

Customizing ArcGIS for spatial decision support - Case study: Locating potential small water reservoirs in Benin -

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ABSTRACT

This paper presents a software development approach to customize the GIS software ArcGIS (by ESRI) for spatial decision support. For the case study, example data of the Quémé catchment in Benin (Africa) is used to program such a system which will be used to plan the establishment of potential small water reservoirs. Therefore, a new user menu in ArcGIS is introduced which allows (i) the integration of available GIS data from geo-databases, (ii) the easy application of spatial analyses by using implemented expert knowledge, and (iii) the automatic production of maps and reports for potential locations. To fulfil these requirements, the developer software Visual Basic for Applications (VBA) in combination with the ArcObjects library is used as the programming environment. ArcGIS comes with a VBA interface and with the above-mentioned library. Therefore, the software engineer is able to create a comprehensive and user friendly system for spatial decision support which includes numerous analyses tools of ArcGIS. Additionally, various user views can be realized basing on the same platform. First preliminary results show the potential capability of the above-described approach and justify the usage of the ArcGIS software to create spatial decision support systems.

Keywords: Spatial decision support system, Water, Management, ArcObjects, Visual Basic for Applications

1. INTRODUCTION

The relevant literature does not show a consistent definition of decision support systems (DSS) (Leung, 1997; Singh, 2004; Turban et al., 2005). Nevertheless, a DSS is basically characterized as a computer based system which helps stakeholder to solve semi-structural processes by using data and analytical models (El-Najdawi and Stylianou, 1993). This definition points out that results generated by decision support systems are not easy to produce. Complex results are in general interdisciplinary solutions and therefore, the major task of a DSS is to provide several different approaches, methods and outputs. Thus, a DSS needs to incorporate the visualization, interpretation and evaluation of the selected data. With regard to spatial data, GIS functionalities need to be implemented which allow the potential users to generate spatially different decisions. Therefore Spatial Decision Support Systems (SDSS) are required (Malczewski, 1999; Manoli et al., 2001). Additionally, such SDSS need to provide the opportunity to integrate several different analysis models, to visualize and evaluate the model results and to develop management strategies together with various other information data (Keenan, 1997; Leung, 1997; Yeh, 1999). With respect to the model approaches, numerical as well as statistical and expert models need to be applicable.

The IMPETUS project is investigating essential aspects of the hydrological cycle in selected catchments in West Africa. IMPETUS is the acronym for *Integratives Management-Projekt für einen Effizienten und Tragfähigen Umgang mit Süßwasser in Westafrika* (An integrated approach to the efficient management of scarce water resources in West Africa). One major focus of the project is to analyse and to forecast the effects of the Global Change on the water resources in Benin and Morocco (Africa). In order to be able to quantify future development simulation models were adapted and applied. Researchers from several departments of the Universities of Cologne and Bonn are involved in this interdisciplinary project: Agricultural Economics, Agricultural Politics, Biodiversity, Ethnology, Geography, Geology, Geophysics, Meteorology, Plant Nutrition, Plant Production, Soil Science, and Medical Science. More information about the overall project is given by Speth et al. (2006). One major task in the 3rd project phase of IMPETUS is the development, implementation and application of GIS based SDSS for the water resource management in the selected catchments of Benin and Morocco which will be part of the IMPETUS SDSS (ISDSS). The major tasks of the ISDSS are

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to provide decision support for various aspects of fresh water resource management and for spatial planning and management considering the requirement of various stakeholders in the Benin and Morocco. Consequently, for the ISDSS a DSS toolbox and several user interfaces have to be developed.

Essential for the success of such a system is to consider the potential users and their knowledge and needs. Due to the research activities IMPETUS cooperates with a large amount of decision-makers on different levels. Most of these decision-makers are experts in their research topics but have limited experience with computer technology and software concerning GIS and SDSS. Nevertheless, the ISDSS should also be useable for advanced users, who have detailed knowledge in computer models and GIS and who are able to implement additional functionalities into the decision making processes. Therefore, the ISDSS has to consist of standard as well as advanced GIS functionalities. Besides that, interfaces are developed which guarantee the import and export of required geo-data: Tools are implemented which generate specific outputs in terms of maps and reports.

