthesis of the data, the inspection of the temporal and spatial evolution of meteorological events, as well as the elaboration and dissemination of derivative information through the Internet for public awareness. The entire procedure has been standardized for easy implementation in other similar networks.

Key words METEONET; telemetry; hydrometeorological network; Athens; Greece; database; Internet; public awareness

INTRODUCTION

A well-organized hydrometeorological station network is a basic requirement for the monitoring and processing of the relevant hydrological and climate data, especially in urban areas with high growth rates where all activities are related and mutually influenced by the alterations of the natural environment. Such systems are mainly used for the monitoring of extreme rainfall events and consequently for flood-related events, and this is so in metropolitan Athens, capital of Greece, where intense flood-producing rainstorms often occur, resulting in the loss of human lives and property (Mimikou *et al.*, 2000). The importance of such networks is also enforced by the European Union Water Framework Directive's provisions that require the installation of representative monitoring networks of all the parameters of the hydrological cycle (Grammatikogiannis *et al.*, 2005).

Recently, there is a strong tendency of using data from hydrometeorological networks not only for conventional climatic or hydrological studies, but also for bioclimatic or energy studies (Matzarakis & Balafoutis, 2004; Unger, 1999; etc.). It is clear that the ability of these networks to provide reliable data for further processing in various fields depends on the quality and kind of instruments installed and also their correct placement, which is based on specific criteria.

Unfortunately, in Greece, there is still no hydrometeorological station network organized under a main administration that works through a unified scientific and technical medium (Baltas *et al.*, 2005). Various state services have established sectional networks of specific coverage, but the standardization of the equipment used or the procedures followed for all services has not yet been achieved. For example, the network is very variable, with dense networks covering only the lowlands; the majority of stations are not equipped with automatic recording and telemetry systems, there is no unified method of data recording and the specifications of international organizations (e.g. the World Meteorological Organization) are not always fulfilled.

The operational utilization of the networks has serious disadvantages, such as low reliability and accuracy; delay in the availability and the detection of instrument malfunctions; and a lack of compatibility in data measurement and processing between different agencies. Thus, the existing conventional measuring systems cannot efficiently support the need for the development of modern management plans in the relevant fields of interest (Mamassis *et al.*, 2002).

PROJECT OVERVIEW

From the above, it can be appreciated why the absence of a modern fully-automated hydrometeorological network, which could provide processed hydrometeorological information in real-time, led to the development of the METEONET project in Greece. In the project, emphasis was put on the collection and exploitation of all available knowledge together with the latest technological achievements in each of the contributing scientific fields (measuring sensors, software applications, GIS techniques, etc.).

The project is a pilot implementation of what will become a complete monitoring hydro-meteorological network. Based on the experience gained from this project, a proposal is under preparation for the formation of a National Network of Gauging Stations, an operational extension of the Greek National Data Bank of Hydrological and Meteorological Information (NDBHMI). This aims at providing a basic infrastructure in Greece for the pilot implementation of the European Union's Water Framework Directive for the protection, rational management and exploitation of the water resources. The NDBHMI was a technological infrastructure project which comprised, among others; a database necessary for the exploitation of the water resources of the country; the planning of important technical works; the estimation and mitigation of natural hazards; and the protection and management of the aquatic environment in general (Mimikou, 2000).

Within this scope, the METEONET project is intended to summarize and standardize all the necessary procedures for the implementation of a reliable network and it is considered as one of the first attempts in Greece at the integrated management of hydrometeorological data, that is: the collection, storage, elaboration and dissemination of climatic conditions in real-time.

As shown in Fig. 1, the network consists of 11 automated telemetric hydrometeorological stations, installed so as to provide the optimum recording of the weather conditions in the Athens Metropolitan area (687 km^2). The siting of the stations was based on the following criteria:

(a) meteorological, because the low barometric systems arrive from the west, southwest or northwest (Mimikou, 1999);
(b) elevation, so as to record the increased amounts of precipitation in upland areas;
(c) security, accessibility and infrastructure facilities;
(d) topographical, according to the World Meteorological Organization (WMO) regulations (WMO, 1983, 1996).

Each of the stations is equipped with sensors that monitor weather conditions (precipitation, temperature, relative humidity, wind and radiation); a data logger for recording data; a transmission system; and finally an energy supply unit.

