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Rural Water Supply in the 21st Century: Myths of the Past, Visions for the Future

Topic: *Promising ways of dealing with the emerging challenges*

Long Paper

Title: Factors affecting costs of groundwater development in Sub-Saharan Africa

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Abstract

Greater use of groundwater in Sub-Saharan Africa is a pre-requisite for improved human welfare, and achievement of the Millennium Development Goals. However, the costs associated with groundwater development are poorly defined. Also, at the macro-scale, little attention is given to indicators which may influence groundwater development in Sub-Saharan Africa. This study initially identifies the costs of groundwater drilling in eleven Sub-Saharan African countries. A cross-country analysis between representative development indicators and the groundwater drilling costs is used to identify distinguishing features. The results indicate that mobilization and demobilization costs, together with pumping test costs most significantly affect the total costs of groundwater drilling. Further, demographic, land, water and health related parameters may influence groundwater development. Better attention to the individual cost factors and to the examined indicators could help to design more coherent groundwater policies in Sub-Saharan Africa.

1. Introduction

In recent years, driven by the need to improve water services and to ensure food security in Sub-Saharan Africa, there have been major efforts to enhance the level of groundwater development. Access to drilling technologies that are technically and economically suitable is the foundation that enables such development to occur. The economics associated with groundwater drilling have been investigated through various theoretical and experimental studies that focus on the various costs of drilling and equipping shallow wells and deeper boreholes (Ball 2004; Danert 2009; Danert et al, 2010a). However, these studies are often concentrated on specific cost-related factors that are derived from fragmented data sources, often with limited geographical coverage.

Rarely has the total drilling value been systematically disaggregated into the component-wise drilling costs and compared at a cross-country level. Also, another aspect hardly addressed in the literature, is the potential linkage of crucial development indicators with drilling (Kemper et al, 2003). Very little attention is given to socio-economic and biophysical indicators which potentially affect the drilling expenditures over a time period.

The current analysis initially attempts to categorize in a systematic manner all the relevant fixed and variable costs pertaining to groundwater development in selected countries of Sub-Saharan Africa. Further, a cross-country correlation analysis signifies the potential significant effects of individual cost factors to the total groundwater costs. In turn, selected macro-economic, demographic, institutional, land and water related indicators are examined to gauge their potential influence on drilling development over the last twenty years.

The study area is focused on specific Sub-Saharan African countries which were selected within the

context of a groundwater research project lead by the International Water Management Institute (IWMI, 2011), i.e. Burkina Faso, Mali, Ghana, Kenya, Ethiopia, Mozambique, Niger, Nigeria, Tanzania, Uganda, and Zambia. The data collection was conducted through published reports and grey literature related to the selected countries.

It should be noted that the study focuses only on machine drilling conducted in the selected countries. Whilst it is acknowledged that manual and low-depth drilling occurs to varying degrees in many of the aforementioned countries, and strong encouragement to such practices is currently underway (Van der Wal et al, 2005; Van Herwijnen, 2005ab; Strand, 2010; Van der Wal,2010; Vuik, 2010; Vuik et al, 2010), such practices are not included in the analysis.

2. Description of the Case Study – Approach or technology

2.1. Value allocation analysis

It is widely acknowledged that a high variability in the economic assessment of groundwater value is apparent due to the broad social, institutional and hydrogeological characteristics met in each country (Strand, 2010). The study initially attempts to capture the most relevant costs along with some auxiliary data related to technical parameters for a better comprehension of the economic value of drilling, testing and equipping boreholes.

The absence of up-to-date data was a major barrier in mapping the relevant cost factors as occurred for instance in the case of Burkina Faso, Niger and Mali (Duffau and Ouedraogo, 2009; Suton, 2010; Obuobie and Barry, 2011ab) Also, the assessment of the economic parameters in each country was often unclear because of the different cost categorization and the individual terminology used in each country as indicatively occurred in the case of Ethiopia (Ayenew et al, 2005).

Further, a high discrepancy in the information provided for the same countries or even the same regions in one country was frequently noted, which decreased the data reliability. For instance, in the case of Ethiopia and Nigeria, some reports conducted by regional authorities presented more intensive and successful drilling activities than demonstrated by the central government (Ayenew et al, 2005; Adelana, 2010).

The analysis attempted to capture each individual cost factor by indicating the ranging frame of these estimations. The costs are partitioned as either fixed or variable costs, where the variable costs are associated with drilling classified on a per meter basis. Surcharges due to previous failed drilling attempts are also estimated. The fixed costs factors encompass the siting costs (which incorporates the cost of supervision), the mobilization/demobilisation and water quality testing costs. Optional fixed cost categories for aquifer pump testing and pump purchasing and installation costs are used where applicable. The total drilling expenditures are the sum of the aggregated variable and fixed costs, plus the added values from taxation and depreciation practices.

It is well perceived that the added values from taxation and depreciation costs are not always assessed in groundwater related studies. Even in cases where an assessment of these indirect costs is applied, the calculation is frequently obscure (Strand, 2010). However, for the conducting of an even cross-country assessment we presume that the examined studies have considered the indirect cost factors (tax and depreciation) unless clearly stated otherwise. These indirect costs are mainly enclosed in siting, drilling and mobilisation/demobilization expenses (Foster et al,2009; Danert et al, 2010b).

