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Reliability of indigenous knowledge in monitoring and mapping groundwater fluctuations in Zimbabwe

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Abstract

The research was aimed at assessing the accuracy of indigenous knowledge data on groundwater fluctuations when compared to scientific measurements in order to ascertain if it can be used for practical groundwater management. The study was done at three sites in ward 28 of Zaka district in Zimbabwe. Firstly the study located local community individuals knowledgeable on groundwater issues in the area. Questionnaires were then used to extract semi statistical information on the patterns of seasonal groundwater fluctuations from the year 2004-2010. The data was then entered into SPSS to review trends and facilitate correlation analysis with actual groundwater data. Correlation analysis was done using the Spearman correlation coefficient to determine if the two variables in question were related to each other and the strength of their relationship. The results at all sites showed that the correlations between estimated groundwater levels from indigenous knowledge and actual recorded levels had correlation coefficients between 0.755 and 0.991 that were statistically significant. This means that estimation of groundwater fluctuations can be reliably made based on indigenous knowledge in the absence of hydrological monitoring and the data can be used for groundwater resources development and management.

Keywords: Indigenous knowledge, climate change, groundwater fluctuations, Zaka district, GRACE satellite.

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1. Introduction

Groundwater is a major source of drinking water across the world and plays a vital role in maintaining the ecological value of many areas (IPCC, 2007; UN/WWAP, 2006). With the projected climate change and related increases in duration and intensity of droughts, groundwater is projected to become even more critical in sustaining society and agriculture not only because it constitutes an important part of available freshwater on earth, but also because groundwater is relatively less sensitive than surface water to short term and seasonal climatic variations. Groundwater can therefore provide the means for quick community adaptation against the negative impacts of climate change (Chen et al., 2004; IPCC, 2007).

Groundwater fluctuation data provide a direct means of measuring the impacts of climate change to groundwater resources. Knowledge on groundwater fluctuations is also important in the management and regularization of the resource because it is shows its level of availability, vulnerability, accessibility and sustainability (Taylor and Alley, 2001). Groundwater levels are declining in many areas of the world though there is often lack sufficient data to assess the magnitude of this decline (Lightfoot et al., 2009). A critical problem associated with management of groundwater, especially in resource constrained countries is the low density of groundwater instrumentation networks that are both cost and management intensive. This becomes an impediment to informed management of groundwater (Krishnan et al., 2008; Lightfoot et al., 2009).

Were available existing monitoring networks established by scientific institutions and current management measures also fail to bring out in sufficient detail, information of the local setting, thereby hampering adaptive, context-specific and appropriate groundwater resources management. Global and conceptual pictures of groundwater are easily made, but localised pictures are less available (Sengupta, 1993; Krishnan et al., 2008; Lightfoot et al., 2009). Local knowledge can fill in the gap of lack of localised groundwater scenarios because it is perceptive, has greater spatial coverage and can be obtained at a relatively lower cost (Shah, 1993; Lightfoot et al., 2009; Jiang, 2003). Both scientific knowledge and traditional local knowledge have their own benefits and disadvantages and a fusion of both can achieve the best in terms of scale, tools used, spatial coverage, precision, repeatability, communication and purpose (Krishnan et al., 2008). Table 1 shows a comparison of scientific knowledge and local knowledge in groundwater management.

People maintaining personal or village wells are familiar with local groundwater conditions and can provide details where scientific data are absent. This is because people acquire intuitive knowledge that is essential for his work which is built over time from experience and differs from one profession to another depending on experience, interest and ability of deduction and abstraction. If such professions continue over generations, especially within families and communities as traditional occupations, knowledge gained gets passed by word of mouth and becomes part of common sense. It is no wonder that different authors have documented rich cases of knowledge of local hydrology in communities closely associated with agriculture (von Hayek, 1974; Rosin, 1993; CSE, 2001).

Due to limited groundwater monitoring networks, the Gravity Recovery and Climate Experiment (GRACE) satellites, can be used to fill these observational gaps. The GRACE satellites do not measure variations in groundwater level directly, but instead measure the Earth's gravitational field. The GRACE system consists of two chasing satellites. When the amount of gravitational pull rises, because of the presence of a certain mass of groundwater, the first GRACE satellite to fly over this mass senses and expenriences a slightly larger gravitational pull than before due to the additional mass of water, this the satellite accelerate. When the chasing satellite approaches the same mass of water it also accelerates and catches up with the leading satellite (Tapley et al., 2004). The differences in gravitational pull of places around the world will then be calibrated to denote groundwater fluctuations around its long term mean level over specific areas (Wahr et al., 2004; Tapley et al., 2004).

