Evaluation of the Effectiveness of the Current Irrigation Scheduling Strategies in Perkerra Irrigation Scheme, Kenya

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Abstract: ***Irrigation scheduling helps the farmer to know when to irrigate, water flow rate (quantity), and duration of water supply to the farm. Improper irrigation activities can lead to irrigation water loss by percolation and surface runoff, soil erosion due to surface runoff, leaching of the useful minerals through percolation, high energy consumption in pumping irrigation water and increase in operation and maintenance cost. Irrigation scheduling can help in reducing such problems and boost productivity. The main objective of this study was to evaluate the effectiveness of the irrigation scheduling strategies that are currently being practiced in Perkerra irrigation scheme. Four fields of 0.5 ha in average cultivated with maize crop, were selected to assess and compare irrigation water use efficiencies. Data collection included soil types, crops grown, soil water monitoring, meteorological data, irrigation system, discharge received per plot level and a total times irrigation is done. The average interval for applying irrigation water was found to be 2 to 3 days irrespective of rainfall. Over-irrigation to saturation is common in Perkerra Irrigation Scheme. Measurements carried out on the Perkerra irrigation scheme showed that there can be losses of more than 100%. The water use efficiency in PIS is very low and there should be improvements. The determined results were then used to evaluate the most efficient and reliable schedule for future irrigation and also to provide needed information for improvement of irrigation interval for Perkerra Irrigation scheme.***

Keywords: Evaluation of performances; Irrigation scheduling; Water scarcity; Irrigation efficiency; Evapotranspiration.

1. Introduction

Irrigation is the artificial application of water to the soil to supplement water required for plant growth (FAO, 1996). Scheduling refers to the sequence of events in a chronological order in which water application is intended to take place. Therefore, Irrigation scheduling refers to the process of defining the most desirable irrigation frequencies and depths. It is meant to avoid negative effects of under or over-irrigation while maximizing on the crop yield (Kamble *et al.*, 2013). Irrigation scheduling entails the determination of the right amount of water required by crops and estimation of the sequence to apply the water to crops.

Water scarcity has been a major problem in many African countries. The scarcity may be due to theclimate change, increasing demand for freshwater by the competing users in various sectors like industries and the problems caused by the environmental destruction such as desertification and over-exploitation of the water resources (Adeboye *et al*., 2009). Kenya has one of the most skewed distributions of income amongst low-income economies in the world (Ngigi, 2002). Approximately 56% of its entire population live below the poverty line out of which 80% are living in the rural areas. More than 75% of the entire population in the rural area depends on agriculture for their livelihoods (FAO, 1996).

Rainfall has been insufficient to grow crops in most parts of the world as rain-fed food production is affected by the change in rainfall (Levidow *et al.*, 2014). Therefore, to increase crop production irrigation is the only option to be adopted.

Irrigation infrastructure has increased over the quarter of the past century, for example, limited surface water has been diverted and groundwater exploited for irrigation purpose. The area under irrigation has escalated by 25% over a period of three decades (FAO, FIDA, and PMA, 2015). However, in recent times, the irrigation expansion rate has reduced because of the unreliable surface water and over-exploitation of the groundwater resources (Smith, 2000). There is an immediate need to decrease losses of water for irrigation and establish an effective irrigation strategy and management. This implies that water abstracted for irrigation is not efficiently used for crop growth due to losses. Only 45% of the water supplied to crops is taken up by the crop, with an estimated 15, 15 and 25% being lost in the water conveyance, water field channels and inefficient application on the agricultural land respectively (FAO, 2012).

