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Impacts of Legal and Institutional Changes on Irrigation Management Performance: A Case of the Gezira Irrigation Scheme, Sudan

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Abstract: This study aims to offer a comprehensive assessment of the impacts of policies and institutional arrangements on irrigation management performance. The case study, the Gezira Scheme, has witnessed a significant decrease in water management performance during recent decades. This situation led to several institutional changes in order to put the system on the right path. The main organizations involved in water management at the scheme are the Ministry of Irrigation & Water Resources (MOIWR), the Sudan Gezira Board (SGB), and the Water Users Associations (WUAs). Different combinations from these organizations were founded to manage the irrigation system. The evaluation of these organizations is based on the data of water supply and cultivated areas from 1970 to 2015. The measured data were compared with two methods: the empirical water order method (Indent) that considers the design criteria of the scheme, and the Crop Water Requirement (CWR) method. Results show that the MOIWR period was the most efficient era, with an average water surplus of 12% compared with the Indent value, while the most critical period (SGB & WUAs) occurred when the water supply increased by 80%. The other periods of the Irrigation Water Corporation (IWC), (SGB & MOIWR), and (WUAs & MOIWR) had witnessed an increase in water supply by 29%, 63%, and 67% respectively. Through these institutional changes, the percentage of excessive water supply jumped from 12% to 80%. Finally, the study provides general recommendations associated with institutional arrangements and policy adoption to improve irrigation system performance.

Keywords: irrigation; performance; water management; Gezira scheme

1. Introduction

The need for more food production and water supply have become urgent with significant growth of the world population [1]. Irrigated agriculture is of major importance to overcome these challenges, since it provides food, public investment, and rural development. Regardless of their potential for food production, there is a remarkable decrease in the performance of many irrigation projects, particularly in developing countries in drought-prone regions [2–4]. This situation has increased the attention directed towards enhancing the performance of irrigation projects [5]. There have been several studies in the literature reporting performance assessments of irrigation systems, and many researchers have shown an increased interest in linking management practices to irrigation project performance [6–11]. All these studies have shown the importance of having good regulators and institutions, and how they enhance water management performance.

In this study, the performance of water management at the Gezira scheme is represented and analyzed. The project is considered one of the largest irrigation projects in Africa [12]. The scheme had played a vital role in the history of irrigation in the region since it became a model for many irrigation schemes in the colonial period of sub-Saharan Africa [13]. The system is more typical for projects developed in countries such as Niger and Mali, where irrigation schemes are similar to Gezira in terms of design and operation system [14]. These facts reflect the historical importance of the scheme; therefore, any research to improve water management in Gezira scheme is not only beneficial for the project, but also for similar systems on the national and regional scale.

There is a large volume of published studies describing the performance of water management in the Gezira scheme from different perspectives [12,15–21]. In spite of the wide range of topics covered by these studies, however, to the best of authors' knowledge, there is no deep analysis for the organizational role and its impact on the performance of irrigation systems. The attention is usually focused on hydrological, engineering, economic, and agricultural aspects. In this study, the legal and intuitional impact on the performance water management is illustrated to identify the suitable water management organization for the scheme. A critical analysis has been carried out for different organizations to show the reasons that led to the institutional changes, and after that, to judging the performance of each institute to identify the most suitable form of water management for the Gezira scheme. The results presented here may facilitate improvements in the institutional arrangements related to different irrigation systems.

2. Materials and Methods

2.1. Study Area

The Gezira Scheme is located between the Blue Nile and the White Nile Rivers to the south of the capital Khartoum in a semi-arid zone (Figure 1). The early start of the scheme was in 1911 when an experimental farm was established at Tayba village on the west bank of the Blue Nile. The scheme is one of the largest irrigation schemes in the region, comprising 880,000 hectares (ha) [12]. Each farmer has 8.4 ha (as average) divided into 4 plots; the farmers' main crops are cotton, wheat, sorghum, groundnuts, and vegetables [22].