Table 1. Comparison of scientific knowledge and local knowledge

Characteristic	**Science**	**Local Knowledge**
Scale	Large scale, general, conceptual Aquifers	Smaller scale, specific, practical Can describe nature of local flow
Tool	Designed instruments, limited, focused, recorded. Rain gauge, Water level recorder, drill logs	Many undefined instruments, unfocussed observation, mostly unrecorded Different sensors, word of mouth, passing of information through generations
Spatial coverage	Time and space sparse, interrupted time-series Depends on monitoring network	Dense in space and time, long term Observations. Every individual is an observer
Precision	More precise, errors more objective and amendable Results from repeated measurements	Perceptive, individual, errors difficult to evaluate Every individual has different perception, possible bias
Repeatability	Repeatable measurements Can use same monitoring equipment at different places	Possibly poor repetition Cannot expect similar perception and experiences for same observation
Communication	Easy to translate and communicate Somewhat standardized terms, such as porosity	In local language and need to be interpreted
Purpose	Observations useful for scientific interpretation and modelling Measurements such as hydraulic conductivity	Observations of importance to daily life and water use How fast does water fill into a well?

Studies have conducted around the word to validate the GRACE computed groundwater changes with actual measurements from ground based monitoring wells and boreholes. These ground confirmation studies have been done in most environments of the world like the humid tropics like Brazil, monsoon regions like India and in semi arid areas with similar climatic trends as Zimbabwe (e.g. Australia and Central United States). All these researches confirm significant relationships between GRACE obtained groundwater changes and ground based well and borehole records, with discrepancies between the two data sets varying from 0.1-2.5cm (Syed et al., 2005; Yeh et al., 2006; Rodell et al., 2007). In this regard, we can conclude that when used to assess groundwater levels over Zimbabwe, GRACE Satellite data will still maintain a comparably reasonable accuracy (Chikodzi, 2013).

No research has been done in Zimbabwe as of now to determine the level of accuracy of indigenous knowledge in measuring and analysing groundwater fluctuations. The need for this research arises because of the lack of groundwater monitoring stations at local community level and importance of groundwater in these semi-arid areas to help communities cope with drought and climate change. An assessment needs to be done to measure the accuracy of oral data on groundwater fluctuations when compared to actual measurements in order to ascertain if it can be used for practical groundwater planning, monitoring and management therefore.

The research was aimed at assessing the accuracy level of local knowledge on groundwater fluctuations when compared to actual measurements on groundwater fluctuations in ward 28 of Zaka district in Zimbabwe. The research question that the paper sought to answer was if groundwater scenarios could be reliably constructed using indigenous knowledge in the absence of hydrological groundwater monitoring?

2. Materials and methods

2.1. Study area

The research was carried out in the Zaka district of Zimbabwe. The area falls under the administration of Zaka Rural District Council in Masvingo province. The district is situated in the south eastern parts of Zimbabwe with an area of 3,125.95 km^2 and a population of 181,106 people.

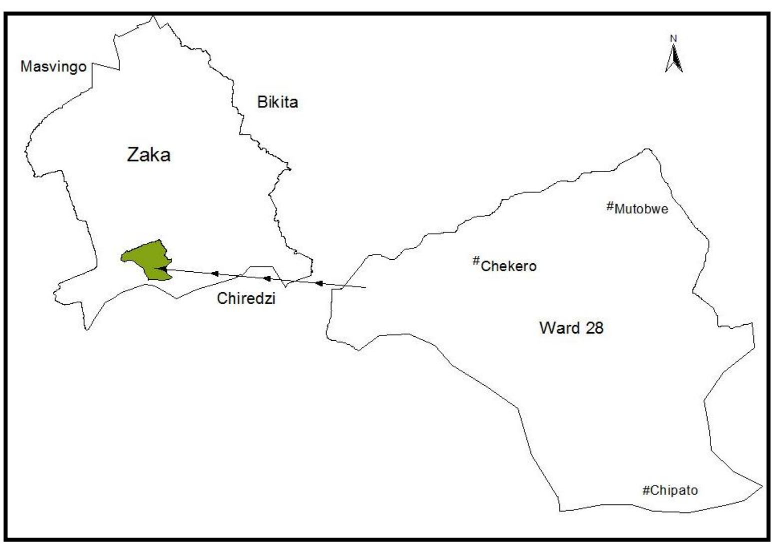

Figure 1. Study area, Ward 28 Zaka District

Specifically the study was executed at three sites in ward 28 of the district which are Chekero, Mutobwe and Chipato villages. The ward has got a population of 3000 males and 3600 females (Government of Zimbabwe, 2012) and according to the PASS Report (2003), the ward has high incidences of poverty ranging from 54% -78% and most of the households are female headed. Figure 1 shows the study area of the research.