Within one subproject of IMPETUS an interdisciplinary study (PK Be-E4) is engaged in locating potential small water reservoirs in Benin (Thamm, 2006). The objective of this investigation is the evaluation of possibilities for yield increase by construction of small scale reservoirs which can be an important measure for improving food security against the background of decreasing precipitation. The SDSS should provide information about suitable locations and a calculation of water availability and water loss due to evapotranspiration as well as yield increase. Because in the past, use of small scale reservoirs has often created conflicts, it is important to develop applicable management concepts for a sustainable use of the reservoirs.

This paper presents the development concept to customize the standard GIS software ArcGIS for spatial decision support based on that specific question as an example.

2. MATERIAL

Several different datasets were used to realize the case study. The area of interest is defined by the catchment of the river *Ouémé (Haute Vallée de l'Ouémé, HVO)* which is located in the central part of Benin. As input data, raster-, vector- and alphanumeric geo-referenced data as well as model based data establish the basis for the SDSS development framework. In detail, the following datasets were used:

- Point data of the settlements and climate stations (precipitation)
- Line data of the rivers and roads
- Polygon data of the catchments and protected forest areas
- Raster data concerning land use and elevation

In addition expert knowledge in terms of default class breaks, buffer distances and weighted index parameters are needed as input for the decision making process. As the SDSS is still under construction, several other datasets (e.g. soil, geology, etc.) need to be implemented to fulfill the requirements of being a comprehensive tool for the decision support.

The combination of a personal geo-database (MS[®] Access) and the software ArcGIS[™] by ESRI[®] was used as the GIS framework for the development. ArcGIS[™] is the most commonly used GIS software and comes with a powerful Visual Basic for Applications (VBA) interface. The ArcInfo version comes with a Visual Basic for Application Interface which allows the developer to implement specific additional tools. By using this interface, database connections can be realized automatically and complex GIS processes can be implemented into the program code by using the ArcObjects library. This library is part of the ArcGIS package and is accessible via VBA. As the case study was accomplished with a limited amount of data, a personal geo-database was adequate to fulfill the given demands. Thus, Microsoft[®] Office Access 2003 was applied as the database management system.

3. METHOD

Figure 1 shows a generalized float chart of the methodological approach which was used to customize ArcGIS for spatial decision support. The first step was to convert the input data into an usable data format and transfer it into several

personal geo-databases (Geo-DBs). These Geo-DBs were coupled to the GIS software ArcGIS by using VBA in combination with the ArcObjects library. With focus on the specific question of the sub-project (in this case study: Locate potential water reservoirs), a routine has been developed to select only these data layers out of the Geo-DB which were used for the decision making process. These layers are loaded automatically into the graphical user interface (GUI) and are visualized according to user pre-defined requirements (classification mode, color, style, etc.). After this initialization the user is asked to start the decision making process. This is provided by a programmed windows form which invites the user to select one single catchment out of all available catchment polygons by using the programmed IMPETUS selection tool. This tool selects one catchment out of the Geo-DB by using the Structured Query Language (SQL), stores it's unambiguous ID and geometry and uses both as input parameters for the following clip and intersect procedures. Afterwards the user starts the program code for the decision making process.