Further, it is well acknowledged that in some studies, the drilling expenditures also encompass the total or a part of the net revenues which actually mirror the net profits of a drilling company (Tsur, 2005). However, in most of the cases, the profits are added on the top of the total expenditures and could highly range from 5%-50% of the entire costs, depending on the hydro-geological and socio-political settings (Harvey, 2009). Since we could not acquire sufficient data about the average net revenues earned from groundwater machine drilling in the eleven countries, the analysis was only focused on the groundwater cost factors.

A set of auxiliary technical data encompasses the design parameters, the well yield and the materials used to complete the borehole. . An explanatory description of the cost related factors and the technical data used in the analysis, is presented in Table 1.

Table 1. Cost related and technical factors

Fixed Costs ($/drill)
Siting costs: The costs required for hydrological tests before drilling
Mob./Demob.costs : The costs of moving the construction units to and out of the construction site
Water Qlt. Costs : Costs for testing water quality
Variable Costs ($/meter)
Drilling costs : Cost of drilling including site clearing and preparation
Mtr.&Cas.Costs : The material costs for drilling, the installation costs of casing and the sand pack gravel costs
Surch. of failed drill.: Costs of unsuccessful drillings in case they are not included in the agreement
Pump related Costs (Optional) ($/drill)
Pump Purch. costs: The costs of pump purchasing including gear box, fittings, meter, installation, motor protection costs
Pump Purchasing Costs Var.: The range of cost purchasing in the examined pumps
Pump Testing costs : Costs of pump testing for the functionality of drilling
Aggregated Cost Factors
Aver.var. costs ($/meter): Average variable costs of groundwater drilling process per meter of drilling
Fixed Costs ($/drill)-NP: The total fixed costs of groundwater drilling process without including the relevant pumping related costs
Fixed Costs ($/drill)-YP: The total fixed costs of groundwater drilling process by including the relevant pumping related costs
Aver. Fixed Costs ($/meter)-NP: The average fixed costs of groundwater drilling process per meter of drilling without including the relevant pumping related costs
Aver. Fixed Costs ($/meter)- YP: The average fixed costs of groundwater drilling process per meter of drilling by including the relevant pumping related costs
Aver.+Fixed cost incl. fail –NP ($/meter) = The sum of the average and fixed costs per meter by including the surcharge of failed attempts without however considering the pump related costs
Aver.+Fixed cost incl. fail –YP ($/meter) = The sum of the average and fixed costs per meter by including the surcharge of failed attempts and considering the pump related costs
Costs variability (%) : Variability of costs due to technical and institutional settings
TC_Meters ($/drill) : Total Costs per drill considering the average depth level
Technical Parameters
Depth (metres/drill) : The weighted average depth
Depth Range (%): The range of depth within the wells
Diam.(inches/drill): The weighted average diameter of well
Diam. Range (%):The range of diameter within the wells
Well yield(m3/day) : The weighted average yield
Well Yield Range (%) : The range of well yield
Constr. Mat. -uPVC(m/drill) : The construction with uPVC inside the well
Contsr. Mat. Steel (m/drill) : The construction with steel screening inside the well
Eng.type and pump model: The type and model of the pump

The data required for the capturing of the cost related factors was given from the following sources:

1. Eleven National Groundwater reports conducted in each country for the project “Groundwater in Sub-Saharan Africa: Implications for food security and livelihoods” in the year 2011, funded by Rockefeller Foundation. The reports provided an integrated profile of hydrological and economic groundwater aspects in each county

2. More than 25 up-to-date reports published by the Rural Water Supply Network (RWSN) for the examined countries, which offered concise data about the individual cost factors pertaining to variable and fixed costs.

3. Individual research papers focused mainly on a country specific context.

It should be mentioned however that our study could not identify the exact number of wells related to the cost analysis since the data captured from the above sources mostly comes from governmental organizations, associations or professional drillers where an approximate number of wells is indicated. We however manage to identify whenever possible the number and type of companies and the drilling features presented in a country as below (Table 2) :

Table 2. Drilling activities in a country scale

Drilling Companies (Nos.)			Drilling Capacity (mm/machine)		Construction methods (Nos.)			
State	Private	NGOs	Lightweight	Heavyweight	DTH	Percussion	Rotary	Manual

The data analysis initially examines the aggregated fixed and variable cost categories in a cross country level along with the average drilling depth while also the cost ranging within each country is underlined. For a better understanding of the association between the total groundwater costs and the individual costs factors, a correlation analysis is conducted. The findings identify the cost categories that appear to mostly influence the sum of the groundwater costs in the eleven countries.

2.2 The effects of development indicators to groundwater costs

The relationship between key development indicators and groundwater policies has begun to be explored in the literature (Kaufmann and Kraay, 2007; Björkman and Svensson, 2007). However, in most cases, only very few and specific development indicators are adopted for the explanation of the groundwater cost trends within a time period (Aidt, 2009). A systematic review concerning the potential effects of representative development indicators on the drilling costs over a sufficiently long time horizon is still missing.

To this purpose, this study employs development indicators pertaining to the economic, demographic, land, water and health related fields for the investigation of potential effects in groundwater cost trends. The indicators are regressed against the drilling costs in the eleven countries on a yearly basis over a time period of 19 years (1990-2008). The total groundwater costs are measured per meter of drilling for a better clarification of the potential cause-effect relation between the selected indicators and the groundwater expenditures.