The design of the system addressed three main issues: the selection of the appropriate technologies for data measurement, transmission and storage; the location of the stations at appropriate sites; and software applications that were suited for different categories of users, from

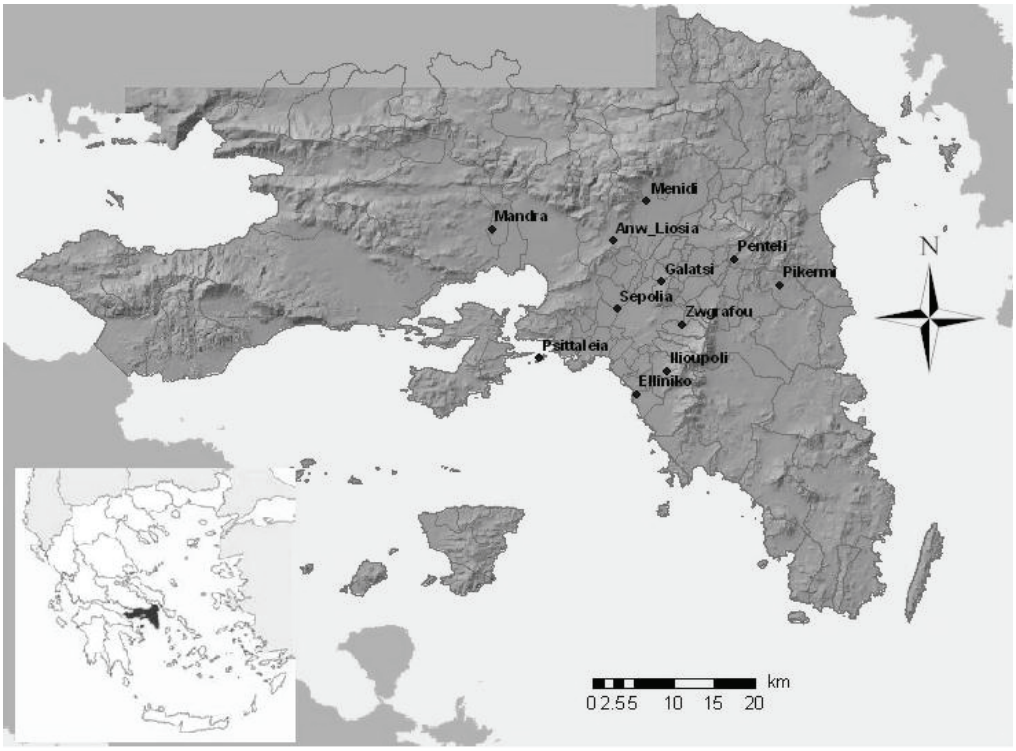

Fig. 1 The METEONET network.

researchers and scientists to the general public who are not familiar with the terminology. For all issues, international and local experience proved to be very important for the effective system design. Experience with a pilot telemetric station, located on the campus of the National Technical University of Athens and operated for seven years, provided the basis for decisions regarding the network design: types of sensor and energy supply; as well as data acquisition, logging and transmission techniques.

PROCESSING AND MANAGEMENT OF POINT DATA

According to the system's general architecture (Fig. 2) the ASCII files from the stations data loggers are transmitted to and stored in the main server, via a mobile telephone network. A subprogram transfers and allocates the data from the ASCII files to the relational database, by taking into account the correspondence between the ASCII files columns and the time series identification numbers. The main aspects considered in the design of the data base were the following:

(a) data reliability, integrity and availability;
(b) data security and database performance;
(c) friendly user interface.

The processing of point measurements includes the following procedures in three consecutive stages (Fig. 3):

(a) range and time consistency checks;
(b) conversion of irregular to a strictly regular time step;
(c) detection of missing or false values;
(d) aggregation and generation of derived time series (Fig. 4).

In order for the dynamic system to manipulate successfully more than 15 million records per year, several triggers, functions, rules, constraints and sequences were implemented, resulting in an easing of the load on the network and server, reducing the necessary disk space (20 times less than storing times series with conventional methods) and speeding up the frequently needed operations (e.g. retrieving the first and last records).

GIS APPLICATIONS

As well as point measurements, the system is equipped with a GIS platform so as to provide standardized maps, depicting the spatial evolution of the measured variables within the research