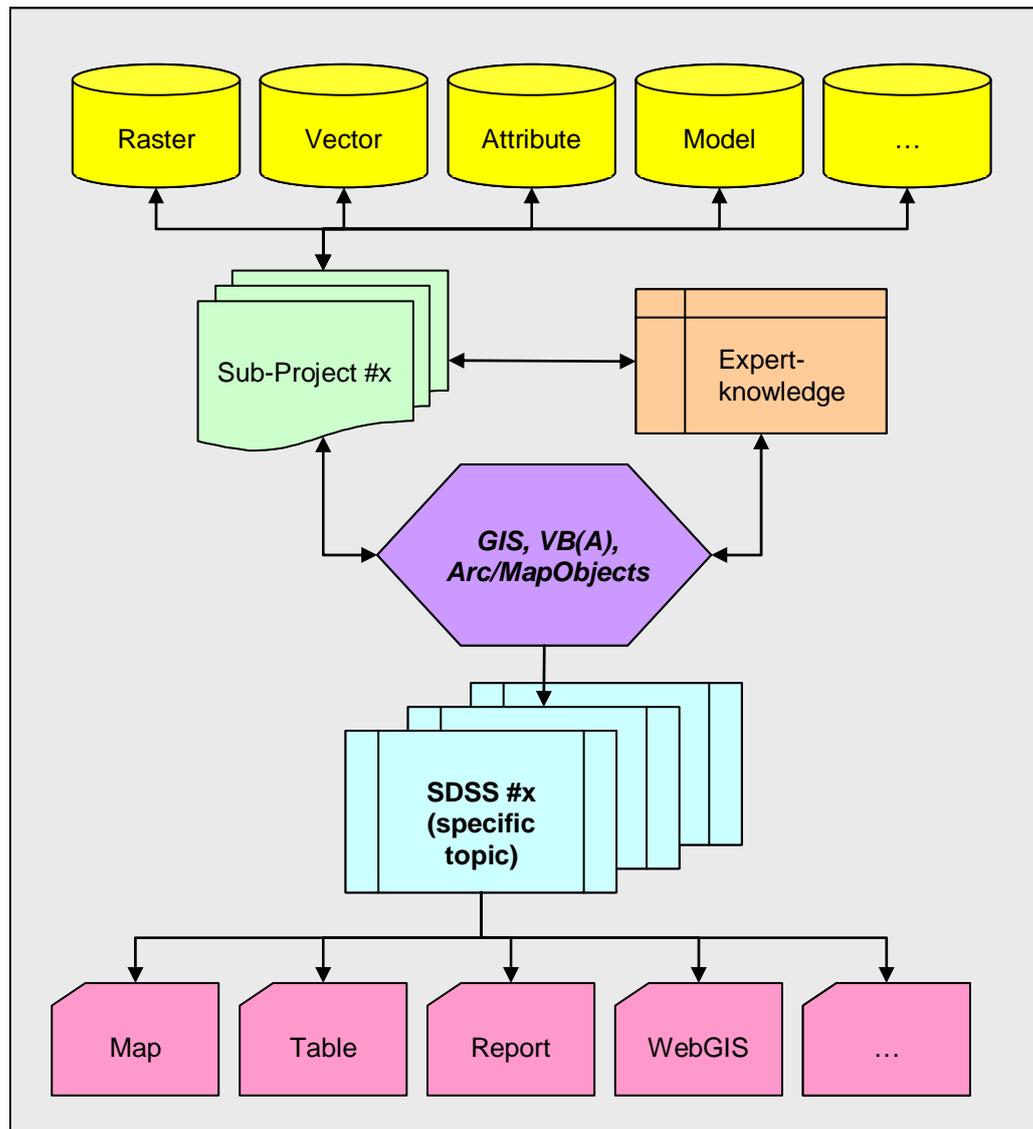


Fig. 1. Flow chart of the methodological approach which was used for the development of the SDSS.

Firstly, the file sizes of the input datasets are reduced to increase the program performance. This is done by clipping all input layers with the selected catchment polygon. After the extent of all input layers is aligned according to the catchment boundary, the subsequent analysis steps which are based on a pre-defined knowledge based decision tree are

executed automatically. In detail, vector-raster conversions, several different raster analysis (e.g. create hill shade, calculate slope, estimate rain volume, calculate flow direction and accumulation), classifications, intersects and overlays as well as other mathematical algorithms were implemented into the program code to generate the decision making result. The above described analysis steps are common GIS tools which are programmed to run automatically.

To fulfill the requirement of developing a SDSS instead of a user-friendly GIS, additional expert knowledge was added at the last analysis step of the decision making process. Default expert knowledge based class break and buffer values were offered in a new window. These values were used to calculate an index, which enables the decision making. All the values of that windows form are editable. Therefore, the user is able to influence the decision result during the decision making. The spatial decision result is a raster layer containing the index values per pixel and can be visualized either in a GIS map or in the form of a table, report, etc.

4. RESULTS

The aim of the development was to realize a comprehensive SDSS which is applicable by different users. Thus, an application has to be programmed which is usable by the unexperienced user as well as by the expert GIS user. Therefore, the development followed a modular approach where several stand-alone components were programmed.