2.2. Materials

The study was carried out using the following materials:-

- Quantitative questionnaire
- Gravity Recovery and Climate Experiment (GRACE) Satellite data on groundwater fluctuations.
- Statistical Package for Social Scientist (SPSS).
- ILWIS GIS
- Excel statistics

2.3. Method

A multi-methodology design was used in the study to obtain and triangulate data from oral sources. The first part of the study involved locating local community individuals knowledgeable on groundwater issues. Local well diggers, borehole repair technicians, groundwater diviners and people who run small scale irrigation schemes based on deep wells and wetlands were deemed to be the best candidates. Amongst these, not all were able to demonstrate the required level of perceptiveness with respect to groundwater level fluctuations. Therefore, an initial scanning of respondents was necessary in order to avoid spurious information.

The next stage of the research involved extracting semi statistical information on the patterns of seasonal groundwater fluctuations from the year 2004-2010. The respondents were then tasked to respond to the questionnaire schedule with regards to their knowledge of local depth to the groundwater level for each season from 2004-2012. Table 2 shows rank scores used to estimate groundwater fluctuations.

Table 2. Rank scores used to estimate depth to groundwater

Depth of groundwater(M)	Score
Less than 1	1
1-2	2
2-4	3
4-6	4
6-10	5
Over 10	6

This was done three times in a season starting with the onset of the rainfall season in November, to the middle of the rainfall season in January and finally the middle of the dry season in September. A total of 30 questionnaires were administered in the study area. The data was then entered and coded in SPSS in order to review trends and facilitate correlation analysis with actual groundwater data for the same period.

The geo-referenced GRACE satellite data covering the whole world were first subsetted to obtain the point data of groundwater fluctuations of the study area (Figure 1). The point data were then saved as delimited text tables, for further processing in ILWIS GIS.

The tables were first imported to ILWIS GIS where they were then converted into point maps showing the distribution levels of groundwater over the study area.The point map was then interpolated using the moving average function in order to obtain a map showing a continous spatial variations of groundwater levels for each month. The moving average function assigns to pixels weighted averaged point values using the inverse distance to an output pixel in order to ensure that points close to an output pixel obtain larger weights than points which are further away (ITC, 2005).

The resulting raster maps were then combined into a maplist that showed the monthly trends and patterns of groundwater fluctuations from 2004-2010 about their long term mean level. The groundwater scenarios of each respective site were then extracted using the maplist graph of each of the villages. The time series data were then exported to SPSS, a statistical package and Microsoft excel for further analysis.

The questionnaire and actual groundwater data for the area were first subjected to normality tests using the Kolmogorov-Smirnov test in SPSS exploratory data analysis (EDA) in order to evaluate how well the data satisfies assumptions of parametric or non-parametric statistical analysis methods. Unless the assumption of normal distribution for parametric statistics is met, it is generally advisable to use nonparametric tests (Lettenmaier, 1976; Hirsch et al., 1993). Since the data was not normally distributed, non-parametric statistical methods were used in this study.

Finally correlation analysis was done in order to determine if the two variables in question (oral data from questionnaires and actual groundwater fluctuations) are related to each other and the strength of their relationships. Spearman correlation coefficient (rho) was used because it is more robust when used to analyse non parametric data and also because the data is monotonic. It assesses how well variables or rank orders are related. This was done is SPSS and the correlations were tested for statistical significance ($p=0.05$) in order to assess whether observations reflected a true pattern or just occurred by chance.

3. Results

Results from the Spearman's rho correlation analysis run for the Chipato village site showed strong a positive correlation coefficient of 0.775 between the measured groundwater values and those estimated from indigenous knowledge. These correlations were also determined to be significantly correlated ($\rho = 0.041$, $\alpha = 0.05$). Figure 2 shows the distribution and relationship between estimated and measured groundwater fluctuations at Chipato village. Both the measured and estimated values show a declining groundwater trend as shown by the negative trend line equation. The relationship between the two set of values is also shown to be significant as shown by the r^2 value which is 0.5621.

