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Predicting Groundwater Potentials Using Case Based Reasoning

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ABSTRACT
Water is one of the basic necessities of life but the available surface water is inadequate to meet up with human's demand for water. Hence, groundwater which is the sub surface water beneath the earth's surface is exploited to complement surface water based on different parameters. These parameters include its potentiality, amount of water stored/ found in a particular media at a time and the ability to recharge. The potential to recharge is the major indicator in groundwater search; this is done by carrying out extensive geological and geophysical survey of the area. This paper proposes the prediction of groundwater potentials using Case Based Reasoning (CBR). Geological and geophysical survey data including electrical resistivity survey data also known as Vertical Electricity Survey (VES) was acquired from three local government areas in the southern part of Oyo State, Nigeria. The problem attributes of each case include the coefficients of resistivity, VES data, geo-electric section data while the solution attribute is the groundwater potential with values poor, moderate or high. Given a new set of problem attributes, our CBR technique retrieves the most similar case from our casebase as a potential solution. The retrieved solution is then adapted as solution to the current problem is the similarity meets a particular threshold. An accuracy of 80% was obtained from our experiments where moderate and high groundwater potential were assumed to be identical. We intend to experiment with data from other parts of the country to further validate the CBR technique and investigate the effects of a three-way classification, instead of the two solution classes used in this study.

Keyword: Groundwater, Geological and Geophysical, Electrical Resistivity, Vertical Electricity, Survey

1. INTRODUCTION

The fact that "water is life and a gift of nature to mankind" cannot be overemphasized as the importance of water to life is invaluable and immeasurable since every living cell require a water medium to attain optimum functional state (Buchanan & Triantafilis, 2009; Oladapo, Olorunfemi, & Ojo, 2008). Water naturally exists as both surface water and sub-surface water (groundwater). Surface water is found in streams, rivers, springs, ponds, lakes, seas and the ocean bodies while groundwater is contained beneath the earth surface in hidden places where it occupies openings, cavities and spaces in the rocks (Clark, 1985; Ademilua & Olorunfemi, 2000). Groundwater becomes a significant part of water supply system because surface water is never adequate in supply for human use (Buchanan & Triantafilis, 2009). The need to search for water has been part of man and a burden from inception of life. Heavy investments have been done on water project (search and provision) to meet the demand for safe and portable water and to improve socio-economic development. Nevertheless, water has never been available in the needed quantity and quality in several parts of the world, especially the developing countries. Hence, the need to search for water in all perceived available means and medium.

Surface water is not always found at the point of need and have to be supplied through physical means with high cost that mostly require treatment to remove pollutants. On the hand, ground water is often found near the point of need and less susceptible to pollution and can be distributed faster at reduce cost. Groundwater development is the alternative means of solving the problem of ever-increasing water requirement for human survival (Oladapo, Olorunfemi, & Ojo, 2008). Groundwater is exploited based on the search of its potentiality, an indication of amount of water stored and found in a particular media at a time, and the ability to recharge with the rate to recharge. This replenishment rate and potential for recharging is the major indicator for groundwater search, which is done by carrying out extensive Geological and Geophysical survey of the area of need by governmental, organizations or individuals.

Case-Based Reasoning is a machine learning paradigm that solves a new problem using the experiences of a previous similar problem directly or by adaptation (Aamodt & Plaza, 2001; Nwiabu & Adeyanju, 2012; Adeyanju, Wiratunga, Lothian, Sripada, & Craw, 2008; Deng & Li, 2020). The basic assumptions are that similar problems have similar solutions and similar problems will always re-occur. Hence, the solution to a retrieved similar problem is reused and revised to cater for slight differences between the new problem and the retrieved problem. The validated revised solution can be retained as a new case for future use. This paper focuses on using case-based reasoning for prediction of groundwater in an environment based on data from geological and geophysical surveys. Section 2 provides a theoretical background to our work while Section 3 gives details of our methodology. Discussion of our experimental results is given in Section 4 followed by a conclusion in Section 5.

2. THEORETICAL BACKGROUND

This section gives an overview of relevant theories to that support our methodology with respect to case-based reasoning and groundwater potentials.

2.1 Case Base Reasoning

Case-based reasoning (CBR), is an approach to solve a new problem using solution(s) from previous similar situation(s) (Adeyanju I. A., 2011; Adeyanju I. , 2012). The CBR Cycle, as shown in Figure 1, is generalized as 4R's; Retrieve, Reuse, Revise and Retain (Aamodt & Plaza, 2001). A new problem is solved by *retrieving* one or more previously experience cases and solution(s) from the retrieved similar case is *reused* in one way or the other. There is typically the need to *revise* the reused solution so as to take into account any difference between the new problem and retrieved similar problem. The new experience (new problem and revised solution) are then verified as a confirmed case and *retained* by incorporating it into the existing knowledge-base (case-base). In real life, the problem space is N dimensional; feature vectors can therefore be weighted to reflect their relative relevance, tolerant of noise and missing data.