The data for the development indicators was originated from the following sources :

1. Food Agricultural Organization (FAO). The Aquastat data base of FAO offered reliable information on land and water related indicators for the last 25 years.
2. World Bank, The book of "Africa: Development Indicators" offered all the economic and demographic data as well as some water and economic indices in a consistent manner for 30 years time horizon.

It should be mentioned however, that not all the indicators were available on a yearly basis for all of the countries. In cases where missing values hindered the data analysis, the indicator was either discarded or replaced with interpolated values (Osborne, 2002). Interpolated values where also used for the total groundwater cost data because in most cases a yearly cost assessment was unavailable.

It is also acknowledged that the time series regression could frequently violate the assumption of uncorrelated errors (Garson, 2011) by presenting high significant levels and goodness-of-fit statistics. This has been considered in our analysis by initially introducing cross-correlation techniques for the identification of the leading indicators to be affecting the groundwater costs.

Then, its transformation in times-series variables was conducted while the lags were identified.

The development indicators to be selected for the analysis are presented in table 3.

Table 3. Development Indicators

Types	Development Indicators
Economic	GDP per capita, PPP annual growth (%)
	Real agricultural GDP per capita growth rate (%)
	Inflation, consumer price index (% change)
	Household final consumption expenditure per capita growth (annual %)
	Income share held by highest 10%-20%
	Income share held by lowest 10%-20%
	Poverty headcount ratio at $2 a day (PPP) (% of population)
Demographic	Population total (nos.)
	Rural Population (% of total population)
	Rural population density (rural population per sq. km of arable land)
Land and Infrastructure	Agricultural land (% of land area
	Arable land (% of land area)
	Access to an all-season road (% of rural population)
	Road to total land density (road km/1000 sq. km of land area)
Water Status and Use	Total water withdrawal per capita (m3/inhab/yr)
	Agricultural water withdrawal as % of total water withdrawal (%)
	Total agricultural water managed area (1000 ha)
	Area equipped for irrigation: total (1000 ha)
	Water productivity, total (per cubic meter of total freshwater withdrawal)
	Improved water source, rural (% of rural population with access)
	Total water withdrawal per capita (m3/inhab/yr)
Health related	Reported clinical malaria cases (total)
	Malaria mortality (annual, per 100,000 population)

3. Main results and lessons learnt

3.1 Groundwater cost allocation and correlation analysis

An initial description of the aggregated costs factors with regard to the average drilling depth is given in the country level. The total groundwater costs sum up the fixed costs which are presented per drilling basis and the variable with the failed surcharge costs which are assessed on per meter basis. As exhibited in table 4, the total groundwater costs, excluding the pump-related costs, increase as the average drilling depth is getting higher. A similar situation occurs in the case where the pump-related expenditures (pumping test and pump purchasing) are contemplated. Noticeable exceptions occur in the case of Niger and Mozambique, where although the depth level is considerably low (40m-50m), the total expenditures are disproportionately high. Also for the case of Mali (100 m average depth), the cost appears to be disproportionately low. Further, the motorized pumps (MP) appear to distinctively increase the total groundwater costs in comparison to hand pump (HP) installations.

Table 4. Drilling depth and groundwater cost allocation

Countries	A.D(m/drill)	D.R. (%)	TC_NP ($/drill)	TC_YP ($/drill)	P.T.	FC_NP ($/drill)	FC_YP ($/drill)	VC ($/m)	F.DR.S. ($/m)	C.R.(%)	R.YR.	S
Burkina Faso	40	40	5,860	8,760	HP	895	3,795	99	25	50	2005	NI
Ghana	43	35	3,619	5,343	HP	1,335	3,058	38	15	40	2006	N RV
Mozambique	43	45	13,166	14,946	HP	2,553	4,333	110	27	40	2009	NI
Niger	50	80	11,904	12,194	HP	519	809	175	53	90	2004	
Nigeria	50	80	4,741	6,241	HP	1,463	2,963	41	25	90	2008	N RV
Zambia	60	45	6,028	6,028	HP	1,350	3,112	100	32	50	2008	
Uganda	65	45	7,475	10,476	MP	539	3,539	107	45	30	2009	RV
Tanzania	73	35	13,540	16,540	MP	4,531	7,531	98	25	45	2007	NR
Kenya	80	80	15,905	20,906	MP	4,300	9,300	97	48	70	2006	N RV
Ethiopia	100	80	23,267	23,268	MP	6,199	6,199	142	28	90	2008	N F

Mali	100	60	15,697	15,697	MP	6,440	6,440	74	19	50	2010	NR

Note: A.D. = Average depth, D.R. (%)= Depth Range, TC_NP= Total costs for a drilling when no pump is installed, TC_YP= Total costs for a drilling when pump is installed, P.T.= Pump Type, MP= Motorized Pump, HP= Hand pump, FC_NP= Fixed costs for a drilling when no pump is installed, FC_YP= Fixed costs for a drilling when pump is installed, VC= Variable costs, F.DR.S. = Additional costs for failed drilling attempt, R.YR= Reference Year, SRC= Origin of the source, NR= National Report, RW= RWSN Report, IR= Individual country related report

The fixed groundwater costs are positively correlated with the drilled depth level, although less distinctively than the total groundwater costs, with the exception of Niger and Uganda where rather low fixed costs are observed. The situation is different for Uganda though, when the motor pump expenditures are included in the fixed costs. However, for the case of Niger the situation remains almost unchanged because the widespread use of low-cost hand pumps, rather than motorised pumps seems to keep fixed costs to relatively low levels.