2. Materials and Methods

2.1 Study Area

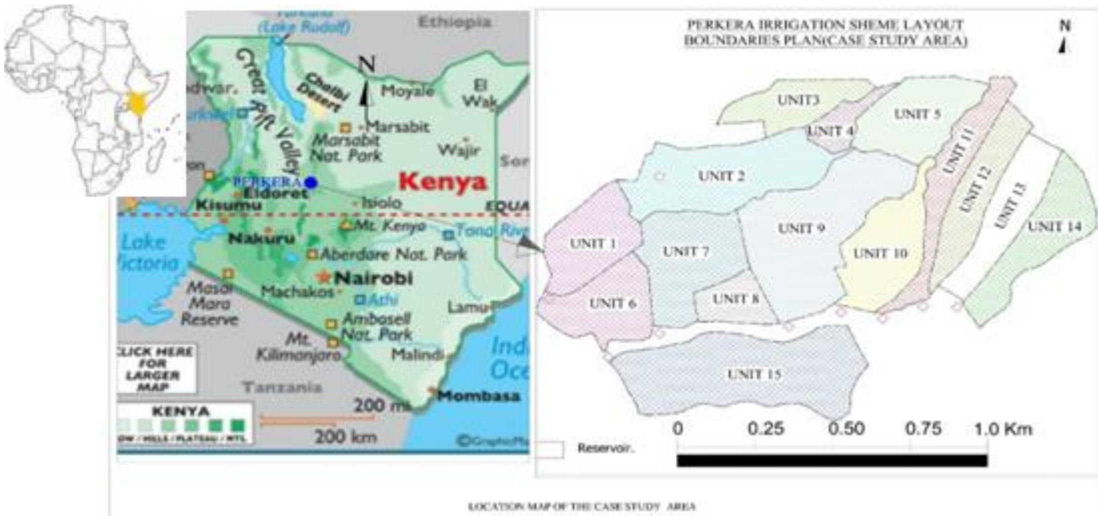

Figure 2.1: A map showing an area covered by Perkerra Irrigation Scheme

2.1.1 Location

The Project was implemented in Marigat in the Western part of Baringo county located between latitudes 00o 28' S and longitudes 36o 01' E. Marigat District covers an area of 1,677.5 km^2 which lies between Latitudes 000 13" North and 10 40" North and Longitudes 350 36" and 360 30" East. The altitude varies from 1,000m to 2,600m above sea level.

Perkerra Irrigation Scheme is found about 100km from Nakuru town along the famous river Perkerra that is the main source of water in the region. The name came from the River Perkerra which is the only source of water for irrigation and the only permanent river in the Margat district. The District borders East Pokot, Baringo Central District, Koibatek District, and Nyahururu District (Thom and Martin, 2016). The total area covered by the District is 1677.5km^2.

2.1.2 Climate

Climatic patterns in Perkerra Irrigation Scheme range from humid subtropical in the highlands to semi-arid in the lowlands. Agroecologically, the area is sub-humid with mean annual rainfall ranging from 600mm in the lowlands of Njemps Flats to 1000-1500 mm in the highlands. The rainfall has a high variability in duration and amount making up two fairly distinct seasons. It receives one rainy season between April and August and the rest are prolonged the dry season. It is receiving low to average annual rainfall. Though in the Neighbouring Kabarnet District there are high potential areas neighboring the highlands that receive high rainfall (GoK,2010). There is high rainfall variability in Marigat District. The mean annual maximum temperature is 32.4 ^{0}C, the mean annual minimum temperature is 16.8 ^{0}C and the mean annual temperature in the highlands is 14^{0}C and in the lowlands 24^{0}C.

2.1.3 Topography, Soil, and Vegetation

The area has varying textures and drainage conditions. Generally, the land slopes gently in the direction of Lake Baringo. The topography of the irrigable land earmarked for the scheme is fairly gentle slopes of approximately 5%. Soils within the plains are well-drained, deep, friable silty loams or heavy cracking clays and very rich in calcium phosphate (Thom and Martin, 2016). The original Acacia woodland has been degraded over time due to human settlement and agriculture. Eucalyptus Euphorbia, Aloe Vera, indigenous and exotic tree species are also present (GoK, 2010).

2.1.4 Economic activities

Population in the area is predominantly of the three ethnic groups; the Tugen, the Keiyo, and the Il-Chamus. The Tugen and the Keiyo practice a mixed subsistence agriculture, the Tugen in the Tugen Hills and the Keiyo on the Elgeyo Escarpment. The Il-Chamus are pastoralists in the lowlands of Njemps Flats adjacent to Lake Baringo (Thom and Martin, 2016). The majority of the farm households have cattle.

