Potential energy and water efficient irrigation technologies for smallholder agriculture in Tanzania

Hans C. Komakech, Kelvin M. Mtei, and Cecil K. King’ondu

NM-AIST, PO Box 447 Arusha, Tanzania
Acknowledgement

This study was conducted under VECO East Africa’s synergy project dealing with integrated water and land management in 4 villages in Northern Tanzania. The project aims to improve agricultural productivity and year-round income for 200 farmers while ensuring that water and soil are exploited in a controlled and sustainable way by the various interests groups (pastoralists and farmers). We acknowledge VECO EA for facilitating the processes of this study. Particularly we would like to thank Mr. Paul Mbuthia Kamau, Dr. Edith Gathoni, Ms. Denise Lapoutre and Mr. Gerald Sakaya, all are staff of VECO EA for their support and critical review of the earlier version of this report. We also would like to acknowledge and thank very much the farmers we worked with during the study.
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## List of acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>SSA</td>
<td>Sub-Saharan Africa</td>
</tr>
<tr>
<td>IPTRID</td>
<td>International Programme for Technology and Research in Irrigation and Drainage</td>
</tr>
<tr>
<td>PEP</td>
<td>Concrete Peddle Pumps (p. 13)</td>
</tr>
<tr>
<td>I/s</td>
<td>Litres per second</td>
</tr>
<tr>
<td>m3/h</td>
<td>cubic metres per hour</td>
</tr>
<tr>
<td>PV</td>
<td>photovoltaic</td>
</tr>
<tr>
<td>SWPS</td>
<td>Solar water pumping system</td>
</tr>
<tr>
<td>PSI</td>
<td>Pounds per square inch</td>
</tr>
<tr>
<td>WPWPS</td>
<td>Wind powered water pumping system</td>
</tr>
<tr>
<td>LCC</td>
<td>Life cycle cost</td>
</tr>
<tr>
<td>TLCC</td>
<td>Total life cycle costs</td>
</tr>
<tr>
<td>SPVWPS</td>
<td>solar PV water pumping system</td>
</tr>
<tr>
<td>TIP</td>
<td>Traditional irrigation improvement project (Should be TIIP??) check in text</td>
</tr>
<tr>
<td>SESEDO</td>
<td>Sustainable Energy Services, Environment Management and Development Organisation</td>
</tr>
<tr>
<td>TPC</td>
<td>Tanzania Planting Corporation</td>
</tr>
<tr>
<td>DADP</td>
<td>District Agricultural Development Plans</td>
</tr>
<tr>
<td>ATC</td>
<td>Vi-Agroforestry training centre</td>
</tr>
</tbody>
</table>
Executive summary

Agriculture provides food and income for many households in Sub-Saharan Africa (SSA), and is therefore of great importance for both food security and economic development. However, the majority of agricultural land is rain-fed and depends on unreliable seasonal rainfall; a situation expected to be exacerbated by increased climate variability and change. Specially, five critical challenges face smallholder farmers in most sub-Saharan African country like Tanzania, namely: 1) the need for appropriate water lifting technologies; 2) the need for efficient water delivery system; 3) the need for better-on farm water application practices; 4) the need for fertilizers and pesticides; and 5) the needs for markets for the agricultural produce. To overcome some of the above challenges, a detailed analysis and documentation of the existing and potential irrigation systems is needed. The analysis should include available water sources, lifting, delivery and on-farm application technologies, as well as the energy requirements for each of these technologies.

This review provided analysis of existing energy and water technologies in use in the east African region and beyond. It is a first attempt at analysing more critically irrigation technologies that are available for smallholder farmers in Africa but specifically for Tanzanian context. The report presents such an analysis for smallholder irrigation in the Pangani basin in Tanzanian context. It provides an in-depth literature review of energy and water efficient irrigation technologies, as well as the results of a field study of irrigation technologies currently used by smallholder farmers in the Pangani basin. The study explored water sources such as springs, rivers, boreholes, macro and micro storages; water lifting technologies including pumping by motorised systems or manual fetching; water delivery methods through canals, pipes and buckets; and on-farm water application techniques comprising of flooding, furrow, sprinkler and drip. Alternative options of energy sources (petroleum, solar, wind and grid electricity) for lifting and conveyance along the irrigation system were investigated. From the literature review, field observations, and discussions with local suppliers a selection of energy and water efficient irrigation technologies are recommended for this specific location.

From the review, shallow groundwater, springs, rivers and lakes were the most commonly used water sources by small-scale farmers due to the easiness to lift and convey water. Water lifting technologies in use include manual lifting by using bucket and cans, manual and motorized pumping, wind and solar pumps and hydram-pumps. Solar power would be suitable for irrigation, as it can be used for all water sources, is very reliable, lasts longer and has a higher efficiency than the other energy sources. Wind power would be a good alternative. However, both of these technologies are currently uncommon, partly due to their high initial investment cost. The use of motorized pumps on the other hand, has just recently been taken up by farmers. These pumps are relatively cheap and have the potential of being adopted by many more small-scale farmers.

Water conveyance methods include canals (lined or unlined) and pipes (surface or buried). The buried pipes have the highest efficiency (90%) followed by lined canals (80%) while unlined canals are the least
efficient (efficiency as low as 15% is frequently reported in literature). On-farm application methods include drip, sprinkle, flood, furrow and bucket and cans. Drip is reported to be the most efficient (90%) while flood is the least (25%). The review noted that on-farm ponds, rainwater harvesting and storage can be used to meet supplementary water requirement in farmers’ fields.

Selected smallholder irrigation schemes were visited to study and discuss with the relevant stakeholders (i.e. farmers) issues of irrigation pertaining to water, energy and application methods. Places visited were: 1) Rural Moshi: Uchira, Miwaleni, Kisangesangeni and Oria villages; and Meru District: Mlangarini and Nduruma villages; 2) Same district: Chome ward, Mmeni and Mhero-Champishi villages. Irrigation technologies such as buried pipes and macro/micro-on-farm water storages were particularly found to be very successful in Same district; 3) Qsem commercial seed farm and the Asian Vegetables Research and Development Center –AVRDC with modern irrigation system for commercial and research purposes; and 4) the lake zone: Nyashimo village in Busega district (SESEDO project site), Bweri (Vi-Agroforestry Training Center) and Nyabange villages in Musoma district) were visited to study the use of alternative energy sources (solar and wind energy) in irrigation schemes. Suppliers of irrigation technologies (in Arusha town); Balton (T) Ltd, and IRRICO International Ltd companies were visited to obtain technical and financial information of the supplied irrigation technology packages. Some of the key findings from field studies include:

- Natural springs, shallow groundwater and rivers were identified as the main sources of water for irrigation. However the growing number of water users and increased uses coupled with the changing climate worries farmers of the sustainability of these water sources.

- Water lifting is mainly by motorized pumpsets operated by fuel (petro/diesel) or grid electricity. Renewable energy sources such as wind and solar energy are not very much in use. Windmill is still faced with a number of management challenges which in most cases have made it fail. Solar pumps stand to be the most reliable source of energy to recommend to smallholder farmers.

- Water delivery is mainly through unlined canals with excessive water losses. Surface pipes are also used but to a lesser extent. Farmers complain of the quality of pipes and costs. Concrete lined and or stone-pitched canals were observed to the most used mechanism of irrigation improvements and water loses control. However, buried irrigation pipes were observed to significantly reduce water losses and could be the most economic and efficient method for irrigation improvement.

- On-farm water application technologies vary with crop/cropping type. Basin, furrow and flood irrigation were the most commonly used techniques by farmers. However, their application efficiency are very low. Drip irrigation is not common yet it is considered the most efficient. In places where drip is implemented, farmers are faced with a number of challenges e.g. such as extreme dry conditions, poor quality materials drip kits which makes it clogging, and drying. However, is likely to be the preferred technology for farmers with financial and management capacity.
• A number of other challenges were observed in the field including diminishing water sources with increased water demands and users, high energy needs for water lifting, significant water losses through the conveyance and application techniques. Most losses were observed in the unlined canals and flooding type of irrigation.

• However, suppliers are aware of these challenges facing farmers and have designed solutions such as agro-support programs, including post-installation and maintenance services.

In conclusion, this review raises a number of important issues on smallholder irrigation improvement. First the rising demand for water sources necessitates the use of water efficient irrigation technologies. Second, to consequently improve efficiency in both conveyance and on-farm water application, the following lifting devices are considered suitable for smallholder irrigation – solar powered water pumps for deep wells, wind powered pumps for shallow and deep groundwater, motorized pumpsets for shallow wells and pumping from irrigation canals. Grid powered water pumps are viable but require proper community organization particularly for paying monthly electricity bills and other related operation costs. A pre-paid system could be used for tariff collection. Wind powered water pumps may appear to be a cheap approach but existing technology in the market are not reliable. Several failures were observed during this study which makes wind powered technology not to be considered as an appropriate technology for smallholder farmers at this time, in this place. Treadle pumps are being used by farmers but the drudgery involves makes this technology less attractive to smallholder irrigators in the region. However, recent modification with minimum labour requirement could be useful. Our observation is that treadle pumps are still inefficient (about 40-50% efficiency). Other water lifting technologies e.g. hand pumps are attractive for domestic water supply.

Third, conveyance system for smallholders remains one of the main problems. Unlined irrigation canals have been quoted to have efficiency as low as 15%. Several attempts to improve this have not been successful. It was observed that buried pipes though expensive can be relatively cheap in the long run. Particular evidence is from Chome in Same district whereby a buried pipe irrigation network constructed in 1995 was found still operating with little or no leakage. Using buried pipes conveyance efficiency of 80-90% can be realized. Concrete canals was found to be the most common conveyance system in use, however, turn up to be the most expensive ways of modernizing irrigation canals. Surface pipes were also observed being used by farmers in the areas visited. Surface pipes can be suitable for individual farmers but can also be connected with buried pipes or motorized pumpsets. Although easily movable, this is not to be preferred for medium scale irrigation system of more than 20 farmers. Depending on availability of funding, the choice of conveyance system could be in the following order i.e. high to low efficiency: buried pipes, lined canals with control gates, surface pipes, and unlined canals.

Fourth, the common on-farm water application technologies include bucket and cans, flooding, ridges, basins, drip. Buckets and cans is suitable for very small area e.g. backyard gardening. Flood irrigation is highly inefficient, leads to over-irrigation and should be avoided as much as possible. Ridges and basin irrigations require significant labour inputs for their preparation. However, they are relatively efficient when compared to flood irrigation techniques. Drip irrigation is the most efficient field water application technology. However, there are several challenges faced by smallholder farmers in managing this system.
Failures were observed due to clogging, damages by rats and UV radiation. Most drip kits being promoted for smallholder farmers were found to be of poor quality material. Our conclusion is that drip irrigation requires proper technical support and that it may work for farmers with sufficient financial capacity. The construction of small ponds to capture and store rainfall for irrigation to bridge the gap between water turns can lead significant improvement in crop yields.

Our recommendations therefore are to mix and match technologies to fit a local environment and users capacity and skills of the small-scale irrigators. Second, it is important that users are given the opportunity to choose what suits their individual situations and financial capacity. Third, advocate for community collective action approach to water point management to ensure sustainability of water resources and to mitigate any future water upstream – downstream water conflicts.

Specifically we recommend field trials of the following technologies – solar powered water lifting system for boreholes, and buried pipes for water conveyance. For on-farm application we recommend small-scale trials of drip irrigation, and this should be coupled with basin and furrow irrigation to allow farmers to gain more insights in the management of drip systems but also to be able to compare it with existing techniques – basin and furrow. Other technologies e.g. wind pumps, concrete canals and sprinklers can also be promoted. The use of pumpsets for shallow groundwater exploitation is on the rise and appears to be a short-term solution to the problem of water lifting for smallholder farmers, mainly because they are cheap, easy to operate and the spares are available. However, atomisation of water lifting if not well managed is likely to lead to over extraction of the water resource. Thus the promotion of pumpset should be done with proper understanding of the resource dynamics such as groundwater recharge zones, surface-groundwater interactions and land use pattern.
Access to reliable sources of water is a major limiting factor to agricultural production in many smallholder farms in Sub-Saharan African (SSA). In places where water is still plentiful, access may be limited by the cost of available abstraction technologies, while in other cases there is physical lack of water resources. In both cases, however, it is important that available water resources be used effectively i.e. efficiently and economically (Hanjira et al, 2009; Giordano and de Fraiture, 2014).

More importantly, the above challenges raise five critical issues for smallholder agriculture in a country like Tanzania: 1) the need for appropriate water lifting technologies; 2) the need for efficient water delivery system; 3) the need for better-on farm water application practices; 4) the need for fertilizers and pesticides; and 5) the needs for markets for the agricultural produce. In the past (1960s - 1970s) the solution to these problems was considered to be possible in large-scale investment in centralized irrigation systems combined with intensive fertilizers and pesticides application often termed as "The Green Revolution". According to Bourney et al. (2013) these large-scale investment in irrigation enabled year-round crop production, higher yields, growth in rural incomes, and a dramatic reduction in acute and chronic hunger in many countries around the world. However, this was never the case in SSA where only about 4% of agricultural land was irrigated, even then majority of this land is concentrated in just four countries - Madagascar, Nigeria, South Africa and Sudan (Bourney et al., 2013).

More recently, in sub-Saharan Africa there is a new push in finding the 'right irrigation', also termed as “the uniquely African Green Revolution”, to enhance agricultural production in smallholder farms. The right technology for irrigated agriculture in SSA is not easy to find. In the bid to find the right approach, policy makers, development agency, donors, and governments active in SSA struggles with dilemma of whether to promote investment in large-scale irrigation infrastructure or small-private system. To boost farm productions, smallholder farmers on the other hand are proactively and privately trying diverse sets of irrigation technologies. Against this backdrop, the need for identifying appropriate energy and water efficient technologies to support farmers’ investment in the sector is thus eminent and urgent. The general hypothesis is that, farmers with access to affordable technology can achieve higher yields and earn greater income than farmers relying on rainfall.

This review provides analysis of existing energy and water technologies in use in the east African region and beyond. But also include review of relevant literature on smallholder irrigation published in peer reviewed international journals. It is a first attempt at analysing more critically irrigation technologies that are available for smallholder farmers specifically for Tanzanian context.
2 Review of energy and water efficient irrigation technologies

Any irrigation system can be analysed by separating it into four aspects: a) water sources; b) water lifting technologies; c) water delivery and distribution technologies; and d) on-farm water application technologies. In the next section we present a review of each of these aspects. One of the main aims of the proposed work is to provide users and development partners with the information and skills required for choosing the most appropriate energy and water efficient technology for their particular situations and applications.

