ASSESSING PERFORMANCE OF SMALL-SCALE PUMPED IRRIGATION SYSTEMS IN SUB-SAHARAN AFRICA: EVIDENCE FROM A SYSTEMATIC REVIEW[†]

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ABSTRACT

Small-scale irrigation (SSI) has significant potential to increase crop productivity in Sub Saharan Africa (SSA). Pumped irrigation systems are one of the technologies increasingly being used by smallholder farmers. The aim of this study was to systematically review evidence on the performance of SSI pumped systems, including motorized, treadle, rope and washer, solar and wind pumps. The study revealed a lack of standardization and use of a wide range of indicators to assess performance. Most evidence related to motorized pumps, these studies confirmed mixed levels of performance; studies relating to other types of pumped system mostly reported a positive impact, although the method of assessment used was critical. Studies reporting positive impacts tended to be those that used socio-economic based factors such as yield and profitability, whereas studies reporting mixed performance tended to be those that relied more on technically based indicators such as pumping and irrigation system efficiency. The analysis highlights the sensitivity of interpreting findings from different studies, and how caution should be exercised when comparing performance within and between different types of irrigation system. The implications for supporting policy development and identifying future research gaps are discussed.

KEY WORDS: small pumps; impact; technology; agriculture; performance factors

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RÉSUMÉ

L'irrigation à la parcelle (SIP) a un grand potentiel pour améliorer les rendements agricoles de l'Afrique subsaharienne (ASS). La technologie la plus utilisée par les petits agriculteurs est celle des systèmes d'irrigation sous pressions. L'objectif de cette étude est d'effectuer une recherche systématique sur la performance des systèmes d'irrigation à la parcelle fonctionnant avec des pompes alimentées par des moteurs, pédales, cordes et rondelles, énergie solaire et éoliennes. L'étude a révélé un manque de norme de sécurité afin de vérifier les systèmes malgré le nombre conséquent d'indicateurs de performance utilisés. La plupart des études menées jusqu'à présent se sont focalisées sur les pompes à moteurs et ont démontré différents niveaux de performance; les études sur les autres types de systèmes ont largement signalés un effet positif de la SIP, même si la méthode d'évaluation utilisée est critique. Les études rapportant des résultats variables ont tendance à s'appuyer principalement sur l'évaluation des facteurs techniques utilisant des indicateurs tels que l'efficacité des systèmes de pompage et d'irrigation. L'analyse met en lumière la difficulté d'interprétation des résultats entre différents types de système d'irrigation. Leurs performances doivent être comparées et interprétés avec précautions.

MOTS CLÉS: pompes de taille réduite; l'impact; la technologie; l'agriculture; les facteurs de performance.

INTRODUCTION

Enhancing agricultural productivity remains a key strategy for poverty alleviation in most low income countries, where the majority of rural livelihoods depend on agriculture (Hussain and Hanjra, 2004). Sub-Saharan Africa (SSA) requires a rapid growth in agriculture to meet Millennium Development Goals and other targets for poverty alleviation and food security (Inocencio *et al.*, 2007). There are thus increasing efforts to expand irrigation development. According to You *et al.* (2011) Africa has potential for both large and small-scale irrigation development, but there are concerns regarding the performance of large-scale irrigation systems as they are perceived as being too expensive and bureaucratic (Adams, 1990).

Small-scale irrigation (SSI) is considered one of the options for increasing agricultural productivity and supporting development in SSA. It is characterized by the use of simple technologies to access water for irrigation. Burney and Naylor (2012) defined water access technology as any method of moving water from its source to where it was previously unavailable.

This includes all types of pump, from human powered, rope and treadle pumps to liquid fuel engine driven systems and solar powered pumps as well as gravity/river diversion methods. In SSA, a wide variety of such technologies have been introduced for SSI development since the 1990s. Gravity technology typically involves diverting water flows using open channels without pumping. Motorized systems include engine driven pumps, while treadle and rope and washer pumps are manual and wind and solar use renewable energy (Table I). Previously, most rural farmers in SSA have relied on traditional methods on small plots of land using for example, shadoof, buckets, watering cans, calabashes or blocking streams (Baba, 1993).