2.2 Evaluation of the effectiveness of the existing irrigation scheduling strategies

First, a literature review was conducted on irrigation scheduling techniques and crop evapotranspiration with the aim of investigating the technologies in Perkerra Irrigation Scheme and later refine these methods to develop an improved irrigation scheduling model. The field data collected during the review is presented in the following section (s).

2.2.1 Primary field data collection

- Primary field data collection commenced with a reconnaissance survey of various sites and discussions with relevant government agencies.

- The collection was from frequent field observations, informant interviews, semi-structured interviews and focus group discussions.
- The data collected include irrigation scheduling in use, crops cultivated, the size of the field, the problem facing farmers, farm management practices, local food security, water application and practices related to water management techniques carried out by the farmers.
- Canal water flow at the diversions discharge was taken at an interval which helped us in estimating the total volume of water that is being diverted by the irrigation scheme.
- Moisture contents of the soil of the selected irrigation fields before and after irrigation were determined by using the digital soil moisture meter and by taking soil samples at different depths of the soil profile.

2.2.2 Secondary data collection

- Secondary sources of data from Irrigation Offices at Regional and sub-region levels was collected as required.
- The Secondary data included best irrigation scheduling strategies, crop types, farm gate prices of irrigated crops, area irrigated per crop per season, production cost per season and cropping pattern.
- Meteorological data for each irrigation projects was obtained from the library, the internet, and the nearby weather station.
- The design documents of the irrigation project were obtained from the National Irrigation offices (Mark *et al.*, 1992).

3. Results and Analysis

3.1 Evaluation of the effectiveness of the existing irrigation scheduling strategies

The losses incurred from the current irrigation scheduling used in PIS was estimated. The first one was estimated when irrigation was done by farmers in every two to three days till the maize crop matures.

The moisture content of the maize field was taken before irrigation using the digital soil moisture meter. The inflow into the individual plots as measured from the farm ranges from 2.5 - 7.0 l/s as shown in Table 3.1.

Table 3.1: Inflow of water in the individual farmer's field

Farmer	Inflow (l/s)	Inflow per irrigated area (mm)	Inflow per ha (mm)
Kibet	5.5	15.84	31.68
Yegon	2.5	7.2	14.4
Lekitire	3.0	8.64	17.28
Charles	7.0	20.16	40.32
Average	4.5	12.96	25.92

Irrigation was averagely done 4 hours per day.

$$4.5 \times 4 \times 60 \times 60 = 64800/1000 = 64.8m^3$$

$$= 64.8/5000 = 12.96mm$$

$$= 12.96 \times 2 = 25.92mm/ha$$

$$= 47 \times 25.92 = 1209.6mm$$

Assuming that irrigation was done after 3 days

The total number of days needed for maize to fully grow is 140 days (from CROPWAT).

From the digital soil moisture meter, it was noted that many farmers irrigated their farms when the moisture content was still very high. This amount was found to surpass the irrigation requirement from CROPWAT estimate by more than 100%.

Many farmers irrigated at a moisture content of 70 - 80% which was too high to the maize depletion fraction of 50%. The soil moisture content before irrigation was found as presented in Table 3.2.

Table 3.2: Soil moisture content before irrigation

Farmer	Soil moisture before irrigation (%)	Amount of water needed to fill soil to FC, mm	Number of days before the next irrigation (RAW/ETc)	The number of irrigation done	Inflow per irrigation (mm)	Total water applied (mm)	Quantity of water wasted (mm)
Kibet	70	18.72	4	1.3	31.68	41.18	22.46
Yegon	77	25.27	6	2.0	14.40	28.80	3.53
Lekitire	80	28.08	6	2.0	17.28	34.56	6.48
Charles	73	21.53	5	1.7	40.32	68.54	47.01
Average					25.92	43.27	19.87

$$ETo = 4.69mm/day$$

This implies that irrigation is done to saturation point and hence a lot of water is wasted through percolation and runoff.

$$loss = k \times t$$

$$= 1.3cm/hr \times 4hrs \times 10mm/cm\text{s}$$

$$= 520mm$$

This implies that a lot of water is being lost through percolation.