A user is primarily interested in irrigation cost (in terms of both money and effort), and in this context, specifically, in what a certain technology will do and what it will cost over its lifetime. The balance between these factors represents the return or advantage to be gained by use of the technology. The main criteria (as proposed by IPTRID 2004) could involve (Table 2.1):

Table 2.1: Technology choice score cards

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Short form of the criteria</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial cost or purchase price (taking into account any subsidies or device-specific credit terms that may be offered);</td>
<td>Initial costs</td>
<td></td>
</tr>
<tr>
<td>Closeness of the technical matching of the devices performance to the required application, including discharge, suction characteristics, delivery head if needed, and priming arrangements;</td>
<td>Closeness/matching of technology</td>
<td></td>
</tr>
<tr>
<td>Reliability and expected life;</td>
<td>Reliability</td>
<td></td>
</tr>
<tr>
<td>Fuel or energy source (some fuels cost more than others, or are sometimes scarce);</td>
<td>Energy used</td>
<td></td>
</tr>
<tr>
<td>Efficiency of use of energy, whether human or animal power or fuel (efficiency is usually the main determinant of running cost, where a value is placed on an operators time);</td>
<td>Efficiency</td>
<td></td>
</tr>
<tr>
<td>Other running costs and ease of maintenance and repair;</td>
<td>Operation and Maintenance costs</td>
<td></td>
</tr>
<tr>
<td>Local availability and cost of spare parts, and confidence in their future availability;</td>
<td>Availability of parts</td>
<td></td>
</tr>
<tr>
<td>Local availability of repair skills for tasks that the user cannot manage himself or herself;</td>
<td>Repair skills</td>
<td></td>
</tr>
<tr>
<td>Convenience in use, especially comfort for human-powered devices, and ease of priming;</td>
<td>Convenience of use</td>
<td></td>
</tr>
<tr>
<td>How the technology fits with the users habits, family situation and culture (for instance, gender dimensions and increasing area under cultivation); and</td>
<td>Fit to users habits</td>
<td></td>
</tr>
</tbody>
</table>
Obviously, the relative importance of these and other criteria will vary according with users’ situation. However, any initiative to promote informed choice of technology must cover most if not all of them. For instance, engine manufacturers may publish nominal specific fuel consumption figures but these usually relate only to particular conditions of altitude, load and speed. Pump makers publish characteristic curves, but they refer only to the pump, and experience shows that other parts of the pumpset, especially the foot-valve, may have a drastic effect on energy consumption. For human-powered devices there does not appear to be any comparable database or selection aid, indeed it would be impossible to compile one because of the lack of complete and mutually comparable descriptions of the devices available. Manufacturers do not publish energy input figures, and even research projects have very rarely measured them. Currently the above criteria may be difficult to apply because there is a lack of information for many of them, as well as a lack of understanding by farmers (especially small-scale) of the basic technical principles. We use the above criteria to gain general insight into energy and water efficient technology for smallholder irrigators in Tanzania.

2.1 Water sources and access

The types of water sources available in a particular place are the main determining factor in selecting any irrigation technology. Generally, irrigation water sources include surface water (rivers, lakes etc.), groundwater (shallow and deep aquifers) and rainfall but also canals, and reservoirs. Shallow groundwater, springs, rivers and lakes are the most commonly used water sources by small-scale farmers. This is driven by the relative ease of accessing water from these sources. Deep groundwater are not commonly used because of the large initial capital requirement. However, as river water gets overly committed, groundwater development and use by small-scale farmers is likely to be an alternative way to achieve water security in the sector.

2.2 Water lifting technologies and devices

2.2.1 The setting

Demand for water-lifting technology is strong in the eastern Africa region mainly for domestic water as well as for agriculture (food) production. In general, domestic water involves the lifting of water from groundwater (often many meters 7-15m for shallow wells and 30150m for deep wells) but in relatively low volumes. Irrigation, on the other hand, is supplied from surface waters or shallow groundwater but

In Tanzania particularly, the URT (2009) and the URT (2002) states that there are many types of water lifting and application technologies in use. They differ in scale, complexity and origin. For example, water lifting that was traditionally done by the “rope and bucket system” is now transitioning to the use of mechanized boreholes. With increased knowledge on energy sources, there are initiatives on developing renewable energy based systems such as wind and solar powered pumps. Water lifting technologies in use include; manual lifting by using bucket and cans, manual pumping (mainly treadle- and hand-pumps), motorized-pumps, wind and solar pumps and hydram-pumps. The use of motorized pumps has just recently been taken up by farmers in Tanzania, although it is reported 85% of the small-scale farmers are still using just buckets and watering cans (Keraita and de Fraiture 2012). Motor pumps are popular and have the potential of being adopted by many more farmers subject to accessibility. The use of efficient water lifting technologies could improve farmers control over their production systems by creating a reliable water supply for the irrigation systems especially where rainfall is erratic.

However, their actual potential to improve water management, agricultural productivity and household income is not well quantified and adoption rate and dynamics of water lifting technologies are not well understood. Technologies that can improve the efficiency of lifting and using water for irrigation can reduce waste and release more water for other sectors, particularly domestic use, and improve crop production. From the review, it is evident that water-lifting technologies in use by smallholder farmers in eastern Africa are limited in their application due to a combination of technical, economic, and social reasons. While reasons for the low rate of uptake efficient technologies are due to high purchase price, running-cost, and lack of support services for maintenance, repairs and spare-parts; there is a pressing need to identify opportunities, constraints and appropriate actions on water-lifting technologies, for agriculture, in the region. The successful use of surface and groundwater by resource-poor families depends greatly upon their access to appropriate water-lifting technologies and the availability of suitable sources of water.

2.2.2 Water lifting technologies
Generally, water-lifting technologies/devices can be grouped based on the source of energy as follows (Young 2013):

- Human-powered water-lifting devices.
- Animal-powered water-lifting devices
- Motorized pump sets.
- Devices powered by electric motors connected to remote electricity supplies.
- Renewable energy devices: sunshine, wind or waterpower.
• Biological energy sources.

In the context of this assignment, it is imperative to describe these groups with respect to availability to the users, energy requirement, and efficiency in water delivery, gender implications, needs for skills, costs and labour. Additionally, relevant study cases and stakeholders (suppliers, users etc.) in the region were visited for more detailed studies in terms of field visits, observations, in-depth interviews and analysis.

a) Human-powered water-lifting devices

There are many different types of human-powered water-lifting device in place. However, their efficiency is rarely measured or investigated, even by the developers and makers of the devices, possibly because the input energy is not easily measured. This is unfortunate, since human muscle-power has scarcity value (and thus economic value) as with any other kind of power, and is a critical resource for some farm families. As far as can be determined, the efficiency of human-powered water-lifting devices is variable, even among the modern types. Some people are unwittingly wasting a great deal of their time and effort lifting water with inefficient devices when more efficient ones are available.

• Buckets and cans

In this region, the simplest traditional way of lifting water is the carrying in buckets, gourds or other containers by hand. Water is lifted and, at the same time, transported and sometimes distributed to crops. When it serves all these purposes, it may be an appropriate technology for some situations.

This technology requires a considerable labor input in terms of time, which is highly dependent on the scale of the work to be done. In this regard, this technology has since not be very efficient way of lifting water especially in large-scale undertakings. Slightly more efficient is the shadouf, a long-established device in many parts of Asia and northern Africa. Other devices known in Asia and Africa include swing gourds and swing baskets, which are reported to be reasonably efficient and very cheap, although their output per operator is low. However, the efficiency is still hampered by time consumed and the smaller size of water. In the African context, simple manual work is done by women but the more muscles required it turns to the other sex (male). Water lifting can thus be women intensive or male depending on the volume to be carried or lifted. Generally, in this region the technology is more women oriented than male.

Regardless of its outdated nature, this technology is still in use in many rural settings. This then calls for further analysis on its efficiency gender implication and any other related aspects. To achieve the proposed analysis, field visit and in-depth interview was conducted with users in areas where this technology has since been practiced e.g. in the vegetable production areas of Meru district, in Arusha region.

• Treadle pumps

Probably the best-known group of modern human-powered devices is the wide range of treadle pumps (Figure 2.1). One type was developed in Bangladesh in the 1980s. It is very widely used there for relatively small suction lifts. Other types have been developed entirely in Africa. In Tanzania, there are three main types of treadle pumps used by farmers; the Money-Maker pumps, hip pumps and Concrete Peddle
Pumps (PEP). Most treadle pumps comprise two vertical-axis cylinders whose pistons are operated by two levers, called treadles, which one or two operators work with their feet. A mechanism causes the two pistons to operate alternately. The principle can be applied to a wide range of uses by varying the cylinder dimensions and the lever geometry: total heads range up to about 15 m, and discharges up to about 3 litres per second (l/s) (11 cubic metres per hour (m$^3$/h)). Useful power outputs can range up to about 100 W (AgWater solutions, 2011).

Most treadle pumps release water into furrows, as they have no delivery pressure. The ‘Super Money Maker’ treadle pump manufactured by ApproTEC in Kenya has a delivery pressure of about 10 meters, and thus can release water through a flexible pipe on top of the crops. A reasonably fit man between 20 and 40 years old can produce a steady power output of 70 Watts (= 0.1 hp). However it is not possible to convert all the 70 Watts into useful water pumped because of losses through friction in the pump, valves, and pipes. A useful water lifting power of 35 Watts is a reasonable estimation for a man operating a treadle pump. The discharge and head for a useful power of 35 Watts can be estimated to 3.6, 1.8, 1.2, and 0.9 l/sec for 1, 2, 3, and 4 m head, respectively, using the equation P = 9.81QH, where Q is discharge in litres per second (litres/sec).

**Figure 2.1:** A typical treadle pump in the region

Some treadle pumps are efficient and relatively cheap, though some are surprisingly inefficient. Information about particular treadle pumps apparently never state the input power needed or the efficiency, so it becomes impossible for potential users to find out how efficient the different models are. The treadling exercise is energy intensive. Literature reports the energy intensity might limit women to operate these pumps.

The treadle pump is ideal for areas where the water table is high, ranging from 3 to 7.5 m below the ground. Besides, most of the models of the treadle pump can be used for drawing surface water, such as from ponds, canals, streams and dug wells.

- **Hand pumps**

Hand pumps are widely used for small-scale water supply purposes but are occasionally used for irrigation. There is, however, a ground-level two-cylinder two-person hand pump, which can lift enough water for
small-scale irrigation. It appears not to be as efficient as a good treadle pump but may be appropriate for people, who for cultural or other reasons, are not able or willing to use a treadle pump. A rower pump is another kind of low-lift hand pump; a few prototypes have been tested in Africa but are not used on any significant scale. The rope and washer pump has an endless rope that draws a succession of round discs upward through a plastic pipe to lift water. In some models, developed and tested in Zimbabwe, the rope was driven by hand cranks, and the cost was kept low by using recycled materials such as old car tires. URT (2009) indicated this as may be one of the more efficient water-lifting devices, partly because it does not involve a reciprocating motion or valves, but it is not often used for irrigation.

One of the great merits of treadle and other human-powered water-lifting devices is their low cost relative to the motorized types. Many development efforts are aimed at achieving cheaper versions. Details information and analysis of these pump types require consultation with the suppliers and users.

b) Animal-powered water-lifting devices

Animal power has been used for lifting water since ancient times, especially in Asia, though these devices are now almost entirely superseded by motorized pump-sets. Various ingenious devices have been developed in African countries, but very few are still in service. It appears from the sparse data that the animal-powered devices have relatively low efficiencies. They are also quite expensive and mechanically complex, even if made of traditional materials such as wood and natural fibres. In most cases, farmers who have access to animal power are usually able to afford the more convenient and efficient modern alternatives; conversely, farmers who cannot afford modern motorized or renewable energy devices usually cannot afford animal power as well. Literature speculates that a large-scale development of animal-powered water-lifting in Africa is unlikely to emerge.

c) Motorized pump-sets

There are several types of motorized pump-sets available in Africa that burn fossil fuels: mostly gasoline or diesel, but sometimes kerosene (Figure 2.2). Information about the pump-sets is fragmented and incomplete, and they are often poorly matched to their applications. Recent tests done in West Africa covering heads of 4, 6, and 10 m at discharges of 2, 3, and 4 L/s, reported the tested pump-sets working at between 3 to 40% of their rated power. This illustrates the degree of mismatching of equipment to application that is common on all continents. For instance one of the tested diesel pump-set used about four times as much fuel as an efficient pump-set would, while most of the gasoline pump-sets were using more than seven times more fuel than an ideally matched gasoline pump-set, and the best of them more than four times. These very low overall pump-set efficiencies are reported to be caused by the fact that the engines are in most cases running on part load.
Researchers have suggested a number of possibilities to improve efficiency of this technology including; reducing fuel consumption through manipulation of the cooling system and paying extra attention to the idling adjustment and use of kerosene as a fuel for small pumpsets. Many gasoline engines can easily run on kerosene once they are warm, but they have to be started on gasoline, so they have to be modified to have two fuel tanks and a fuel-switching valve. There may be strong financial incentives for farmers to seek such engines, even though they cost somewhat more than normal gasoline pumpsets. From an economic (national) viewpoint, as opposed to the local financial, there may be little or no advantage in using kerosene instead of gasoline. Further suggestions were on the production and marketing of smaller engines, better matched to the common African applications than those marketed up until now. There is also an initiative to use pumps that are more efficient. In addition to ordinary diesel and gasoline-driven pumpsets, there are small numbers that use electricity for the transmission of power from engine to pump, via a generator and motor. These are usually for applications with a static lift of more than 7 m so that the pump needs to be below ground level. Technically this is a complicated and expensive compromise, but it may have advantages for a few users. Other motorized technologies include the Venturi jet pump and the airlift pump, but low efficiencies make these unattractive for most applications.

The International Programme for Technology and Research in Irrigation and Drainage (IPTRID) (Snell, 2004) has been associated with the development and testing of an engine-driven axial pump capable of delivering up to 18 L/s at very low heads, or 10 L/s at about 2.5 m suction head. All these pumpsets are often used in applications for which they are seriously overpowered, resulting in unnecessarily high running costs. Not surprisingly, in view of the above-mentioned fuel consumption comparisons, there are various reports of big reductions in pumping cost achieved by improved matching of device to application. It will be worthwhile to observe and if possible measure the in practice.
The problem of uncontrolled proliferation of individual irrigation (motor pumps) can lead to environmental damage (over-abstraction, degradation, pollution from agro-chemicals, and conflicts). Vulnerable groups may be harmed - better access, information and technology to richer users - raising the issue of gender and equity (ownership, sharing, water markets, rental). It is important that this effect be mitigated.

**Sustainability of motorized pump-fed irrigation**

In addition to poor efficiency, sustainability of motorized irrigation pumps is a big issue in Tanzania due to poor maintenance. There are several cases of farmers abandoning irrigated agriculture because they could not afford to replace their old worn out pump. This particularly occurs when pumps have been donated or subsidized and in group-based irrigation scheme with a relatively large number of farmers, from experience more than 30. This problem is not unique to motorized irrigation, it is very common with windmills. This is due to lack of shared responsibility, ownership, and lack of good saving practice for future breakdown and replacement (URT, 2009).

d) **Devices powered by electric motors connected to remote electricity supplies**

These devices can be suitable in places where there is a public supply of electric power near the farmland. It could be economically, financially and technically appropriate to drive small pumps by means of electric motors using the remote power supply. In African rural settings, however, there are not many such places. This type of water-lifting technology is little used for small-scale irrigation. It is, of course, more common for domestic water supply. Where such devices are used, the usual problems of matching the device to the application still arise, but they are not as significant as for the engine-driven pumpsets because electric motors are available for almost any power output.