Table I. Key attributes of SSI water access technologies in Sub-Saharan Africa

Attribute	River diversion	Treadle Pump	Motorized pump	Solar/Wind Pump	Rope and washer pump	Traditional Methods
Power source	Gravity	Human	Fossil fuel	Renewable	Human	Human
Type of lift/pump	Gravity	Piston pump	Centrifugal pump	Centrifugal Pump	Rope and washer	Bucket, watering can or calabash
Typical discharge	> 10 l/s	Up to 2 l/s	>2 l/s	>2 l/s	Up to 1 l/s	<1 l/s
Water sources	Surface water	Surface and groundwater	Surface and groundwater	Surface and groundwater	Surface and groundwater	Surface and groundwater
Initial cost	Low	Moderate ($20-$100)	High ($300-1500)	Very high ($3,000-10,000)	Low	Very low
O & M costs	Low	Moderate	High	High	Low	Very low
Typical irrigated area (ha)	> 10 ha	< 0.3 ha	> 10 ha	> 10 ha	< 0.2 ha	< 0.1 ha

Source: This review

Gravity irrigation systems are usually the simplest and cheapest. However, their use is limited to specific topographical and hydrological conditions such that not all smallholder farmers can adopt such technology. SSI pumped systems are therefore a suitable alternative, and their use has substantially increased in SSA. Whilst there has been increased interest in pumped (manual and engine driven) systems, studies reporting on their performance and success have been mixed. Some claim they have had positive impacts on development (Mangisoni, 2008; Adeoti, 2008; Namara *et al.*, 2010; Kamwamba-Mtethiwa *et al.*, 2012) whilst others argue that they are too expensive and do not make any significant impact on smallholder farmers (Adams, 1990; Ashah

et al., 2002; Inocencio *et al.*, 2007; Chidanti-Malunga, 2009).

The term 'performance' has several meanings. In general terms it means the accomplishment of a given task measured against pre-set known standards of accuracy, completeness, cost and speed. Bos *et al.* (2005) described performance assessment as the comparison of the measured value of a parameter against a target or intended value. Irrigation system performance assessment is described as a systematic observation, documentation and interpretation of activities related to irrigated-agriculture with an objective of continuous improvement (Bos *et al.*, 2005). Performance assessment indicators can be categorized into five broad domains including: (i) water delivery and utilization; (ii) agricultural production; (iii) agricultural economics; (iv) socio-economic; (v) environmental. It is recommended that all performance indicators are used to achieve an efficient, productive and effective irrigation system at all levels; however, the choice of which indicators to use in the assessment depends on researchers' interests. We argue here that evidence on performance of SSI pumped systems can only be obtained if the key drivers are identified and their measurement standardised. Although studies (Kimmage and Adams, 1990; Namara *et al.*, 2010; Fujiie *et al.*, 2011; Daccache *et al.*, 2012) have attempted to review the performance of irrigation development in SSA, no systematic review (SR) has been undertaken on small-scale pumped irrigation development. We contribute to addressing this gap in knowledge by applying an SR approach to synthesize published science and grey evidence to identify the key factors affecting performance of SSI pumped systems and use the evidence to inform policies promoting SSI pumped system in SSA.

A number of recent studies have adopted the SR approach to gather evidence. For example, Knox *et al.* (2012; 2013) assessed the impacts of climate change on yield of eight major crops in Africa and South Asia, and on the infrastructural impacts on agricultural development including irrigation, respectively. That latter study reported that about a third of evidence on irrigation development impacts on agricultural productivity were positive. The authors used measures such as income and poverty reduction. Fernandez *et al.* (2011) used a SR methodology to summarize knowledge relating to the usability evaluation methods (UEMs) to evaluate web applications over 14 years. That study was able to identify research gaps which subsequently provided researchers with a framework for new research.

