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WATMAPGIS: Preparing of Groundwater Maps by Using Geographical Information Systems

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Abstract: For a sustainable irrigation, it is necessary to monitor and evaluate fluctuations of groundwater level and salinity. In this study, WATMAPGIS (creating of the groundWATer MAPs using Geographical Information System) software, which was prepared by in order to create groundwater observation maps on environment of ArcInfo GIS software, will be presented. Program, by using groundwater maps that have been created by State Hydraulic Works of Turkey (SHW) up to now and created by hand, is capable to create different kinds of groundwater maps automatically such as; Depth-to-Watertable (Isobath) Map in Intensive Irrigation Season (IMII), Critical Highest Isobath Map (CHIM), Critical Lowest Isobath Map (CLIM), Electrical Conductivity Map (ECM), Water-table Contour Map (WCM) and Seasonal Probable Problematic Areas Map (PAM). By using WATMAPGIS program, groundwater monitoring results can be mapped and made questionable rapidly. Thus, fluctuations of groundwater on a monthly basis can be rapidly displayed.

Key words: Groundwater map, Geographical Information System (GIS), Monitoring and Evaluation (M and E)

INTRODUCTION

A prime requirement for successfully irrigated agriculture is the development and maintenance of a soil zone in which the moisture-oxygen-salt balance is favorable for plant growth. The proper balance between soil moisture and oxygen is maintained to a considerable extent by adequate drainage. Studies of the water table produce information necessary for the solution of a drainage problem. Areas where a high water table has developed or is anticipated must be mapped. Information concerning depths, trends and movements is essential for an understanding of the problem. The water table investigation provides data on the position, extent, and fluctuations of the water table; the quantity and direction of movement of the groundwater, and an indication of water sources and areas of discharge. The investigation is made using observation holes and piozemeters, and analyses of periodic measurements (Demir, 2002).

According to Cetin and Diker (2003) soil productivity is affected by soil physical properties that play a crucial role in planning drainage systems. Improper planning of drainage systems can create high water table problems and, in turn, an unsuitable environment for plant growth. Therefore, drainage systems should be well planned and monitored regularly. It is very labor-intensive and time-consuming to determine the spatial and temporal changes in drainage parameters such as groundwater (GW) depth, elevation, hydraulic gradient and salinity by conventional methods over large areas. Geographic information systems (GIS) can be used to assess the spatial and temporal changes efficiently and rapidly.

The Monitoring and Remediation Optimization System (MAROS), a decision-support software, developed to assist in formulating cost-effective ground water long-term monitoring plans (Aziz *et al*., 2003). MAROS optimizes an existing ground water monitoring program using both temporal and spatial data analyses to determine the general monitoring system category and the locations and frequency of sampling for future compliance monitoring at the site.

Monitoring and evaluating studies have been performed by making good use of developed technology in the recent years. Gundogdu *et al.* (1998) carried out studies aiming at preparing the maps that are created according to the results of hole observations through GIS environment. Dubey *et al.* (1989) performed a study of estimating ground water depth by using distant perceiving data.

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Aim of this study is to present WATMAPGIS program, which was developed to prepare ground water maps, which were created by State Hydraulic Works of Turkey (SHW) according to monthly observation results, in geographical information system environment.

WATMAPGIS approach: ArcInfo ver. 7.1.2. was used as Geographical Information System software in the study. WATMAPGIS program operates on Arc/Info software. It was created at the Agricultural Structures and Irrigation Department of Agricultural Faculty of Uludag University, Bursa-Turkey. It uses Arc, ArcEdit, ArcPlot, Grid, FormEdit, Arc Press modules of ArcInfo and was written in ArcMacro programming language (Anonymous, 1997).

Groundwater observation values belonging to 2002 year of the groundwater observation holes in Mustafakemalpaşa (MKP, Turkey) irrigation project area were used to test the software. MKP irrigation project covers an area of 15500 ha and there are 200 groundwater observation holes in the irrigation area (Anonymous, 2000). In the study, groundwater observation holes data were obtained from SHW First Region Administrative Office. Maps that were shown in MKP Irrigation Groundwater Reports were created by using GIS in this study (Anonymous, 2000).

WATMAPGIS Software consists of two main modules. First of these modules is data input and the second is the module which was created for mapping and evaluating. Data input was handled in two groups within itself. These are; a) stable data input about irrigation project area and groundwater observation holes and b) monthly groundwater observation values input. In mapping and evaluating module, process of preparing groundwater maps is performed. General chart of WATMAPGIS is given in Fig. 1.