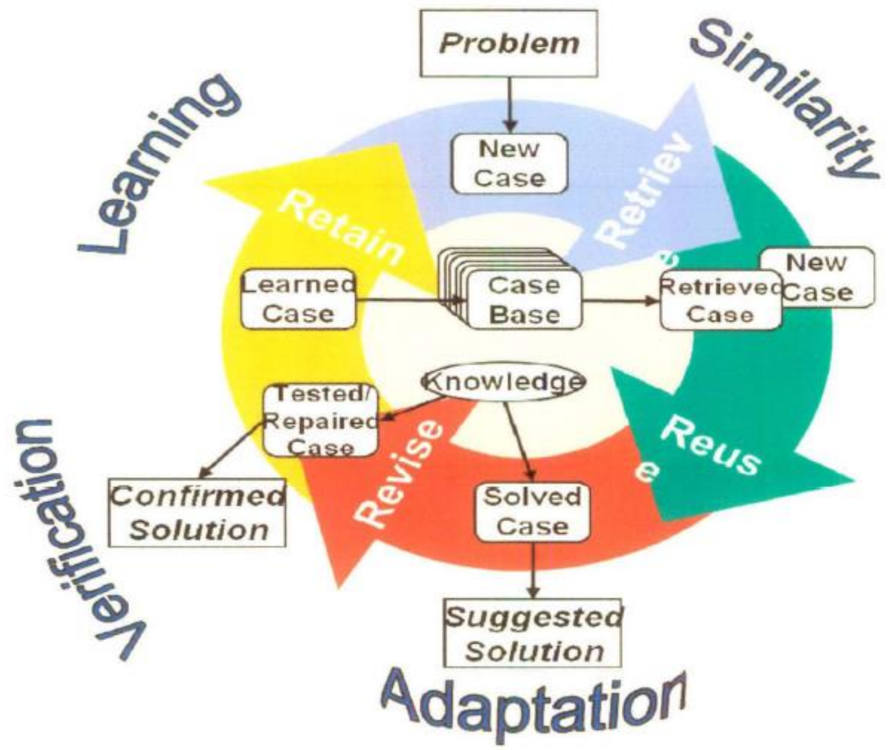

Fig. 1: A descriptive framework of case-based reasoning techniques (Aamodt & Plaza, 2001)

2.2 Groundwater Exploration

Groundwater exploration or prospecting is a multidisciplinary approach, the success of which depends on using more than one investigation techniques including geomorphological, geological/hydrogeological and geophysical surveys. Geomorphological survey captures the surface topography of the area such as water resources, drainage pattern, vegetation and structural trends while geological/ hydrogeological investigation are the reconnaissance and lineaments. Geophysical investigation for groundwater development in a basement complex area is therefore to delineate the subsurface geoelectric sequence and determine its parameters. It also identifies aquifer unit(s) and determine the lateral/ depth extent. The investigation maps geological structures such as faults and fracture zones, network of joints, buried stream channel and basement depression that are favourable to groundwater accumulation Lastly, it determines bed to the rock head and the bedrock topography with groundwater flow direction. The availability of groundwater in basement complex environment depends primarily on the geology, that is, rock types and tectonics, degree of fracturing and weathering, weathered overburden and fractured bedrock.

In Oyo State located in south-western part of Nigeria, there are two types of geological structures: pore-type water in sedimentary cover and the fissure-type water in crystalline rocks These can be further broken down to three types: fissure-type water in Precambrian crystalline rock, Pore-type water in sedimentary deposits and Pore-type water in superficial deposit. The integrated Very Low Frequency (VLF) Electromagnetic and Resistivity Survey for Groundwater in a Crystalline Basement Complex Terrain of South-west Nigeria is as contained in Table 1 (Nigeria Geological Survey Agency, 2012).