4. Discussion

The justification for irrigation development entails both technical and socio-economic reasons. From the technical point of view, irrigation allows the stabilization of crop production by supplementing irrigation during the rainy season and supplying water to crops throughout the dry season. Socio-economically, it is a mechanism to fight poverty by ensuring that there is enough food and farm produce for the development of agribusiness which relies on the produce from irrigated farms.

4.1 Evaluation and analysis of proposed irrigation scheduling strategies for Perkerra Irrigation Scheme

Interviews and discussions with local farmers, the PIS management, and published documents were all used to evaluate the existing irrigation scheduling strategies and propose the most appropriate for the scheme. This was also based on geologic, hydrologic and institutional conditions with respect to finance. The economic costs and benefits of water savings were analyzed while taking into account existing practices. The evaluations were done as follows.

4.1.1 Volumetric Measurement of Irrigation Water

This entails the fitting of water measuring gadgets to quantify water streaming into the farm. In PIS, Parshall flume was initially being used to measure water intake to specific farm blocks from the main irrigation canals. Parshall meters are used in open channels and measure water in cubic meter/second. Individual farms are not metered. Volumetric measurements of irrigation water are not currently adhered to in water delivery. For instance, in India farmers have an incentive to apply water efficiently and water saved can be used to irrigate additional area or stored for the next irrigation (Kulkarni, 2007). The water metering system in PIS can be very effective with high potential for future water savings. As this can make farmers use water more responsibly data earned used to actualize other water preserving methodologies

4.1.2 Crop residue management and conservation tillage

Conservation tillage like no-till help in conserving the soil water. Tillage is reduced or kept to zero and crop residue from the previously harvested crop is retained on the soil surface as a mulch (Levidow *et al.,* 2014). The retained crop residues help in enhancing the ability of the soil to hold moisture and decreasing water loss from the soil to the atmosphere which then cools the soil. The soil is exposed to drying each time it is plowed. In the event that the strategies are correctly executed, water application might be decreased by one or more applications (Shock, Shock, & Welch, 2013).

These methods are not currently practiced in PIS and are considered inappropriate due to soil types and also pastoralism issue as many farmers use the crop residue especially from maize crop to feed livestock. There are no water savings anticipated from these two strategies at the moment.

4.1.3 On-farm irrigation audits

This is a method used to assemble and deliver information about the uniformity of water application, the rate of precipitation, and overall condition of an irrigation system. It helps to identify opportunities to improve water use efficiency in the farm (TWDB, 2013). The irrigation audit will collect information such as the type of irrigation system, topography, flood vulnerability, field size, obstructions, previous and current records of crops and water use (Gulma *et al.*, 2005).

On-farm irrigation audits are being carried out in PIS. It is applicable to PIS but the amount of water saved depends on the farmer's will to follow recommendations made by the auditors which make quantification of the water savings very difficult.

4.1.4 Land Management Systems

Land management systems include land leveling which is majorly used in irrigation field to regulate the soil surface and standardize its slope, facilitate the distribution of irrigation water and improve field conditions for other agricultural practices (Maria *et al.*, 2014). Land Levelling is majorly used by farmers who use furrow, border, or basin irrigation methods. It is used to increase the uniformity, effectiveness, and efficiency of water applied to an irrigation field or where crops are growing (Maria *et al.*, 2014). Water saved from land management system is difficult to quantify and its cost differs from one field to the other (Rapp and Defined, n.d.).

Land leveling is used by PIS farmers. The furrows are also made uniformto ensure there is auniform distribution of water to the farm and eventually crops. Almost all farmers within PIS level their field to conserve water and make the production of crops uniform.

4.1.5 The lining of on-farm irrigation canals

This entails the establishment of impervious lining material in a current or recently built irrigation field trench. This conservation strategy has not been practiced in PIS. Currently, all of the on-farm irrigation canals in PIS are not concrete-lined. Water savings involve minimized the amount of seepage from the establishment of a lining material. Concrete liners are estimated to retrieve 80 percent of the original seepage (Keller, 1995).We cannot quantify the exact water that can be conserved by reducing seepage losses in Perkerra Irrigation Scheme but it can be more than enough to double the area under irrigation.