The trend between the depth level and the costs factors is absent in the case of variable costs and a random fluctuation is noticed instead. Noteworthy are the distinctively low variable costs incurred in the case of Ghana whilst contrastingly high variable costs occur in Niger and Ethiopia. The variable costs are further augmented for Niger when the expenditures from failed drilling attempts are added while a sizeable increase is also noticed in the case of Kenya and Uganda.

It is also noteworthy that the most expensive drills which are presented in Ethiopia, Kenya and Niger, present an equally high cost range. This is mainly due to the greater depth at which aquifers are found in the three countries, which in turn exacerbates the mobilization/demobilization costs and the need for drillers to get equipped with various and costly rigs. Also, the poor contract packaging noticed in these three countries, does not help the drillers to undertake sufficient number of well and further augments the total costs as indicatively occurs in Uganda and Zambia (Sloots, 2010; Nonde, 2011).

A similar situation arises in Nigeria although a lower cost is achieved which is possibly due to the relative technological and institutional progress met in the country (Adelana, 2010) in comparison to Niger, Ethiopia and Kenya.

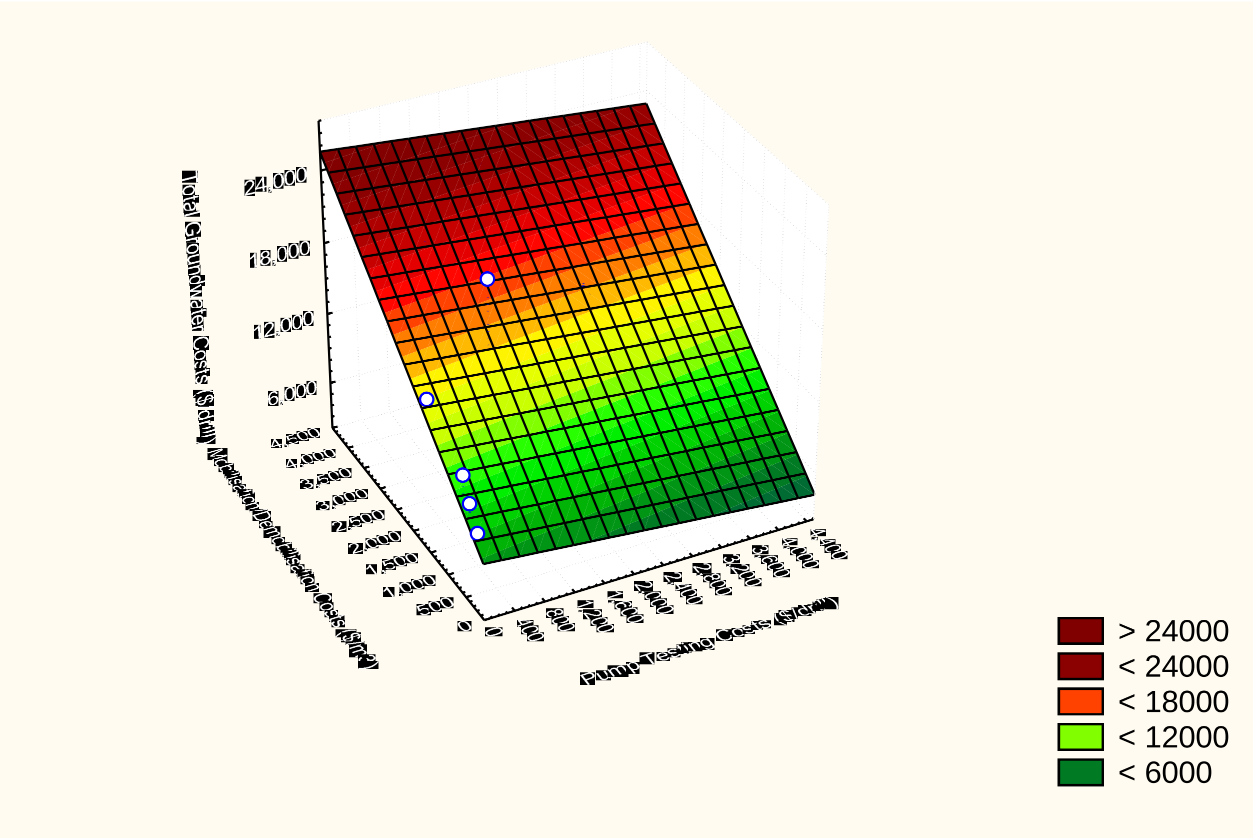
The correlation analysis between the individual variable and fixed cost factors and the total groundwater costs reveals that only the mobilisation/demobilisation and to a lesser extent the aquifer pump testing costs seem to be positively associated with the total groundwater expenditures to a level that is significant (Table 5).

