1 *Article*

2 Application of Benchmarking and Principal 3 Component Analysis in Measuring Performance of 4 Public Irrigation Schemes in Kenya

5 **Faith Muema[1],*, Patrick G. Home [1] and James M. Raude[2]**

6 ***** Pan African University, Institute for Basic Sciences, Technology and Innovation, (PAUSTI). P. O. Box
7 62000-00200 Nairobi, Kenya: faith.mawia@yahoo.com; Tel.: +254713009267
8 [1] Jomo Kenyatta University of Agriculture and Technology, (JKUAT).P. O. Box 62000-00200 Nairobi, Kenya;
9 pghome@jkuat.ac.ke
10 [2] Soil, Water and Environmental Engineering Department, Jomo Kenyatta University of Agriculture and
11 Technology, (JKUAT).P. O. Box 62000-00200 Nairobi, Kenya; ramesso@jkuat.ac.ke

12

13 **Abstract:** The Inefficient water use, varying and low productivity in Kenya public irrigation
14 schemes is a major concern. It is therefore necessary to periodically monitor and evaluate the
15 performance of public irrigation schemes. The performance of public irrigation in western Kenya
16 was assessed by combining benchmarking methodology and principal component analysis. The
17 aim was to quantify and rank the performance of pumped public irrigation schemes in Kenya.
18 Eleven benchmarking indicators were computed for the period from 2012 to 2016 and compared to
19 global benchmark values. The indicators used fall under agricultural productivity, water supply
20 and financial performance categories. The computed agricultural productivity was 36%–51% in
21 Ahero, 23%–42% in West Kano and 26%–50% Bunyala irrigation scheme. Water supply
22 performance in Ahero, West Kano and Bunyala irrigation schemes varied from 24% to 58%, 3% to
23 49% and 19% to 43% respectively. Financial performance varied from 46% to 54% in Ahero, 25% to
24 32% in West Kano and 54%–56% in Bunyala irrigation scheme. An average overall performance
25 efficiency of 46%, 39% and 31% was obtained in Ahero, Bunyala and West Kano irrigation schemes
26 respectively. The performance of the irrigation schemes is very poor and measures on improving
27 performance are needed.

28 **Keywords:** Benchmarking, Evaluation of performance, Performance indicator, Principal
29 component analysis.
30

31 1. Introduction

32 Water is a limited resource facing stiff competition among various economic sectors. In
33 addition, the increasing population is exerting more pressure on the finite water resources making it
34 increasingly scarce [1].Agricultural activities in Kenya use 70 per cent of water available, majorly in
35 irrigation [2]. Therefore, efficient utilization of water is needed in irrigation to save water; increase
36 productions per water used and reduce negative effects on the environment such as salinization and
37 water logging because of applying excess water.
38 The population in Kenya has been growing rapidly having an increase from 28.7 million in
39 1999 to 38.6 million in 2009 and is expected to reach 69.5 million by 2030 [3-4]. The country is
40 therefore faced with need to provide adequate food supply by employing various strategies to
41 increase agricultural production to match the raising demands for food. Production in agriculture
42 can be increased through irrigation since expansion of land under agriculture is limited by
43 availability of rainfall [3]. Irrigation leads to increase in yield of most crops by 100 to 400 per cent and
44 it is projected that 70 per cent food produced in 30 years' time will be from irrigated agriculture [5].

45   According to [6]   irrigation in arid and semi-arid lands improves economic growth and can increase
46   production by up to 400 per cent.
47   Irrigated agriculture is faced with challenges such as inefficient water use, low returns in
48   investment, management and poor operation [1]. Increasing efficient water use promotes equity in
49   water distribution and reduces the difference between potential crop water requirement and actual
50   water use. Moreover, farmers can use less water to achieve high production while the remaining
51   water of water can be left to maintain ecological cycle and the environment of the river basin.
52   According to Kenya's National water Master Plan 2030,   the total irrigated area in Kenya as of 2010
53   was   estimated   to be 141,900 ha which is way below the potential irrigable area of 765,379 ha[7].
54   Irrigated agriculture utilises 4 per cent of the country's total area under agriculture. This accounts for
55   18 per cent of the total value of all agricultural produce therefore contributing 3 per cent of the gross
56   domestic product. There exists a greater potential in increasing production and productivity in
57   agriculture through irrigation[7]. Irrigation potential in Kenya is under-utilized as indicated inTable
58   1.

59   Table 1. Irrigation potential in Kenya

Basin	Irrigation potential (Hectares)	Current Irrigated Area (Hectares)	Balance
Tana	226,224	64,425	161,799
Athi	91,006	44,898	46,108
Lake Victoria basin	297,213	15,094	282,119
Kerio valley	101,753	9,587	92,166
Ewaso Ngiro	49,379	7,896	41,483
Total	765,379	141,900	623,675

60   Kenya's irrigation systems can be broadly categorized into; smallholder schemes, large-scale
61   private/commercial irrigation schemes and public schemes [8]. Large commercial farms occupy 40
62   per cent of total irrigated land while smallholder irrigation schemes account for 42 per cent and the
63   rest 18 per cent is occupied by Government-managed schemes [9].The main irrigated crops grown
64   are rice, vegetables, coffee, fruits, sugarcane, cotton, maize and horticulture   [3].The public
65   irrigation schemes in Kenya are characterised by poor performance hindering their expansion [8].
66   Heavy investments are channelled in these irrigation schemes and are therefore expected to be
67   operating efficiently and effectively to meet rising food demands [3]. However, the level of
68   performance and sustainability of the public irrigation schemes in Kenya is not known. This has
69   prompted measurement of performance of public irrigation schemes using benchmarking indicators
70   and principal component analysis. The study provides information to scheme management to
71   enable monitoring of irrigation operations and evaluation of efficiency of utilisation of resources at
72   system, scheme, catchment and national levels. Furthermore, it sheds some light to stakeholders and
73   policy makers on area that require policy interventions and reformulation of strategies needed to
74   achieve food security.
75   Performance assessment in irrigation sector looks into optimizing resource use with the aim of
76   achieving maximum possible produce [10]. Performance of an irrigation scheme is the measure of
77   the   degree to which it achieves target objectives [11]. Evaluation of performance of an irrigation
78   system gives an indication of how far the goals and objectives set during project formulation have
79   been met [12]. It compares the actual results to the expected results. To promote efficient utilisation
80   of resources, irrigation sector should be benchmarked. Benchmarking was developed by
81   International Programme for Technology and Research in Irrigation and Drainage (IPTRID) as a
82   management tool to be used in improving productivity and efficiency in irrigation and drainage
83   sector [13]. It is a process of analysing and comparing performance of an organisation either
84   internally with desirable target standards or externally against similar organisations [14]. It enables

identification gap in performance between current and better achievable standards and changes required to achieve higher performance standards [15].