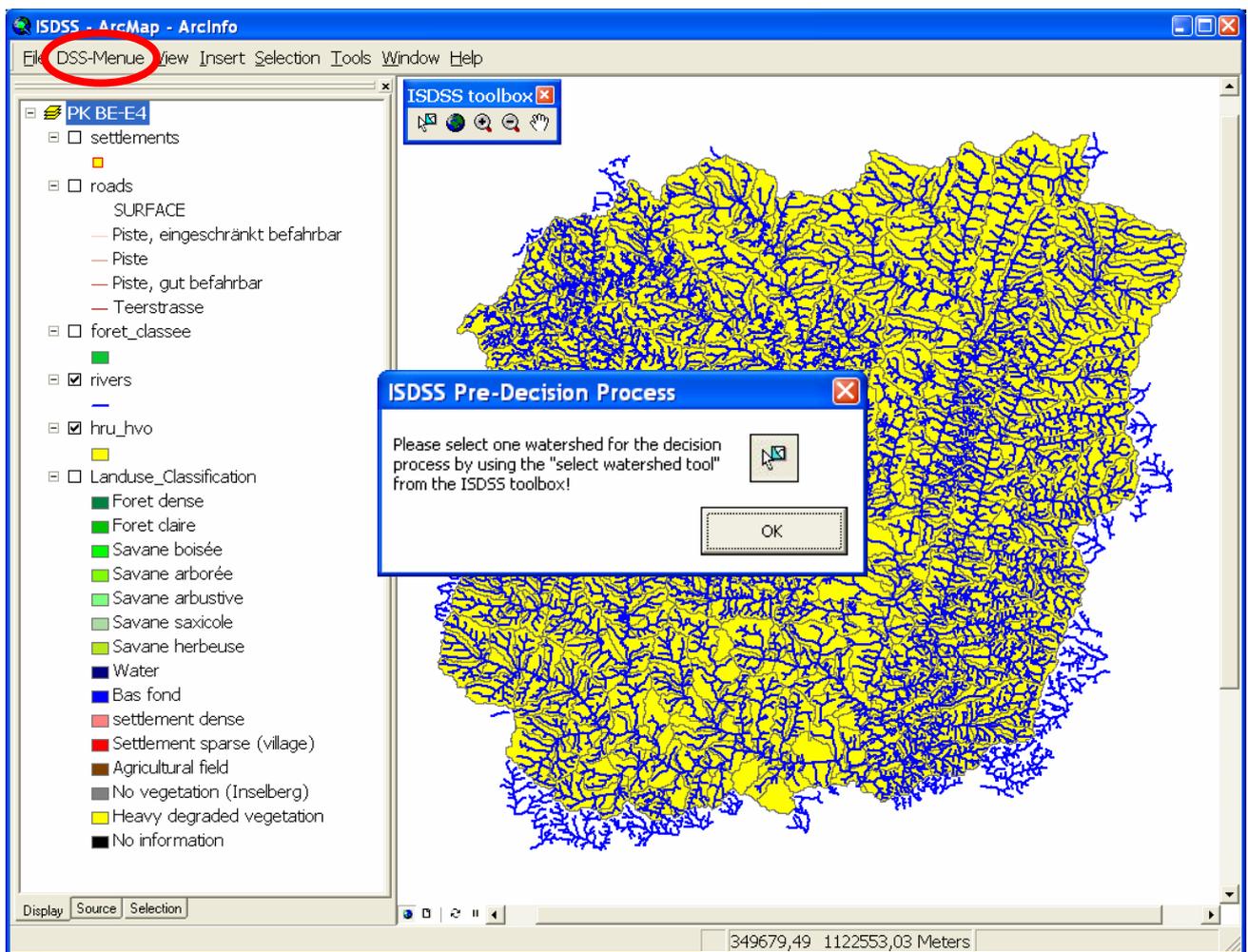


Fig. 2. Screenshot of the GUI for selecting a certain catchment (= watershed).

Figure 2 shows the first pre-result of the decision making process. By clicking the DSS-Menu button (see red mark in Fig 2) a sub menu pops up where the user can choose one specific SDSS from a list. In this case, the user selects the “PK Be-E4” which locates potential small water reservoirs in Benin. By clicking on the sub menu, the main program code of the application starts. Firstly, several question specific input information layers are loaded from the geo-databases into the ArcGIS graphical user interface (GUI). After the geo-databases is connected to the GUI via program code, the legends of the information layers are re-adjusted based on user needs and are visualized in the ArcGIS data frame (left side of Fig. 2). Secondly, a message box pops up and asks the user to select one catchment. By using the self developed tool for selecting a specific catchment (see ISDSS toolbox), the following program code only considers data which contains information about the selected catchment. By reducing the amount of data in that early stage of the analysis, the application performance increases significantly.