METHODOLOGY

This study used a robust SR methodology to synthesize evidence from published and grey literature. The main advantage of the SR approach is that it helps to realise the potential of data to inform whilst minimizing bias and uncertainty. It differs from conventional literature reviews in that it is a rigorous critical appraisal that draws on all relevant evidence with reference to a defined research question. The study followed the SR guidelines developed by the Collaboration for Environmental Evidence (CEE) and Centre for Evidence Based Conservation (CEBC) (2010). This included drafting a protocol to define the methodology followed by systematic literature searches and selection based on a set of 'inclusion criteria'. Relevant literature was screened in two stages; initial filtering was undertaken based on the title; a second filter was then based on the abstract. Full texts were only reviewed for those articles, reports and papers that passed all inclusion criteria. These inclusion criteria included specifying all relevant subjects, types of interventions, expected comparators, methods and outcomes. This involved (i) identifying potential 'effect modifiers' (other variables that might influence the outcomes) in the studies, (ii) specifying the data extraction techniques used to obtain qualitative and quantitative data, (iii) outlining quality assessment criteria for the studies which included validity of the methodologies and data analysis methods and (iv) identifying data interpretation and synthesis techniques depending on the amount and quality of data collected.

Based on CBEC guidelines (2010), we split our research question into elements considering: (i) population (agriculture narrowed down to beneficiaries- smallholders, rural communities, farmers, growers, households), (ii) intervention/exposure (small-scale pumped irrigation systems also known as irrigation technologies or water management including treadle, rope and washer, motorized (diesel and petrol), solar and wind pumps), (iii) comparator (changes relative to the intervention either before and after or with and without the interventions) and (iv) outcomes (change factors as a result of the intervention including changes in average yield, irrigated area, labour demand, energy need, farm income, food security). These elements are collectively referred to as PICO or PECO terms. Specific keywords were then selected, relevant scientific databases identified, search terms developed and then applied to each bibliographic database.

The search period was limited to studies published between 1990 and 2013 based on indications of increased interest SSI development in Africa (Baba, 1993; Fujiie *et al.*, 2011). The search used trials in Scopus and finally two search strings *(Irrigat* pump* AND Agricultur*)* and *(Irrigat* Pump* OR Water management OR Irrigat* technolog*" AND (Smallholder* OR Farmer* OR Grower* OR Rural Communit* OR Household*)* were used to search all relevant

scientific databases (Scopus, Science Direct, Web of Knowledge, Environmental Complete and Direct Access Journals), organization websites (e.g. World Bank, Food and Agriculture Organizations of the United Nations (FAO), Consultative Group on International Agricultural Research (CGIAR), African Development Bank (ADB), International Food Policy Research Institute (IFPRI), International Water Management Institute (IWMI) and International Fund for Agriculture Development (IFAD) and search engines (Google scholar and google.com). All references retrieved were exported into bibliographic software (Refworks) prior to assessment of relevance using the inclusion criteria. The bibliographies of identified sources were also searched. Only literature published in English was reviewed. Academic sources were sampled first, to avoid duplication from other databases. For search engines, a maximum 50 'hits' were reviewed using the same search strings.

This SR approach resulted in 1442 articles; based on the inclusion criteria these were screened by title (331) then abstract (101) and 35 papers finally selected for full review (Figure 1). It should be noted that 2 papers reported two pumped systems. Data extracted included year of publication, country where the study was conducted, size of irrigated area, types of pumped system, crops studied, performance indicators and final outcomes/impacts reported from the studies. The results were analysed using narrative synthesis categorised by performance factor. Attempts were also made to quantitatively analyze data based on crop yield information, however there were too few observations available.