Submersible axial pumps are easy to use when the power is a remote electric supply, which makes this category especially attractive where groundwater is deeper than 7 m. The technology of any pumpset involving electric-power transmission is significantly more complicated than that of the ordinary engine-driven pumps. Safety considerations are important. For these reasons, as well as cost and the limited availability of public electricity supplies, this category of water-lifting device is not considered likely to have much of an impact on small-scale irrigation in Africa. However, this aspect is subject to field observations.

e) **Renewable energy devices: solar, wind or waterpower**

These energy sources do not have the long-term and loss-free energy storage inherent in fossil fuels. The energy supply is therefore usually unreliable, while the equipment needed to capture and apply a useful amount of power to a pump is expensive.

Solar power is widely used for applications requiring relatively small power inputs at remote locations. Despite many years of intensive research attempting to develop cheap and robust solar energy gathering devices, they remain expensive relative to their power output. Both the energy source and the associated
equipment for bringing the energy to a pump or other load are quite delicate and sensitive. Experience of their use in remote locations for pumping potable water has been mixed, with pumpsets often out of operation for long periods awaiting repair or spare parts. Solar-powered devices must be kept on the list of potential technologies, hoping for future improvements in cost and robustness. In the meantime, they are not cost-effective for most but a few low-power and specialized applications, certainly not for water-lifting for small-scale irrigation.

**Solar water pumping systems.**

Solar pumping systems are commonly used for three applications; village water supply, livestock watering, and irrigation. Solar pumping technology continues to improve in terms of efficiency and price. In the early 1980s solar energy to hydraulic energy was 2%, photovoltaic (PV) efficiency was 6-8%, pumpset 25%. Currently solar energy to hydralic efficiency is > 4%, while PV monocrystalline type is 18%.

Solar powered water pumping systems have been recognized as suitable solution for grid-isolated rural areas especially in poor countries where solar insolation is high. Photovoltaic (PV) solar panels are often used for small-scale agricultural operations such as drip irrigation and livestock watering systems. Large scale agricultural application/irrigation requires pumping large volumes of water and this necessitates for large solar PV arrays which small-scale farmers can not afford. The majority of the pumps are fitted with a 200 watt - 3,000 watt motor that receives energy from a 1,800 Wp PV array. The larger systems can deliver about 140,000 litres of water/day from a total head of 10 meters.

A solar water pumping system (SWPS) for irrigation consist of the following minimum components:

1. Water source e.g. borehole or lake
2. Pipes
3. Storage tank
4. Tank floatation switch
5. Photovoltaic array (200 watt to 5 kWp recommended)
6. DC/AC motor (with brushes or brushless)
7. Pump
8. Pump controller
9. Battery bank (optional)
10. Inverter (optional but required if AC motors are used)
11. Solar tracking unit (optional but very important to maximize power)
12. Others e.g mounting, cables, On/Off switch etc

SWPS may also include an inverter, battery bank, and solar tracking unit, however, these translate to extra cost that most small-scale farmers can not afford.

**Pumps**
Solar water pumping system (SWPS) can use both DC and AC powered pumps. AC pumps are usually cheaper than their DC counterparts, however, for the case of solar, the use of AC pumps require inverters. Inverter significantly reduces the efficiency of an SWPS and should be avoided if possible. In addition, though the initial cost of an efficient DC pump (designed for PV power) is usually greater than an equivalent AC pump, the cost is usually regained in 5 to 10 years of operation as running and maintaining an AC pumps is costly. DC powered pumps are used for deep and shallow well pumping, stock tanks, and irrigation among others. DC pumps come in a variety of types. One of the most common is the small pressure booster pumps (Shurflo). Others include diaphragm and piston positive displacement pumps for wells, booster (pressurizing) pumps, circulating pumps, ground water sampling pumps etc. Solar DC low power pumps are suitable for low yield water source where conventional pumps may suck dry in minutes. Pumps fall along a spectrum of high-flow/low-head to low-flow/high-head. In other words, for a given power input, the pump produces a unique combination of flow and pressure. In selecting a pump one basically selects a combination of performance characteristics. Solar pumps are rated according to the voltage of electricity that should be supplied, for instance, 12 volt pump (which is the smallest for irrigation), 24 volt (the common one for small-scale irrigation), and 48 volts and larger. Some pumps require certain accessories to function optimally. These include filters, float valves, switches, etc.

**Solar Powered Pumpset**

i) **Submerged multistage centrifugal pump:** This is the most common type of solar pump used for irrigation. The advantages of this configuration are that it is easy to install, often with lay-flat flexible pipework, and pumpset is submerged away from potential damage. Either AC or DC motors can be incorporated, though an inverter would be needed for AC system. If brushed DC motor is used then it need to be pulled out after like 2 years for the brushes to be replaced. Brushless DC motor would require electronic commutation.

ii) **Submerged pump with surface mounted motor:** This configuration gives easy access to the pump motor for brush change and other maintenance. It has low efficiency due to power loses in the shaft bearing and has high cost of installation.

iii) **Reciprocating Positive Displacement pump:** Commonly known as the jack or nodding donkey. It is very suitable for high head and low flow application. The output is proportional to the speed of the pump. At high heads the frictional forces are low compared to hydrostatic forces hence they are more efficient than centrifugal pumps. These pumps create a cyclic load on the motor, which for efficient operation needs to be balanced. Therefore power controllers for impedance matching are often used.

iv) **Floating motor pump:** This pump is versatile and is ideal for irrigation pumping from canals and open wells. It is portable and they have little chance of running dry. Most common type uses brushless DC motor. Often the PV panel array has a handle or a wheel barrow-type trolley for transportation.
v) **Surface suction pump:** This pump is not recommended if the operator is not always present. It experiences self-start and priming problems even with primary chambers and non-return valves. Impractical for heads more than 8 meters.

**Pump Controllers**

Solar pumps require a linear current booster, usually referred to as controller, if they are to be powered directly by PV array. The purpose of pump controllers is to maximize the daily water delivery. They work by boosting the current, especially under low light conditions, cloudy days, and early morning or late evening. The voltage output of the PV panels is often too low to run a pump under these conditions, so the controller boosts the voltage enough to run the pump. In effect, these act like a perfect "gearbox", and match the output of the panels to the pump. Controllers typically increase water flow by 25 to 50% over the day. Secondly, a controller provides a low voltage protection, whereby the system is switched off, if the voltage is too low or too high for the operating voltage range of the pump. This increases the lifetime of the pump thus reducing the need for maintenance.

**Photovoltaic (PV) Array**

Photovoltaic (PV) panels: The photovoltaic panels make up most (up to 80%) of the systems cost. The size of the PV-system is directly dependent on the size of the pump, the amount of water that is required (m³/d) and the solar irradiance available. A panel is rated in watts of power it can produce. The SPV water-pumping systems are normally operated with PV array capacities in the range of 200 to 5000 Watts peak, measured under Standard Test Conditions (STC). Sufficient number of modules in series and parallel is used to obtain the required PV array power output. 5000 Watts peak PV array can deliver more than 140,000 liters of water/day from a total head of 10 meters.

**Pipes**

The commonly used pipes are the flexible black polyethylene pipes with at least a 100 PSI rating. This flexible pipe allows easy installation and removal by hand, without the need to disassemble joints. In most cases, 1/2 inch diameter pipe are used. Minimum pipe diameter is recommended for low power solar pumps since small pipe allows the water to flow at a higher velocity, so that sand or sediment is be exhausted from the pipe. With large pipe diameter, the water flows slowly that the sand settles within the pipe. When sand accumulates, it causes abrasion and pump problems. In addition, low power solar pumps usually have problems to start with large diameter pipes.

**Storage Tank**

Because of the low flow capacity of solar DC pumps, water must be accumulated in a tank so that it can be released on demand. There are three ways to do this: (1) pumping directly to a tank, (2) using storage tank with a booster pump and pressure tank, or (3) using an elevated storage tank with gravity flow.

**Initial Cost of Solar Water Pumping System**
The initial investment cost of solar pumping system is dictated by water demand, head and hence the panels and the pumpset. For instance, a solar pumping system to pump 25m³/day at 20 m head requires PV array of about 800 Wp. This translates to about USD 6000. The cost especially that of the pumpset, could vary from USD 800 to 2000 depending on the application.

**Performance of Solar Pumping System**

The output of a solar pumping depends on good system design. Good system design depends on; i) accurate site data on available solar resource; ii) water demand/ pattern of use; iii) well yield; and iv) expected water level drawdown.

**Solar Pumping System Design Steps.**

While designing a solar water pumping system, the following steps are important namely;

- **STEP 1:** Determine basic amount of water required per day OR the flow
- **STEP 2:** Determine the total dynamic head OR the pressure
- **STEP 3:** Determine solar insolation of the site
- **STEP 4:** Select pump, controllers, solar array
- **STEP 5:** Select the right solar array mounting method
- **STEP 6:** Select the right cables and pipes

**Determining the flow needed:** Flow is the amount of water needed or how much water is needed to irrigate in one minute or one hour.

**Determining the pressure:** The pressure to be determined is the total pressure in psi or head (m) including:

i) Pressure needed to overcome elevation difference which is the difference between level of source and the discharge.

ii) Pressure required to force water through any filter, special valve etc

iii) Pressure to overcome frictional loss in the piping

**Selecting the pump:** Pumps are rated to produce a certain flow at a certain pressure when supplied with a certain amount of power. Sizing the pump to get the right flow and per the amount of power available is shown in the section that follows.

**Sizing solar pumps**
The hydraulic energy required (kWh/day) is given by:

\[
\text{Hydraulic energy (kWh/day)} = \frac{(\text{volume required (m}^3/\text{day}) \times \text{head (m)} \times \text{water density} \times \text{gravity})}{(3.6 \times 10^6)} = 0.002725 \times \text{volume (m}^3/\text{day}) \times \text{head (m)}
\]

The solar array power required (kWp) is given by:

\[
\text{Solar array power (kWp)} = \frac{[\text{Hydraulic energy required (kWh/day)}]}{[\text{Av. daily solar irradiation (kWh/m}^2/\text{day}) \times F \times E]}
\]

where \( F = \) array mismatch factor = 0.85 on average and \( E = \) daily subsystem efficiency = 0.25 - 0.40 typically

**Wind powered water-pumping systems (WPWPS)**

Wind power is a non-polluting renewable energy resource that can be harnessed where access to power lines is not practical. Wind energy is an abundant source of renewable energy that can be exploited for pumping water in remote locations, and windmills are one of the oldest methods of harnessing wind energy to pump water.

Wind power has been used extensively for centuries to lift water, usually for pumped drainage in places with very flat land and persistent winds. Relative to their water-lifting output, both ancient and modern wind-powered devices are large and expensive in comparison with other currently available technologies. They tend to be unreliable, or at least to need a good deal of attention and maintenance. An additional factor is the regional and seasonal availability of strong winds. For much of the time, wind speeds are not very high over most of the cultivable African lands. Thus, although its scope as an intermediate technology must not be ignored, and some modern developments have improved outputs, the potential use of wind power for water-lifting in African settings is yet to be fully explored.

**Water delivered by wind-powered pump**

The amount of water a wind-powered water pumping system can deliver depends on the speed and duration of the wind, the size and efficiency of the rotor, the efficiency of the pump being used, and how far the water has to be lifted. The power delivered by a windmill can be determined from the following equation:

\[
P = 0.0109D^2V^3\eta
\]

Where \( P \) is power in watts, \( D \) is the rotor diameter in metres, \( V \) is the wind speed in kilometres per hour, and \( \eta \) is the efficiency of the wind turbine.

As can be seen from this expression, relatively large increases in power result from comparatively small increases in the size of the rotor and the available wind speed; doubling the size of the rotor will result in
a four-fold increase in power, while doubling the wind speed will result in an eight-fold increase in power. However, the efficiency of wind turbines decreases significantly in both low and high winds, so the result is that most commercially-available windmills operate best in a range of wind-speeds between about 15 km/hr and 50 km/hr.

Types of windmills

There are two types of windmills, with the classification depending on the orientation of the axis of rotation of the rotor blades. Vertical-axis wind turbines are efficient and can obtain power from wind blowing in any direction, whereas horizontal-axis devices must be oriented facing the wind to extract power. Most windmills for water-pumping applications are of the horizontal-axis variety, and have multi-bladed rotors that can supply the high torque required to initiate operation of a mechanical pump. The rotor blade can be made from metal or cloth and wood. Wooden and cloth type windmills are common with poor small-scale farmers in East Africa. The tower on the other hand is made from either wood or steel with wood being the best choice for poor farmers. Though steel is expensive, it has good mechanical strength and this allows for sufficiently tall towers/masts that can harness wind of high speed as the speed of wind increases with altitude.

Materials of Construction and the amount of torque generated

The tower could be made from wood, concrete and metal while the rotor/windmill head could be made from metal, plastic, cloth, carbon fibre, and fibreglass. The cost and the life time of the wind pumping are heavily depended on the material of construction.

The amount of torque generated for pumping water increases with the diameter of the rotor, the speed of the wind, the solidity of the rotor (which is the ratio of the area covered by the blades to that of the rotor), and the height of the mast/tower.

Types of wind powered water pumps

Three types of wind powered water pumps are commonly used. Two of them use mechanical power to pump water, while the third converts wind power to electrical energy. (i) Mechanical—piston pump—This system converts rotary wind power to vertical motion, using a snake rod and a piston pump to lift water; (ii) Mechanical—air lift pump—This system uses wind power to charge a compressor that pumps air to lift water; (iii) Electrical pump—The electrical pumping system channels the energy generated directly to the water pump, and/or to a battery storage system. Batteries account for more than 20% of the total capital investment, so these system may not be affordable to small-scale farmers. However, farmers’ association may be able to manage such as system.

Choosing a site for a windmill

The main consideration in choosing a site for a windmill is whether there is sufficient wind. Obtaining site-specific measurements of wind speed and duration during the period over which water pumping is
required is therefore imperative and the only reliable way of determining whether a wind powered pumping unit will be a viable option. Inadequate evaluation of available wing resource in terms of speed and duration is one of the primary reasons for the failure of many windmill systems for irrigation in Tanzania. Though hand-held anemometers are normally used to take wind speed measurements, a better way of gathering wind data would be to mount an anemometer (with an automated data recording device) on a tower similar in height to the proposed windmill for the entire period of interest. This is hardly done in Tanzania and hence most of the installed windmills do not perform as per expectations.

![Local material in wind-powered water lifting technology](image)

**Figure 2.3:** Local material in wind-powered water lifting technology (Source: SESEDO)

All these renewable energy sources are in principle attractive to resource-poor people because the energy itself comes without financial cost or muscle-work (Figure 2.3). They should all be included in any inventory of relevant technologies. Nonetheless, the high initial costs, and the limitations mentioned here, mean they are unlikely to have a positive impact on livelihoods in the context of Africa in the next few decades. Research into these technologies continues, because of the commercial and economic potential for developed countries. Therefore, it would be cost-effective to pursue fundamental research into such technologies especially for African water-lifting applications.