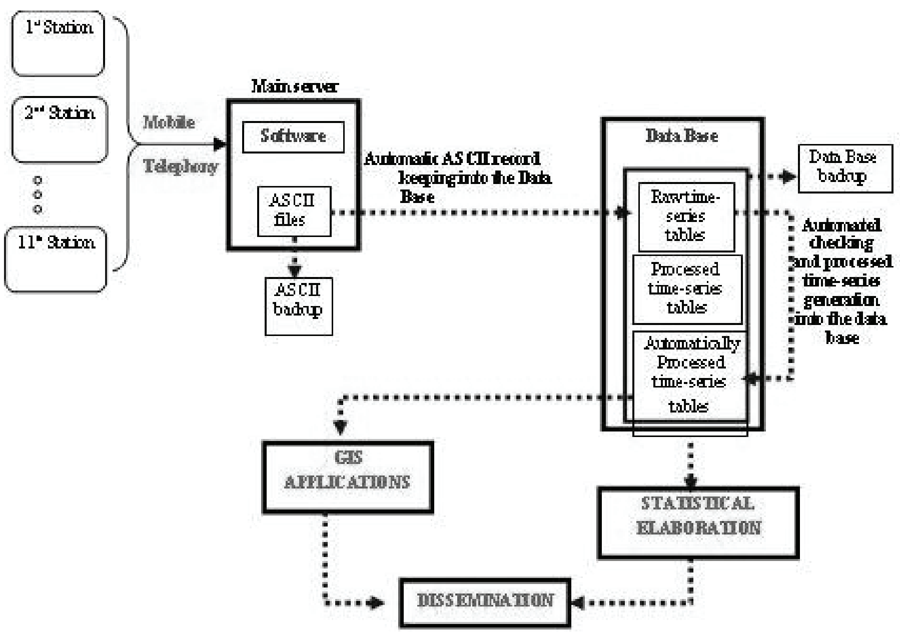

Fig. 2 METEONET architecture.

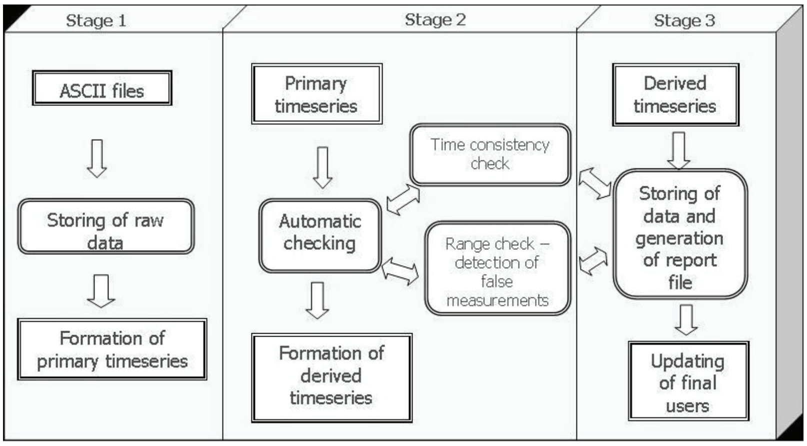

Fig. 3 Data manipulation and processing.

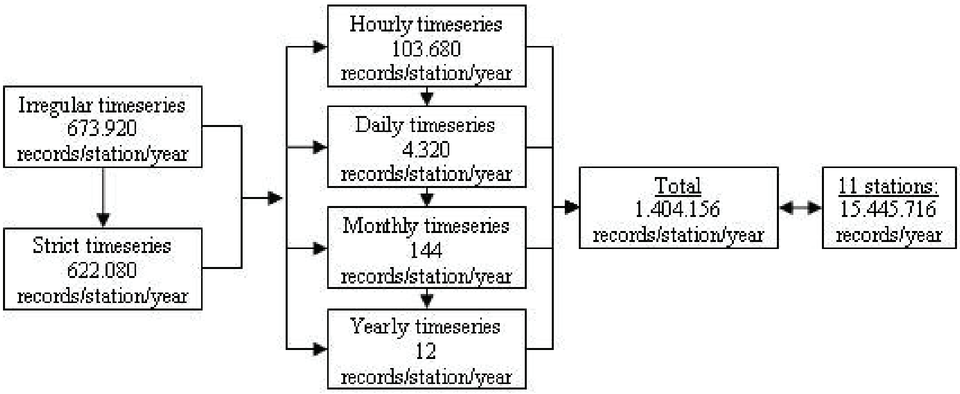

Fig. 4 Time series generation.

area. The developed application collects data measurements for all monitored meteorological variables in various time periods and generates the corresponding maps. The program is executed after every data entry and the completion of all data checks. Three basic steps are included within this function:

(a) automated generation of Thiessen polygons. It must be stressed that Thiessen polygons are dynamically generated to take account of all possible combinations between the stations (in case a number of stations are deactivated);
(b) automated areal integration of the stations' measurements using the Inverse Distance Weighted method and the Kriging method;
(c) production of the corresponding maps for the area of interest.

The entire function has been developed independently from the rest of the functions so that the area of application will not be limited to the particular geographical region, thus allowing it to be adapted according to different needs.

During data entry, the following checks are carried out:

(a) incoming data are ignored if they are not followed by the station's coordinates;
(b) station files with no data are ignored, as well as files with multiple data entries for the same station;
(c) if the total number of stations with valid data entries is less than a predefined limit (e.g. three stations), the program's execution is terminated.