Table 1. Groundwater Potential Yields of the Basement Hydro-Geological Environment in South-west Nigeria

S/N	Hydrogeological Sub Environment	Description	Potential Yields	Groundwater Target
1	Highly weathered and/or fractured basement	Ancient crystalline and metamorphic rocks can be highly fractured. They can also decompose	Moderate 1.0-10	Possible quartz veins within the deep Weathered zone. Fractures at the base of the weathered zone. Vertical fractures
2	Poorly weathered sparsely fractured basement	Ancient crystalline and metamorphic rocks where they have not been weathered or fractured. Groundwater may be difficult to find	0.1-1.0	Widely spaced fractures and localized zone/ pocket of deep weathering

2.3 Related Work

Successive water supply provision from groundwater option has always being based on correct prediction and assessment of groundwater potential in the area of need. The amount of water in a media and replenishment ability on depletion indicates the potential. In Oyo state, south-west Nigeria, borehole selection and optimum drill depth in basement complex terrain were investigated purely based on geophysical exploration techniques (Oladapo, Olorunfemi, & Ojo, 2008). Extensive geoelectric investigations for siting borehole projects, by the Oyo State Rural Water and Sanitation Agency, for groundwater supply with optimum yield was considered ahead of political factors. The aquifer characteristics and groundwater recharge pattern in a typical basement complex was previously investigated (Badmus & Olatinsu, 2010). They concluded that borehole drilling in the study area should be executed in the peak of the dry seasons because recharge of existing boreholes is largely due to falling precipitation.

The Geographical Information System (GIS) with the capacity to be analyzed and queried has greatly improve the understanding of groundwater potential leading to better decision effort in utilizing groundwater potential for improving water projects (Akinwumiju, Olorunfemi, & Afolabi, 2018). The GIS environment directly provides such answer with respect to the area of best yield, hazardous zone based on pollution and exploitation or use based on population, accessibility and other human factors. Groundwater potential zones in the upper Nile Basin of Ethiopia were delineated using GIS and remote sensing with a multi-criteria decision analysis (Andualem & Demeke, 2019). The result was validated using the existing pumping wells with a 75% accuracy. Risk assessment of geological disasters using CBR was proposed (Deng & Li, 2020). Their experiments indicated that their approach is effective and exhibits a higher classification performance compared to traditional data mining methods.

3. METHODOLOGY

The research approach involves: data acquisition, design of the CBR module, software design/implementation and the evaluation of the system; this is shown in Figure 2

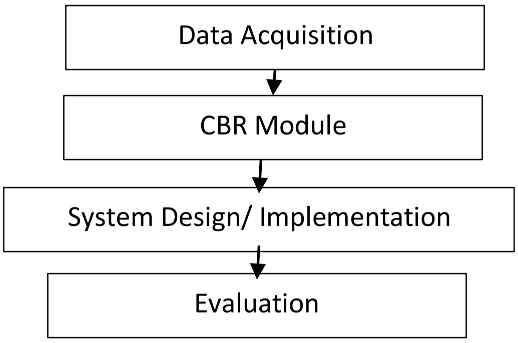

Fig. 2: Methodology Overview

The main data requirements for this work are geological and hydrogeological data captured on field which are mainly primary in nature. The geological data from the geology of the area, lineaments, geological structures and features, soil data are also essential while the hydrogeological data are primarily drainage pattern, landform, vegetation cover land usage and general lithology (Oladapo, Olorunfemi, & Ojo, 2008; Akinwumiju, Olorunfemi, & Afolabi, 2018). Geophysical survey data and interpretation led to geoelectric coefficients and aquifer parameter that are secondary data which are important parameters in the determination of groundwater potential (Omosuyi, Ojo, & Olorunfemi, 2007). The geophysical survey data (Electrical Resistivity Meter) were captured with the use of Terrameter on the field and the other collected data were subjected to manipulation and processing using software. The latitude and longitude positions coordinates were captured with the use of hand held Global Positioning System (GPS). These two set of data were structured and interpreted using Resist software package to produce the groundwater potential map and pattern of the project area.

The data were structured into a table and stored from where they are retrieved for further qualitative and quantitative analysis and modelling. The Resist and arithmetic graphs produced were indications of the groundwater potential of the area since the point of highest conductivity values with other factors correspond to the point of least resistance to the flow of current. The structured data Win2resist software interpretation and resist graphs from the iteration process were modelled into layers which are the geoelectric sections as shown in Figure 3.