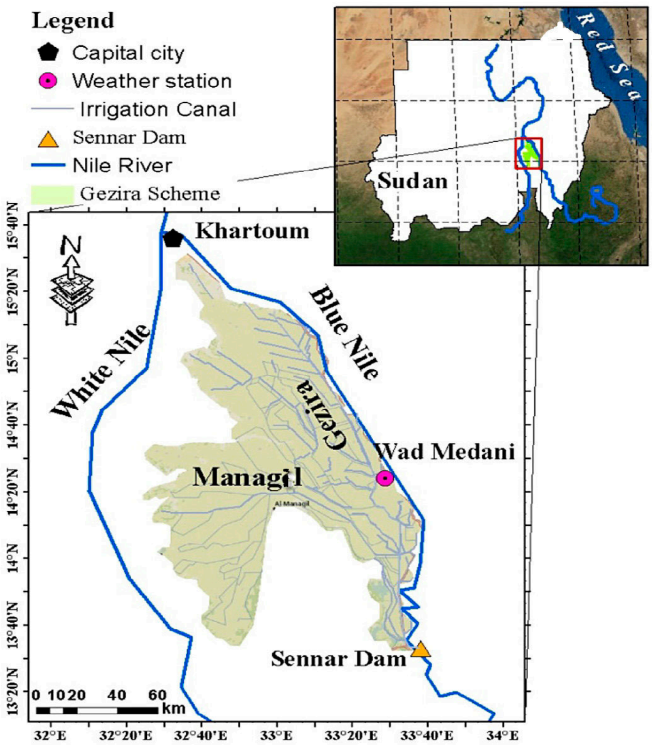

Figure 1. The location of the Gezira scheme. Source: Adapted from [19].

2.2. Climate

The Gezira scheme is located in a hot and semi-arid region. There are three distinct seasons: winter (November to February), summer (April and May), and autumn (July to September), while March, June, and October are transitional months. Rainfall intensity increases from north to south. The long-term annual rainfall is 156 mm at Khartoum, 354 mm at Wad Medani, and 472 mm at Sennar (Figure 1). The daily mean temperatures at Wad Medani are 25 °C, 29.4 °C, and 31 °C in winter, autumn, and summer, respectively [23].

2.3. Irrigation Management

The irrigation system consists of two main canals running from Sennar Dam; the Gezira canal with a capacity of 168 m^3/s and the Managil canal with 186 m^3/s [17,24]. Figure 2 below shows the main canal, which delivers water to Major canals. Then, water is conveyed to minor canals with determined and fixed levels; these levels are used to ensure equity in distribution at field canals (Abu Ishreen). The internal canals (Abu Sitta) are used by farmers to irrigate their farms.

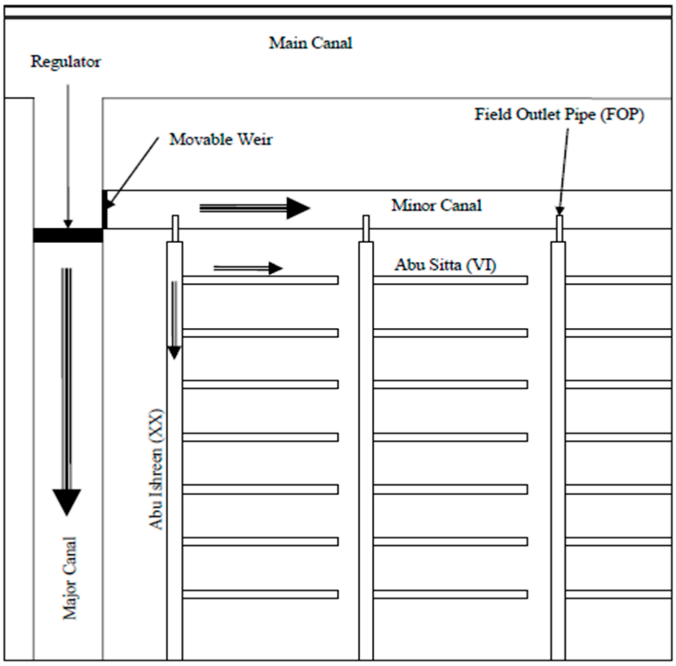

Figure 2. Field irrigation system in Gezira scheme.