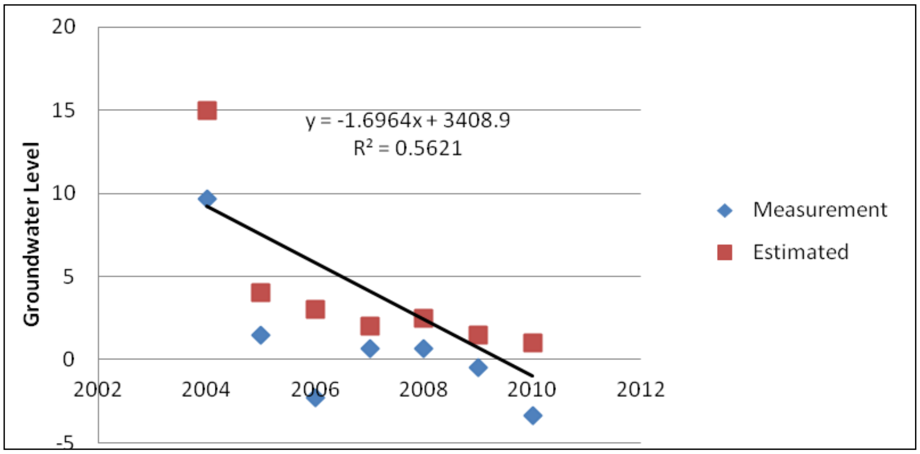

Figure 2. Relationship between estimated and measured groundwater fluctuations at Chipato village

At Mutobwe village, the results of the Spearman's rho correlation analysis was stronger than at Chipato village with a positive correlation coefficient of 0.964 between the measured groundwater fluctuations and those estimated from indigenous knowledge. These correlations were also determined to be significantly correlated at the 0.01 significance level ($\rho = 0.000$, $\alpha = 0.01$). Figure 3 shows the relationship and distribution between estimated and measured groundwater fluctuations at Mutobwe village. The r^2 value of 0.5014 confirms that the relationship is significant and also like the Chipato scenario, groundwater at this site is also in a state of decline.

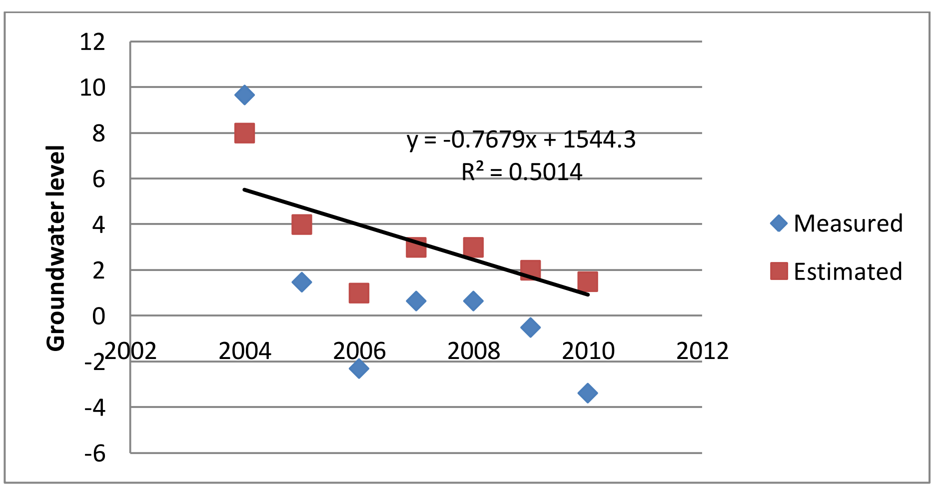

Figure 3. Relationship between estimated and measured groundwater fluctuations at Mutobwe village

At Chekero village, the results of the Spearman's rho correlation analysis were the strongest compared to two other sites. The correlation coefficient was 0 .991 between the measured groundwater fluctuations and those estimated from indigenous knowledge. These correlations were determined to be significant at the 0.01 significance level ($\rho = 0.000$, $\alpha = 0.01$). Figure 4 shows the groundwater scenarios of both estimated and measured fluctuations at Chekero village. The figure also confirms the relationships to be the strongest by the highest r^2 (0.6225) value than all the other sites.