IPTRID, Food and Agriculture Organization (FAO), World Bank, International Water Management Institute (IWMI) and International Commission on Irrigation and Drainage (ICID) have laid emphasis on measuring performance in irrigation and drainage sector as a way of achieving sustainable development in agriculture. However, benchmarking has received little attention for most irrigation projects in developing countries and has not been embraced in Kenya. The process of benchmarking involves six stages: identification and planning; data collection; analysis; integration; action; and monitoring and evaluation [15]. It is a data intensive activity and is limited by availability of data since it requires day to day data collection. Benchmarking looks into comparison of input and outputs without considering the internal processes which affect the level of output. The main goal of benchmarking is to improve performance of an organization [15]. There are several drivers to improving performance of an irrigation system. These include; increasing competition for water, rising food demand, need for more water use efficiency, water prices, pressure to increase productivity for less cost[14]. Undertaking benchmarking enables project managers and authorities to identify problems and measures required to bridge the gap between current and desirable performance standards.

Performance in irrigation systems is measured using performance indicators which inform the stakeholders on the level of performance. A performance indicator is a description of actual achievement in relation to one of the goal of irrigation system [14]. In comparing performance indicators, irrigation schemes that are less or more efficient in comparison to others are identified and necessary measures needed to correct the inefficiency undertaken [16]. However, the irrigation schemes cannot be ranked using indicator to indicator comparison. Stakeholders and policy makers are interested in aggregated performance scores which give them an indication of level performance of an irrigation schemes compared to the others [13]. In this paper, combination of performance indicators and principal component analysis (PCA) was applied in evaluating the performance of irrigation schemes. Combination of benchmarking and PCA enabled the determination of a single performance score which indicates the performance level of an individual irrigation scheme in comparison to the others.

This study was based on two domains: service delivery and Productive efficiency: Service delivery domain contains two areas of service provision: (a) water supply efficiency - the adequacy of managing water delivery to meet water demand; and (b) financial performance - the efficiency of resource use to offer irrigation service. Productive efficiency measures the efficiency.

2. Materials and Methods

2.1. Description of study area

The study was carried in three rice growing irrigation schemes namely; Ahero, West Kano and Bunyala, located in western Kenya (Figure 1)which are managed by National Irrigation Board (NIB). All the schemes use pumped-gravity surface irrigation water distribution method. Water is abstracted using electric powered pumps and conveyed with open earth canals. The western Kenya region has a hot and humid weather with bimodal rainfall pattern. The schemes are underlain by deep black cotton soils [17].
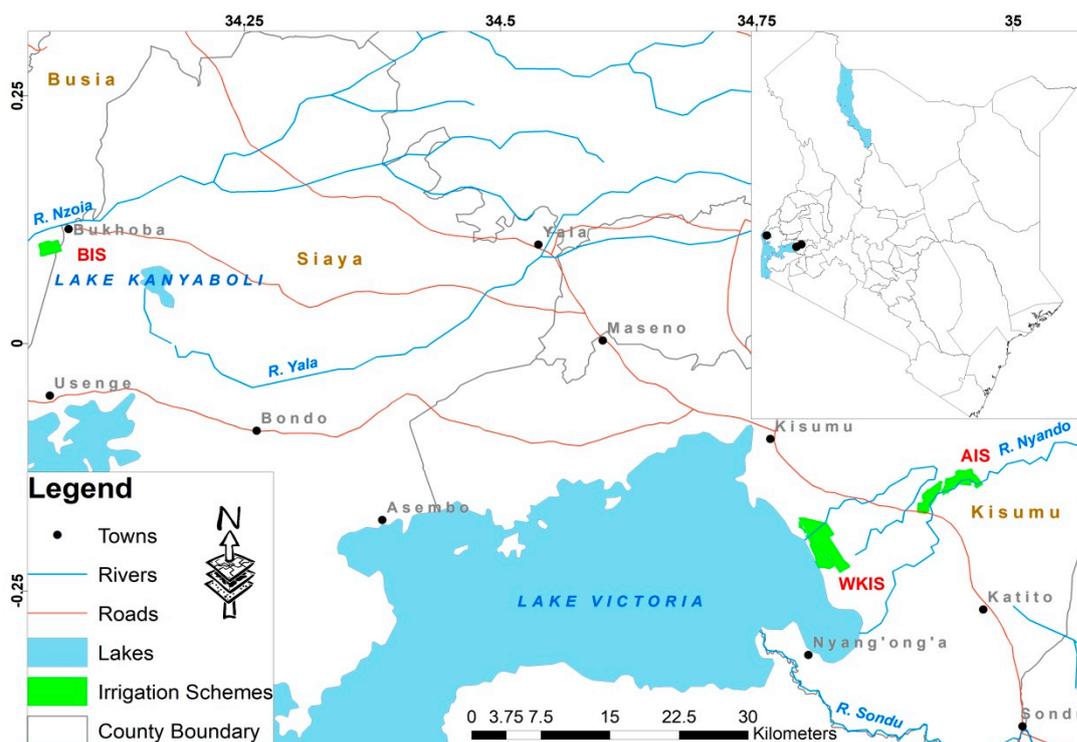
126

127   Figure 1. Study Area

128   **Ahero Irrigation Scheme (AIS)** lies at longitude 34°58′ east and latitude 00°10′ south in Kano
129 plains, Kisumu County and abstracts water from river Nyando. The Scheme has a gross area of 1540
130 ha out of which 900 ha has been developed for crop production supporting 556 tenant farmers. The
131 area gets mean annual rainfall of 1233 mm and the mean monthly temperature ranges from 23.4°C to
132 25.6°C. **West Kano irrigation scheme (WKIS)** is located between longitudes 34°48′ East and 35°02′
133 East and between latitudes 00°04′ South and 00°20′ South along the shores of Lake Victoria in Kano
134 plains, Kisumu County[17] . Water is abstracted from Lake Victoria by pumping. The scheme has a
135 service area of 1780 ha out of which 980 ha has been developed for crop production serving 845
136 tenant farmers. The area gets mean annual rainfall of 1100 mm and the mean diurnal temperature is
137 23°C. **Bunyala irrigation scheme (BIS)** is located at longitude 34°`04′ East and latitude 00°06′ North
138 in Kisumu Busia / Siaya County. The scheme has a total gazetted area of 728 ha with 702 ha under
139 irrigation supporting 1934 farmers. Water is drawn from River Nzoia. BIS gets mean annual
140 rainfall of 1620 mm and the mean monthly temperature ranges from 24.5°C to 31.5°C.

141 *2.2. Data collection and analysis*

142   Time series secondary data was collected for a period of five years (2012-2016).   Data on total
143 yield per season, local crop price per season, cropped area, total command area, revenue collected,
144 expected revenue, cost of production, water supplied, pump speed and pumping hours was
145 obtained from records kept by irrigation scheme offices, NIB regional office and field survey.
146 Meteorological data was obtained from Ahero research station, West Kano weather station, Kenya
147 Meteorological Department (KMD) and NASA POWER centre. Key informant interviews,
148 observation and focus group discussion methods were used to collect data on farming practices,
149 cropping pattern, status of the irrigation systems and maintenance of the system.
150   Crop pattern, transplanting date and weather data was used in calculating crop water
151 requirement using CROPWAT8 software[14]. Performance of the irrigation schemes was evaluated
152 using standard performance indicators proposed by IPTRID [14]. The indicators were computed and
153 compared among the three schemes in each year. Eleven indicators were evaluated under water
154 supply, financial and agricultural productivity domains. Some of the recommended indicators
155 were not computed because of lack of data.