4.1.6 The use of pipelines

Replacement of on-farm irrigation ditches with pipelines entails replacing open ditches with an underground pipeline that is generally 12 inches in radius. It is also estimated that 80% of the losses from seepage and evaporation could be saved with the use of pipeline (Keller, 1995).

Replacing the on-farm irrigation canals with pipelines has never been practiced in PIS. From the scheme engineer, this is due to high installation cost, the difficulty of maintenance and repairs. Canal lining costs are about 10 percent higher than installing and operating a pipeline for any irrigation scheme because of the difference in operation and maintenance costs. Lower pipeline operation and maintenance costs are attributed to the reduced clean-up costs of trash and other debris in canals. The amount of water lost to evaporation is little compared with drainage misfortunes. It is established that water savings from minimized evaporation are less than 10% of the seepage losses (Keller, 1995).

The use of pipelines on top of seepage loss control, it can also save water by reducing evaporation even though it is negligible compared to seepage losses.

4.1.7 Regulatory reservoirs

Irrigation water reservoirs play an important role in areas with limited precipitation where water can be stored and redistributed later for different purposes (USDA, 1997). PIS has one regulatory reservoir which is not in use due to poor engineering design that resulted in the lower irrigation head than the farms it is supposed to irrigate. One or more reservoirs should be constructed to store water during dry season.

4.1.8 Irrigation systems

Drip irrigation is the best system according to the study of agronomic practices impacts on maize yield which stated that water applied for irrigation was 41% and 20% less under pivot and conservation tillage than under surface irrigation and conventional tillage, respectively (Rogers *et al.*, 1997). Surface irrigation losses that include runoff, deep percolation, ground evaporation and surface water evaporation in which runoff losses can be significant if tailwater is not controlled and reused (Rogers *et al*., 1997).

The sprinklers and trickle irrigation systems are currently not used in PIS. This is due to the availability of water, water quality, soil types, and costs. A continuous steady flow of water is needed for the pressurized systems to function properly. They are also not economically in terms of cost. Trickle irrigation system requires clean water to avoid clogging of the nozzles yet the water from river Perkerra contains a lot of silt. It also needs regulatory reservoirs to hold the silt and make water available throughout the season.

4.1.9 Deficit irrigation

This is the irrigation that applies less water than the crop needs for its full development. Some crops lose little yield and quality with deficit irrigation by saving water. Deficit irrigation normally works with deep-rooted crops (Shock *et al.*, 2013). This technique points on precisely timing the utilization of a deliberate measure of water within the crop growth with the point of balancing out yield by applying water when the water in the soil has been depleted (Geerts and Raes, 2009).

The maximum soil moisture depletion for maize is 50% (Allen *et al*., 1998). Like in PIS when the irrigation is delayed to a depletion of 70% for instance, the yield reduction will be 3.1% as indicated in CROPWT which will be disadvantageous to the farmers and the Kitale Seeds company who expect good quality maize seeds from the farmers. The volume of water applied to a given field can also be reduced by shifting to crops that require less water but these practices reduce the net income to the farmers. Thus, we will not be considering them in this analysis.

4.1.10 Tailwater recovery

Tailwater recovery and reuse systems are relevant to any irrigation system where a large quantity of water runs through to the end of the fields being irrigated. This strategy consists of ditches or pipe network that gather tailwater and conveys it to another field to be used for irrigation purposes or to a storage reservoir. The amount of water collected from the tailwater reuse system depends mostly on the water supply and the current on-farm water management practices of the farmer. Water savings varies between 5 - 25 percent of the water applied to the upper segment of the field (Gilley *et al*., 2003).

There is little tailwater recovery in PIS because the most percentage of the water applied is used for irrigation. Interview with farmers indicates that there is little tailwater with a limited loss from the bottom of the fields but the little available tail water is channeled to the uncultivated farms which then flow via gravity to Lake Baringo. The water is allowed to flow to lake Baringo because there is no water storage facility for the tailwater that may be collected.