Table 5. Correlation of individual cost factors with total groundwater expenditures

Stat.	**Fixed Costs ($/drill)**			
	Sitting Costs	**Water Quality**	**Pump Purchasing**	**Pump Test**
Corr.	.2454	.2072	.0308	.6102
Sign.	P=.467	p=.541	p=.928	p=.036
	Variable Costs ($/meter)			
Stat.	**Mob/Demobilisation**	**Drilling**	**Material and Installation**	**Failed Surcharge**
Corr.	.8222	.3838	.1993	.2383
Sign.	p=.002	p=.244	p=.557	p=.480

The diagrammatic association of the mobilization/demobilisation and pumping factors with the groundwater expenditures is given in Figure 1. As presented, there is a high positive correlation between the two cost individual cost factors which is reflected in a ration of about 2:1 among the mobilization/demobilization and pumping costs. If for instance, USD 1,000$ of pumping costs expenses were incurred during drilling, a corresponding amount of approximately USD 2,000$ of mobilization/demobilization costs is additionally required. This relation is also underpinned by recent studies which indicate that the exacerbating mobilisation/demobilisation costs mainly occurring in remote areas are usually coupled with costly pumping tests due to the rough hydrogeological texture met in these areas (Foster et al, 2011).

Figure 1. Schematic correlation of pump and mobilization/demobilisation costs



The drilling activities in the examined countries are unfortunately poorly demonstrated in our analysis due to the insufficient published data related to this issue. It should be however mentioned that the amount of the drilling companies operating in a country was cautiously examined. It is not a few cases where fake drilling agencies are established just for the participation in specific tenders and then they assign an actual drilling company to execute the contract after having received a commission. In this study we tried to identify and discard such companies from our assessment. The results underscore the blossoming of private drilling companies in some eastern and western African countries which represent active entrepreneurs. Data for lightweight and heavyweight rigs is given only for very few countries while when investigating the rig types it appears that the down-to-the-hole (DTH) and the percussion ones are more prevalent.

However, the status of the drilling machinery is mostly aged with many malfunctions, rare and expensive rare parts and inappropriate drilling rigs to the responding hydrological features.

Table 6. Drilling activities in a country scale in the years 2005-2008

Countries	Drilling Companies (Nos.)			Drilling Capacity (mm/machine)		Construction methods (Nos.)				Status m.
	State	Private	NGOs	Lightw. (100-300)	Heavyw. (>300)	DTH	Perc.	Rotary	Manual	
Burkina Faso	-	40	-	-	-	-	-	-	-	O
Ghana	1	20	5	26	-	30	-	-	-	R.O
Mozambique	10	21	5	-	-	-	-	-	-	O
Niger	-	-	-	-	-	-	-	-	50	V.O
Nigeria	-	100	-	-	-	-	-	-	-	R.N
Zambia	1	11	7	-	-	10	25	14	-	O
Uganda	-	42	3	67	10	-	-	-	-	R.O
Tanzania	4	2	10	10	3	8	-	-	4	O
Kenya	-	-	-	-	-	-	-	-	-	R.N
Ethiopia	10	25	8	17	26	77	18	5	2	V.O
Mali	-	-	-	-	-	-	-	-	-	O

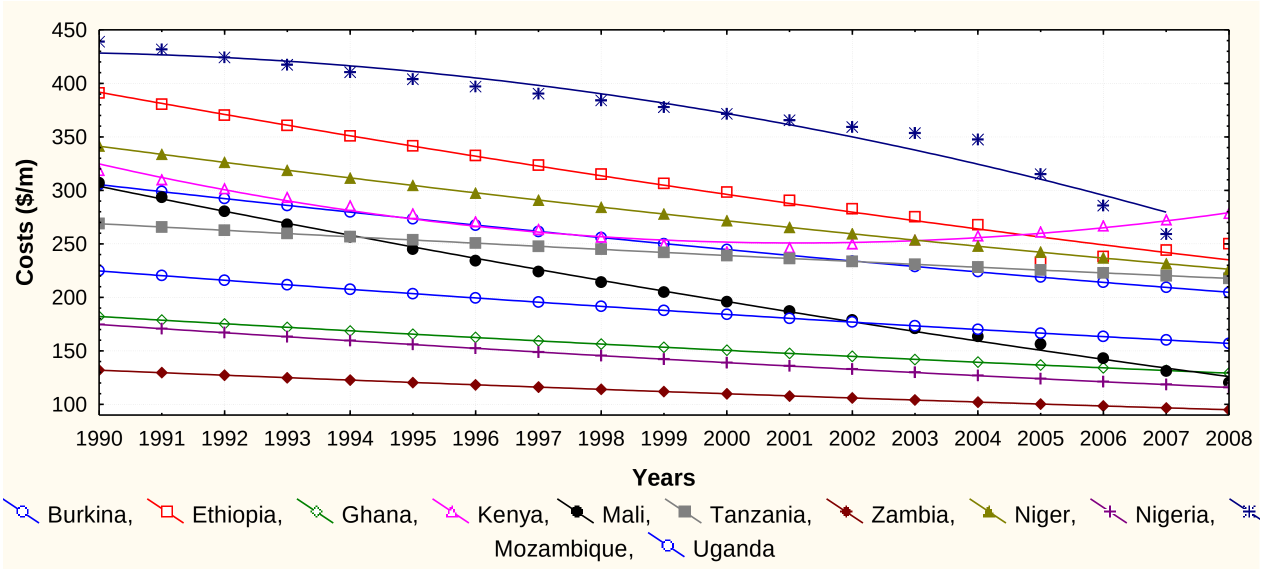
Note : Lightw.= Lightweight, Heavw.= Heavyweight, Perc. = Percussion, V.O. = Very Old, O. = Old, R.O= Relatively Old, R.N= Relatively New, N.=New, Status m.= Status machine

Effects of development indicators to groundwater costs

By initially assessing the total groundwater costs per meter for all the eleven countries a general downward trend is exhibited over the last 20 years with the exception of Kenya as presented in Figure 2. A more distinctive downward slope is apparent in the case of Mali while in Ethiopia an interim upward trend seems to be significantly decreased after the year 2000.