156   *2.3. Computation of Performance indicators*

157   The indicators were computed as shown in Table 2.

158   Table 2. IPTRID performance indicators

Performance category	Performance indicator	Indicator equation
	Relative water supply(RWS)	$\dfrac{\text{total annual volume of water supply}}{\text{total annual volume of crop irrigation demand}}$
	Relative irrigation supply (RIS)	$\dfrac{\text{total annual volume of irrigation supply}}{\text{total annual volume of crop water demand}}$
Water Supply	Annual irrigation water supply per unit irrigated area (m3/ha)	$\dfrac{\text{Total annual volume of irrigation supply}}{\text{Total annual irrigated area}}$
	Annual irrigation water supply per unit command area (m3/ha)	$\dfrac{\text{Total annual volume of irrigation supply}}{\text{Total annual command area}}$
	Output per unit irrigated area(kg/ha)	$\dfrac{\text{Total annual agricultural production}}{\text{irrigated area}}$
Agricultural Productivity	Output per unit command area (kg/ha)	$\dfrac{\text{Total annual agricultural production}}{\text{command area}}$
	Output per unit irrigation supply (kg/m3)	$\dfrac{\text{Total annual agricultural production}}{\text{total annual volume of irrigation suply}}$
	Output per unit water supply (kg/m3)	$\dfrac{\text{Total annual agricultural production}}{\text{total annual volume of water suply}}$
	Output per water consumed(kg/m3)	$\dfrac{\text{Total annual agricultural production}}{\text{total annual volume of crop water demand}}$
Financial performance	Water fee collection performance (WFC)	$\dfrac{\text{Gross revenue collected}}{\text{Gross revenue invoiced}}$
	Average revenue per unit irrigation supply(KES/m3)	$\dfrac{\text{total annual revenue collected}}{\text{Total annual volume of irrigation supply}}$

159
160   The computed indicators were compared amongst the schemes and performance threshold
161   values presented in Table 3.

162   Table 3. Indicative benchmark values

Performance indicator	Threshold values	Reference
Relative water supply	1	[18]
Relative irrigation supply	≤1	[18]
Annual irrigation water supply per unit irrigated area	≤700 mm	[19]
Annual irrigation water supply per unit command area	≤700 mm	[19]
Output per unit irrigated area	8800 kg/ha	[20]
Output per unit command area	8800 kg/ha	[20]
Output per unit irrigation supply	2kg/m3	[21]

Output per unit water supply	2kg/m3	[21]
Output per water consumed	2kg/m3	[21]
Water fee collection performance	100%	[14]
Average revenue per unit irrigation supply	KES. 7.5	[22]

163
164   The overall scheme performance was determined by computing a composite indicator for each
165   domain; one for water delivery, one for financial performance and one for agricultural productivity.
166   The indicators were normalized using reference to target technique in order to convert them to the
167   same scale as follows:

168
$$I_{qs}^t = \frac{x_{qs}^t}{x_b} \tag{1}$$

169   Where; I_{qs}^t = normalised value of indicator q for scheme s at time t; x_{qs}^t = indicator value for
170   scheme s at time t; x_b= benchmark indicator value.
171   Indicators were then tested for statistical correlation using Pearson to enable choice of only
172   indicators with low degree of correlation. The chosen indicators (ten) were then weighted and
173   aggregated using principal component analysis.

174   *2.4. Principal Component Analysis (PCA)*

175   This is a statistical multivariate technique which is used in weighting of indicators based on
176   eigenvalues and eigenvectors[23]. This method is objective and relies on the underlying data
177   structure to generate non-subjective weights which are less biased. Multicollinearity and presence of
178   outliers can be detected using this method [16]. Also, the analysis of multidimensional phenomenon
179   is simplified when variables are correlated using this method. Principal factors are generated
180   through linear combination of representative indicators which account for maximum variance and
181   are uncorrelated. Only principal factors with eigenvalues greater than one are considered since
182   eigenvalues below one account for insignificant variation [23]. The data was tested for suitability for
183   PCA using Kaiser-Meyer-Olklin (KMO) and Bartlett Test of Sphericity (BTS). The extracted factors
184   were rotated using orthogonal verimax method to achieve significant factors. The composite
185   indicators were then computed using rotated factor loadings and eigenvalues as follows [16].

186
$$CI_{st} = \sum_{k=1}^{k=n} w_k I_{ks} \tag{2}$$

187   Where; w_k= normalized indicator k for scheme s; CI_{st}= composite indicator for performance for
188   scheme s at time t

189
$$w_k = \sum_{j=1}^{j=n} \left\{ \frac{(\text{Factor loading}_{kj})^2}{\text{eigen value}_j} \times \frac{\text{eigen value j}}{\sum_{j=1}^{j=n} \text{eigen value}_j} \right\} \tag{3}$$

190   Note that only principal factors (j=1…n) with Eigenvalues greater than 1 are included in the
191   calculation.

192   **3. Results**

193   *3.1. Performance indicators*

194   The computed performance indicators under the three performance criteria are presented as
195   follows.

196   3.1.1. Water supply performance

197   The indicators give a measure of water supply relative to demand of an individual irrigation
198   system. Water abundance or scarcity of water can be deduced from these indicators [18]. The results
199   of water supply indicators are presented in Table 4.

200   Table 4. Water supply indicators

| Irrigation Scheme	Year	Relative water supply	Relative irrigation supply	Annual irrigation supply per unit Irrigated area (m³/ha)	Annual irrigation supply per unit Command area (m³/ha)
	2012/2013	1.98	2.15	7,785	7,586
	2013/204	1.14	0.86	5,837	5,487
	2014/2015	1.45	1.31	6,217	5,409
	2015/2016	1.28	0.86	5,294	4,847
Ahero	2016/2017	1.24	0.68	5,487	4,389
	2012/2013	2.31	3.38	11,238	7,687
	2013/2014	1.94	1.64	12,310	2,817
	2014/2015	2.21	2.74	11,376	2,465
	2015/2016	1.92	1.75	10,955	7,888
West Kano	2016/2017	1.86	1.58	12,191	9,326
	2012/2013	1.98	1.94	6,287	6,050
	2013/2014	2.17	2.25	8,868	8,533
	2014/2015	2.06	2.26	7,706	7,415
	2015/2016	2.24	2.40	8,622	7,396
Bunyala	2016/2017	2.44	2.46	12,130	11,089