Clarification of terminologies and analytical methods

Studies on irrigation performance assessment can be broadly divided into those providing methodological guidelines and those reporting irrigation performances (Yakubov, 2012). This review focused on studies that reported on actual performance. In the synthesis, the 35 selected papers were categorized according to the type of pumped systems studied (motorized, treadle, rope and washer and solar pumps). Data were further analysed by the reported impacts (positive, negative and mixed) and the performance assessment factors used. In order to identify key factors, it was apparent that the final outcomes of the studies be highlighted and linked to the key drivers used to assess performance. Studies were then classified as being positive if the intervention resulted in success, negative if the intervention failed and mixed if the outcomes included both elements of success and failure. Interpretation considered a factor as significant if performance assessment evidence resulted in mixed or failure outcome.
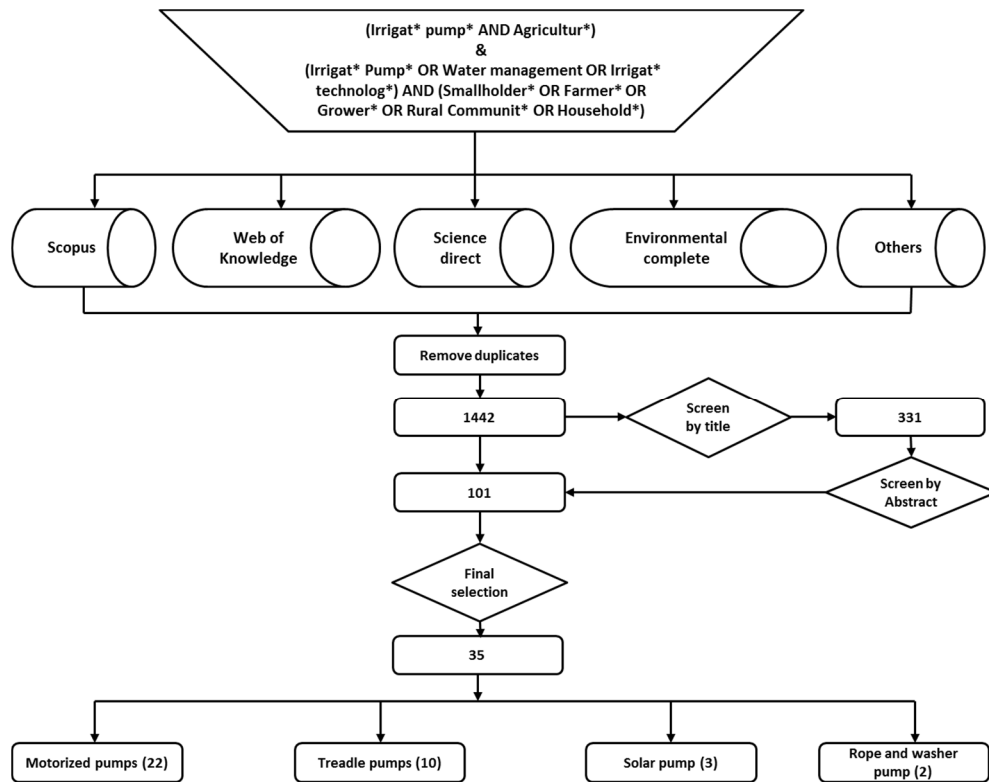
Figure 1 Schematic summary of the systematic review process

Given that the choice of performance factors used in studies largely depends on the researchers choice, this study aggregated the proposed five performance assessment domains by Bos *et al.* (2005) into social (SO), socio-economic (SE), agronomic (AG), technical (system/pump) efficiency (TS &TP) and biophysical (BY). This was based on the reporting patterns in the selected studies. It was noted that studies were directly referring to these identified classes in their assessments although the specific performance indicators varied between the studies (Table II). There was also no clear separation in the studies between economic and financial factors and therefore the economic category in this classification included financial performance. Ideally these classes fit into the five broader domains as proposed by Bos *et al.* (2005) and Córcoles *et al.* (2010).

Table II. Performance factors used in for screening the evidence.

Performance factor	Parameters /indicators used
Social	Management, technological, product organization, access and knowledge.
Socio-economic (SE)	Human capital (age, household size, education level) poverty levels, association membership, number of extension visits, location, adoption, access to credit, numbers of people emerging out of poverty, gender, threshold increasing levels (with gender, household dependency ratio, distance to the market, owning land, access to irrigation and association membership), food access, food utilization and availability, household consumption
Economic (EC)	Water productivity, land productivity, returns to labour, return to land, return to water, yield, net farm income under rain fed, net farm income under irrigated area, rain-fed land holding size, irrigated production, net revenue, farm size, labour costs, input costs, fixed/capital costs, gross margins, pump repairs costs, fuel costs, marketing, income total per capita daily consumption, net farm income, household expenditure, income from other sources, ability to pay back pump loan, set up costs, labour, production cost, willingness to pay, operation and maintenance, asset accumulation, financial capacity, energy costs, pump prices.
Agronomic (AG)	Crop water use efficiency, yield, plant height, fruit size, water consumption, water use productivity.
Technical system efficiency (ST)	Irrigation efficiency, relative irrigation supply, water depth applied, irrigation supply, irrigation frequency, labour efficiency, adequacy, reliability, flexibility, equity, irrigation intensity, relative water supply, water source reliability, water delivery capacity, main canal losses, seasonal irrigation requirement, uniformity distribution, Christiansen coefficient, wetted diameter, water use efficiency.
Technical pump efficiency (PT)	Body Mass Index (BMI), pump power output, pump discharge rates, pump head range, pump volumetric efficiency, pump mechanical efficiency, rope and washer space, pump pulley rotational speed and pump hydraulic output, pump efficiency, flow rate, hydraulic energy, daily volume, pump fuel consumption, labour input/man-hours.
Biophysical (BY)	Straw/fodder production, stock carrying capacity and shrubland management sustainability.