Although it has been already mentioned that some of these cost values are inserted with interpolation analysis which may bias the results, it is well perceived displayed that the groundwater expenditures are slowly decreased in the eleven examined countries. It is noted that the groundwater costs which encompass the pump related expenses are examined since in almost all the eleven countries a motorized or hand pump is employed for water fetching from machine drilling wells.

Figure 2. Average groundwater cost per meter of the eleven countries for the period 1990-2008



By assessing the effects of development indicators to groundwater costs in the time-series analysis, it appears that the economic indicators present a slight effect only in the case of Uganda. In the case of demographic indicators however, both the eastern and western African countries seem to be probably affected by population dynamics. In effect, for the eastern countries of Kenya and Ethiopia the steady total population increase seems to correlate with a slow decrease in well costs which is well explained by the model to a significant level (for Ethiopia R^2 = .96, β = .-98, p=.000 and for Kenya R^2 = .95, β = .-1.03, p=.000). Also, the general decrease of rural population as a percentage of the total population in the western African countries of Nigeria and Ghana seems to have parallels with a gradual groundwater cost reduction. As it has been also suggested by Titus et al (2009) the increasing water consumption in urban centres encourages more drillings across smaller territorial areas thereby gradually lowering the groundwater costs .

In the case of land related indicators combined with water use, it appears that the western African countries are may affected along with the additional case of Mozambique. Particularly, the increase of agricultural water managed areas in the case of Burkina Faso may present a moderate influence to the groundwater cost decrease (R^2= .90, β =-.320, p=.006). A similar situation seems to occur for the case of the area equipped for irrigation in Nigeria and full control irrigation in Mozambique. (Nigeria R^2= .88, β = -.074, p=.000 and Mozambique R^2= .93, β = .-541, p=.000).

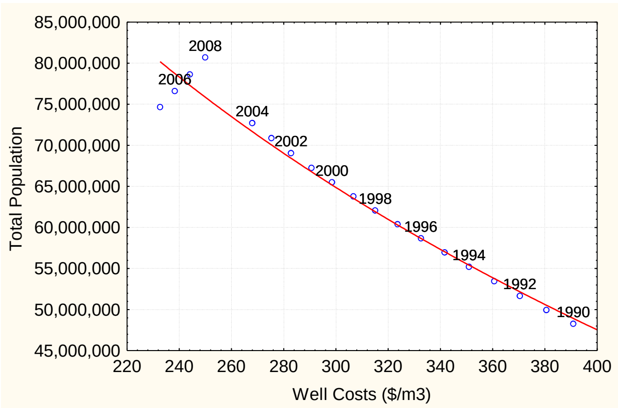
In the case of the water related indicators it seems a small but distinctive increase of water

withdrawal per capita in Kenya, may positively affect the groundwater costs falling (R^2= .93, β = 1.92, p=.000). The increased percentage of improved water resources per annum may get better linked with the reduced groundwater cost mainly for Tanzania and secondly for Ghana (Tanzania R^2= .93, β = -1.08, p=.000 and Ghana R^2= .91, β = .-301, p=.002).

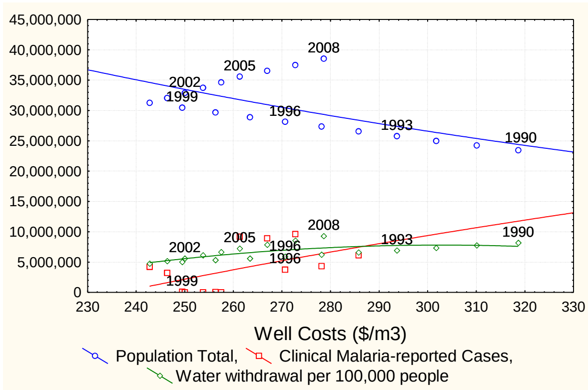
For the case of health related indicators an influence of the clinical malaria indicator maybe noticed in the eastern African countries. Particularly, the countries of Kenya, Tanzania and Zambia present a steady decrease of malaria incidents which could be probably associated with the groundwater costs decrease in the three countries. . The diagrammatic presentation of the development indicators effects is presented in Figures 3 and 4.