201
202   The relative irrigation supply (RIS) values varied from 0.68 to 3.38 during the study period**.**
203   Values above1 indicate abundance of water supply while below 1 indicate water deficit [24].   RIS
204   values close to 1 are recommended [24]**.** In addition, a value of 0.8 implies deficit irrigation is
205   practised to optimise crop production due to shortage in water supply. Supply of excess water in
206   Bunyala and West Kano is evident from the high values of RIS obtained during the study period. On
207   average, Ahero irrigation scheme recorded the least RIS values majority of which were below 1. This
208   means that deficit irrigation is practiced in Ahero irrigation scheme. Farmers have been trained on
209   water management and water saving. West Kano has the highest RIS of 3.38-1.68. This depicts excess
210   water supply and wastage. Farmers in West Kano irrigation scheme have not been trained on water
211   use and saving and believe the farms should be flooded all the time. The relative water supply
212   (RWS) varied between 1.14 and 2.44 for all the schemes which is above 1 indicating condition of
213   surplus water. Furthermore, these results could probably offer the answer to why excess drainage
214   water from Ahero is used to irrigate a block (Nyatini) which is unaccounted for. A lot of water goes
215   to waste in Bunyala and West Kano in the form of drainage water which could be utilised in
216   expanding the command area. Supply of excess water in West Kano adds up to extra cost of
217   pumping it back to Lake Victoria since the terrain does not allow for free gravity flow. The quantity
218   of water supplied per unit area varies with availability of water, climate, soil type, cropping
219   pattern, system conditions and system management [25]**.**
220   The amount of water supplied per unit area is presented inTable 4.The annual irrigation water
221   supply per unit command area (ISCA) varied between 2,465 m3/ha (west Kano in 2014/2015) to 11,
222   089 m3/ha (Bunyala in 2016/2017). The determined ISCA are 4,389 m3/ha -7,586 m3/ha; 2,465 m3/ha
223   -9,326 m3/ha and 6,050 m3/ha -11,089 m3/ha for Ahero, West Kano and Bunyala Irrigation Schemes
224   respectively. These corresponds to depth of water supplied of 5.29m-7.79m,1.0m-1.23m and
225   0.63m-1.21m in Ahero, West Kano and Bunyala Irrigation Schemes respectively. According to FAO,
226   the average crop water need for paddy rice should be 0.45m-0.7m[19]. This means that Ahero
227   irrigation scheme supplies enough water to meet crop water needs while Bunyala and West Kano
228   irrigation schemes supply excess water. On average Bunyala has the highest ISCA of 8096 m3/ha
229   while Ahero has the least ISCA of 5544 m3/ha.   The annual water supply per unit irrigated area

230 (ISIA) varied between 5,294 m3/ha (Ahero in 2015/2016) to 12,310 m3/ha (West Kano in2013/2014).
231 The calculated ISIA values for Ahero, West Kano and Bunyala irrigation schemes are 5,294 m3/ha
232 -7,787 m3/ha, 10,955 m3/ha -12,310 m3/ha and 6,287 m3/ha -12,130 m3/ha. On average West Kano has
233 the highest ISIA of 11,614 m3/ha while Ahero has the least value of 6,124 m3/ha. From the results, it
234 is evident that Ahero irrigation scheme experiences water scarcity compared to Bunyala and West
235 Kano which experience surplus supply of water**.** In another similar study, water supply in Mwea
236 was estimated to be 23,747 m^3/ha for the period 2007/2008 [26]. Mwea irrigation scheme supplies too
237 much water in excess compared to the schemes in western Kenya.

238 3.1.2. Financial performance

239 The Financial performance indicator measures the   efficiency with which the organization uses
240 resources to provide service to the farmers [27].   Water fee collection performance (WFC) values
241 obtained are 80-90%, 45-57%, and 92-97% for Ahero, West Kano and Bunyala irrigation schemes
242 respectively as shown in Figure 2.
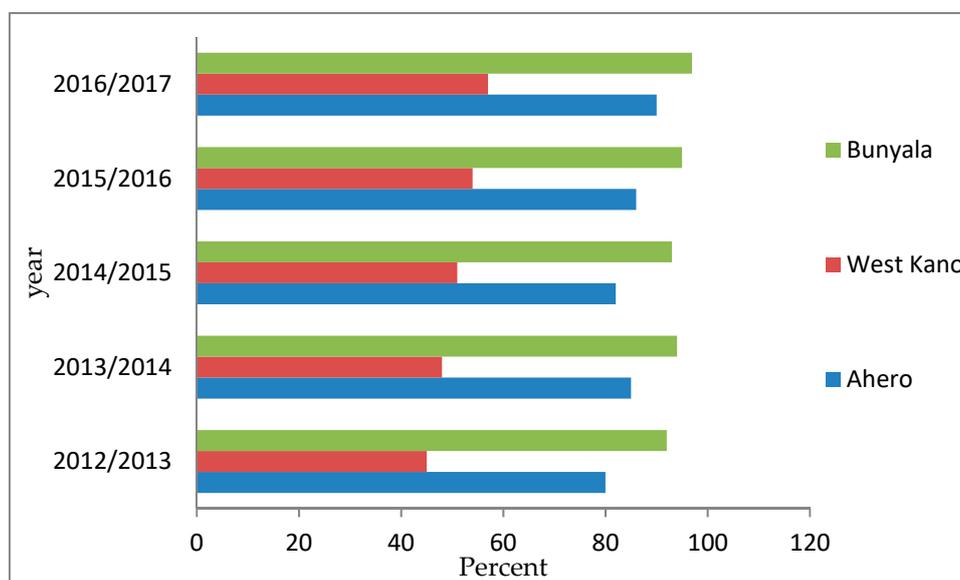
243