RESULTS

The review identified studies relating to thirteen countries of which eight (Mauritania, Ethiopia, Nigeria, Mali, Niger, Kenya, South Africa and Malawi) included motorized pumps, four (Malawi, Zimbabwe, Ghana and Kenya) treadle pumps, two (Benin and Ethiopia) solar pumps and one (Zimbabwe) rope and washer pumps. The types of pumped systems studied were regionally localised such that the majority that covered motorized and solar pumps were from West and East Africa whilst Southern African studies mostly related to treadle and rope and washer pumped irrigation systems. The majority of literature (63%) focussed on motorized pumped systems, followed by treadle pumps (23%), solar pumps (9%) and rope and washer pumps (6%). The review did not find any relevant studies on the use of wind pumps for irrigation. The majority of studies on motorized pumps related to rice followed by tomatoes, maize, onions and beans and sorghum. Very few studies reported the crop types under treadle pumps. No crops were reported by the studies on solar and rope and washer pumps. Different methodologies were reported to assess irrigation performance. The majority (60%) used statistical methods based on quantitative data; however, due to 'effect modifiers' it was difficult to compare the quantitative findings. The review also attempted to analyse the impact of different pumped systems on crops; however, interpretation was limited by the very small sample size.

Motorized pumped systems

Table III summarises the evidence on motorized pumped irrigation, the comparators and performance factors used and reported outcomes. We then aggregated these results into studies that reported on positive, negative or mixed performance.

Technical Efficiency, BY-Biophysical

Socio-economic factors, followed by agronomic and economic factors; dominated studies that reported positive performance. Five of the eight studies reporting positive impacts used socio-economic factors with measures in yield, profits, resource use, outputs, willingness to invest, household consumption, assets, crop revenues and informal insurance. The majority of these studies used yield and profit indicators. Three studies that assessed impact using agronomic and economic factors also used productivity (returns to land, water and fuel) and yield to measure impact. This reflects the importance of measuring agricultural productivity in understanding performance of small-scale pumped systems. While it may be difficult to compare the findings from such studies, the trends and patterns on use of common indicators in the assessment implied that the factors were significant indicators for positive outcomes of the motorized pumps.

Studies that reported a negative impact had used varied factors linked to productivity

(returns to water, labour and energy, initial costs). However, effect modifiers within the studies made it difficult to separate out the direct impacts. Almost all had different comparators and were conducted at different scales.

Nearly half (41%) of the evidence reported mixed impacts; only a few of these studies had used socio-economic factors for assessment. The use of technical (system and pump) efficiency factors was widespread. Positive impacts were mainly attributed to socio-economic assessments and negative impacts mainly related to technical assessments. This highlights the attributes that particular performance assessment factors can have on expected outcomes suggesting the significance of technical factors on performance.

Treadle pumped systems

Nearly a quarter (23%) of evidence selected in the SR related to treadle pumps, possibly implying that these are the technologies that are the preferred choice among developing organizations, donors and researchers. Most studies were from Malawi reflecting the fact that they are being heavily promoted by the Government of Malawi (2010). The majority (70%) of studies reported positive performance impact relating to food security, poverty reduction and crop revenue (Table IV). Most studies reporting positive impact used socio-economic factors. Those that reported a negative impact attributed poor performance to the pump labour demand. One study reported mixed performance based on both technical and socio-economic factors. These findings concur with the observations above on motorized pumps.