Figure 3. Effects of development indicators in eastern African countries

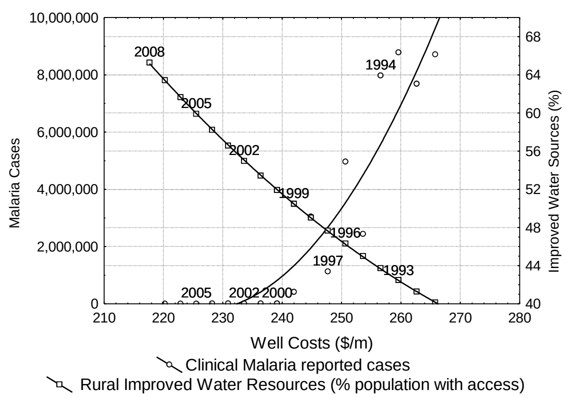
1a. Ethiopia



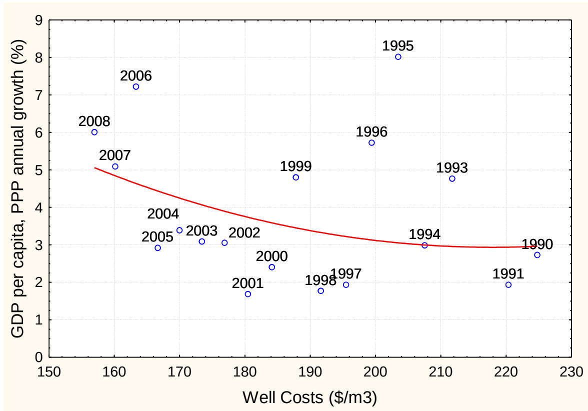
1b.Kenya



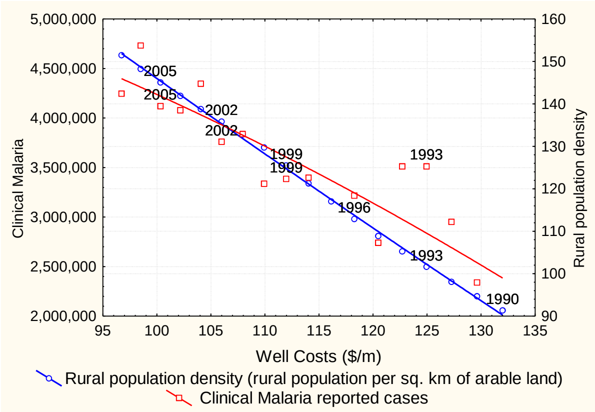
1c.Tanzania



1d.Uganda



1e.Zambia



1f.Mozambique

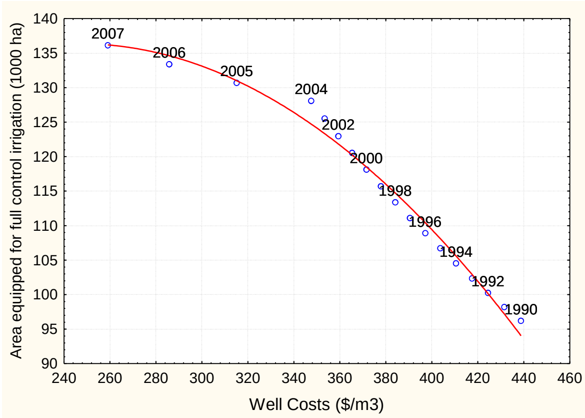
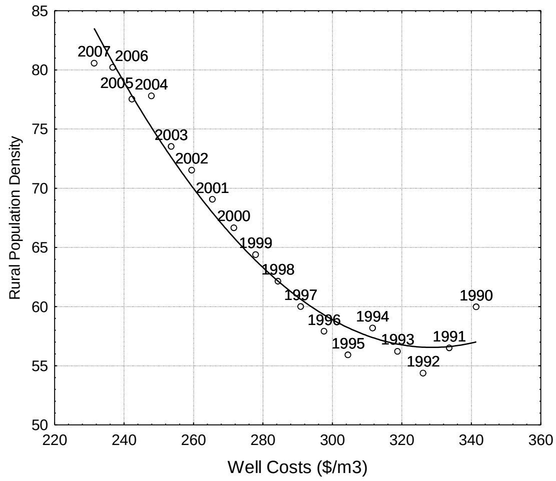
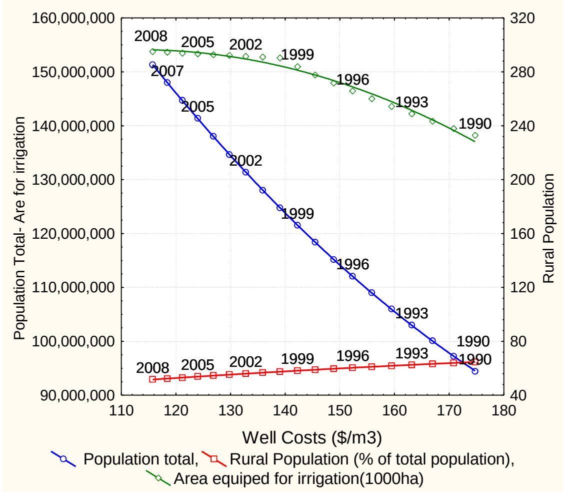


Figure 3. Effects of development indicators in western African countries (about here)