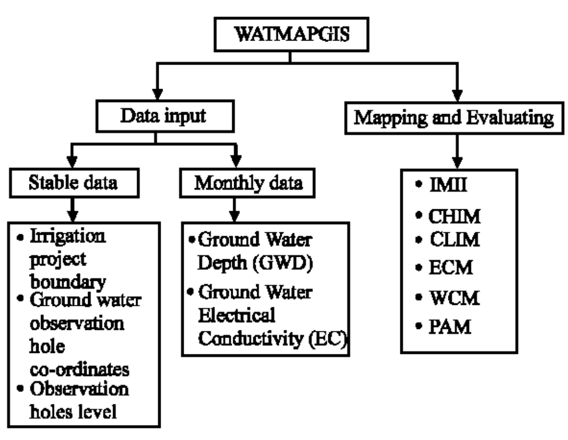

Fig. 1: General Chart of WATMAPGIS which was developed to prepare groundwater maps

Two different environments were used for the input of stable and monthly data. Irrigation project boundaries and groundwater observation hole co-ordinates are entered in ArcEdit graphic screen. As groundwater observation holes level and observation values of groundwater depth are tabular data, they can be transferred to the system via data entry screen which was prepared with FormEdit module. If groundwater observation holes co-ordinates are available in a ASCII file, they can be directly transferred to the system.

To prepare groundwater maps which were shown in the chart listed in Figure 1, the following processes were performed. An isobath map of any month of the user's choice can be taken as groundwater isobath maps as well as Depth-to-Watertable (Isobath) Map in Intensive Irrigation Season (IMII). While preparing Critical Highest Isobath Map(CHIM) and Critical Lowest Isobath Map (CLIM), observation holes which have missing data are not evaluated. In order to find out which month's data to use, to prepare these maps, program gathers groundwater depth values of each month. Within the year, Groundwater Depth (GWD) data of the month whose data total is big is used to prepare CLIM and is little is used to prepare CHIM. Summing is done by using Eq. 1.

$$Td_i = \sum_{j=1}^{n} D_{ij} \quad (1)$$

Here,

- i = 1...12 , Month number
- j = 1...n , Hole number
- n = Total active hole number
- Td_i = Total of groundwater depth value for i^{th} month
- D_{ij} = Groundwater depth of j^{th} hole for i^{th} month

While creating isobath maps (IMII, CHIM and CLIM), irrigation project boundary coverage which was entered in the system and the coverage including groundwater observation holes and their monthly measurement values are turned into GRID format. TOPOGRID command, which was used for this purpose, is an interpolation method specially designed for the creation of hydrological correct Digital Elevation Models (DEMs) from comparatively small, but well selected elevation and stream coverages (Anonymous, 1994). To eliminate the anomalous varying values among the obtained GRID file's pixel, filter process is performed. The process, performed with FILTER command, smooth the entire lattice file and reduces significance of anomalous mesh points (Anonymous, 1994). Thus, a groundwater isobath surface without sharp lines is obtained. On this surface, a transformation into polygon format is made with GRIDPOLY command in order to classify groundwater depths and display them in different colours and to obtain spatial distribution. During the creation of polygon, groundwater depth value of each polygon area is recorded at the attribute table of the coverage which is formed automatically. Groundwater depth values are classified in five groups. These are; areas with a groundwater depth of between; 0.0- 0.5 m, 0.5-1.0 m, 1.0-2.0 m, 2.0-3.0 m and areas with a groundwater depth of over 3.0 m.

By adding "color" fieldname to the attribute table of the polygon coverage, a different color code is appointed for each defined class and with POLYGONSHADE command, isobath map is created in ArcPlot module. Spatial distribution of each class is displayed on legend.

The same processes are repeated to obtain Electrical Conductivity Map (ECM) of groundwater. Groundwater salinity (EC value) was classified in six groups. They are; 0-100, 100-250, 250-750, 750-2500 and 2500-5000 micromho cm^{-1} areas and over 5000 micromho cm^{-1} areas.