244 Figure 2. Water fee collection indicator

245 According to [28]water fee collection value below 70% is considered unsatisfactory. Bunyala
246 has the highest average fee collection performance of 94% while West Kano has the least average
247 value of 51%. The ideal value recommended should be close to 100% [14]. Low value points out
248 unwillingness of farmers to pay water fee, poor organization of Irrigation Water Users Association
249 (IWUA), poor collection program and financial problems within the schemes. Bunyala is able to
250 sustain a value above 90% because of the well-organized farmer groups that are mandated with
251 mobilization of water fee. Also in Bunyala, the policy of water fee payment prior to ploughing is
252 strictly followed. Pricing of water is an economic aid to improving water allocation and sustainable
253 water utilization [29]. The water fee charged is KES.3100,   KES.3640 and KES.4000 per acre in
254 Ahero, West Kano and Bunyala Irrigation Schemes respectively. The pricing is based on area
255 cropped and farming season and not the quantity of water consumed. This means that there is no
256 limit to the quantity of water that a farmer can use. This is a weakness since it is unsuitable in terms
257 of efficiency of water use and water conservation.
258 The average revenue per unit irrigation supply (ARIS) indicator   accounts for every drop of
259 water supplied [30]. The values obtained varied from KES.0.79 to KES.1.26; KES.0.35 to KES.0.44 and
260 KES.0.79 to KES.1.45 per cubic meter in Ahero, Bunyala and West Kano irrigation schemes
261 respectively Figure 3.
262
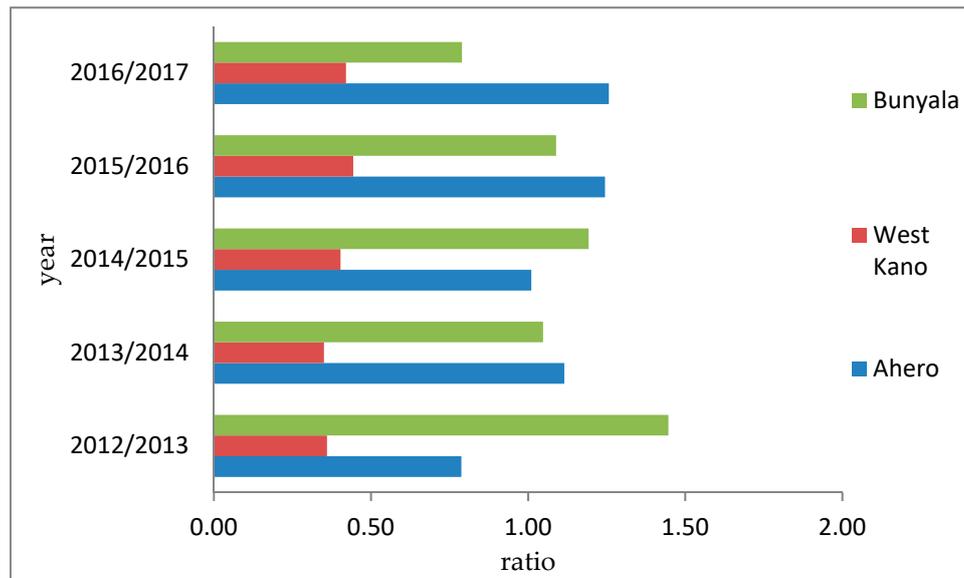
Figure 3. Average revenue per unit irrigation supply

This translates to 1 cubic meter of water being charged at an average of KES. 1.08, 0.4 and 1.11 in Ahero, West Kano and Bunyala irrigation schemes respectively. This is equivalent to less than1$/m³. These values are below the economic value of irrigation water of KES.7.54/m3 proposed byby [22] in Ahero irrigation scheme. Bunyala is the leading irrigation scheme in terms of financial performance indicator.

3.1.3. Agricultural productivity

Agricultural productivity gives the relationship between inputs and output.   It is an indicator of efficiency of crop production in terms of land used, amount of water used and the income generated [31].   The indicators are grouped into land productivity and water productivity. Water productivity relates amount of agricultural production to volume of applied or diverted. The output per unit irrigation supply (OIS) ranges between 0.35 kg/m³ and1.03 kg/m³ in all the schemes Figure 4.
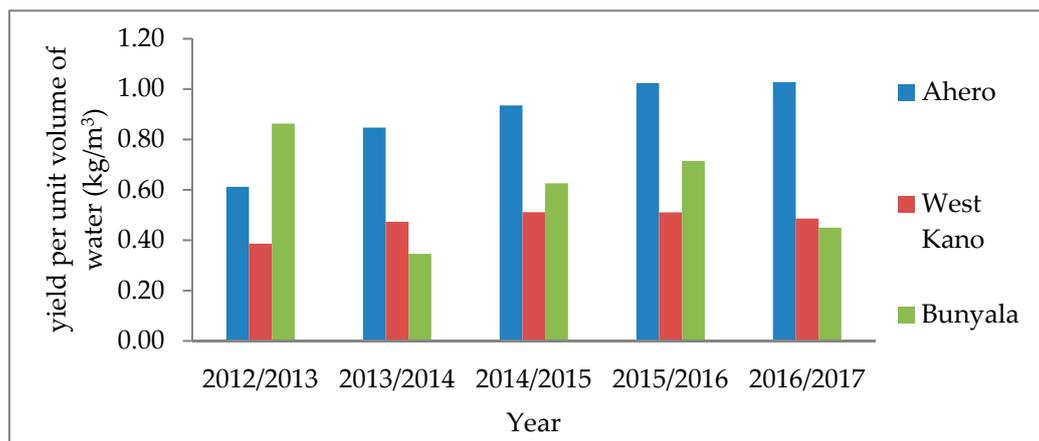
Figure 4.   The output per unit irrigation supply
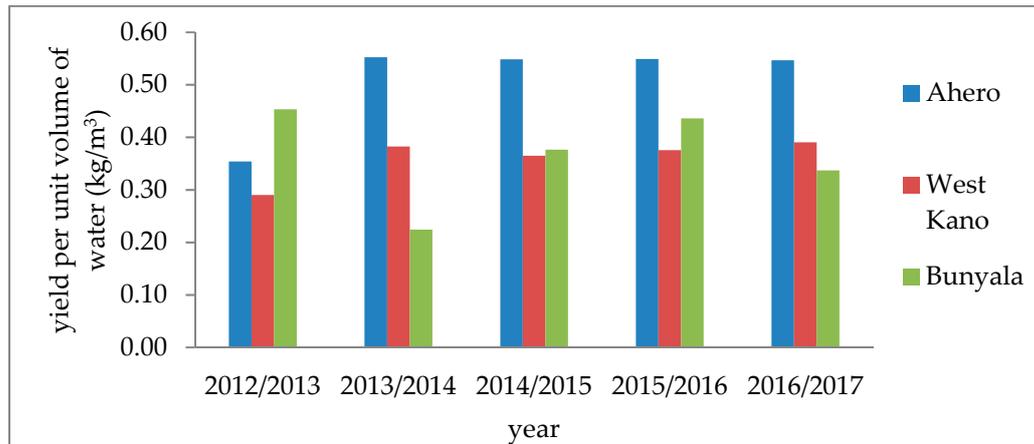
The average values for Ahero, West Kano and Bunyala irrigation schemes are 0.89 kg/m³, 0.47 kg/m³ and 0.60 kg/m³ respectively. West Kano and Bunyala with 0.47 and 0.60 kg/m³ have low water productivity below the average global grain productivity ranging from 0.76 to 1.23 kg/m³ [27]. A mean average water productivity of 0.1962kg/m³ was registered in Mwea irrigation scheme in 2007/2008 [26].   Ahero utilises water more efficiently compared to the others. The output per unit

283   water supply (OWS) puts into consideration the contribution of effective rainfall. The values vary
284   between 0.22 and 0.55 kg/m3 during the study period as shown in Figure 5.