Solar pumps

There was very limited evidence found on the use of solar pump technology (Benin and Ethiopia only). All studies on solar pump systems were published relatively recently (Burney *et al.*, 2010; Jeffries, 2010; Burney and Naylor, 2012), indicative of a recently introduced technology in the region. All these studies reported a positive impact; two-thirds used socio-economic factors for assessment; the remainder focussed on assessing the technical efficiency of the pumped system.

Rope and washer pumps

There were only two (Faulkner *et al.*, 1990; Faulkner and Lambert, 1990) studies identified, both from Zimbabwe reporting a positive impact; No recent publications possibly suggest that this is now an abandoned technology.

Table III. Selected studies for motorized pumped systems, comparators, performance indicators and outcome (impact)

No	Country of study	Comparator	Performance factor assessed**							Outcome	Indicator used to quantify impact	Source
			SO	SE	EC	AG	PT	ST	BY			
1	Nigeria	Traditional		✓						Positive	Resource-use, yield & profit	Baba (1993)
2	Mali	Pumped irrigation		✓						Positive	Household consumption, assets & informal insurance	Dillon (2011)
3	Mauritania	Pumped irrigation-sorghum Vs rice			✓	✓				Positive	Crop profitability	García-Ponce *et al.* (2013)
4	Nigeria	Adoption with and without rainfall risks		✓						Positive	Willingness to investment	Takeshima & Yamauchi (2012)
5	Niger	Traditional			✓	✓				Positive	Profits	Woltering *et al.* (2011)
6	Ethiopia	Drip and furrow pumped systems				✓				Positive	Crop yield	Yohannes and Tadesse (1998)
7	Nigeria	Rain fed agriculture		✓				✓		Positive	Outputs and tech efficiency	Adeoti (2006)
8	Ethiopia	socio-economic performance		✓						Positive	Crop revenue	Mengistu *et al.* (2008)
9	Malawi	Different pump and traditional irrigation		✓		✓				Negative	Water and fuel productivity, labour, yield and revenue	Kadyampakeni *et al.* (2012)
10	Mauritania	Traditional		✓						Negative	Return to labour and inputs/ workload	Comas *et al.* (2012)
11	Mauritania	Pumped systems-scheme performance			✓			✓		Negative	Productivity of land, water and fuel	García-Bolaños *et al.* (2011)

No.	Country	Topic									Indicators	Reference
12	Kenya	Pumped system-pump efficiency					✓			Negative	Pump efficiency	Kang'au *et al.* (2011)
13	Nigeria	Adoption with & without transaction costs		✓						Negative	Transaction costs, gender	Takeshima *et al.* (2010)
14	Mauritania	Large scale						✓		Mixed	Technical efficiency-Land productivity and energy cost	Borgia *et al.* (2013)
15	Niger	Technical capacity with other pumps					✓			Mixed	Pump water discharge and hydraulic output	Norman and Walter (1994)
16	South Africa	Economic productivity of pumped systems			✓					Mixed	Water value and productivity	Yokwe (2009)
17	Ethiopia	Large scale	✓							Mixed	Technological management	Awulachew (2010)
18	Mauritania	Other production systems			✓	✓			✓	Mixed	Irrigated area, crop diversity and stock carrying capacity	Connor *et al.* (2008)
19	Ethiopia	Scheme efficiency of pumped system			✓			✓		Mixed	Water & land productivity, rate of returns on investment	Hassen (2004)
20	Mauritania	Before and after rehabilitation						✓		Mixed	Reliability, flexibility and pumping capacity	Mateos *et al.* (2010)
21	Mali	Social changes with flood irrigation	✓							Mixed	Organization capacity, water access & knowledge	Ton and De Jong (1991)
22	Ethiopia	Socio-economic performance		✓				✓		Mixed	Income and water use efficiency	Van Halsema *et al.* (2011)
	Total		2	9	6	5	2	6	1			

**SE-Socio-economics, EC-Economic, AG-Agronomic, PT- Pump Technical Efficiency, ST Scheme

Table IV. Summary evidence on treadle pump performance, by country and performance factor