Nonetheless, there are several efforts on the ground that worth observation and analysis under this assignment. The review team visited Sustainable Energy Services and Environmental Development Organisation (SESEDO, 2010) and Swedish Cooperative Center-Vi Agroforestry Training Center (Salomonsson and Thoresson, 2010) wind energy irrigation projects in Musoma and Magu respectively in the Lake zone. Details are provided below in section three

**Table 2.2:** Comparison of Pumping Technologies

<table>
<thead>
<tr>
<th>Pump technologies</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| Hand pumps                          | • Local manufacture is possible.  
  • Easy to maintain  
  • Low initial capital  
  • No fuel cost  
  • No noise and pollution | • Loss of human productivity  
  • Often an inefficient use of boreholes  
  • Only low low flow rates are achievable |
|------------------------------------|--------------------------------------------------------------------------------|
| Animal driven pumps                | • More powerful than humans  
  • Lowers wages than human power  
  • Dung may be used for as fuel for cooking | • Animals require feeding all year round  
  • Often diverted to other activities at crucial irrigation periods |
| Hydraulic pumps (rams)             | • Unattended operation  
  • Easy to maintain  
  • Low cost  
  • Long life  
  • High reliability  
  • No noise and pollution | • Require specific site conditions  
  • Low output |
| Wind pumps                          | • Unattended operation  
  • Long life  
  • Some suited for local manufacture  
  • No fuel is needed  
  • No noise and pollution | • Water storage required during low winds  
  • High system design and maintenance, planning needs  
  • Not easy to install |
| Solar PV pumps                      | • Unattended operation  
  • Low maintenance  
  • Easy to install  
  • Long life  
  • No noise and pollution | • Relatively high initial cost depending on size  
  • Water storage is required during cloudy periods  
  • Repaired often require skilled technicians |
| Diesel and gasoline pumps           | • Quick and easy to install  
  • Low initial capital  
  • Can be portable | • Fuel supply erratic and expensive  
  • High maintenance cost  
  • Short life expectancy  
  • Noise and fume pollution |

Estimated Initial Investment Cost of Solar PV, Wind, Diesel Powered Water Pumping Systems with 6-inch pumpsets
The initial investment cost of a water pumping system is generally dictated by water demand, head and pumpset. Depending on the energy used, however, the initial cost is also dependent on other factors such as the component(s) for harnessing/extracting energy and/or controlling power. For instance, in solar PV powered water pumping systems, the initial investment cost is heavily dependent on the panels, pump controller, solar trackers, and inverters while for wind systems, the cost is dictated by the tower (mast) and the rotor. Tables 2.3 - 2.5 give the estimated initial investment cost of the diesel, solar PV, and wind powered water pumping systems with 6-inch pumpset.

**Table 2.3:** Estimated Initial Cost of a 6-inch Diesel Water Pump (4.9 m$^3$/h flow rate at 31 m head pressure.

<table>
<thead>
<tr>
<th>Item</th>
<th>USD</th>
<th>TShs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel Engine 6 Inch Diesel Water Pump</td>
<td>500</td>
<td>835,000</td>
</tr>
<tr>
<td>Installation</td>
<td>180</td>
<td>300,600</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>680</td>
<td>1,135,600</td>
</tr>
</tbody>
</table>

**Table 2.4:** Estimated Initial Cost of a Solar Water Pumping System Capable of Delivering 5 m$^3$/h Flow Rate at an Head Pressure 28 m

<table>
<thead>
<tr>
<th>Item</th>
<th>USD</th>
<th>TShs</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 PV panels (200 W each)</td>
<td>850</td>
<td>1419500</td>
</tr>
<tr>
<td>24V DC stainless steel solar deep well pump</td>
<td>1,100</td>
<td>1837000</td>
</tr>
<tr>
<td>Pump controller</td>
<td>750</td>
<td>1252500</td>
</tr>
<tr>
<td>PV mounting</td>
<td>250</td>
<td>417500</td>
</tr>
<tr>
<td>wiring and brackets</td>
<td>300</td>
<td>501000</td>
</tr>
<tr>
<td>Installation</td>
<td>700</td>
<td>1169000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>3,950</td>
<td>6596500</td>
</tr>
</tbody>
</table>

**Table 2.5:** Estimated Initial Cost of a 4 m Rotor Diameter, 9 m Mast Windmill with 6-inch Pump Capable of Delivering 6.4 m$^3$/h Flow Rate at an Head Pressure of 28 m.

<table>
<thead>
<tr>
<th>Modern Windmill (all metal)</th>
<th>Made from Local materials (wood and cloth)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item</td>
<td>USD</td>
</tr>
<tr>
<td>------</td>
<td>-----</td>
</tr>
<tr>
<td>Item</td>
<td></td>
</tr>
</tbody>
</table>
Flow Rate and Head pressure for the Diesel, Solar PV, and Wind Powered Water Pumping Systems Selected

The diesel water pump, model AHD30C selected in this review is able to deliver 4.9 m³/h at a head pressure of 31 m based on the manufacturer’s specifications. On the other hand, the solar-powered pump selected in this review is able to deliver 5 m³/h at an head pressure of 28 m assuming performance ratio of 0.85 to 1; standard solar irradiance of irradiances of 1000 W·m⁻²; and 250 watt peak. However, the actual duration of pumping of water on a particular day and the quantity of water pumped could vary depending on the solar intensity, location, season, etc. For an average daily solar radiation of 7.15 KWh/m² on the surface of PV array, the 24V DC solar pump selected in this review would deliver 8.75 m³/h per 250 watt peak at ahead pressure of 30 m.

For the case of the wind system, the mast (elevation of the windmill head) and the rotor diameter should be such that the mill will start pumping in light breezes of under 12 k. m. p. h. Since the average wind speed in most parts of Tanzania is 12 k. m. p. h, the tower height and rotor (windmill head) diameter chosen in this review would enable the syphon pump-side discharge (6 inch) to deliver 6.4 m³/h at a head pressure of 28 m.

Total Life Cycle Cost (LCC) Analysis for Solar PV, Windmill, and Diesel Powered Water Pumping Systems (25 years projection)

Economic viability of solar water pumping system, diesel generator technology and windmill was investigated by using life cycle cost (LCC) as given in the equation 1 below.

\[ LL = CC + OM + R + F \]  \( \text{(1)} \)

Where, \( CC \) is the Initial capital costs (these are investment costs of any project that includes feasibility studies, system design costs, and equipment purchase, transportation and installation); \( OM \) is the
Operation and maintenance costs (all costs that involve maintenance and operation of the project for example administrative, wages, and transport costs); $R$ is the Replacement costs (the costs to buy spare parts and the repair of equipment); $F$ is the Fuel costs (the costs that consider the market value of the annual costs of a given fuel) (Woodruff, 2007).

Replacement cost for the pump and pump controller was calculated using equation 2

$$R = C (1 + i)^{n-1} \quad (2)$$

Where, $R$ = future cost, $C$ = Current cost, $i$ = inflation rate. $n$ = life span (Ardalan, 1999).

Net present value was calculated using equation 3

$$\text{NPV}_c = P_w + Fn (P/Pn,dn)$$

Where, $\text{NPV}_c$ is the Net Present cost; $P_w$ is initial cost ; $Fn$ is the future cost while $d$ is discount rate (Ardalan, 1999)

(a) LCC for PV Solar Water Pumping System.

For a period of 25 years, only the pump controller and the pump will be replaced for both have a lifetime of 8 to 10 years. Replacement is calculated as shown below. For one to cost pump systems of exactly same capabilities in terms of discharge and head, one must be ready to design them from the scratch or request manufacturers to customize. What is possible for our case, and that's what have done, is looking for pumps with comparable systems in the market and cost them.

(i) Replacement of the pump.

$$F_{\text{pump (PV)}} = Tshs 1837000 (1 + 0.065)^{10-1} = Tshs 3237841.8$$

For 25 years, cost of pump = $(Tshs 3237841.8 \times 25)/10 = Tshs 8094604$

$$\text{NPV}_{c \text{(pump)}} = 3237841.8 + (8094604 \times 0.1264) = Tshs 4,260,998.8$$

(ii) Replacement of the pump controller.

$$F_{\text{pump controller}} = Tshs 1252500 (1 + 0.065)^{10-1} = Tshs 2207619.4$$

For 25 years, cost of pump controller = $(Tshs 2207619.4 \times 25)/10 = Tshs 5519047$

$$\text{NPV}_{c \text{(pump controller)}} = 2207619.4 + (5519047 \times 0.12645) = Tshs 2,905,226.4$$

(iii) Maintenance: Assume maintenance cost is 3 times initial cost of the pump. This translates to
3 x 1837000 = Tshs 5,511,000

It is worth noting that total life cycle cost (TLCC) of a project is the sum of initial investment, replacement, fuel, and maintenance costs. Therefore the TLCC of the solar PV water pumping system (SPVWPS) without consideration of salvage value is given by;

TLCC\(_{(SPVWPS)}\) = 6,596,500 + 2,905,226.4 + 4,260,998.8 + 5,511,000 = Tshs 19,273,725.2

(b) LCC for Wind Powered Water Pumping System

For a period of 25 years, only the pump will be replaced for it has a lifetime of 8 to 10 years. Replacement is calculated as shown below.

(i) Replacement of the pump.

\[ F_{\text{pump - wind}} = \text{Tshs } 534,400 \times (1 + 0.065)^{10-1} = \text{Tshs } 941,917.6 \]

For 25 years, cost of pump = \((\text{Tshs } 941,917.6 \times 25)/10 = \text{Tshs } 23,547,940\)

\[ \text{NPV}_{c\,(\text{pump-wind})} = 941,917.6 + (23547940 \times 0.1265) = \text{Tshs } 12,397,990 \]

(ii) Maintenance. Assume maintenance cost is 3 times initial cost of the windmill. This translates to

3 x 45,925,000 = Tshs 137,775,000

Total life cycle cost of the wind powered water pumping system (WPWPS) without consideration of salvage value is given by;

TLCC\(_{(WPWPS)}\) = 50,100,000 + 137,775,000 + 12,397,990 = Tshs 200,272,990

(c) LCC for 6-inch Diesel Powered Water Pumping System.

For a period of 25 years, both the pump and diesel motor (which come as one unit) will be replaced as for the unit has a life time of 10 years. Replacement is calculated as shown below.

(i) Replacement of the pump.

\[ R_{\,(\text{diesel pump})} = 835,000 \times (1 + 0.065)^{10-1} = \text{Tshs } 1,471,746 \]

For 25 years, cost of pump = \((\text{Tshs } 1471746 \times 25)/10 = \text{Tshs } 3,679,365\)

\[ \text{NPV}_{c\,(\text{diesel pump})} = 1471746 + (3679365 \times 0.1265) = \text{Tshs } 1,937,185 \]
(ii) **Maintenance:** Assume maintenance cost is 3 times initial cost of the pump. This translates to

\[3 \times 835,000 = \text{Tshs 2,505,000}\]

(iii) **Fuel cost for the 6-inch pump**

5 gallons of diesel runs a pump for 1 round of irrigation in an acre (onion needs 10 rounds to harvest based on information from field visits. Bulb onions take between 100 to 175 days to mature. This translates to 2 planting seasons of taking 350 days (i.e. 175 days \(\times\) 2) per year.

Total amount of diesel required for 2 planting seasons = 5 gallons \(\times\) 10 \(\times\) 2 = 100 gallons

For one year, total fuel consumption = 5 gallons \(\times\) 10 \(\times\) 2 = 100 gallons.

1 gallon of diesel = 4.546 litres, so total amount in litres = 100 \(\times\) 4.546 = 454.6 litres

Taking Tshs 2500 as diesel price per litre. Total cost per year = 454.6 L \(\times\) 2500 = Tshs 1136500. If this machine operates for a life time of 25 years, its fuel cost in the given duration is calculated by using

\[F = C (1 + i)^{-n}\]

\[F = 1136500 (1 + 0.065)^{25-1} = \text{Tshs 5,151,812}\]

\[\text{NPV}_{c(fuel)} = 1136500 + (5151812 \times 0.1265) = \text{Tshs 1,788,204}\]

Total life cycle cost of the diesel pump system without consideration of salvage value is given by:

\[= 1,135,600 + 2,505,000 + 1,788,204 + 1,937,185 = \text{Tshs 7,365,989}\]

---

**Table 2.6:** Comparison of Total Life Cycle Cost for Solar PV versus Windmill versus Diesel Generator (25 years projection).

<table>
<thead>
<tr>
<th>Cost</th>
<th>Solar PV</th>
<th>Windmill (modern)</th>
<th>Diesel generator</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>USD</td>
<td>TShs</td>
<td>USD</td>
</tr>
<tr>
<td>Initial Capital</td>
<td>3,950</td>
<td>6,596,500</td>
<td>30,000</td>
</tr>
<tr>
<td>Replacement</td>
<td>4,291.1</td>
<td>7,166,225.2</td>
<td>7,424</td>
</tr>
<tr>
<td>Maintenance</td>
<td>3,300</td>
<td>5,511,000</td>
<td>82,500</td>
</tr>
<tr>
<td>Fuel</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

---

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Note: Though diesel water looks economically viable from this analysis, the picture might be different if other crops are considered, and actual fuel consumption is factored in. The fuel consumption used was based on farmers information (Rate used in calculation: 1 USD = 1670, this was the rate when we started this review)

Table 2.7 Comparison of Solar PV, Wind, and Diesel Water Pumping Systems in terms of Initial Cost, Cost after 25 years, Flow Rate, and Head.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Solar PV</th>
<th>Windmill (modern)</th>
<th>Diesel generator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial cost (Tshs)</td>
<td>6,596,500</td>
<td>50,100,000</td>
<td>1,135,600</td>
</tr>
<tr>
<td>Estimated cost after 25 yrs of operation (Tshs)</td>
<td>19,273,470</td>
<td>200,273,080</td>
<td>7,364,700</td>
</tr>
<tr>
<td>Flow rate (m$^3$/h)</td>
<td>5 m$^3$/h</td>
<td>6.4 m$^3$/h</td>
<td>4.9 m$^3$/h</td>
</tr>
<tr>
<td>Head (m)</td>
<td>28 m</td>
<td>28 m</td>
<td>31 m</td>
</tr>
</tbody>
</table>

2.2.3 Comparison of selected water-lifting technologies

Based on the scorecard in Table 2.7, solar PV water pumping technology passes most of the criteria compared to the rest. It is therefore more likely to perform much better in Northern Tanzania than the other technologies.