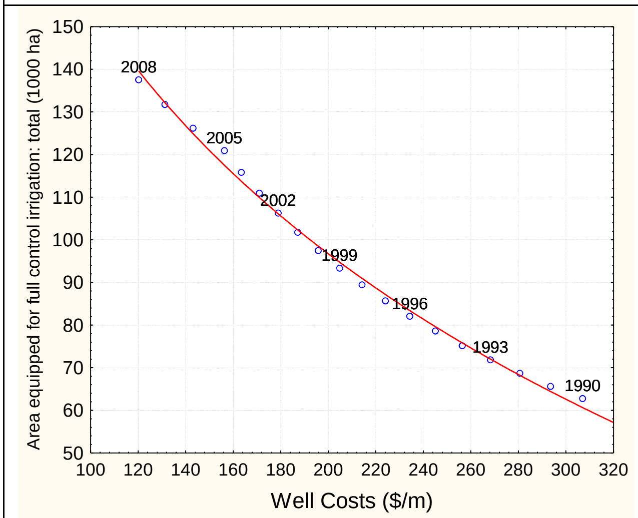
2a.Niger



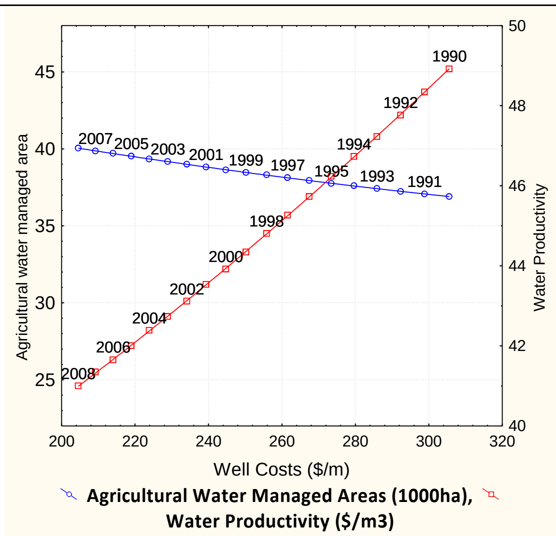
2b.Nigeria



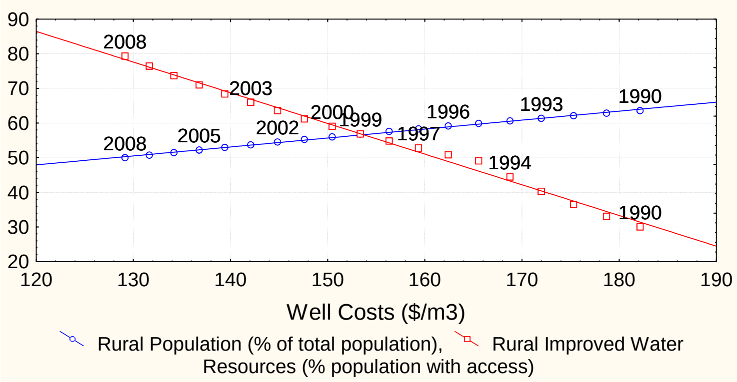
2c.Mali



2d.Burkina Faso



2e.Ghana



Conclusions and Recommendations

The current study attempted to systematically categorize groundwater costs as well as to evaluate the significance of individual fixed and variable costs with respect to the total costs across eleven Sub-Saharan African countries. Further, the potential relationships between groundwater development and representative development indicators were examined through time-series analysis.

The findings present some interesting cross-country comparisons. It appears that the groundwater development costs in Ethiopia and Kenya are higher, although well yields are also anticipated to be commensurately higher than the other countries. This is not however the case for Mali and Niger where higher than average costs are not adequately compensated by well yields. Moreover in the case of Niger, although the fixed costs are of the lowest among the thirteen countries, however the low success rate and the increasing mobilization/demobilization costs exacerbate the average variable costs.

At a broader level, the mobilization/demobilization costs together with the pumping costs are positively correlated to a high extent and appear to significantly contribute to the increasing groundwater costs at a cross-country level.

The results from the development indicators analysis convey a hopeful indication of a downward or steady groundwater cost trend among all of the countries. This is mostly attributed to the increasing use of drilling for domestic and agricultural purposes while recently the industrial sector is benefiting from groundwater use (MoWR, 2011; Canuto, 2011). Additionally, higher competition, upgraded machinery, introduction of free market initiatives and efforts in capacity-building seem to have helped to drive the cost downwards (Word Bank, 2010). However, it is also admitted that the misuse of market principles (Aidt, 2009), the corruption of the regulating authorities and the poor performance of knowledge dissemination mechanisms still keep groundwater costs in significantly higher levels than in other developing countries (Ndiritu, and Githae, 2010).

The regression analysis results reveal an almost insignificant role of the economic indicators which is probably attributed to the multiple components comprising these indicators. For instance, the GDP growth and the inflation rate could be the outcome of a series of endogenous or exogenous economic factors which may only superficially be connected with groundwater use. However, for the case of the demographic factors, the total and rural indicators seem to possibly constitute a driver for the groundwater costs trends. The same situation occurs with land and water related indicators where the increase in land under irrigation may encourage more efficient water use and groundwater cost decrease. Another potential positive effect may derive from the expansion of groundwater sources with implications on the mitigation of malaria incidents in the eastern Africa countries.

This study is subject to some data and methodology related limitations. In principle, the absence of groundwater cost data in some cases inhibited a sufficient cross-country analysis. Also, the data used here is unverified by other independent sources thereby creating some uncertainty in the accuracy of the results. Further, the widely diverging ranges in groundwater costs can in turn

question the value of average values. It is therefore proposed that the cross-country analysis be accompanied by a deeper institutional and societal context for a better comprehension of the differences and similarities between cases.

The effect-driven analysis of the development indicators is still in an early stage and further clarifications are required. Particularly, the reasoning of the potential effects should be better investigated through a disaggregation of the development indicators into its constituents. Also, the conducting of regional analyses whenever there is data available would better help in the understanding of potential local trends in the groundwater costs which in turn influence the national conditions.

Future work will focus on the enrichment of the current study with additional groundwater cost-related data and disaggregation of the examined indicators into their main components in order to attribute a more concise and comprehensive analysis of the conditions affecting groundwater costs in sub-Saharan Africa.

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