286   Figure 5. Output per unit water supply

287   The highest (0.55 kg/m3) and the least (0.22 kg/m3) were obtained in Ahero in 2013/2014 and
288   Bunyala 2013/2014 respectively. On average Ahero has the highest value of 0.51 followed by
289   Bunyala (0.37) and the least is West Kano (0.36). The output per unit water consumed (OWC) varied
290   between 0.49 and 0.98kg/m3 as shown in Figure 6.
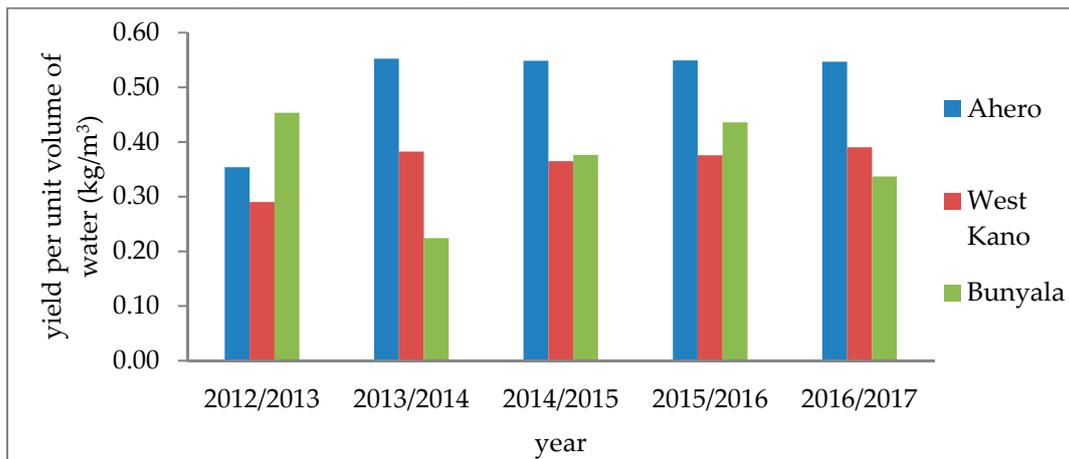
292   Figure 6. Output per unit water consumed

293   These values are within global rice water productivity range of 0.5-2kg/m3[21]. The highest
294   global values of rice water productivity of 1.77, 1.75 and 1.51kg/m3 have been reported in USA, Sri
295   Lanka and Spain respectively [21]. Ahero irrigation scheme is leading in terms of water productivity
296   while West Kano is the poorest. This means that Ahero irrigation scheme uses water more efficiently
297   than Bunyala and West Kano schemes. This is depicted by higher output per unit water consumed
298   than output per irrigation supply in Bunyala and West Kano insinuating inefficient water utilization.
299   According to[24], if output per unit water consumed is greater than output per irrigation supply,
300   some of irrigation water supplied is unproductive. The difference in water productivity is associated
301   with the difference in farming practices and water management amongst the schemes. In Ahero
302   irrigation scheme, some good agronomical practices have been adopted. Such practices include:
303   system of rice intensification (SRI), use of high yield hybrid seeds, use the right fertilizer (sulphate of
304   ammonia that lowers soil pH as opposed to urea) and high fertilizer application (an average of
305   175kg/acre). On the other hand, West Kano which is the least performing Irrigation Scheme in this
306   category suffers from; use of traditional seeds, and low fertilizer application (average 100kg/acre).

307 Land productivity indicators give a reflection of crop intensity[32]. The output per unit
308 command area (OCA) varies between 1260 kg/ha and 5285 kg/ha.
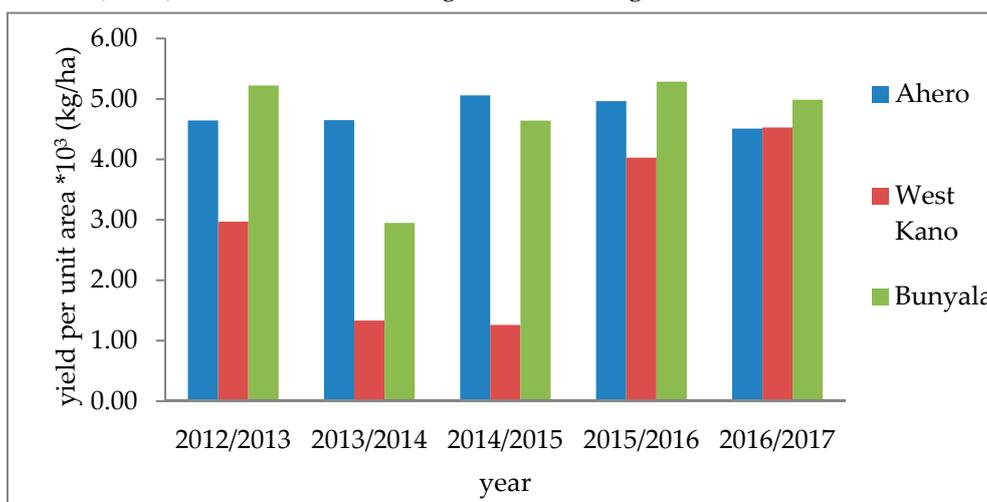
310   Figure 7. Output per unit command area

311   The highest value (5285 kg/ha) was registered in Ahero in 2015 while the least value (1260
312 kg/ha) was recorded in West Kano in 2013. The average values for Ahero, West Kano and Bunyala
313 are 4763 kg/ha, 2823 kg/ha and 4616 kg/ha respectively. High value indicates that there is intensive
314 irrigation. The sudden fall in output per command area in West Kano between 2012 and 2014 can be
315 attributed to collapse of Revolving Fund Committee.   The committee was mandated with
316 responsibility of production and marketing in the whole scheme. Consequently, there was a decline
317 in production activities during that period associated with governance issues. From 2015 each block
318 in the scheme established production management structure which saw competition amongst the
319 blocks in terms of production activities hence an increase in production as well as the area under
320 crop. Bunyala irrigation scheme experienced hail stone in 2013 which shattered mature rice crop in
321 one of the phases (Muluwa phase 1). This contributed to a low harvest as depicted by sudden decline
322 in output per unit area in the scheme. The output per unit irrigated area (OIA) for all the schemes
323 varied from 3062 to 66160 kg/ha as shown in Figure 8. The values are comparable to global average
324 rice yield of 3800 kg/ha reported by [20].
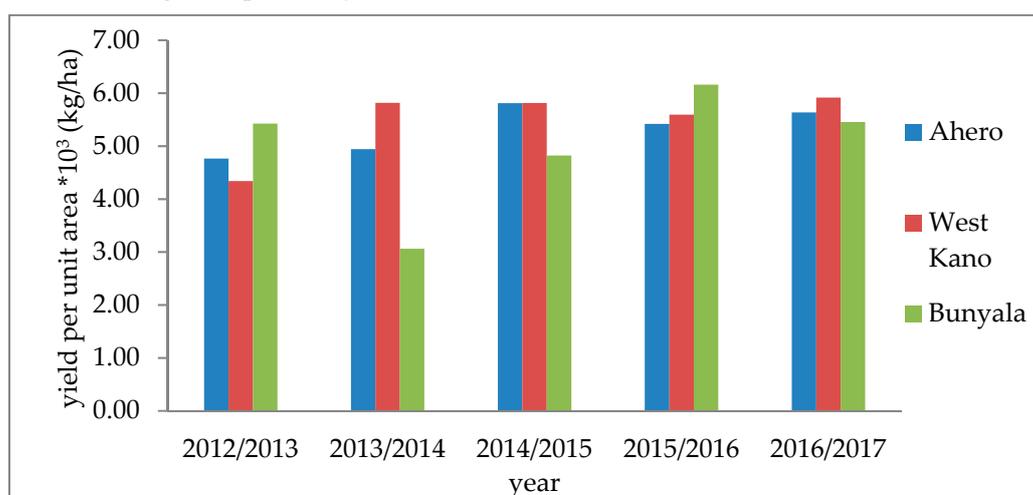
326   Figure 8. Output per unit command area