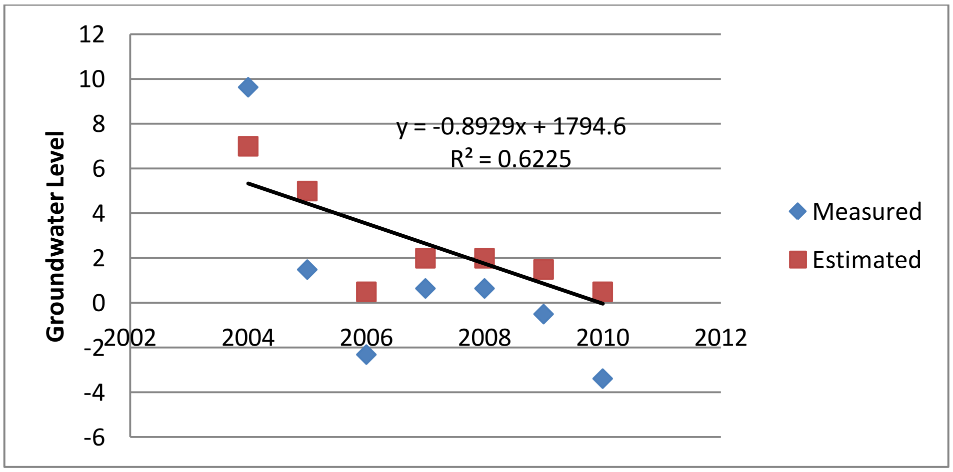

Figure 4. Relationship between estimated and measured groundwater fluctuations at Chekero village

4. Discussion

Both measured groundwater fluctuations and data from indigenous knowledge systems agree that there is a declining trend in groundwater levels on the study area. The level of agreement between these two data sources has been shown to be significant hence with just the estimated values of groundwater fluctuations from indigenous data, if is possible to predict the possible actual measurement. Lightfoot et al. (2009) did a similar research in central Africa and concluded that in all cases they looked at, the correlation between well water depths was at least 0.9 and the regression coefficient was between 0.797 and 0.867, indicating that estimation of depths to the water table can be reliably made based on oral reporting from traditional wells in the absence of hydrological well monitoring.

In another research by Patrick, (2002) in Kenya and Jordan, two approaches to analyzing and interpreting satellite imagery in order to find suitable areas for water harvesting were compared. Results of this study indicated that visual interpretation by local land users was more fruitful that computer-based analyses of spectral data by an external researcher thereby showing that additions of indigenous technical knowledge and expanded applications of modern science will bring improvements to the practice of conjunctive water use.

However, some scholars like Cruikshank (1998) and Kublu et al. (1999) warn against comparing of local indigenous wisdom with scientific data in order to assess it's how accurate it can be. This is because the accuracy and value of indigenous knowledge is mainly within the community in which it was developed. Its accuracy therefore depends on use and application of the knowledge, not external evaluation. By trying to assess accuracy from an external view, a concern arises because information is being applied and evaluated for purposes that may not be the same from which it was originally created (Feldman and Norton, 1995; Cruikshank, 1998; Kublu et al., 1999).

There are also many occasions in which indigenous knowledge exceeds scientific understanding in advancement and has been the best source of knowledge for scientists to make significant progress in their studies. This is especially applicable in remote parts of the world, where scientific inquiry is a relatively recent and researchers depend on the knowledge and skills local guides (Freeman, 1992; Krupnik and Jolly, 2002).

However, incorporating indigenous knowledge into water resources management should not be done at the expense of scientific knowledge. Indigenous knowledge should complement, rather than compete with global knowledge systems. Scientific knowledge is conceptual, focused, sparse, potentially unbiased, repeatable and communicable; local knowledge is specific to the observation, unfocused, dense, possibly biased, generally non repeatable and relatively difficult to communicate.

5. Conclusion

The research question that this paper sought to answer was if groundwater levels could be reliably estimated by oral reporting from traditional wells in the absence of hydrological groundwater monitoring? From our study, it has been possible to answer this question, well diggers, borehole repair technicians, groundwater diviners, people who run small scale irrigation schemes based on deep wells and wetlands do possess a good amount of information on local groundwater fluctuations. The indigenous knowledge that these people have could be compared and combined with science-based knowledge and thereby verifying the correctness of the local knowledge.

This means that the knowledge that these people have can be used for practical groundwater management and planning. These people by virtue of their in depth knowledge of local groundwater scenarios must be involved in water development projects planned in their area as part of community participation in development projects in their area and can provide invaluable information to complement the scientific geo-tech data.

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