4.2 Current irrigation scheduling methods used in PIS and optimal irrigation requirement for maize crop

An estimated 93 percent of farmers interviewed in Perkerra region confirmed that they use some form of soil moisture monitoring strategies to aid in estimating the next irrigation date. For maize crops, irrigation should start when soil water content drops below 50 % of the total available soil moisture (Allen *et al*., 1998). Irrigation scheduling methods are to measure soil moisture so as to establish if it has dropped below 50% so as to enable irrigation to be initiated (Wright, 2002).

Most farmers in Perkerra irrigation scheme use hand feel and appearance of the soil and plant monitoring to determine when the next irrigation is needed.Hand feel and appearance of soilmethod is very cheap and does not require any special skills in order to achieve results as compared to other methods that are expensive and require technical know-how to operate (Martin, 2009). This method estimates soil moisture by obtaining a handful of soil and squeezing tightly between fingers from which various moisture content available in the soil can then be estimated (Maithya, Gibendi, & Asempah, 2010). Though hand feel and appearance of soil is the cheapest and readily available method, *Speer* states that it has disadvantages such asit cannot quantify the amount of water required, it does not estimate the time for irrigation and it is only limited to a specific area.

It takes the time to become familiar with this method and it requires a lot of experience (Martin, 2009). Silvia Lekitirne who grows new rice for Africa (NERICA) in PIS says she usually apply water to her farm after 2-3 days when the soil becomes dry. Apart from hand feel and appearance of the soil method, many farmers in PIS monitor their crops to help them in scheduling irrigation.

Methods to monitor the state of water in the crop include; estimation of transpiration using excised leaves, observations of stomatal aperture, monitoring stem diameter, pressure cell and psychometric measurements of leaf water potential among others (Ingvaldsen, & Gulla, 2015). These are the most direct methods used to determine when to irrigate. A keen farmer can detect signs of water stress by the appearance of the foliage (leaves, stems or branches) during the period of peak transpiration demand (Savva and Fenken, 2002). The methods used mostly by Perkerra farmers include; Appearance and growth method is a trial and error method of direct visual inspection. This method entails the monitoring of the crop growth characteristics like wilting when other factors such as fertilizer, pest, and diseases have been met. It involves visual interpretation of the leaf and shoots wilting, leaf colour and measurement of the stem diameter and height at a given interval. It is the simplest method that has been used by farmers in remote areas. Douglas Yego a farmer who grows maize and tomatoes say that he normally apply water when the leaves of the crop start to wilt. Monitoring the weather method has not been practiced in Perkerra as a way to schedule irrigation.

Monitoring the weather method gives meteorological information that can be used to measure the amount of evapotranspiration as it changes with time and to set the amount of water needed for irrigation. The timing of irrigation can then be determined with reference to the soil's residual wetness (Hillel, 1990).

We used the meteorological data from KALRO and Perkerra weather station to obtain the weather variables that we needed to calibrate the CROPWAT to develop an irrigation schedule that ensures the precise quantity of water is applied to the field at the right time.

5. Conclusion and Recommendation

Four irrigation management strategies were found to have water saving potential with respect to Perkerra Irrigation Scheme; Irrigation scheduling using CROPWAT, the lining of canals, replacement of canals with pipeline and on-farm audits. Regulating reservoirs are paramount for water storage. Irrigation scheduling strategy using CROPWAT is the only strategy found to have a water saving potential in Perkerra irrigation scheme.

The regulatory reservoir cannot guarantee water saving but it ensures availability of water throughout the growing season. There is a need to construct regulatory reservoirs which can hold and store water during the rainy season to be used for irrigation when needed in a dry season. This reservoir should be built at a strategic point to ensure water can flow via gravity to the directed fields. The lining of canals and replacement of canals with pipelines can save a lot of water but they were found to be expensive for the scheme to implement being that they are currently in short of funds. They should mobilize for funds and implement either of them in the near future so as to reduce the water loss through seepage and evaporation.

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