327   The values are comparable to global average rice yield of 3800 kg/ha reported by [20]. However
328 ,the highest value (6160 kg/ha) registered in Bunyala 2015 is way below the average produce yield in
329 Egypt of 8800 kg/ha which is the leading country in rice productivity within Nile basin [20]. In

330 2012-2013, there was strong sensitization on System of Rice Intensification (SRI) technology in Ahero
331 and West Kano. SRI is involve changes in plants, water soil and nutrients management aimed at
332 increasing productivity of rice under irrigation. Most farmers adopted SRI and this saw increase in
333 average yields from 4341 kg/ha to 5818 kg/ha and from 4765 kg/ha to 4943 kg/ha in West Kano and
334 Ahero Irrigation Schemes respectively. The output per irrigated area is higher than output per
335 command area in all the schemes indicating a cropping intensity of less than 1.

336 *3.2. Estimation of overall scheme performance*

337 Correlation analysis of the 11 indicators is presented in Table 5. RWS and RIS are strongly
338 positively correlated (r2= 0.950). This means that the indicators measure the same element. To avoid
339 double counting, only one of them can be used in computation of composite indicator. RIS is more
340 important because it relates irrigation water supplied to crop water demand.

341 Table 5. Correlation matrix Pearson (n)

Variables	RWS	RIS	ISIA	ISCA	WFC	ARIS	OIA	OCA	OIS	OWC	OWS
RWS	1	0.950	0.711	0.458	-0.168	-0.425	-0.185	-0.305	-0.801	0.278	-0.855
RIS	0.950	1	0.648	0.455	-0.259	-0.457	-0.273	-0.292	-0.778	0.189	-0.845
ISIA	0.711	0.648	1	0.283	-0.645	-0.873	0.092	-0.570	-0.870	0.060	-0.701
ISCA	0.458	0.455	0.283	1	0.284	-0.029	-0.312	0.475	-0.432	-0.047	-0.471
WFC	-0.168	-0.259	-0.645	0.284	1	0.889	-0.180	0.696	0.469	0.125	0.278
ARIS	-0.425	-0.457	-0.873	-0.029	0.889	1	-0.125	0.662	0.723	0.109	0.514
OIA	-0.185	-0.273	0.092	-0.312	-0.180	-0.125	1	0.156	0.375	0.741	0.553
OCA	-0.305	-0.292	-0.570	0.475	0.696	0.662	0.156	1	0.566	0.301	0.480
OIS	-0.801	-0.778	-0.870	-0.432	0.469	0.723	0.375	0.566	1	0.217	0.936
OWC	0.278	0.189	0.060	-0.047	0.125	0.109	0.741	0.301	0.217	1	0.245
OWS	-0.855	-0.845	-0.701	-0.471	0.278	0.514	0.553	0.480	0.936	0.245	1

342 RWS-relative water supply; RIS-relative irrigation supply; ISIA- irrigation supply per unit irrigated area; ISCA-
343 irrigation supply per unit command area; WFC- water fee collection; ARIS- annual revenue per unit irrigation
344 supply; OIA- output per unit irrigated area; OCA- output per unit command area; OIS- output per unit
345 irrigation supply; OWC- output per unit water consumed; OWS- output per unit water supply

346 3.2.1. Principal Component Analysis results

347 The extracted principal factors, Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and
348 Bartlett's sphericity test (BTS) results are presented in Table 6.

349 Table 6. Extracted Principal component factors

		F1	F2	F3	F4
sum of squared factor loading	Eigenvalues	4.929	2.312	1.740	-
	Variation (%)	49.287	23.123	17.397	-
	Cumulative variation (%)	49.287	72.410	89.806	-
rotated sum of squared factor loading	Eigenvalues	3.182	1.415	1.939	3.120
	Variation (%)	31.822	14.154	19.387	31.201
	Cumulative variation (%)	31.822	45.976	65.363	96.564
	Kaiser-Meyer-Olkin (KMO)				0.510
	Bartlett's sphericity test (BTS)		Chi-square =211.443		P<0.0001

350
351   According to [33],   if KMO value is greater than 0.5 and BTS less than 0.05,   the data is suitable
352   for   PCA.   In this study, KMO co-efficient of 0.510 is adequate and Bartlett's test is significant at
353   99% (P (< 0.0001). The weighted performance score per category of each scheme from 2012 to 2017 is
354   presented in Table 7.

355   Table 7. Weighted performance score for each category

Year	Irrigation scheme	Performance category			Weighted Performance Score (%)
		Water Supply (%)	Financial Performance (%)	Agricultural Productivity (%)	
	Ahero	24	46	40	36
	West Kano	9	25	32	24
2012/2013	Bunyala	20	56	48	41
	Ahero	58	50	43	49
	West Kano	24	27	33	29
2013/2014	Bunyala	29	55	26	31
	Ahero	33	48	49	44
	West Kano	3	29	34	23
2014/2015	Bunyala	21	55	41	37
	Ahero	57	52	47	51
	West Kano	37	30	40	38
2015 /2016	Bunyala	19	55	50	41
	Ahero	55	54	46	50
	West Kano	49	32	42	42
2016/2017	Bunyala	43	54	43	45
Weights		0.311	0.159	0.530	1.00
Average:					
Ahero Irrigation Scheme		45	50	45	46
West Kano Irrigation Scheme		24	28	36	31
Bunyala Irrigation Scheme		26	55	42	39

356
357   The computed agricultural productivity was 36% -51% in Ahero, 23%-42% in West Kano and
358   26%-50% Bunyala irrigation scheme. Water supply performance in Ahero, West Kano and Bunyala
359   irrigation schemes varied from 24% to 58%, 3% to 49% and 19% to 43% respectively. Financial
360   performance varied from 46% to 54% in Ahero, 25% to32% in West Kano and 54%-56% in Bunyala
361   irrigation scheme. Generally, financial performance category is the leading while water supply is the
362   least performing category.   Ahero irrigation scheme is leading in both agricultural productivity and
363   water supply performance while Bunyala irrigation scheme is leading in financial performance.
364   Bunyala and West Kano should therefore adopt the best agronomical, farming and water
365   management practices from Ahero irrigation scheme. Best practices in financial management in
366   irrigation schemes should be adopted from Bunyala irrigation scheme. An average overall
367   performance efficiency of 46%, 39% and 31% was obtained in Ahero, Bunyala and West Kano
368   irrigation schemes respectively.
369   The water supply, finance and agricultural productivity categories have a relative weight of
370   0.311, 0.159 and 0.530 respectively. Agricultural productivity is the most important category having
371   an effect of 53% on the overall performance. Therefore, a lot of focus should be put on adopting right
372   farming technologies such as use of systematic of rice intensification (SRI) instead of flooding
373   method, use of high yield seeds, timely and application of right amount of agro-inputs. Only two
374   financial indicators could be calculated from the existing record. A good record keeping is required