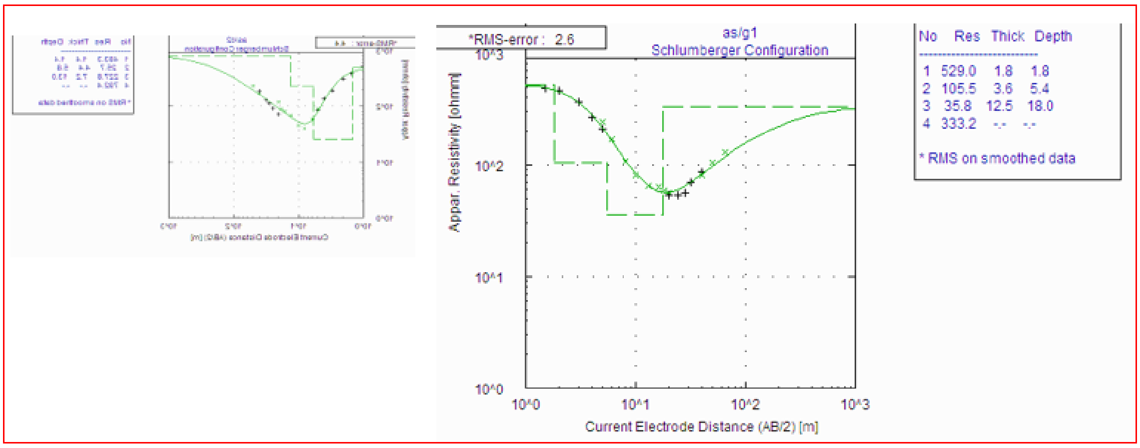

Fig. 3: The Resist/VES Graph Showing Geoelectric Section

Data quality was ensured with all necessary correlations and output normalized by reducing size and the removal of redundancy error without losing any important information. All primary data and the generated geoelectric data from Resist interpretation were subjected to GIS operation by input them into Arc-GIS software to produce spatial database which was created based on conceptual, logical and physical design, and construction phases with the database quality enhanced by corrections.

3.1 Case- Based Reasoning Module

The CBR approach carried out for the development of this spatial decision support system for predicting groundwater potential is structured from a well-programmed and interpretation approach This was done using collected data and review of field survey, identification and selective evaluation of geological and geophysical data in the following three phases:

(i) Data collection and review of previous work

(ii) Data analysis and interpretation
(iii) Validation of results.

All data integrated in GIS environment and analysed to assess the groundwater controlling features can be grouped majorly into physical features and non-physical features. The physical features are geographical and geological that control groundwater presence and potentiality while the non-physical factors are generated from calculations, maps, graphs and drawing extrapolated from the electrical resistivity and other data captured. The physical characters were classified by their properties, shape substance and occurrence while the non-physical features were derived by graphical and formulae calculations based on arithmetic operation. The physical features considered include soil, geology, geologic structures, water flow pattern map and rock type. The non-physical features are electric resistivity graphs and modelling, resistivity data range, geoelectric section and coefficient of resistivity (CoR). These attributes possess their unique value evaluations of which are important in predicting groundwater potential as shown in Tables 2 and 3.

Table 2. Physical Attributes

Attributes	Values
Soil	Top soil, Lateritic, Fine, medium, weathered soil, sandy, coarse, gravely, and rocky
Geology	Sedimentary, Igneous, metamorphic
Geomorphology/ Land form	Gentle scope, steep slope, flat terrain, alluvium plain, flood plain, Riverine
Geological Structures	Fractures, Cracks, Aquifer, Regolitics
Rock Type	Quartzite, Granite, Schist, Gneissic, Laterite, Sandstone, Siltstone, clay, loamy
Water flow Pattern Map	Direction of flow presence of ground water.

Table 3. The Non-Physical attributes

Attributes	Values
Electrical Resistivity	Models, Graph
Resistivity Range	Data Range, Data Bound, sequence
Geoelectric section	Graphical table
Coefficient of Resistivity	Computation product, sum

The problem attributes of each case in our groundwater potential is made up of the following physical characteristics: geology, geomorphology/land form, soil, rock type, geological structures, water flow map). The non-physical problem attributes are electric resistivity, resistivity range, geoelectric section and coefficient of resistivity. The only solution attribute is the groundwater potential predicted as Low and Moderate or High yield. Case retrieval was done using K-Nearest Neighbours (with k=1) with cosine similarity measure (Oduntan, Adeyanju, Falohun, & Obe, 2018; Oduntan & Buoye, 2018). The retrieved similar solution was reused directly without any revision, as long as the similarity was greater than 0.7; else we assume that a similar solution could not be retrieved from the casebase. The threshold was determined empirically from experiments.

3.2 Software Design and Implementation

The system is composed of both hardware and software resources based on the simplified block diagram in Figure 2. Hardware resources such as Terrameter were used for data acquisition together with the Resist software for initial analysis. The CBR module was implemented using MATLAB with a graphical user interface for seamless interaction. Figure 4 shows the developed decision support system for predicting groundwater potential. The interface has sections for the casebase, input, processing parameters and output. The output (result) is displayed on the lower left corner of the interface. The lower right corner displays the summary of the nearest neighbour retrieved as most similar with the input the upper right corner. The middle (central) section displays the profile of existing cases in the casebase. The actual borehole yield analysis was used as ground truth to authenticate the developed system.