Table 2.8: Water Lifting Technology choice Score card.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Solar PV</th>
<th>Windmill (modern)</th>
<th>Diesel generator</th>
<th>Treadle pump</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial costs</td>
<td>Tshs 6,596,500 to 10,020,000 (USD 3,950 to 6000)</td>
<td>Tshs 50,100,000 to 58,450,000 (USD 30000 to 35000)</td>
<td>Tshs 1,135,600 to 18812550 (USD 500 to 11265)</td>
<td>Tshs 75,150 to 334000 (USD 45 to 200)</td>
</tr>
<tr>
<td>Closeness of technology</td>
<td>Fit with the application and good for all water sources, deep borehole to shallow rivers/canal</td>
<td>Fit with the application but not good for small and shallow water sources</td>
<td>Fit with the application but not good for boreholes</td>
<td>Fit with the application but not good for boreholes</td>
</tr>
<tr>
<td>Reliability</td>
<td>Very reliable and long life</td>
<td>Not reliable, pump rods break frequently due to friction</td>
<td>Reliable</td>
<td>Reliable</td>
</tr>
<tr>
<td>----------------------</td>
<td>----------------------------</td>
<td>-------------------------------------------------------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>Energy used</td>
<td>Solar energy</td>
<td>Wind energy</td>
<td>Fossil fuel energy</td>
<td>Human energy</td>
</tr>
<tr>
<td>Efficiency</td>
<td>High &gt;75% for all sources of water, boreholes and shallow wells</td>
<td>50 – 75%. Efficient for borehole, large rivers and lakes</td>
<td>30-50%. Inefficient for borehole.</td>
<td>&lt;30%. Inefficient for borehole. Only low flow rates can be achieved</td>
</tr>
<tr>
<td>O&amp;M costs</td>
<td>Low maintenance</td>
<td>Medium to high maintenance</td>
<td>Low maintenance</td>
<td>Very low maintenance</td>
</tr>
<tr>
<td>Availability of parts</td>
<td>Available but most parts are not locally made.</td>
<td>Not readily available especially for modern (all-metal) windmills. But readily available if cloth and wood is used</td>
<td>Available but most parts are not locally made.</td>
<td>Readily available as most parts are locally made.</td>
</tr>
<tr>
<td>Repair skills</td>
<td>Require skilled technician</td>
<td>Require skilled technician</td>
<td>Require skilled technician</td>
<td>Does not require skilled technician</td>
</tr>
<tr>
<td>Convenience of use</td>
<td>High</td>
<td>Medium to high</td>
<td>Medium to high</td>
<td>Low</td>
</tr>
<tr>
<td>Fit to users habits</td>
<td>High fit for all gender</td>
<td>High fit for all gender</td>
<td>Medium to Low. But not suitable for all gender especially if it has to be moved around</td>
<td>Low fit. But not suitable for all gender especially if it has to be moved around</td>
</tr>
<tr>
<td>Portability</td>
<td>Portable as it can be configured in a movable trolley,</td>
<td>Not portable at all</td>
<td>Portable</td>
<td>portable</td>
</tr>
</tbody>
</table>

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2.3 Water delivery technologies

Irrigation water delivery system can be open canal (lined or unlined) or buried-pipe distribution systems. The delivery system can be privately owned or managed by groups. It can also be centralized that is publicly operated by delegated agency. Centralized systems normally consist of large water abstraction and large network of distribution canals.

2.3.1 Open irrigation canals

Open channel are the most common method of irrigation water delivery to command areas (over 40% of the world's irrigation water supply is dependent on open channel). Open channel can be constructed in the form of lined or earthen canals. Earthen canals are simply dug in the ground and the bank is made up from the removed earth. In Tanzania earthen canals (often referred to as furrows or *mferiji* in Swahili) is the oldest irrigation system (see for instance studies on establishment of irrigated agriculture at Engaruka in Manyara region); it has been used by smallholders' farmers throughout the country. However, since the colonial times this form of irrigation water delivery has been considered wasteful, and highly inefficient (most quoted efficiency is 15%). Past attempts to 'modernize' them e.g. by lining, and installing control gates have not improved water use efficiency in the system (Figure 2.4). It is important to note here that the problem is likely to be compounded by poor on farm application practices.

![Figure 2.4: Traditional and improved irrigation canal found in the Pangani.](image)

Reducing conveyance loses by lining of the furrows may not lead to water saving at the level of the entire irrigation system or basin, as any recovered loses may already be in used downstream. It is important that any attempt to modernize irrigation infrastructure should start at the farmers plot and slowly crawl to the water intake.

2.3.2 Buried pipelines

Introducing buried pipe irrigation system in place of surface canals can simplify water management and significantly reduce conveyance loses (Figure 2.5). Buried pipe distribution systems for surface irrigation have been argued presents an intermediate solution between lower-cost earthen channels and the more
expensive sprinkler and drip systems (Kay, 2001). Kay (2001) list buried pipelines benefits to include: a) makes water delivery demand driven rather than supply oriented. Pipe systems respond rapidly to changes in water demand; b) it reduces wastage, allows greater flexibility and reliability of supply; c) short water transit times enable water to be moved around a command area more rapidly than with channels; and d) less land is taken up with the irrigation system. However, the investment costs of pipes systems are relatively high. Although cost saving can be made from its low operation and maintenance requirements. Buried pipes are suited for water scarce areas and could be recommended.

Figure 2.5: Buried pipes used by TPC in Moshi (LHS) and for domestic supply in Usa river.

Information on buried pipes irrigation projects in Tanzania is very limited. Under the Traditional irrigation improvement project (TIP) some earthen irrigation canals were converted to pipe-system in Chome village, Same district. The project will be visited to gain first-hand experience of farmers using buried pipes in the region.

2.3.3 Comparison of the conveyance system used by smallholder irrigators

Table 2.8 compares the three conveyance systems used in irrigation water delivery. The comparison is based on a hypothetical canal of 1.2 m wide by 0.5 m deep and side wall thickness of 0.2 m while the bottom thickness is 0.75 m. Using current market prices for labour and local material (e.g. cement, sand, stone etc) we derived the unit cost per metre of lining the canal in concrete and stone masonry (or pitching). Unlined canals we used the prevailing labour cost to excavate one metre of a canal with the above dimensions. Buried pipe cost were derived from Plasco Ltd who dealing in pipes of diverse specifications. The results are summarised in the table below. If investment cost is not considered, the choice of suitable and efficient conveyance technology for smallholder farmers would be (in the order high to low suitability): buried pipes, concrete lined canals, stone mason canals, and unlined canals. However, where cost is a major factor one can consider going for concrete lined canals. Looking at other issues like fit for purpose, closeness of the technology, low operation and maintenance costs, efficiency of conveyance, corruption and reliability, buried pipes should be the preferred water conveyance options. An important factor to consider is the source water, if it is groundwater we strongly recommend the use of buried pipes. One cannot spend energy in pumping and then allow the water to disappear through high conveyance loses on the way.
Table 2.8: Comparison of open unlined and lined canals and buried pipes.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Unlined canals</th>
<th>Concrete lined canals</th>
<th>Stone mason canals</th>
<th>Buried pipes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial costs</strong></td>
<td>Tsh. 2000 - 5000 (USD1-3) per metre</td>
<td>Tsh.30,000 (USD17) per metre</td>
<td>Tsh. 35,000 (USD20) per metre</td>
<td>PN6 (160mm HDPE Tsh. 36,900 per m or USD20.50; 160mm PVC Tsh. 24,500 per m or USD13.61)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>PN6 HDPE (180mm costs Tsh 45,600 per m or USD25.33; 200mm costs Tsh 55,800 per m or USD31.00; 250mm costs Tsh 88,800 per m or USD49.33)</td>
</tr>
<tr>
<td><strong>Closeness of technology</strong></td>
<td>Fit with the application but very wasteful</td>
<td>Fit with the application</td>
<td>Fit with the application</td>
<td>Fit with the application</td>
</tr>
<tr>
<td><strong>Reliability</strong></td>
<td>Unreliable, easily destroyed by floods</td>
<td>reliable</td>
<td>reliable</td>
<td>Very reliable and can respond to demand</td>
</tr>
<tr>
<td><strong>Energy used</strong></td>
<td>No energy input needed when under gravity</td>
<td>No energy input needed when under gravity</td>
<td>No energy input needed when under gravity</td>
<td>No energy input needed when under gravity</td>
</tr>
<tr>
<td><strong>Efficiency</strong></td>
<td>Very inefficient, only 15-25%</td>
<td>Efficient 70-80%</td>
<td>60-70%</td>
<td>90%</td>
</tr>
<tr>
<td><strong>O&amp;M costs</strong></td>
<td>High labour input for maintenance</td>
<td>Low maintenance cost</td>
<td>Low maintenance cost</td>
<td>Very low maintenance cost</td>
</tr>
<tr>
<td><strong>Availability of parts</strong></td>
<td>Use simple farm tools e.g. hoes, spades, machetes etc</td>
<td>Use simple farm tools e.g. hoes, spades, machetes etc</td>
<td>Use simple farm tools e.g. hoes, spades, machetes etc</td>
<td>Parts available but quality varies</td>
</tr>
<tr>
<td><strong>Repair skills</strong></td>
<td>Low skills requirement</td>
<td>Masonry skills required</td>
<td>Masonry skills required</td>
<td>High skill requirements – water technicians</td>
</tr>
<tr>
<td><strong>Convenience of use</strong></td>
<td>Low</td>
<td>Medium – high, when control gates are included it is very convenient</td>
<td>Medium - high when control gates are included it is very convenient</td>
<td>High, can respond quick and easy to automate</td>
</tr>
<tr>
<td><strong>Fit to users habits</strong></td>
<td>Medium but not so suitable for all gender</td>
<td>Medium but not so suitable for all gender. Can improve with control gates</td>
<td>Medium but not so suitable for all gender. Can improve with control gates</td>
<td>High but not so suitable for all gender. Can improve with control gates</td>
</tr>
</tbody>
</table>
2.4 On farm water application technologies

Common on-farm water application practices include flood irrigation, sprinkler irrigation, furrow irrigation and buckets and cans. The review as presented here is not to provide leverage to any technology over the other; however, it seeks to uncover important element in each technique that can be promoted.

2.4.1 Drip irrigation system

Drip or trickle irrigation involve dripping water at very low rates (2-20 L/h) from a system of small diameter plastic pipes fitted with outlets called emitters or drippers (Brouwer et al., 1988). Water is delivered directly into the immediate vicinity of the plant, allowing uniform distribution of water and better application of nutrients (fertigation) thereby improving crop yield (Benouniche et al., 2014). Burney et al., (2010) report that yield gains can go up to 100% and water savings of up to 40–80%. Drip irrigation water use efficiency is often quoted to be in the range of 75-90%. It is therefore considered much more efficient than other irrigation techniques such as furrow or sprinkler. Other benefits of the technology include ease of installation. However, it is mostly suitable for row crops (vegetables, soft fruit), tree and vine crops where one or more emitters can be provided for each plant. The main problems of drip system is blockage of emitters particularly if the water is not clean, contains algae, fertilizer deposits and dissolved chemicals which precipitate elements such as calcium and iron (Brouwer et al., 1988).

It is important to note here that the highly promoted performance of drip irrigation is related to only two types of indicators: irrigation efficiency and the uniform distribution of water throughout the plot. Drip irrigation is not just the pipe and emitter as these are just delivery points of a broader technology. It has to be looked at as a set of systems that include the water quality, the delivery system, as well as farmers' practices. Several studies have demonstrated that efficiency of drip irrigation can even be lower than those of surface irrigation (see Benouniche et al., 2014 for a study in Morocco; Wolf et al., 1995 for a study in Jordan). The reported low performance of drip irrigation was attributed to poor maintenance, inadequate use of the equipment and poor irrigation practices. Benouniche and colleagues concluded that the performance of any drip irrigation system will depend on the larger objectives and constraints of the farmer (Benouniche et al., 2014).

Other scholars have also noted that while drip irrigation systems may save water at the plot level, this may not be the case at the basin level, where water that is lost in one location is used in another (Molden et al., 2003; van Halsema and Vincent 2012). Benouniche et al., 2014 argues that even at the plot level, the use of drip irrigation may not lead to water saving.

It is therefore not surprising that despite the great potential of drip irrigation in improving crop production, its uptake and use in Africa remain very limited. In a 2012 report of the International Commission on Irrigation and Drainage (ICID), only about 4 African countries (Morocco, Egypt, South Africa, and Malawi) reported any level of drip irrigation usage between 2007 -2009. Generally less than 1% of Africa's irrigated land area is under drip irrigation system and this in turn accounts for less than 5%
of total arable land (FAO, 2012). Promotion of drip irrigation system in Tanzania started around 2003. Currently, low-pressure drip irrigation kits are available from a range of local suppliers (NETAFIM, Balton Tanzania, Agro-Rain Limited, IRRICO International Limited etc). The components are made in Israel and Germany. For small application the prevailing market prices can be considered affordable. Generally, a drip kits to irrigate plots of up to 250 m$^2$ from Balton or NETAFIM is sold at Tshs 265,000 (about 170 USD). According to Keraita and de Fraiture (2012) more than fifteen farmers have installed the system in Arusha, Kilimanjaro, Manyara, Coastal and Ruvuma Regions.

### 2.4.2 Sprinkler irrigation system

Sprinkler system is mainly developed for large-scale irrigators and very inflexible to implement in smallholder farms. Common types of sprinkler-irrigation system are the centre-pivot systems having a number of metal frames (on rolling wheels) that hold the water tube out into the fields. The least expensive system for irrigating small to medium-sized farms is the piped hand-move system with a low to medium operating pressure (2.0–3.5 bars). Mounted at equal spacing (6–12 m) on the lateral pipelines laid across the field at predetermined intervals (called lateral positions) of 6–18 m, it sprinkles irrigation water uniformly over the area covered. The most suitable system for smallholders is a system using portable pipes (aluminium or plastic) supplying small rotary impact sprinklers (Kay, 2001). Sprinkler irrigation systems are less wasteful and uses less labour, it can also be suitable for erosion prone soils e.g. sandy-soils (Kay, 2001). In Tanzania sprinklers are used by large-scale coffee and sugarcane plantations e.g. Tanzania Planting Corporation (TPC) in Moshi, Two-bridges coffee estate, and Seliani-Burka coffee estate in Arusha.

### 2.4.3 Flood irrigation system

Flood irrigation is a highly inefficient low-tech method of covering the soil surface with water and allowing it to soak down slowly. Sources of inefficiency include, deep percolation, evaporation loses, and excessive surface runoff or tail-water that can lead to soil erosion as well. Despite its high inefficiency, this method is simple and cheap, and it is the most common method of field water application used by smallholder farmers but also rice fields in Tanzania. Where small basins (Figure 2.6) are created, this on-forms water application is often called basin irrigation
Figure 2.6: Basin irrigation in rice field (LHS) and spate irrigation in Makanya village (RHS).

Flood irrigation is not to be recommended in water scarce area. It is important that smallholder farmers should be supported to find the most efficient methods of using their limited irrigation water. If the only possible option (economically) is flood irrigation, then constructing basin as shown in the photos above can help reduce excessive runoff (Figure 2.6).

2.4.4 Furrow irrigation system

Furrows are small, parallel channels (Figure 2.7), and made to carry water in order to irrigate the crop planted on the ridges between the furrows (Brouwer et al., 1988).