In preparing of Water-table Contour Map (WCM), irrigation project boundary coverage and groundwater observation holes coverage, which includes groundwater observation values, were used. Equation 2 was used to obtain groundwater table level values.

$$Wt_{ij} = WTL_j - D_{ij} \tag{2}$$

Here,

- i = 1...12, Month number
- j = 1...n, Hole number
- n = Total active hole number
- Wt_{ij} = Value of j^{th} hole groundwater depth for i^{th} month
- WTL_j = j^{th} observation hole surface level
- D_{ij} = Groundwater depth of j^{th} hole for i^{th} month

For each observation hole, obtained groundwater level values were added up to attribute table of groundwater observation hole coverage. Then, TIN was created from boundary coverage, groundwater observation hole coverage and its attribute table. TIN (Triangular Irregular Network) is a surface model. CREATETIN command which is used for this process, is a versatile command that creates a tin surface model from multiple input sources including Arc/Info coverage, ASCII files containing x, y, z co-ordinates, and breaklines interpolated from a lattice. This command uses the Delaunay method of triangulation. Delaunay triangulation is one of the most popular methods for generation of unstructured meshes. It is composed of two phases: placement of the mesh vertices and triangulation. If the mesh vertices are placed well, the triangulation phase can be simple (Anonymous, 1994).

To obtain water-table contours from TIN surface model, by using TINCONTOUR command a coverage with a wished contour intervals is created. With this command, groundwater level values are automatically recorded to this coverage's attribute table. With this command, contours are generated directly from the tin within its zone of interpolation. The zone of interpolation is defined by the convex hull, and/or the CLIP and ERASE features incorporated when building the tin. This command uses the Douglas-Peucker Algorithm to weed vertices along each contour (Anonymous, 1994). Obtained contour coverage is displayed in ArcPlot module and plotter printout can be get with ArcPress module.

Two criteria are used to determine monthly problematic areas. First one is the areas with a groundwater depth of 1.0 m or less, second is areas with a groundwater EC value of 5000 micromho cm^{-1} or over. These are taken as problematic areas (Anonymous, 2000). Finally, areas with a groundwater depth of 1.0 m or less and areas with EC value of 5000 micromho cm^{-1} or more are mapped as problematic areas and area values of the problematic areas are given.

Description of WATMAPGIS: Screen forms of WATMAPGIS program will be briefly presented here. There are three options in the main menu of the software. These are; data input, mapping and evaluating, and exit.

With the data input option, the form is displayed on the screen. Input of groundwater observation hole and project boundary co-ordinates, which are assumed as constant information, can be input with this screen form, and also monthly groundwater depth and groundwater salinity values can be entered in monthly data entry.

As to give an example for stable and monthly data input screen, the graphical screen which was prepared for input of observation holes co-ordinates can be seen. Here, groundwater observation holes within the irrigation area can be added up to the system. With "Define" option, name of the hole and surface level of the hole can be entered.

Groundwater depth values and groundwater EC values for each hole and each month can be entered in monthly data input screen. With the option "Save", information is saved in the related file. Values of the holes whose data has been entered can be displayed on the screen by entering hole number and it is possible to make any changes.

RESULTS

Outputs of WATMAPGIS, which was created to prepare groundwater maps and is to be used to evaluate measurement data of groundwater observation holes, will be given in this section.