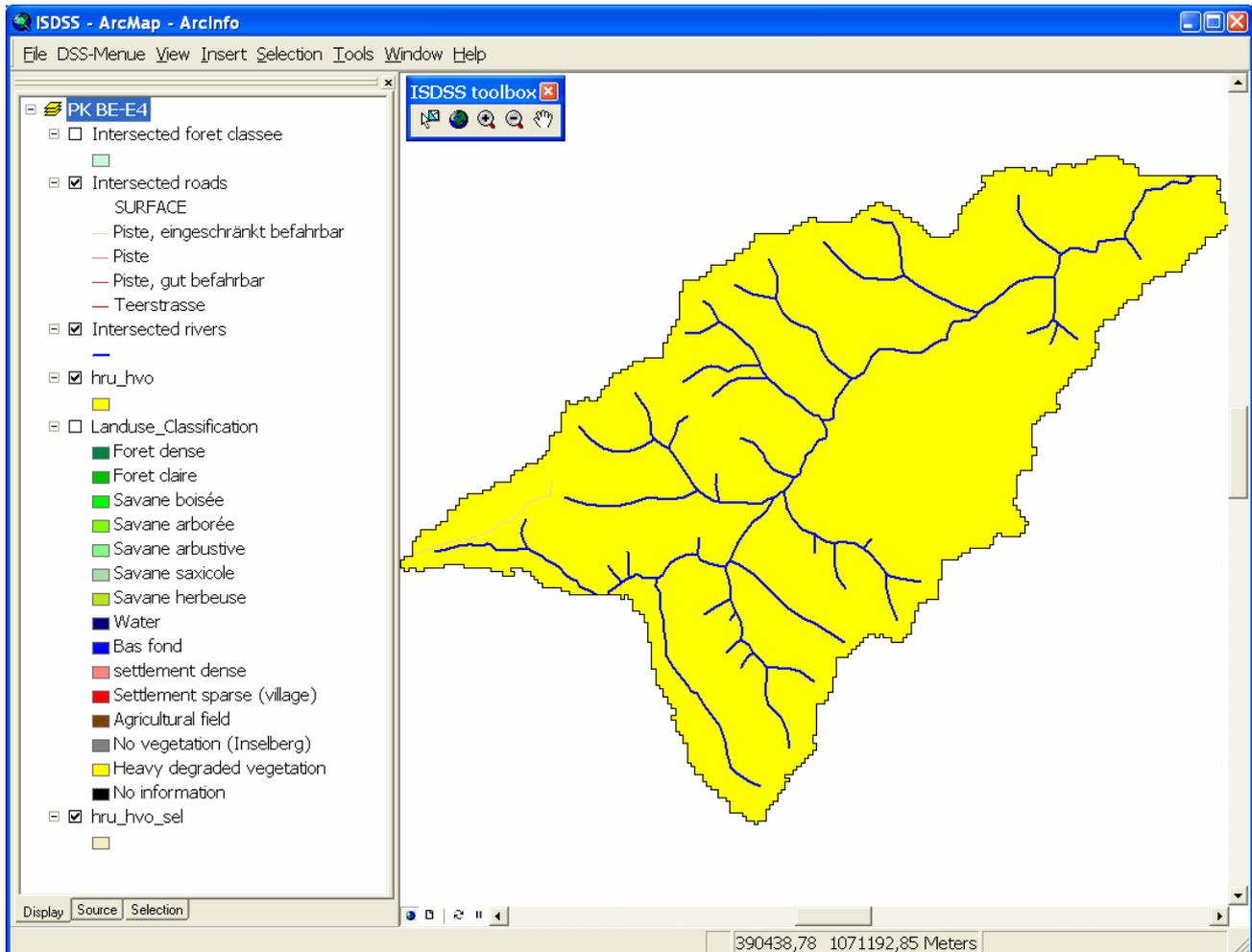


Fig. 3. Screenshot of the selected catchment.

After the user has selected one catchment the windows is automatically adjusted (Fig. 3). At the same time, a windows form (Fig. 4) pops up which shows the progress of the decision process. As the program code runs automatically in the background of the GUI, the user is informed about the processing status. This is realized by a continuous status bar at the bottom of the form and by the green checkmarks in the decision status frame of the form. They are visualized when the associated process is executed. In general, the following tasks steps are executed automatically:

- Clip all relevant layers based on the chosen catchment
- Perform vector-raster conversion

- Create new information based on input data (calculate slope, aspect, hill shade, flow direction, flow accumulation, etc.)
- Create buffers based on expert knowledge (default values) or based on individual values (default values are editable)
- Classify data either based on default or user provided class limits
- Calculate potential areas by using a weighting algorithm which includes all post-processed data of the selected catchment
- Visualize result (e.g. potential map of locations)

Fig. 4. Screenshot of the Decision Support windows form.