Figure 2.7: Furrow irrigated plots.

It is suitable for a wide range of soil types, crops and land slopes. Particularly, it is suitable for crops that would be damaged if water covered their stem. Furrows are labour intensive, requiring significant amount of manual labour to construct and maintain. In Tanzania it is commonly practiced by farmers growing tomatoes, vegetables, and onions on small plots. Large companies such as TPC, Moshi also use furrows to irrigate sugarcane.

2.4.5 Bucket and cans irrigation system

Bucket and cans is the most common manual method of irrigation used by smallholder farmers with plots neighbouring water sources (e.g. river, shallow wells, canal etc.). Partly because it is a very cheap technology (investment cost is less than 10 USD/ha) with almost no maintenance cost. Photo below is of a farmer using bucket to irrigate a sweet potato plot near Weruweruriver in Moshi (Figure 2.8).
Figure 2.8: A woman using bucket to irrigate using Weru-weru river in Mijongweni, Moshi.

However, it is labour intensive; studies have shown that on average it would take 9 h to irrigate 1000 m$^2$ using water from a nearby source (Woltering et al., 2010). The high labour requirement of the technology limits size of land that can be watered to about 0.1 ha. The technique is also highly inefficient as water is just poured onto the soil surface.

2.5 Comparison of selected on-farm application technologies

From the review and the comparison in Table 2.9, it is clear that the right on-farm application technology is more difficult to select. In terms of efficiency drip irrigation is recommended followed by sprinkler, furrow, basin, bucket and cans, and lastly flood irrigation. However, drip irrigation though promising is a technology that does not necessarily fit the users habits (smallholders in this case). Besides there other problems of availability of parts or replacement (there are just a handful of companies selling the kits in Tanzania). With better farmers support and training, this technology can improve agricultural productivity of smallholder farmers. We recommend that a study be conducted to determine the actual costs and benefits of using three of the six on farm application technologies discussed in this report; namely drip, basin, and furrow. VECO can promote drip but should be in conjunction with the use of basin and furrow irrigation. Drip could be piloted for small farm area per farmer to allow them gain experience and slowly adopt the technology if found useful and productive.

Table 2.9: Comparison of on-farm application technologies.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Drip</th>
<th>Sprinkler</th>
<th>Flood</th>
<th>basin</th>
<th>Furrow</th>
<th>Bucket and cans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial costs</td>
<td>High-medium cost,</td>
<td>High costs, in</td>
<td>Low costs, need simple</td>
<td>Low costs, need simple</td>
<td>Low costs, need simple</td>
<td>investment cost is less than 10</td>
</tr>
<tr>
<td></td>
<td>NETAFIM 250m$^2$ drip kit is sold at Tshs 265,000 (170 USD)</td>
<td>Arusha kit of diameter 10 and 15m sold at cost of Tsh 3-4million</td>
<td>hoe of about Tsh. 15,000 (USD 5-10)</td>
<td>hoe of about Tsh. 15,000 (USD 5-10), plus labour of about Tsh.</td>
<td>hoe of about Tsh. 15,000 (USD 5-10), plus labour of about Tsh.</td>
<td>USD/ha</td>
</tr>
<tr>
<td>Closeness of technology</td>
<td>It is fit for purpose of, water saving</td>
<td>Fit for purpose, relatively good for water saving</td>
<td>Simple but wasteful.</td>
<td>Easy to manage but water wasteful</td>
<td>Easy control, wasteful</td>
<td>Simple and fit for small scale – backyard gardening</td>
</tr>
<tr>
<td>-------------------------</td>
<td>--------------------------------------</td>
<td>-----------------------------------------------</td>
<td>-------------------</td>
<td>-----------------------------------</td>
<td>----------------------</td>
<td>---------------------------------------------</td>
</tr>
<tr>
<td>Reliability</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Energy used</td>
<td>Medium</td>
<td>High</td>
<td>High labour</td>
<td>High labour</td>
<td>High labour</td>
<td>High</td>
</tr>
<tr>
<td>Efficiency of application</td>
<td>90%</td>
<td>65-80%</td>
<td>15-25%</td>
<td>60-80%, high if piped</td>
<td>60-70%</td>
<td>60-70%</td>
</tr>
<tr>
<td>O&amp;M costs</td>
<td>Medium - High costs</td>
<td>High costs</td>
<td>Low costs</td>
<td>Low costs</td>
<td>Low costs</td>
<td>Low costs</td>
</tr>
<tr>
<td>Availability of parts</td>
<td>Limited in Tanzania but improving</td>
<td>Limited in Tanzania but improving</td>
<td>Available farm tools</td>
<td>Available farm tools</td>
<td>Available farm tools</td>
<td>Available farm tools</td>
</tr>
<tr>
<td>Repair skills</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Convenience of use</td>
<td>High control and convenient to all gender</td>
<td>High control and not convenient to all gender</td>
<td>Low control but not convenient to all gender</td>
<td>Medium control but not convenient to all gender</td>
<td>Medium control but not convenient to all gender</td>
<td>High control and not convenient</td>
</tr>
<tr>
<td>Fit to users habits</td>
<td>Need training for smallholder</td>
<td>Need training for smallholder</td>
<td>No training</td>
<td>Simple training</td>
<td>Simple training</td>
<td>Simple training</td>
</tr>
<tr>
<td>Portability</td>
<td>Can be vandalised</td>
<td>Can be vandalised</td>
<td>Not a problem</td>
<td>Not a problem</td>
<td>Not a problem</td>
<td>Can be vandalised</td>
</tr>
</tbody>
</table>

### 2.6 Supporting technologies for on-farm water application

The above review looked at the three components of irrigation systems separately. What is important to add here is that there are also supporting technologies that when used in tandem can boost agricultural production. These technologies include: on-farm ponds or storage, shades, greenhouse, seedling preparation methods (Figure 2.9).
Figure 2.9: A farmer using fanya juu canal in Bangalala Same, district (LHS) and large-scale greenhouse.

- On-farm ponds - allows farmers to irrigate when needed. It can be used to store rainfall or for farmers to store water during his/her irrigation turns. In underperforming irrigation schemes this can bridge the gap between irrigation turns. Small reservoirs such as micro-storage dams e.g. Ndivas are being used for night storage in Makanya catchment, Same district.
- Shades - for small areas, shade clothes can be used to reduce the intensity of the tropical sun thereby reducing stress on plants, reducing soil evaporation and enhance crop transpiration. It is a relatively cheap practice.
- Greenhouse - can allow farmers to micro-control environmental factors and thus boost production. However it is relatively expensive and may be out of reach of most smallholder farmers.
- Seedling preparation methods could be done in such a way as to improve water use efficiency.

2.7 General conclusion
The efficiency and appropriateness of irrigation technology depends on aspects related to the source of water and the overall cost, energy and skills required for abstraction and deliver water to the intended field or location. There is a wide range of water lifting, delivery and application approaches that are available in the region, however, their on-site appropriateness and efficiency require field evaluations and suppliers expert opinion. From the literature review we note the following points on energy and water efficient irrigation technologies.

- Motorised pumps (e.g. Chinese version of 1-10 HP) are likely to be the effective water lifting technology for smallholder farmers. They are cheap and lightweight (less than 50 Kg), uses kerosene, diesel or electricity. Motorised pumps costs between 250 - 350 USD and can be used to irrigate 1-2 ha. However they are often of poor quality. Small pumps are reliable and allow autonomous access to groundwater without relying on centralized control.
- Nevertheless the motorised pump technology low skill requirements make it within reach of smallholder farmers in terms ease of operation. The issues of potential water conflict arising from proliferation of motorised pumps needs to be handled carefully e.g. institutionalised clear water use practices.
- Electric pumps though can lift water from deep aquifers require connection to grid which may be limited by high costs of extending power lines to farms and restrictive policies. However, a system for community managed groundwater supply could make it sustainable. One could look at the issue of using pre-paid system for tariff collection.
- Treadle pumps are generally very cheap (costs about 20 USD) and can be used to irrigate about 0.2 ha. The skill requirement is also very low. However, the reported problem of labour and drudgery make this technology less attractive to poor farmers. See Ghana and Zambia for case study.
- Bucket and cans are also low cost (<10 USD) and can be used to irrigate only about 0.1 ha. Its limitation is also the high labour requirement.
• Potential energy sources include electricity grid, solar, wind, diesel and petrol. Wind and solar are very attractive technology in the region. However, they are less common partly due to their high initial investment cost.
• We note that construction of small ponds to capture and store rainfall for irrigation could bridge the gap between water turns thereby improving crop yields.
• Optimising water application in smallholder farms remains to be the single most important intervention. Improving application efficiency can be by using drip irrigation; sprinklers; furrow irrigation, flood irrigation; bucket and cans. All of these techniques have limitation.
• In the review we note that on-farm ponds, rainwater harvesting and storage can be used to meet supplementary water requirement in farmers' fields. This should be explored and promoted
3  Case study of energy and water efficient irrigation technologies

This section presents in-depth analysis of the field studies of the technologies in use, documenting farmers’ experience, and information from suppliers of the technologies.

3.1  Field study of existing technologies

The detailed literature review in the sections above provided guidelines on which areas should the team visit to observe and understand the existing scenario on the ground. Thus, various sites were visited to examine and discuss with the relevant stakeholders (i.e. farmers) issues of irrigation pertaining to water, energy and application methods. The study based mainly on available water sources, water lifting techniques, conveyance methods to the respective fields and appropriate technologies for water application (irrigation) in the farms. The sites were selected based on existing smallholder irrigation schemes (e.g. in Rural Moshi: Uchira, Miwaleni, Kisangesangeni and Oria villages; and Meru District: Mlangarini and Nduruma villages); unique irrigation techniques (e.g. buried pipes and macro/micro-on-farm water storages in Same district: Chome ward, Mmeni and Mhero-Champishi villages); modern irrigation features in commercial and research farms (Qsem commercial seed farm and the Asian Vegetables Research and Development Center -AVRDC); and particular energy sources in use (solar and wind energy in the lake zone: Nyashimo village in Busega district (SESEDO project site), Bweri (Vi-Agroforestry Training Center) and Nyabange villages in Musoma district). To accomplish the required information, suppliers of irrigation technologies (in Arusha town); Balton (T) Ltd, and IRRICO International Ltd companies were visited to obtain technical information of the supplied irrigation technology packages. The sections below therefor comprise of detailed discussion of the observed water sources, energy and water (lifting and delivery) technologies, and the on-farm water application techniques in use. Farmers’ or users experiences and perceptions are as well covered in text boxes (to exclude them from proven scientific findings). Furthermore, details of the technologies from suppliers are provided to supplement actual field observation of the respective technologies.

3.2  Sources of water

The major water sources observed to be used by farmers for irrigation included natural springs, shallow groundwater (7-15 m), deep groundwater aquifers (30 -100 m), river water and stored-rainwater. There was however very few cases of rainwater harvesting in the areas visited. Below we highlight the sources visited.

A.  Springs

- Miwaleni springs which provides large volumes of water for several villages such as Kisangesangeni, Miwaleni and Oria. It is also one of the water source used by the large sugarcane farm Tanzania Plantation Company (TPC).
- Shengena forest reserve springs. This spring provides water for various uses in Chome ward, Same district.

B.  Boreholes (shallow and deep wells)

- Hand dug shallow wells of about 5-7 m deep are common in Miwaleni, Oria villages. (A follow up study found nearly every households having 1-2 shallow wells). These wells are mainly for small and
medium scale irrigation, irrigating farms of less than 1-5 acres, majority of which were planted with vegetables such as tomato and onions.

- Deep wells of 46 to 70 m deep were in Uchira (two boreholes of the incomplete irrigation, project) in the Bwami drip irrigation project and in the Marry Goreti school farm in Miwaleni village. These deep wells are designed for relatively large scale irrigation; 40 acres of the Bwami project, 70 acres of Marry Goreti farm, and 200 acres of the Uchira irrigation project.

![Shallow wells observed in Miwaleni.](image)

**Figure 3.0**: Shallow wells observed in Miwaleni.

<table>
<thead>
<tr>
<th>Box 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farmers’ experience in constructing the boreholes: ‘A complete shallow well costs labor of approximately Tsh. 400,000, while a deep well is normal contracted at around Tsh. 140,000 per meter of the borehole depth drilled (approximately Tsh. 14 -20 million)’.</td>
</tr>
</tbody>
</table>

C. Rivers

Seasonal and permanent rivers. The Rau river flowing through Miwaleni and Oria villages, and other small seasonal streams/rivers were observed in Uchira. Other rivers visited were Nduruma, Themi, and Kikuletwa in Meru district. Most of these rivers are seasonal providing water during and shortly after the rain seasons. The amount of water therefore decrease as the dry spell prolongs and sometimes most rivers (eg. Themi and Ndurmuma) run completely dry especially downstream.

D. Constructed water storages facilities

- *Macro-dams*; these are small-medium in size reservoirs (e.g. Ndiva observed in Same district) used to store water from either the springs, rivers or collected through rainwater harvesting
- *Micro-dams*: secondary farm storage. These provide small storage close to the farm, constructed either above or below ground to store water for future (irrigation) use. These are very common in Chome, Same District.
- ‘*Fanya juu/chini*’ storage mechanisms. These are furrows constructed in the farm for temporary storage of run-off. This was evident in Same district.
3.3 Specific details of energy and water technologies in use in the areas visited

3.3.1 The case of Moshi rural
These villages are located in lower part of Moshi (lower Moshi) displaying relatively flat terrain. Agro-pastoralism is the main economic activity in this area consisting of small-scale farming mainly of vegetables (tomato, onions, and watermelons), cereal crops (maize, paddy) and some legumes (common beans and groundnuts) as well as livestock keeping (mainly cattle, goat and piggery). Most of the farming activities depend on irrigation with water from various sources found this area.

Existing Water Lifting Techniques

i. Motorized and electrical pumpsets: motorized pumpsets were observed all over the place, pumping water from the boreholes, rivers or canals. The sizes ranged from 1.5 to 6.7 Hp. one electrical pumpset was observed in the Uchira borehole project connected to one pilot farmer. The use of motorized pumpsets were mainly for growing vegetables such as tomato, onion, green pepper.

Figure 3.2: Motorized pumpsets along the TPC canal (LHS) and the electrical pump in Uchira boreholes (RHS)

Box 2
Farmers story on the cost of lifting water: Lifting water involves a pumpset of 4’ to 6’ capacity, costing a minimum of Tshs. 3500,000, requiring an average of 5 L of petrol to run for one round of irrigation covering one acre. For instance, onion needs about ten rounds of irrigation from transplanting to harvest. Generally this will cost about 120,000 worth of pumping cost. A farmer operating in one of the Uchira boreholes (on pilot basis) uses Tshs 2000 to buy electricity for one round of furrow irrigation in one acre of watermelon.

... supply in the nearby villages.
**Figure 3.3:** Kisangesangeni solar powered water pump.