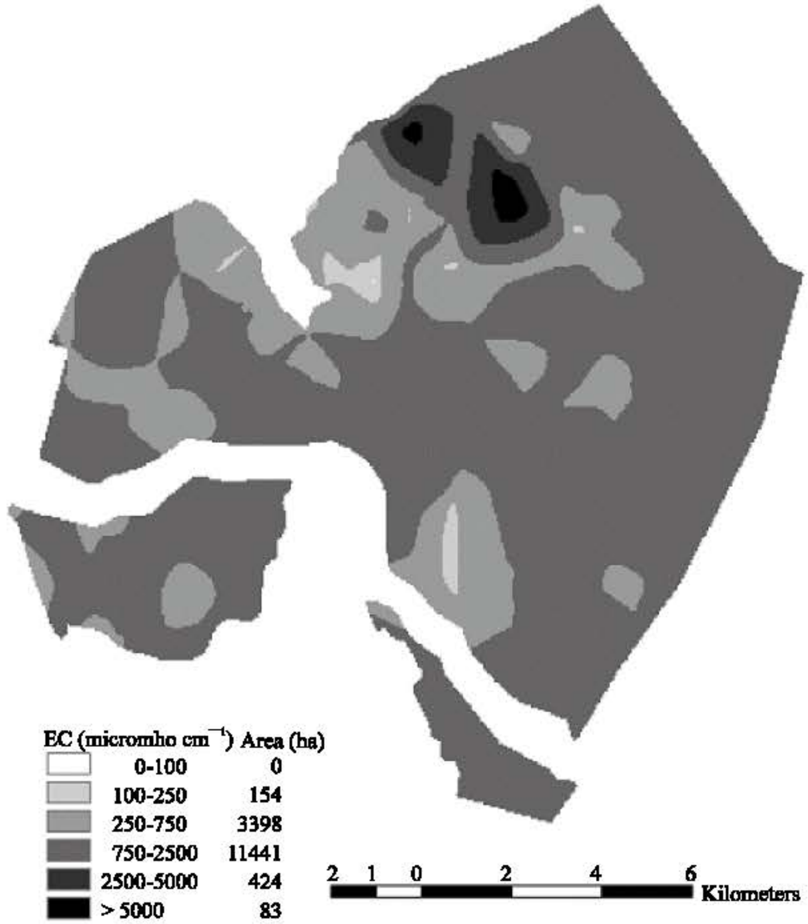

Fig. 2: Groundwater electrical conductivity map of MKP irrigation area at January-2002

Here, isobath of the month when irrigation was the most intensive or/and monthly isobath map and groundwater critical lowest and highest isobath map are in the same style as each other. For this reason, only an isobath map of the month when irrigation was the most intensive will be given as example.

Isobath map of the month when irrigation was the most intensive: With the option monthly isobath map, isobath maps of the month when irrigation was the most intensive and/or isobath maps of various months can be obtained.

Groundwater electrical conductivity map: Groundwater EC map can be taken for any month of the user's choice. January 2002 groundwater EC map of MKP irrigation area is seen in Fig. 2. In this map, areas with various electrical conductivity are shown in different colours. Also, area values of each group are given as hectare in legend. As it can be seen in the Fig. 2, there is no area with an electrical conductivity value of 0-100 micromho cm^{-1}, 154 ha with EC value of 100-250 micromho cm^{-1}, 3398 ha with EC value of 250-750 micromho cm^{-1}, 11441 ha with EC value of 750-2500 micromho cm^{-1}, 424 ha with EC value of 2500-5000 micromho cm^{-1} and 83 ha with over EC value of 5000 micromho cm^{-1}.

Groundwater contour map: By uniting the points where groundwater level is same, contour lines are obtained. Groundwater level values are obtained by subtracting groundwater depth from observation hole surface level value.

Probable problematic areas map: Maps showing problematic areas are prepared by mapping the areas whose groundwater depth is 1.0 m and below and of these areas whose EC value is 5000 micromho cm^{-1} or over. Here, areas which has both conditions can be spatially seen and class area values of these areas can be obtained. Thus, areas which are problematic for plant production can be determined by using monthly measurement results. Besides, areas which develop a drainage problem can be determined and by using different criteria, areas where irrigation water is not used efficiently that is where there is over irrigation can be determined. Considering the criteria given above, there aren't any problematic areas in MKP irrigation area, which was used in the study, according to groundwater observation values of 2002.

DISCUSSION

Monitoring and Evaluating should be performed continuously in irrigated areas for sustainable agricultural activities in Agricultural production. Using too much water in irrigated agricultural area brings about some problems. Most important of these problems is that groundwater table rises up to the root zone and saline content of the soil rises. By long-term monitoring and evaluating groundwater data, efficiency and productivity in agricultural activities will be increase by taking into consideration results.

WATMAPGIS software uses the substructure of geographical information system. Although entering data, especially graphic information co-ordinately, is time consuming at the beginning, this process is to be done only once for each project area. System was designed in a way that it can keep groundwater observation of long years in different files. It creates groundwater isobath map of various months, groundwater electrical conductivity map, groundwater contour map and probable problematic area map (Area which has groundwater depth < = 1.0 m. and groundwater electrical conductivity value > = 5000 micromho cm^{-1}) for any year. Maps and measurement values of previous years can be reached when needed. Thus, it is possible to determine and interpret fluctuations over years. WATMAPGIS has not time-series analyses to interpret fluctuations between years for groundwater depth and EC value. This is a deficient of WATMAPGIS system.

As WATMAPGIS works on Arc/Info geographical information system, it needs this software. This may be taken as a costly component. Less costly GIS software might be used.

To develop an automatic evaluation system which will be used in monitoring and evaluating fluctuations in years, may bring about the need to use more computers in this kind studies.

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