The resulting maps depict the spatial distribution of various meteorological parameters and can be used to assess quantitatively the impact of different regional characteristics of the area's climatic regime (distance to the coast, elevation, etc.) and thus they can become very useful tools for urban planning and management. A typical output of the procedure is presented in Fig. 5.

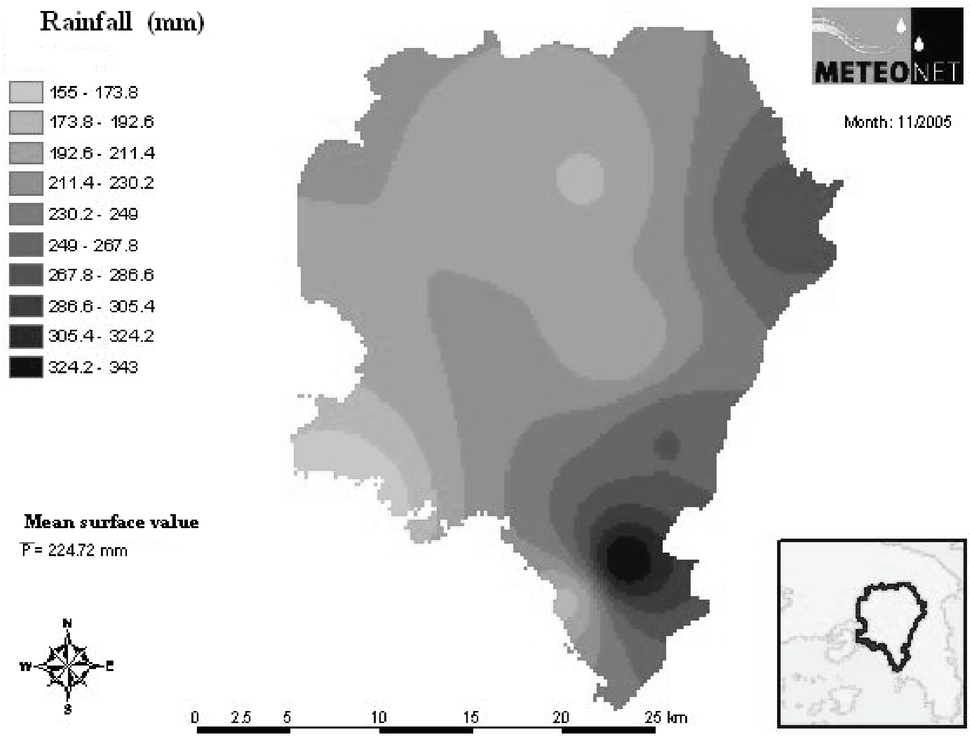

Fig. 5 Automated generation of a rainfall map with the IDW method.

PUBLIC AWARENESS – INTERNET TOOLS

The need for readily available hydrometeorological information, combined with the overall nature of the METEONET project as providing very important infrastructure for the monitoring of the climate conditions of the Athens metropolitan area, led to the design and the implementation of an Internet suite of applications to support researchers, scientists and in general all end-users who are interested in the relevant issues. This platform is the first integrated real-time Internet support system of such extent and with such a volume of data in Greece. The available tools cover a wide range of statistical applications, GIS-based visualizations, and other derivative information in the form of graphs, tables and maps, automatically updated as new data become available.

There can be no doubt as to the importance of the information provided and of making this contribution to public awareness regarding the weather conditions in Athens. During the first year of operational exploitation, the METEONET site was visited by more than 18 000 different users, not only from Greece, but also from more than 40 countries worldwide (Italy, Canada, Denmark, USA, Vietnam, etc). At the time of writing this paper, visiting rates were increasing by approximately 100% per month, indicating that the METEONET web site has become a very useful tool, not only for specialists, but also for the general public.

DISCUSSION

The retrieval of reliable processed hydrometeorological data is considered to be one of the most difficult tasks in integrated hydrological, climatic or urban planning. Experience has shown that problems that arise, not only with the quantity and quality of the available data, but also with the ease of acquisition. New technologies can provide powerful new ways for recording, processing and managing hydrometeorological data.

Nonetheless, automated telemetric networks, support systems and software applications require extensive collaboration between different areas of expertise as well as continuous updating concerning new technologies. The METEONET network is the first attempt at the collection, storage, elaboration and dissemination of hydrometeorological information in real-time on the Internet, thus contributing to the public awareness.

With this system in operation, the definition and the mapping of areas that are most likely to be subjected to extreme events, in relation to a better understanding in general of the evolution of meteorological events over Athens, can lead to the specification of measures that need to be implemented for sustainable management, reliable decision making and the prevention of human suffering and property damage.

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