**Box 3**

Some farmers’ concluded that, ‘though relatively expensive motorized pumps are the most reliable way of delivering water to farms whenever needed. The performance of the pumps relies mainly on maintenance and type of pump. The main challenge in water lifting using this technology is the running (fuel) cost of the pumpsets.’

**Water Delivery Methods**

The observed water conveyance techniques included:

i. *Lined canals:* One constructed by Tanganyika Plantation Company (TPC) was observed running from the Miwaleni springs along Miwaleni, Kisangesangeni and Oria villages to the TPC farms. Farmers along this canal could extract water through different means including motorized pumpsets into open-unlined furrows or through semi-buried pipes to their farms.

![Figure 3.4: Water delivery through the TPC irrigation canal](image)

ii. *Surface water delivery pipes:* These were observed in the Mery Goreti school farm (in Miwaleni village), delivering water from the storage tanks into the drip irrigation-system. In Uchira, one of the boreholes was incomplete, while a second borehole is temporarily connected to movable surface pipes from the pumping system into a trial farm.
iii. *Open-unlined furrows*: In some occasions, farmers pump water from the sources or directly by gravity into open-unlined furrows leading to the farms. There were significant water losses observed in this setup.

iv. *Buckets and cans*: This traditional method was as well observed to be used for water delivery into nearby fields. Particularly in Kisangesangeni where vegetable growers can easily fetch water directly from TPC irrigation canal.
Figure 3.8: Delivering water by buckets and cans.

Box 4:
Farmers’ experience: ‘there are significant water losses in the unlined furrows compared to lined canals and surface pipes, but the problem here is that lined canals are expensive and the available surface pipes are of low quality. This is what has caused most of the farmers to remain in the unlined canals.’

The observed water losses require specific measurements or over-time monitoring to determine the efficiency of each system. Based on the criteria defined in section two, farmers’ assessment of the delivery technologies can be summarized in the table below.

Table 3.1: Summarized Farmers assessment of the water delivery technologies in Rural Moshi.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Lined canals</th>
<th>Surface pipes</th>
<th>Open unlined furrows</th>
<th>Bucket and cans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial costs</td>
<td>Perceived to be very expensive especially to smallholder farmers. Can cost several millions (about 7-10 millions) to line 100 m canal</td>
<td>Affordable. With about Tsh 250,000 initial cost depending on the pipes quality and type can cover 100m length.</td>
<td>Low costs, some labor for digging the furrow can cost about 50,000 for a 100 m</td>
<td>Investment cost is insignificant, just buckets or cans</td>
</tr>
<tr>
<td>Closeness of technology</td>
<td>It matches the purpose of water saving but may not fit the economic situations</td>
<td>Fit for the purpose, reducing water losses but may not fit the economic situations</td>
<td>May match the socio-economic situation but leads to significant water losses.</td>
<td>Simple and fit for small scale gardening</td>
</tr>
<tr>
<td>Reliability</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Energy used</td>
<td>Medium energy during construction</td>
<td>Some labour during installation</td>
<td>Medium labour needs</td>
<td>High labour needs</td>
</tr>
<tr>
<td>Efficiency of application</td>
<td>Most water reaches the farm unless diverted (80% to 90%)</td>
<td>Can get almost all the pumped water into the farm (90-100%)</td>
<td>Less than half of the water reaches the farm (15-30%).</td>
<td>Efficiency is very high (&gt;90%) but not possible to irrigate even half an acre!</td>
</tr>
<tr>
<td>O&amp;M costs</td>
<td>Medium-High costs</td>
<td>High costs</td>
<td>Low costs, some labor for cleaning</td>
<td>Low or no costs</td>
</tr>
<tr>
<td>Availability of parts/materials</td>
<td>Materials not easily available in the villages</td>
<td>Materials might be unavailable in the villages</td>
<td>Available farm materials</td>
<td>Available materials</td>
</tr>
<tr>
<td>Repair skills</td>
<td>Might be a problem in the village</td>
<td>Might be a problem in the village</td>
<td>Not a problem</td>
<td>Not a problem</td>
</tr>
<tr>
<td>Convenience of use</td>
<td>High control and convenient to all gender</td>
<td>High control and convenient to all gender</td>
<td>Low control but may not be convenient to women</td>
<td>High control but may not convenient to all gender</td>
</tr>
<tr>
<td>-------------------</td>
<td>------------------------------------------</td>
<td>------------------------------------------</td>
<td>---------------------------------------------</td>
<td>---------------------------------------------</td>
</tr>
<tr>
<td>Fit to users habits</td>
<td>Need training for smallholder</td>
<td>Need training for smallholder</td>
<td>some training will be needed</td>
<td>No training</td>
</tr>
<tr>
<td>Portability</td>
<td>Not movable and can be vandalised</td>
<td>Can be movable</td>
<td>Not movable and can be vandalised</td>
<td>Not a problem</td>
</tr>
</tbody>
</table>

**On-farm water application (irrigation) techniques**

In these areas, water application or irrigation techniques are based on or determined by the crop/cropping type, water sources and financial capacity of the responsible farmer or company. Mainly, water application was by surface or drip type of irrigation. The surface irrigation is done either as furrow, border or flood/basin technique. These were customized or localized into:

i.  **‘Ridger’**: A furrow irrigation whereby ridges are constructed through which water is directed. The crops are planted on the upper part of the ridge ensuring the root zone is as close as possible to the water line. This is common used in vegetable (e.g. tomato) and maize cultivation.

![Figure 3.9: Furrow (‘Ridger’) irrigation in a tomato field.](image)

ii. **‘Border’**: This resembles check basin or flooding irrigation minimized to designed-blocks of about 3 square meters locally known as ‘borders’. This is most commonly practiced in onion and pepper farming.

![Figure 3.10: Basin/Flood (‘Border’) irrigation in onion fields](image)

**Box 5**

A farmer with ‘Tuliza boda’ story: ‘I usually spend about Tsh 1000 to establish a 5 m² block of onion (with seedlings planted) famous as tuliza boda. I lose a lot of water through this open furrow which then costs more in pumping. The yield is affected by many factors such as soil conditions (salty soils burns the crop) and pests and diseases. Yields can range from 40 to 60 bags of onion of which the selling price depends on the season. We normally fetch high prices during rainy seasons as the demands go high.’
iii. Drip irrigation connected to either piped-main lines or storage tanks. This was observed to work in the Mery Goreti School farm whereby about 3 acres of vegetables are irrigated.

**Figure 3.11:** Drip irrigation at the Mery-Goreti School Farm.

**Box 6**
Marry Goreti Farm manager’s description: ‘the drip system is very efficient in water delivery to the crop. However it is faced with a number of challenges such as being chewed by rats, clogging and, positioning of the holes in different plant spacing. We do flushing to overcome clogging but rats are a big problem. Moreover, recent issues of severe pests outbreak significantly affects crop production’

**Box 7**
The story by a farmer of an observed failed drip irrigation project in Bwami, Miwaleni: This project worth of about Tsh 600 million, involved a huge borehole with a powerful electric pump extracting water from the borehole into 100,000 L storage. Then through a modernized filtration process water is delivered via buried pipes into a nearby 40 acres farm. The design of the system is such that water is pumped into a storage reservoir with little head difference to the farms. To irrigate, pumping is required. This project collapsed only after a few (two) years of operation whereby the drips had been abandoned and farmers have turned into furrow irrigation and the use of surface pipes. Reasons for failing were explained by the farmers to be poor quality of the irrigation water, poor design and general maintenance of the system. Farmers complained of high running cost of double pumping (from the well into the storage, then to the farm). The drip system then clogged only after a few times of use; with the clogged holes, the drip could not provide water enough for the crops especially during the hot-dry seasons leading to crops drying-out besides being irrigated. A failed sunflower crop was observed to have dried (about 75%) though connected to the drip system. In the design of irrigation water requirements and drip emitters soil type was not taken into account. As such the water delivered to the crop was quickly lost to soil evaporation, deep infiltration etc.
Figure 3.12: The failed Bwami drip irrigation project in Miwaleni: a) Storage tank; b) Piles of the abandoned pipes; and c) The failed crop.

Table 3.2: Farmers comparison of the water application technologies in Rural Moshi

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Drip</th>
<th>Border (Flood)</th>
<th>Ridger (Furrow)</th>
<th>Bucket and cans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial costs</td>
<td>High cost, 250m² drip kit is sold at Tshs 265,000.</td>
<td>Low costs, need some labor to construct the</td>
<td>Low costs, need some labor to make the ridges. Costs about</td>
<td>investment cost is minimal</td>
</tr>
</tbody>
</table>


borders/blocks. It requires about Tsh 1000 to make a 5m² border of onion. Tsh. 40,000 for one acre of tomato

<table>
<thead>
<tr>
<th>Closeness of technology</th>
<th>matches the purpose of water saving but not the socio-economic aspects</th>
<th>matches the cropping systems but lot of water is lost</th>
<th>Matches the cropping systems but wasteful</th>
<th>fits only for small scale gardening</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Energy used</td>
<td>Medium labour</td>
<td>High labour</td>
<td>High labour</td>
<td>High labour</td>
</tr>
<tr>
<td>Efficiency of application</td>
<td>Very high, most of the water is directed to the crop (90%)</td>
<td>The crop gets enough water but there is wastage (50 to 70%)</td>
<td>The crop gets enough water (70-90%)</td>
<td>High (60-70%)</td>
</tr>
<tr>
<td>O&amp;M costs</td>
<td>High costs</td>
<td>Low costs for labour</td>
<td>Low costs for labor</td>
<td>Low costs</td>
</tr>
<tr>
<td>Availability of parts</td>
<td>Limited in Tanzania</td>
<td>Available farm tools</td>
<td>Available farm tools</td>
<td>Available farm tools</td>
</tr>
<tr>
<td>Repair skills</td>
<td>Still a problem to farmers</td>
<td>Not a problem</td>
<td>Not a problem</td>
<td>Not a problem</td>
</tr>
<tr>
<td>Convenience of use</td>
<td>High control and convenient to all gender</td>
<td>Low control and not convenient to all gender</td>
<td>Medium control but not convenient to all gender</td>
<td>High control but not convenient to all gender</td>
</tr>
<tr>
<td>Fit to users habits</td>
<td>Need training for smallholder</td>
<td>commonly in use</td>
<td>commonly in use</td>
<td>commonly used</td>
</tr>
<tr>
<td>Portability</td>
<td>Can be movable</td>
<td>Not portable and can be vandalized</td>
<td>Not portable and can be vandalized</td>
<td>not a problem</td>
</tr>
</tbody>
</table>

3.3.2 The case of Same district
This area was visited for the purpose of observing the buried-pipes and secondary water storage structures (Ndiva macro-dams and on-farm storages) which have long been practiced therein. Farmers in these areas cultivate mainly vegetables (brassica sp, amaranth etc.) and maize along with other crops. The following sites were visited;

- *Mmeni and Mhero-Champishi villages*

Modernizations of irrigation infrastructure in these villages were funded through the Traditional Irrigation Improvement Project (TIIP 1995) in Mhero-Champishi, and the District Agricultural Development Plans (DADPs 2010) in Mmeni. In this area, water is obtained from springs originating in the Shengena forest reserves, then channeled by gravity through buried pipes and open canals into macro-storage reservoirs locally known as ‘Ndiva’ down the hills. The *Mmeni Ndiva* costs about Tsh. 40 million in 2010. From the Ndiva, water is delivered into the farms through unlined canals (for *Mmeni*) and buried pipes (for *Mhero-Champishi*). Upon reaching the farms, water is stored in micro-reservoirs (tanks) for later use. From these micro-storages, water is delivered into the farms through gravity and then applied to the crops by horse-pipes. This approach is sustainable and it allows continuous and year around crop production.
3.3.3 The case of Meru District

This area was visited to observe the common traditional flooding irrigation practices and the modern irrigation technologies used in the commercial horticultural farms.

**Mlangarini and Ndurma villages**

Water source is mainly the Ndurma river, extracted through gravity into communal owned open-lined canals running through the farms. Application is mainly by flooding and furrows into vegetable crops (tomato, onions, paprika etc.) maize and beans. Some boreholes were observed especially with individual farms where drip irrigation was successful (Kimaro’s private farm in Mlangarini).
Figure 3.15: Lined canals and flood irrigation in Manyire village.

Box 9
Farmers experience: ‘Although the canals are owned by communities, there is a growing number of water uses and users especially the big flower farms abstracting most of the water upstream affecting downstream farmers. Yet, this limited amount of water is lost through the poorly constructed furrows diverting water from the lined canal to the farms and more is lost through the flooding method of irrigation. The lined canal though expensive reduces water loss from the rivers and its efficiency ranges from 70-90% but flooding irrigation needs a lot of water of which most is lost. The cost of piping or constructing lined canals for the whole system from the water source to the farms is relatively expensive to smallholder farmers. For instance the Manyire canal built in 2009 costed around 70 milion for a length of less than 5kms only.’

Qsem commercial seed farm

In this farm water sources are from rainwater harvesting and groundwater. The water is conveyed through filtration and disinfection system into the buried pipes then leading into mini-storage tanks located closer to the green house. Water is then channeled into specific green house and applied to the crops by drip and/or sprinkler irrigation systems. The whole irrigation system is automated and centrally operated. A fairly different drip system was observed (Figure 3.17) directing water into the specific part of the plant that needs to be irrigated. Sprinklers are only used under special needs such as to balance humidity or to irrigate ungerminated seeds.

Figure 3.16: Specialized drip irrigation in Qsem green houses.
AVRDC-Research farm

The research farm water is diverted from the nearby Tengeru river. Irrigation is mainly by flooding and furrow application. Drip irrigation failed due to poor management/maintenance leading to clogging of which the repair was far too expensive (as explained by the farm manager).

Figure 3.17: Irrigation at AVRDC research farm.

3.3.4 The Lake Victoria zone

The consultant visited the Lake Victoria zone to observe and gain experience on the existing windmills operated water pumps, and the successful SESEDO project on using solar energy water pumps for irrigation.

Nyashimo village in Busega district, Simiyu region

The Sustainable Energy Services, Environmental Management and Development Organization (SESEDO) is located in Nyashimo village, Busega district in the newly formed Simiyu region. The project was funded by WISION (from Germany) in 2008 aiming at improving agricultural productivity through irrigation using solar and wind energy to pump water from the lake. Two solar panels of 100 watts each are used to operate a pump of 6” capacity. Water is pumped to a reservoir (about 100 m), then through buried pipes to the nearby farm of about five acres for vegetables production. Water application is through furrow irrigation.
Musoma district.

- **Vi-agroforestry Training center (ATC)** at Bweri, had a windmill developed in 2010 (Salomonson and Thoresson) for pumping water from the lake to irrigate surrounding fields. The windmill was left to be owned by the training center. One officer in the center informed the consultant that the system stopped working just a few months after the installation and no one could figure out what the problem was. To date, the system has been demolished and only a few parts remain as scrapers.