375   in all the schemes on operation and maintenance expenses to enable in-depth financial evaluation.
376   This explains why a low weight was assigned to financial performance category. The comparison of
377   overall performance of each scheme is presented in Figure 9.
378
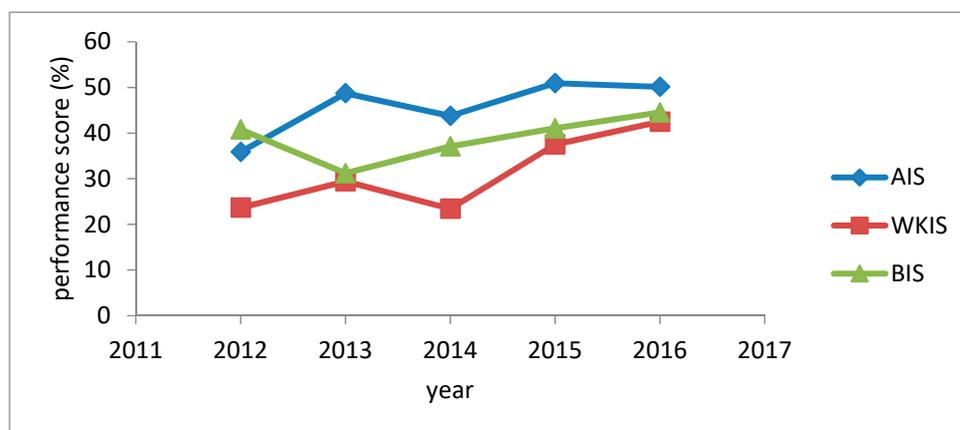
380   Figure 9. Comparison of performance score

381   The performance in irrigation schemes has been fluctuating with time. Generally, the trend
382   show that performance in all the three irrigation schemes has been increasing at a reducing rate. The
383   overall performance in Ahero, West Kano and Bunyala irrigation schemes varied from 35% to 51%;
384   31% to45% and 23% to 42% respectively.   The performance in all the schemes is very low. West
385   Kano irrigation scheme experienced a fall in performance in 2014 due to collapse of Revolving Fund
386   Committee.   The committee was mandated with responsibility of production and marketing in the
387   whole scheme.   The establishment of production management structure which created competition
388   amongst the blocks in terms of production increased performance from 2015. The sudden decline in
389   performance in Bunyala in 2013 was due to hail stone that shattered mature rice crop in one of the
390   phases (Muluwa phase 1).

391   **4. Discussion**

392   The level of performance of irrigation schemes can be sufficiently measured using performance
393   indicators and Principal Component Analysis method. The results of this study show that
394   performance of public irrigation schemes in western Kenya is very poor (below 50%) compared to
395   global benchmark values. This depicts inefficient use of available resources. The average
396   performance in terms of water supply, financial performance and agricultural productivity of
397   irrigation schemes in western Kenya is 32%, 45% and 41% respectively. Water supply performance is
398   the area that needs immediate intervention by scheme managers and policy makers. The inefficient
399   water use depicted by very low water supply performance (32%) is a threat to our scarce water
400   resources.   The trend is worrying since water is a scarce resource. Moreover, Kenya is a water scarce
401   country with only 647 cubic meters   per capita per annum of renewable freshwater   which is way
402   below international acceptable levels of 1,000 cubic meters   per capita per annum [2].
403   Promoting efficient water use is a step towards achieving sustainable agricultural development.
404   Intervention measures geared towards increasing water use efficiency should be adopted. These
405   include: canal lining; systematic of rice intensification (SRI) instead of flooding method; installation
406   on water monitoring devices; proper irrigation scheduling; change in water costing system from
407   area-based to volume-based system to discourage wastage. The low financial performance is a
408   reflection of poor revenue collection coupled with low water fee charges in irrigation sector. This can
409   be improved by increasing the revenue collection to almost 100% and increasing the water fees
410   charged.   Initiating water fee collection by water users association as is practiced in Bunyala can
411   also improve financial performance. In addition, introduction of public-private partnership and use
412   of incentive based fee collection strategy can also improve financial performance [13]. The current

413 water fee for all the schemes is too low to sustain the schemes necessitating government budgetary
414 allocation through National Irrigation Board (NIB). The schemes are not financially self-sustainable.
415   Despite contributing to 53 %, agricultural productivity (water and land productivity) is very
416 low at 39% of the target values. This makes the opportunity cost forgone in utilizing water in
417 irrigation sector other than other sectors of the economy such as manufacturing not worthwhile.
418 More efforts should therefore be put in this area if higher performance levels are to be realised.
419 Better farming technology that focuses on intensive farming and efficient resource use should be
420 embraced. System of rice intensification irrigation technology has been introduced to these schemes
421 but need to be fully adopted. Ahero irrigation scheme is the benchmark for rice farming in western
422 Kenya. Bunyala and West Kano irrigation schemes should therefore copy the best operation and
423 management practices to improve their performance.

424 **5. Conclusions**

425   Combination of benchmarking and Principal Component Analysis forms a powerful tool for
426 evaluating efficiency of irrigation schemes. Benchmarking was applied to investigate the potential
427 factors that can influence performance of the irrigation scheme. The computed performance
428 indicators provided information on the areas of shortcomings in the operation of the irrigation
429 schemes. Application of benchmarking in evaluating performance of irrigation schemes provides
430 individual indicator comparison without quantifying the overall performance of the irrigation
431 scheme. This cannot sufficiently give a measure of the level of performance an individual irrigation
432 scheme in comparison to the others. Computation of overall performance score was achieved by
433 combining benchmarking and Principal Component Analysis. Principal component analysis
434 provided numerical quantification of the best performing irrigation scheme. Combination of
435 benchmarking indicators and Principal Component Analysis provided information on best practices
436 and techniques in irrigation that can enhance irrigation efficiency. The less efficient irrigation
437 schemes (Bunyala and West Kano) can enhance their performance by borrowing the best operation
438 and management practices from Ahero irrigation scheme.

439   The performance of public irrigation schemes in western Kenya is very poor and measures on
440 improving performance are needed. The irrigation managers and policy makers can use this
441 information in championing for efficient utilisation of water through intensive irrigation. Further
442 farming practices that minimise use of inputs and maximize outputs should be adopted.
443 Improvement should focus on adoption of gravity-fed irrigation system instead of pumped system
444 which is very expensive to operate and maintain. Modernization of operation and management of
445 the scheme will enable routine monitoring and evaluation to check if the set targets have been
446 achieved. The schemes need to adopt a systematic routine collection and management of data to aid
447 in monitoring and evaluation of performance. The study could provide an insight to other schemes
448 in Kenya to adopt benchmarking as a tool towards improving performance.

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451 the datasets. Patrick G. Home and James M. Raude guided in analysis and correction of the initial draft.

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457

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