Besides this digital informative sign the form also shows additional information. The frame “user decisions” presents the catchment ID as an example. This grid ID is selected out of the geo-database by using the geometry of the selected catchment and a spatial SQL query. The resulting ID is read out of the specific table of the geo-database and is visualized in the textbox next to the text.

In addition to that, the Decision Support windows form also presents alphanumerical output which is generated by the routine. As an example, the ISDSS Output frame shows the total amount of rainfall of the selected catchment (= watershed).

Up to the step of calculating the total amount of rainfall (shown in Fig. 4), the program code runs automatically. After this process is executed the final decision concerning the support of locating potential areas is still pending. At this point of the analysis the user has the opportunity to influence the decision result according to his guidelines. Another windows form pops up (Fig. 5) where the user is able to either use the default values which are implemented in the program code or to edit these values based on his knowledge. In detail, classified and weighted data of the land use classification, flow

accumulation, the buffered rivers, roads and settlements as well as data of the protected forest areas are used to calculate a weighted index. That index is calculated for every pixel within the selected catchment and represents the potential areas of small water reservoirs as an example based on the SDSS approach.

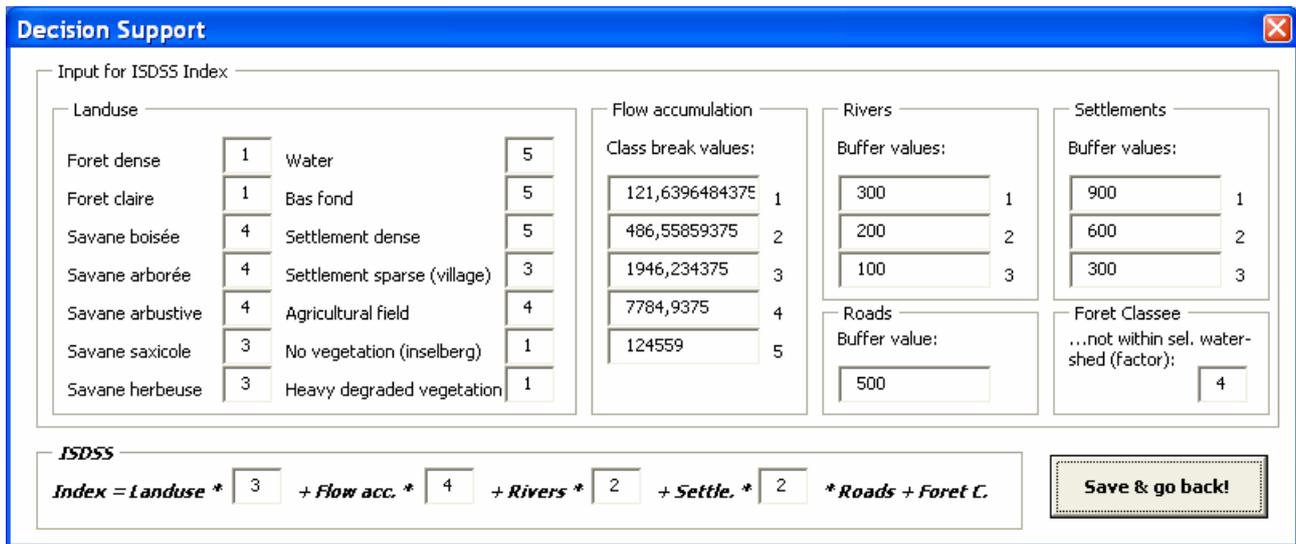


Fig. 5. Screenshot of the expert knowledge based input variables which are used for the decision support.

By clicking the “save & go back” button, the program code uses the input values of that windows form and calculates the index. Several procedures run in the background of the GUI to ensure the decision making. In detail, reclassifications are accomplished by using the class breaks. In addition to that, buffers are drawn around the intersecting rivers, settlements and roads. In a next step, they are converted to raster layers and are classified automatically. All these pre-results in terms of classified thematic raster layers are input layers of the index equation. Within that step it is possible for the user to customize the weighting values of the input layers. The effect of different weights on the output can be analyzed and evaluated and is an essential information for the final decision.