**Box 11**

Experience of the current project field officer: ‘The project was established under a group of about 100 farmers and became very successful in the beginning with good production of both vegetables and fruits. However, the project did not explore market channels for the produce resulting to serious market problems. Most of the group members decided to quit the project. The windmill so installed did not last due to maintenance problems. The blades that were made of cloth got worn-out and none of the members had knowledge on how to replace them. The windmill later collapsed. However, currently the solar panel is still well functioning, owned by about five remaining members of the project. The pumped water is used to irrigate about 5 acres of fruits and vegetable. The remaining members have managed to secure market for the produce’.

- Furthermore, two non-functional windmills were observed in this area. One was established by the USAID (for about Tshs 40 million) back in 2011/12 as a farmers group-owned irrigation project with a windmill as a means of pumping water from the lake. The wind mill installed by KIJITO Co. was for water-lifting from the lake into a reservoir aimed at irrigating a 5 hectare maize farm. However, the
farmers reported that the windmill broke-down just after two crop production seasons. This then became nobody’s responsibility to do the repair. The farmers group then formed has disintegrated after the windmill collapsed. However, we observed the windmill structures still intact and some maintenance might bring the system into function again.

**Figure 3.20:** Windmills for water pumping in Musoma

**Box 12**

Farmer explanation: ‘after the windmill broke-down, there were no means to reach the supplier for technical help. The farming group disintegrated and some members decided to cultivate their land with tractors destroying the pipe system that was installed by the project for water supply in each farm. It is such a waste of money’

- Nyabange village

**Farmer 1:** had a well-functioning windmill installed (by POLDAW Tanzania Ltd.) with a 50,000 L reservoir at a total cost of about Tsh 25 million. The windmill operates a 6” pump which through buried pipes takes about three days to fill the reservoir 200 m away from the lake/water source. Water is then flow by gravity through buried pipes to irrigate a five acre farm by drip irrigation. This project is only one season old and it was not feasible to do the economic/crop yield assessment.

**Figure 3.21:** Windmills pumping water for drip irrigation in Nyabange village, Musoma.

**Box 13**

How the farmer rescued his windmill: ‘Once one of the rotating parts stopped, I tried to reach the supplier but was not reachable. I had to remove the part take it to local mechanics who could easily fix it and now my windmill is ok’.
Farmer 2 had a motorized pump of 5.6 HP, 3 L capacity that pumps water from the lake 450 m away to the four acre farm for furrow and drip irrigation.

Figure 22: A farmer practicing conservation agriculture to improve yield.

Box 14
Farmer’s attestation: ‘Though in a long run a windmill it can be cheaper compared to my diesel pump, I can’t afford the initial costs. Through conservation agriculture techniques such as minimum tillage and biomass incorporation I am able to produce 1 tone maize in 0.25 of an acre (equivalent to 4 tons/acre or about 10 tons/ha).’

3.4 Key issues observed and raised by farmers
1. Water sources:
   - Most of the schemes visited, the water sources were reported insufficient and inadequate to meet the growing demands. The number of water user and uses is increasing which seems to threaten the available water sources unless sustainable plans are put in place. This calls for sustainable land use plans.
   - Water levels in shallow groundwater wells were also reported to decrease significantly during dry seasons. As more people invest in shallow wells this resource is likely to increasingly run dry for most period of the year. Other sources could be thought to supplement for the time of shortage.
   - Some rivers were reported run dry during and immediately after the rain season, particularly because of upstream overuse. Issues of rain water harvest and on-farm storage could be an opportunity at this point.
2. Generally, water lifting practices are faced with energy challenges. Fuel and electricity cost and availability is a problem to the villages. Wind energy has proved failure in most cases, while solar energy looks promising but it is not well explored. Visited farmers reported of having no enough information on solar energy use.
3. In water Conveyance methods:
   - The lined canals were generally perceived expensive especially to smallscale holders but reduce water loses considerably to an estimated efficiency of about 70-90%. However, farmers are optimistic of group efforts to overcome the high costs limitations.
• Open furrows lead to significant water loses and also labour intensive as farmers are often called upon to clear debris after rain season. Farmers are looking forward to change these furrows into lined canals.

• Buried pipes are expensive at individual farmers’ level, but possibly the most reliable technology for irrigation water conveyance. However, the use of poor quality pipes can reduce the life-span considerably. The need for group approach to this technology was always mentioned by farmers.

4. With the farm water application (irrigation) techniques:
• The furrow in ridges practices need enough water to go along the furrow line to the end of the crop row. This very much depends on the soil properties which in most cases have led to water losses rendering this technique very inefficient.

• Blocks/borders method requires water depending on the size of the block. However, still water is subjected to the soil conditions which may cause seepage with possibilities of over irrigation.

• Drip irrigation commonly known as ‘matone’ (drips) is faced with a number of challenges. Besides being expensive in smallholder settings, farmers who tried it are complaining of clogging of pipes, poor pipe materials which can’t stand farm conditions e.g. can be easily be eaten by rats/rodents. Generally the maintenance cost is high and management techniques are not well known to farmers.

• Overhead sprinkler is unsuitable for some crops. However, it is relatively expensive to smallholder farmers. It has been seen to work with large commercial farms. Farmers see this technology as water demanding and there are possibilities of over-irrigation.

• The use of on farm storage, and micro-reservoirs can provide farmers with the needed buffer during period water rotation.

• Crop Pests and diseases were a big challenge especially at the Mery Gorret farm where it was the only green spot in the middle of uncultivated dry land. This farm then succumbed to all sort of pest around this area. E.g. rodents were eating/chewing the drip-pipes besides crops!

3.5 Suppliers of Irrigation technologies in Arusha
Two suppliers of irrigation equipment based in Arusha town were visited to obtain technical information and costs of the available irrigation technologies. Challenges faced by farmers were as well discussed.

Balton is one of the main supplier of NetaFim smart drip and micro-irrigation kits. They supply farmers with two types of drip kits. Type 1: Is a 8 mm drip kit with discharge rate 0.5 L/h, it requires a tank-head of 2 m, and cover an area of 500 m². This type is sold at 264,000 Tsh per 250 m². Type 2: Is a 12-16 mm drip kit with discharge of 1.5 – 2 L/h and can covers 1 ha. This is mainly sold to large-scale farmers. The supplier raised issues on water quality and maintenance/management as the main problem facing their drip irrigation kits. However the company has the following solutions: Using BB5 and Superlinks/Acid compounds for pH regulation, hence control clogging from salt. Changing their model of operation to include working with farmers, and provide after-sale services e.g. providing training supports to farmers
Balton raised important point that investment in technology does not automatically leads to high production. There is still a need to apply pesticides, and fertilizers and also having proper farm management. Improved a access to agro-support and Markets is key in the agricultural business. A major challenge with farmers rushing to adopt new technology is that they assume, once you installed drip
everything will work fine. This “telephone farming” as Balton representative called is the first challenge in promoting new irrigation technology.

IRRICO International Ltd also supply drip irrigation kit plus other agricultural implements such as/Overhead sprinkler: Diameter 10 and 15 m at cost of Tsh 3-4 million; Greenhouse of 8 m wide x 2.2 m high x 15 m long at Tsh 3 million, including plastic covering and insect nettings. The company can supply a maximum of 30 m long greenhouse. Drip irrigation kits for 8 m x 15 m area plus 2000 L tank with fully galvanized emitters pipes at Tsh 4.5 million. The company also raised problem of poor maintenance of drip lines by farmers leading to damages during crop harvesting. Also reported was the problem of clogging of drip lines arising from using water of poor quality. This problem could be solved by regular flushing of the drip lines. The problem of drying and degradation of the plastic drip lines was reported. Of important the representative of IRRICO mentioned that some of the drip kits available in the local market are of poor quality, made of very thin pipes that are easily eaten by rodents. IRRICO International Ltd has designed a special program to work with farmers as well as involving research institutions to solve some of these challenges. They provided turnkey projects to farmers, helping with the installation of the irrigation system as demanded by the client and provide training on the system management.

3.6 General summary of key field findings
The field studies are hereby concluded into the following points:

- Natural springs, groundwater and rivers were identified as the main sources of water for irrigation. However the growing number of water users and increased uses coupled with the changing climate worries farmers of the sustainability of these water sources.

- Water lifting is mainly by motorized pumpsets operated by fuel (petro/diesel) or grid electricity. Renewable energy sources such as wind and solar energy are not very much in use. Windmill is still faced with a number of management challenges which in most cases have made it fail. Solar might stand to be the reliable source of energy to recommend to smallholder farmers. It works with the SESEDO group of farmers, can it be tried somewhere else?

- Water delivery is mainly through unlined canals which lead into water losses. Some buried pipes were observed to significantly reduce water losses. Surface pipes are also used but to a lesser extent. Farmers complain of the quality of pipes and costs. However, buried pipes and lined canals are working in Chome, need to see possibilities of adapting/adopting this to somewhere else. Furthermore, the pilot farmer in Uchira demonstrated how best the surface pipes can work in this area. There is a need to explore possibilities of adopting this for the whole project.

- Application technologies vary with crop/cropping type. Furrow and flood irrigation are the most common though with significant water losses. Drip irrigation is not common yet and is faced with a number of challenges. However, it seems to work with some farmers why not others?

- Suppliers of irrigation technologies are aware of the challenges facing farmers in using the supplied technologies. The suppliers are planning to resolve these challenges through agro-support programs in such plans as farmers training, after installation services.
4 Conclusion and recommendations

It is important to recall here the five critical challenges facing smallholder farmers in a country like Tanzania: 1) the need for appropriate water lifting technologies; 2) the need for efficient water delivery system; 3) the need for better-on farm water application practices; 4) the need for fertilizers and pesticides; and 5) the needs for markets for the agricultural produce. This review provided analysis of existing energy and water technologies in use in the east African region and beyond. It is a first attempt at analysing more critically irrigation technologies that are available for smallholder farmers in Africa but specifically for Tanzanian context. Below we draw important conclusion and recommendations on how some of the above challenges can be mitigated.

4.1 Conclusion

- Based on the review it is evidence that no single technology can be considered the right one for smallholder farmers. The review and field observations find a wide range of technologies being used to deliver water to crops. Our overall conclusion is to mix and match technologies to suit the context in which it will be used. We provide some direction here below.

- In terms of water sources we find farmers predominantly rely on springs, rivers, and shallow groundwater. In a few instances deep groundwater aquifer were being exploited, most of these projects were constructed through the support of donors or government projects. Farmers investment in deep wells or large scale rainwater harvesting for irrigation remains limited by accessibility to capital. Construction of small ponds to capture and store rainfall for irrigation could bridge the gap between water turns thereby improving crop yields.

- Potential energy sources include electricity grid, solar, wind, diesel and petrol. Wind and solar are very attractive technology in the region. However, they are less common partly due to their high initial investment cost.

- Although a wide range of water lifting devices were found to be in use, the following can be considered suitable for smallholder irrigation – solar powered water pumps for deep wells, wind powered pumps for shallow and deep groundwater, motorized pumpsets for shallow wells and pumping from irrigation canals.

- Grid powered water pumps are viable but requires proper community organization particularly for paying monthly electricity bills and other related operation and maintenance costs. Pre-paid system could be used for tariff collection.

- Wind powered water pumps may appear to be a cheap approach but existing technology in the market are not reliable. Several failure were observed during this study which makes wind powered technology not to be considered as an appropriate technology for smallholder farmers.

- Treadle pumps are being used by farmers but the drudgery involves makes this technology less attractive to smallholder irrigators in the region. However, recent modification with minimum labour requirement could be useful. Our observation is that treadle pumps are still inefficient (about 40-50% efficiency). Other water lifting technologies e.g. hand pumps are attractive for domestic water supply.
• Conveyance system for smallholders remains one of the main problem. Unlined irrigation canals have been quoted to have efficiency as low as 15%. Several attempts to improve this have not been successful.
• During the review, it was observed that buried pipes though expensive can be relatively cheap in the long run. Particular evidence is from Chome in Same district whereby a buried pipe irrigation network constructed in 1995 was found still operating with little or no leakage. Using buried pipes conveyance efficiency of 80-90% can be realized.
• Concrete canals was found to be the most common conveyance system in use, however, due to construction challenges (corruption etc.) lined canals are very expensive. In fact concrete canals often turn up to be the most expensive ways of modernizing irrigation canals.
• Surface pipes were also observed being used by farmers in the areas visited. Surface pipes can be suitable for individual farmers. It can also be connected with buried pipes or motorized pumpsets. Although easily movable, this is not to be preferred for medium scale irrigation system of more than 20 farmers.
• Depending on availability of funding, the choice of conveyance system could be in the following order i.e. high to low efficiency: buried pipes, lined canals with control gates, surface pipes, and unlined canals.
• Common on-farm water application technologies include the following; bucket and cans, flooding, ridges, basins, drip. Buckets and cans is suitable for very small area e.g. backyard gardening.
• Flood irrigation is highly inefficient, leads to over irrigation and should be avoided as much as possible.
• Ridges and basin irrigations require significant labour inputs for their preparation. However, they are relatively efficient when compared to flood irrigation techniques. Drip irrigation is the most efficient field water application technology. However, there are several challenges faced by smallholder farmers in managing drip irrigation system. To certain extent the technology may be considered too high-end for unprepared smallholder farmers. We observed failure due to clogging, damages by rats and UV radiation. Most drip kits being promoted for smallholder farmers were found to be of poor quality material. Our conclusion is that drip irrigation requires proper technical support and that it may work for farmers with financial capacity.

4.2 Recommendations
• Farmers should be presented with a wide range of available energy and water technologies. As we discuss in this document appropriate approach will be to mix and match technologies to fit the local context i.e. promote integrated system for a particular environment and let the users choose what suits their individual situations.
• Advocate on community based approach. E.g. development of a central water source to serve a particular community at a cost. This could use various sources depending on the area e.g. wells, rivers or rain water harvesting, pumped through electric, solar or power, conveyed by suitable means (e.g. buried pipes, line canals) and suitable individual final application technique (e.g. ridges, basin, drip).
Specifically we recommend field trials of the following technologies – solar powered water lifting system for boreholes, and buried pipes for water conveyance. For on-farm application we recommend small-scale trials of drip irrigation, and this should be coupled with basin and furrow irrigation to allow farmers to gain more insights in the management of drip systems but also to be able to compare it with existing techniques – basin and furrow.

- The construction of reservoirs for on-farm water storage or overnight storage (e.g. Ndiva) is an important intervention and should be integrated in any irrigation development.
- Other technologies e.g. wind pumps, concrete canals and sprinklers can also be promoted.
- The use of pumpsets for shallow groundwater exploitation is on the rise and appears to be a short-term solution to the problem of water lifting for smallholder farmers, mainly because they are cheap, easy to operate and the spares are available. However, atomisation of water lifting if not well managed is likely to lead to over extraction of the water resource. Thus the promotion of pumpset should be done with proper understanding of the resource dynamics such as groundwater recharge zones, surface-groundwater interactions, energy footprints and land use pattern.
- Finally, investment in smallholder irrigation should also look at the wider impacts on the catchment. This aspect was not studied here but is an important component in ensuring sustainability of water resources in a catchment. It will also mitigate any future water upstream – downstream water conflicts.
References

The section provide suggestions for further readings.


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