The management of Gezira scheme used to be undertaken by three institutions: the Sudan Gezira Board (SGB), the Ministry of Irrigation and Water Resource (MOIWR), and the Water Users Associations (WUAs). The SGB was responsible for agriculture management, the MOIWR was responsible for controlling the irrigation system, and the farmers were responsible for managing and irrigating their farms [18,25]. Through the history of the Gezira scheme, five organizations, in combination from the above organizations, held the responsibility of managing the irrigation system.

The MOIWR was responsible for the whole irrigation system from 1925 to 1994, with limited participation from SGB. In the early 1990s, the Sudanese government adopted a policy of economic liberalization, which is the main reason for establishing the Irrigation Water Corporation IWC in 1994, as part of the MOIWR. The costs of operation and maintenance should be covered by water fees that are collected from farmers [25]. In 1999, the operation and maintenance of the Minor canals, which are the irrigation key in the system, were transferred to SGB, while the Main and Major canals were kept under MOIWR supervision [17]. This situation continued until the issuances of the Gezira Scheme Act of 2005. The law entrusted that the management of the irrigation system be shared between WUAs and MOIWR. The Main and Major Canals were to be managed by the MOIWR, while the Minor canals are the responsibility of the WUAs [17].

In 2010, the Gezira irrigation unit has been moved from MOIWR to SGB, and by 2012 the MOIWR was resolved [26]. At that stage, the responsibilities were shared between SGB and WUAs. The Main and Major canals were under SGB, while the Minor canals under WUAs. Finally, by late 2014, the Act of 2005 was modified; the WUAs were resolved, and the irrigation management at Gezira Scheme returned once again wholly to the MOIWR [27]. Table 1 below shows these organizations and their historical periods.

Table 1. The main organizations responsible for irrigation management.

Organization	Period	Duration (Years)
MOIWR	1925–1994	69
IWC	1995–1998	3
SGB & MOIWR	1999–2005	6
WUAs & MOIWR	2006–2010	4
WUAs & SGB	2011–2015	4

2.4. Methodology

This study is a combination of analytical and descriptive methods, which is based on data collected from the MOIWR and the SGB. Water supply and cultivated areas data were collected for the period of 44 years from 1970 to 2015. The selected data start from 1970 because the scheme area was growing significantly until completion in that year [28]. The criteria for evaluating the irrigation performance are based on a comparison of water supply with the system designed value (Indent) and the Crop Water Requirements (CWR).

The water management performance will be evaluated for the different periods based on comparing the actual water supply (measured data) with the system based Indenting method (calculated). The CWR method is used for justifying the results (calculated). For the calculation of water surplus, the following equation was used:

$$\text{Water Surplus}\ \% = (\text{water supply} - \text{X}) / \text{X} \times 100\% \tag{1}$$

where X is the value of Indent or CWR.

2.4.1. Irrigation Water Requirement Determination Methods

The irrigation water requirement includes water needed for both evaporation and transpiration (Evapotranspiration (ET)), in addition to the losses during the water delivery from the source to the field [29]. In this study, two methods were used to determine irrigation requirements: a crop water requirement method, and a water ordering method (Indenting system).

2.4.2. Crop Water Requirement

This method mainly depends on the determination of the crop evapotranspiration (ET_c), which is affected by two factors: evapotranspiration and crop characteristics. The reference evapotranspiration (ET_o) is the rate of evapotranspiration from an extended surface of a green cover, completely shading the ground, and not short of water [30]. The crop coefficient (K_c) is the factor that represents different ET levels for different types of crops under identical environmental conditions [31]. This coefficient is a function of crop height, roughness, reflection, ground cover, rooting characteristics, and resistance to transpiration. The CWR was calculated as shown in Equation (2) below [32]:

$$\text{CWR} = (\text{ET}_\text{o} \times \text{K}_\text{c}) - \text{R}_{\text{eff}} \tag{2}$$

where

CWR = crop water requirement (mm/day)

K_c = crop coefficient

ET_o = reference evapotranspiration (mm/day)

R_{eff} = effective rainfall (mm/day)

For the evaluation process, the data for CWR calculation was taken from the Nile Basin Initiative Tool-Kit climatic data [32]. Table 2 below shows the average climatic data (from 1970 to 2015) and Kc values for Gezira scheme main crops (for calculations annual climatic data were used, and the average data here were used as a sample). The seasonal CWR for the Gezira scheme was determined by considering annual variations in the cultivated area for each crop.