No	Country of study	Comparator	Performance factor				Outcome	Indicators used	Source
			SE	EC	AG	PT			
1	Ghana	Non adopters	✓				Positive	Adoption factors and poverty	Adeoti, (2008)
2	Zimbabwe	Different pump types				✓	Positive	Pump and drip designs	Chigerwe *et al.* (2004)
3	Zimbabwe	Different pump design				✓	Positive	Pump hydraulic output	Faulkner *et al.* (1990)
4	Malawi	Furrow irrigation		✓	✓		Positive	Labour, yield and drip efficiency	Fandika *et al.* (2012)
5	Malawi	Non adopters	✓				Positive	Poverty levels and household income	Mangisoni, (2008)
6	Kenya	Before and after	✓				Positive	Income and loan repayment	Pandit *et al.* (2010)
7	Malawi	Non adopters	✓				Positive	Net farm income, adoption, household income, expenditure	Kamwamba-Mtethiwa *et al.* (2012)
8	Malawi	Pump efficiency				✓	Negative	Labour and pump discharge	Joseph and Yamikani, (2011)
9	Malawi	Traditional	✓				Negative	Labour, gross margins	Chidanti-Malunga, (2009)
10	Malawi	Motorized pump and traditional	✓		✓		Mixed	Labour, yield, crop revenues and water productivity	Kadyampakeni *et al.* (2012)
	Total		6	1	2	3			

**SE-Socio-economics, EC-Economic, AG-Agronomic, PT- Pump Technical Efficiency

DISCUSSION

The increased use of SSI pumped systems in SSA has been established on the grounds that larger scale irrigation schemes have often failed (Fujiie *et al.*, 2011). It is believed that pumped systems are among the simple technologies that support smallholder farmers to access water from sources that may not be possible with gravity. Furthermore, it is assumed that the benefits from these pumped systems directly benefit smallholder farmers by increasing agricultural production and farmer incomes (Baba, 1993; Dillon, 2011). However, this study found that evidence relating to SSI pumped system performance is limited, lacks standards and is geographically focused within a particular region in SSA. This study proposes that a number of factors have contributed to these differences found in the literature.

Firstly, this SR has revealed that studies assessing performance of small-scale pumped systems are framed to serve the interests of those driving them. This was demonstrated by the biasness in the evidence on particular pumps that were also supported by the developing organizations. For example, we found that there were more studies relating to treadle pumps compared to motorized pumps especially in southern SSA; coincidentally, many developing organizations in this region are supporting the up-take of treadle pumps (Mangisoni, 2008). Similarly, it was found that the only evidence relating to rope and washer pumps (Faulkner *et al.*, 1990; Faulkner and Lambert, 1990), were provided by the authors that participated in the pump design. On the other hand, studies involving the IWMI (e.g. Namara et al, 2013; 2014) have reported a rapid rise in the use of private small motorized pump but their evidence in the region is patchy. It is therefore argued that the current evidence on SSI pumps in the SSA is not entirely based on literature but rather the interest of the various actors involved. This is supported by Sumberg *et al.* (2012), who argued that most contemporary evidence in the literature exposes major epistemological and ontological divisions in relation to the value of different kinds of knowledge and the nature of the innovation since the focus is on performance of the technology. This might help to explain the reasons why some pumped systems are often positively assessed while others are not.

Second, there are no common approaches or standards adopted for assessing the factors that affect system performance. Socio-economic factors such as profits, assets accumulation, yield dominated the reporting of positive performance while most technically based assessments reported mixed or negative performance (Tables III and IV). While the positive socio-economic impact of the systems studied may be consistent with evidence from other SRs (Knox *et al.*, 2013), it is important to recognize that socio-economic changes in smallholder communities could be a result of influences from numerous sources. Considering the household as a unit with a range of

income sources, farmers' socio-economic changes cannot be entirely attributed to the contributions made by the pumped systems interventions. For example, evidence from the New Partnership for Africa's Development (NEPAD) (2003) revealed the goals for many developing organizations in SSA are geared towards the rural poor, thus on socio-economic changes. This could explain why socio-economic studies reported positive impact in their performance assessment. However, this study revealed that technical factors are also important in the success of SSI pumps. This supports previous studies (Adams, 1990; Njiraini and Guthiga, 2013; Borgia *et al.*, 2013) that argued that most small irrigation systems in SSA are not technically effective. Similarly, in Kenya, Kulecho and Weatherhead (2006) suggested that the failure of drip irrigation systems was due to a lack of maintenance and unreliable water supply suggesting that abandonment of most irrigation technologies are likely due to their technical challenges. This has implications for the choice of factors for assessing pumped system performance.