A weighted overlay of the classified raster layers produces the output. That is a generated raster layer which represents potential areas in a predefined color palette. In this case a stretched color ramp (white to blue) is used to point out the spatial differences. Based on the applied approach, the resulting raster layer is added to the ArcGIS data frame. With that program step, the actual decision support analysis is completed. After the refreshment of the GUI another program procedure starts to run. A windows form pops up and asks the user for the formatted output. Figure 6 shows the digital map which is one of the possible outputs. Independent from the thematic content presented in that figure, the output demonstrates a comprehensive development solution which was created by customizing ArcGIS for spatial decision support. Besides the geometric information of the selected catchment, the potential areas are presented by the blue colors. High index values (darker blue tones) represent possible locations of small water reservoirs, low pixel values (lighter blue tones to white color) stand for less valuable potential reservoir sites.

For a better orientation, an additional overview map is added to the digital output map. This overview shows the *Upper Ouémé* catchment area and every single catchment in terms of its boundaries (see Fig. 6, upper right). The red box locates the selected catchment. Besides that overview map, several other layout components (legend, north arrow, scale bar, etc.) are provided. Furthermore, some alphanumerical attribute data are selected from the geo-database and displayed. In this case, the digital output map presents the catchment ID which is selected out of the geo-database via SQL and the amount of rainfall which was calculated by the SDSS during the analysis.

As the development of the decision tree, the usable layers and the decision algorithm is still under construction, this result does not present the final answer to the specific question of the case study (PK Be-E4) in terms of form and content. It rather shows the practicability of the used methodological approach for customizing ArcGIS for spatial decision support.