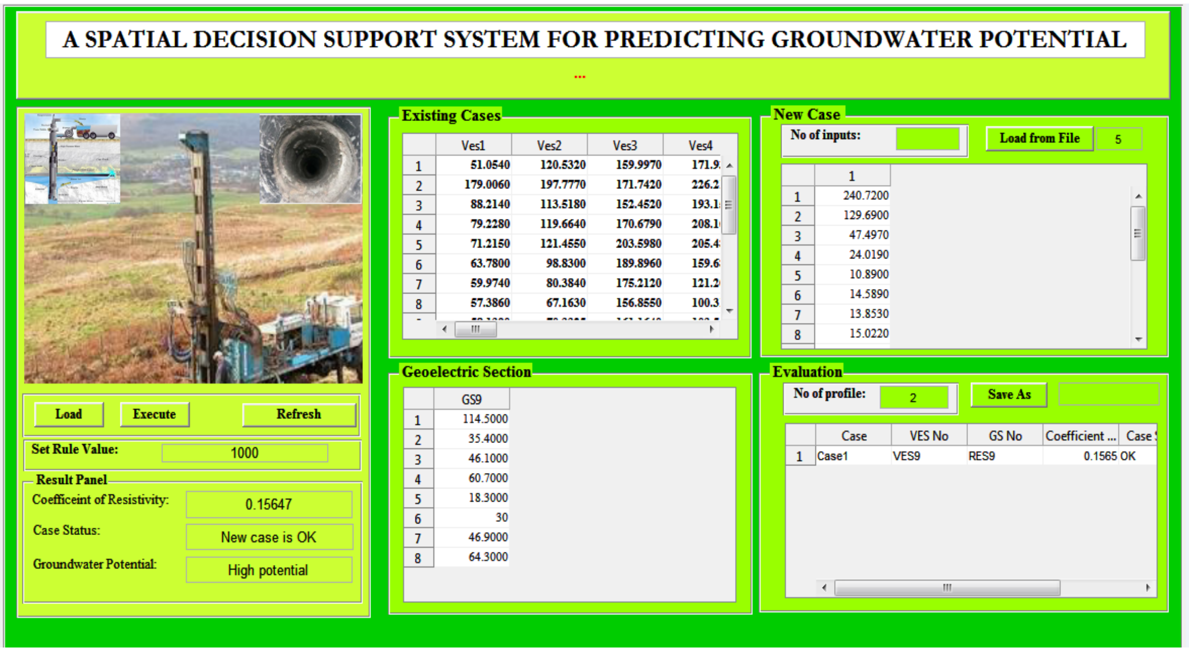

Fig. 4. Screen shot of the developed System Graphical User Interface

4. EVALUATION AND RESULTS

Our casebase consisted of only 15cases due the cost of drilling boreholes and renting the required equipment to acquire the necessary data for our groundwater prediction. Hence, we used a leave-one-out evaluation method for this work. Our experiments resulted in 12 out of 15 test cases being correctly predicted by our developed CBR system. Table 4 shows five (5) sample test cases with the vertical electricity survey (VES), electrical resistivity (RES) and coefficient of resistivity. The output is the Case status which can be compare with the ground truth to compute the evaluation accuracy. Overall, our system has 80% evaluation performance accuracy.

Table 4. Result for Ten tested profiles

Case	VES No	RES No	Coefficient of Resistivity	Case Status	Ground truth
Case1	VES19	RES19	0.43797	OK	Moderate potential
Case2	VES8	RES8	0.62279	OK	Moderate potential
Case5	VES9	RES9	0.15647	OK	High potential
Case8	No Ves	No GS	0	NOT OK	Poor potential
Case10	VES12	RES12	0.41609	OK	Moderate potential

5. CONCLUSION

The development of a case-based reasoning system for groundwater potential was done using parameters captured on the field in a geologic environment. These parameters were interpreted and analysed before being used as input to the CBR system. The results obtained shows that the CBR method can be used as a decision support system for experts to predict groundwater potential, once the geological and geophysical data are available. We intend to experiment with data from other parts of the country to further validate the CBR technique and investigate the effects of a three-way classification, instead of the two solution classes used in this study.

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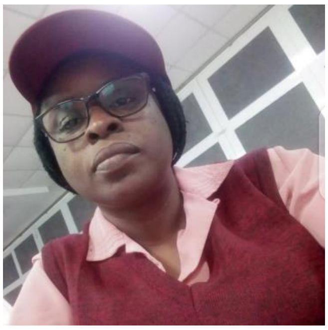

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