Finally, there was a lack of differentiation between rapid and more detailed comprehensive assessments of small pumped systems. For example in Nigeria, Baba (1993) took three years to conduct a socio-economic assessment of the impact of pumped systems; in contrast, it took only three months to socio-economically assess schemes in Ethiopia (Mengistu *et al.*, 2008). The outcomes from both these studies showed a positive impact regardless of differences in their duration of assessment. However, it is possible that other factors such as other previous income sources may have contributed to the positive impact on the evidence found in the short duration study. This demonstrates the potential risks associated with the evidence and likely inconsistencies in the outcomes.

The findings from this study have important implications for policies to promote the uptake of small capacity pumps. The limited evidence base means that current policies (e.g. NEPAD, 2003) in SSA are likely to be based on evidence that is not sufficiently robust. This supports recent studies (Matekele and Lema, 2012) that reported on performance assessment in smallholder irrigation to be rather ad hoc, fragmented and mainly conducted at the outset of projects to serve the interest of those that initiated the process. It is thus suggested that further targeted research should be undertaken to inform policy formulation. For the unclear standards, this study has argued that this was likely to be result of different methods and the lack of clear procedures to differentiate comprehensive and rapid performance assessment methods. Given the importance of understanding the technical and socio-economic factors, we propose that performance assessment standards that incorporate a set of key factors should be developed. This will enable directly comparable evidence on performance of SSI pumped systems to be gathered and more objectively compared. It is also suggested that clear guidelines associated with conducting either rapid or comprehensive performance assessments should be developed. Finally, the differences

in policies in the SSA countries might help to explain some of the reasons why the evidence found was localized. It is suggested that an inventory of the SSI pumped systems should be developed. This will provide a baseline data for developing performance assessment standards that are specific to the pumped system.

Despite the limited evidence base collated from this SR, the study provides valuable insights on the gaps in the knowledge on SSI pumped systems in SSA. Furthermore, the review has used robust methods and processes to gather the evidence and thus the findings are a true reflection of the magnitude of evidence that is available in the SSA.

Methodological limitations

The main limitations in adopting a SR approach typically relates to selection bias, inaccuracy in data extraction and the presence of 'effect modifiers'. Selection bias refers to biases in identifying studies for the subsequent analysis; inaccuracy in data extraction refers to the possibility of extracting wrong or inaccurate evidence from the various bibliographic databases or other literature sources; 'effect modifiers' refers any variable that modify the impact of an intervention or exposure. The evidence identified in this SR differed in terms of its geographical coverage, the varying scales of analysis for example, household to village, and the approaches used for measuring performance impact. In addition, the studies varied widely in their approaches to assessing performance, from comparing pumped systems with rain-fed production, to traditional irrigation, to rehabilitated schemes, to different pumped systems. The time scale over which the studies were conducted was also an important factor; some studies assessed performance over relatively long periods (more than six years) whilst others were carried out over much shorter periods (single irrigation season). Different pump design, pump sizes and irrigation application methods might also have been important effect modifiers. For example, the high frequency or citing in the literature for a certain type of technology, does not necessarily equate to a high significance of the technology in terms of area, production or income. The SR outputs should therefore be interpreted with caution.

CONCLUSIONS

This study provides a valuable contribution to the international science literature by identifying the key factors that affect the performance of SSI pumped systems in SSA and the extent to which technical and socio-economic factors are used as metrics of performance. The study has highlighted the limited evidence on SSI pumped systems and that it is geographically biased

(treadle pumps-southern SSA, motorized pumps-West and East SSA). Nevertheless, the evidence should be helpful in defining where strategic research is needed to improve methods and approaches for assessing performance. Our analysis suggests that current policies to support SSI pumped systems should embrace both technical and socio-economic issues in their development programmes and should adopt more standardized methods for assessment to allow comparison and replication.

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