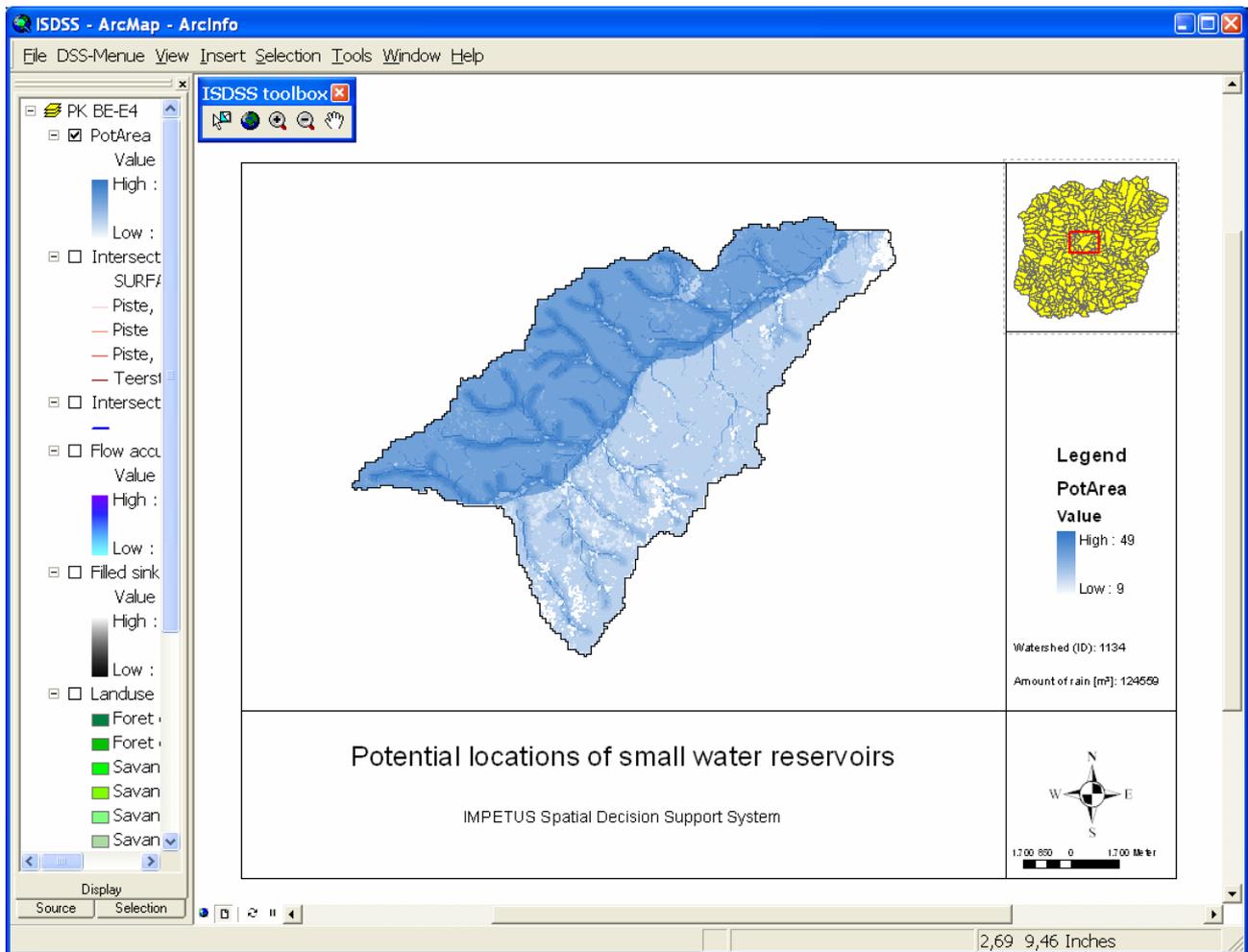


Fig. 6. Screenshot of the digital output map.

5. SUMMARY

The presented approach of customizing the ArcGIS software for decision support shows the potential of creating a comprehensive, multi-user interactive system. ArcGIS offers a usable interface for software engineers to program additional functions.

In this case study, the focus was set on the development of a user-friendly Spatial Decision Support System for locating potential small water reservoirs in Benin/ Africa. With this GIS-based software application, an inexperienced user is able to generate an adequate result. Experienced users have the opportunity of implementing their own knowledge during the program runs.

This paper describes the usage of Visual Basic for Applications in combination with the ArcObjects library. With an ESRI license which includes the combination of VBA and ArcObjects, it is possible to transform numerous GIS analysis steps into one program code and run it automatically. Thus, user caused errors are minimized. The interaction between the ArcGIS GUI and the geo-database as well as all analysis functions and the graphical output are realized by VBA-code. Hence, the potential user does not need to be experienced in geo-database management, SQL, or advanced GIS analysis.

By following up the approach of programming a modular system, the user is only able to influence the executing program where it makes sense (e.g. edit input values for further analysis steps). Therefore, a SDSS can be implemented which answers a specific spatial question semi-automatically and fulfills the requirements of being an easy-to-use tool for spatial decision support.

6. ACKNOWLEDGEMENTS

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REFERENCES

1. M. K. El-Najdawi and A. C. Stylianou, "Expert support systems: integrating AI Technologies," *Communications of the ACM* 36(2), 55-65 (1993).
2. P. Keenan, Using a GIS as a DSS Generator. http://mis.ucd.ie/staff/pkeenan/gis_as_a_dss.html, (1997).
3. Y. Leung, *Intelligent Spatial Decision Support Systems*, Springer - Verlag, Berlin, 1997.
4. J. Malczewski, *GIS and multicriteria decision analysis*, Wiley, New York, 1999.
5. E. Manoli; G. Arampatzis, E. Pissias, D. Xenos and D. Assimacouloulos, "Water demand and supply analysis using a spatial decision support system," *Global NEST: The International Journal*, 3(3), 199-209 (2001).
6. A. Singh, *Towards decision support models for an ungauged catchment in India, the case of Anas catchment*, Dissertation an der Universität Karlsruhe, Fak. f. Bauingenieur-, Geo- und Umweltwissenschaften, Karlsruhe, 2004.
7. P. Speth, B. Diekkrüger, M. Christoph and A. Jaeger, "IMPETUS-West Africa- An integrated approach to the efficient management of scarce water resources in West Africa – Case studies for selected river catchments in different climate zones," ptDLR– Projektträger im DLR (eds.), *GLOWA – German Programme on Global Change in the Hydrological Cycle. Status Report 2005*. 86-94 (2005), <http://www.impetus.uni-koeln.de>
8. H.-P. Thamm, „Ausweisung von geeigneten Standorten und nachhaltiges Management von Kleinstauseen für die Landwirtschaft,“ P. Speth and B. Diekkrüger (2006): *IMPETUS: Sechster Zwischenbericht, Zeitraum: 1.1.2005 – 31.12.2005*, (2006), <http://www.impetus.uni-koeln.de>
9. E. Turban, J. E. Aronson and T.P. Linag, *Decision support systems and intelligent systems*. Prentice Hall, New York, 2005.-O
10. A. Yeh., "Urban planning and GIS," P.A. Longley, M.F. Goodchild, D.J. Maguire, and D.W. Rhind (eds.), *Geographic information system, Vol.2*, John Willey and Sons, New York, 1999.