Table 2. Average climatic data and Kc values for Gezira scheme main crops.

Crops/Month *		ET_o	Effective Rainfall R_{eff}	Cotton	Groundnut	Sorghum	Wheat	Vegetables
		mm/Day	mm/Day	Kc	Kc	Kc	Kc	Kc
June	I	8.3	0.5		0.5			
	II	8.6	0.6		0.5			
	III	8.1	1.2		0.5	0.5		0.7
July	I	7.5	1.7		0.5	0.5		0.7
	II	7.0	2.3	0.5	0.6	0.6		0.9
	III	6.5	2.3	0.5	0.8	0.9		1.0
August	I	6.1	2.3	0.5	0.9	1.1		1.1
	II	5.6	2.2	0.5	1.0	1.2		1.1
	III	5.6	2.2	0.6	1.1	1.2		1.1
September	I	5.6	2.1	0.8	1.1	1.2		1.1
	II	5.6	2.0	0.9	1.1	1.1		1.1
	III	5.7	1.5	1.0	1.0	1.0		1.1
October	I	5.8	1.0	1.1	0.9	0.8		1.1
	II	5.9	0.5	1.2	0.7	0.7		1.0
	III	5.9	0.3	1.2				0.9
November	I	6.0	0.2	1.2				0.9
	II	6.0	0.1	1.2			0.5	0.8
	III	5.8	0.0	1.2			0.5	0.5
December	I	5.6	0.0	1.2			0.8	0.5
	II	5.5	0.0	1.2			1.0	0.5
	III	5.5	0.0	1.1			1.2	0.8
January	I	5.4	0.0	1.0			1.2	1.0
	II	5.4	0.0	0.9			1.2	1.2
	III	5.7	0.0	0.8			1.2	1.2
February	I	5.9	0.0	0.7			1.2	1.2
	II	6.1	0.0				1.1	1.2
	III	6.5	0.0				0.9	1.2
March	I	6.9	0.0				0.7	1.1
	II	7.3	0.0				0.6	1.0
	III	7.4	0.0					0.9

* The cultivation season at Gezira scheme starts at June and ends in late March. The period from early April to late May is located for hydraulic structures maintenance and canals clearance [25].

2.4.3. Water Order (Indent) Method

The empirical Water Order (Indent) method was developed by Farbrother [33] to estimate the water requirements for the Gezira scheme. The method considers crop requirements, soil characteristics, and distribution system efficiency. Based on this calculation, it was estimated that one hectare will require about 71.4 m^3/day (=30 m^3/day/feddan, 1 ha = 2.4 feddan), inclusive of field losses at the head of the farm [34,35]. This method was used at the scheme to schedule irrigations because it is quick, easy, and does not need technical support. These advantages make it more practical for large-scale irrigation systems; however, the estimated amount of water is not very accurate (see Table 3).

Table 3. Comparison between the Indent method and crop water requirement method.

Method	Concept	Measurement	Advantages	Disadvantages
Water order method (Indent)	Gives a fixed amount of water per unit area based on long-term calculation.	Fixed irrigation intervals and volume.	1. Easy to use. 2. Simple. 3. Can improve accuracy with experience.	Low accuracy. Fieldwork and experiments are required to update the values.
Crop Water Requirement	Substituting the water consumed by crop through calculating evapotranspiration from climatic data.	Based on updated climatic parameters: temperature, radiation, wind, humidity and expected rainfall.	1. No fieldwork required. 2. Flexible. 3. Forecast future irrigation needs. 4. The same equipment can schedule many fields.	Needs calibration and high-quality data. Calculations cumbersome without the computer.

2.5. Data Analysis

For the different management periods, the irrigation water requirements were calculated by both CWR and Indent methods considering the seasonal variation in the cultivated areas. Figure 3 represents the seasonal water supply and cultivated area for the Gezira scheme. It was observed that, during the last two decades, there is a significant decrease in the cultivated area; nevertheless, the water supply conversely keeps growing. The analysis of water supply and cultivated area data is shown in the next part.

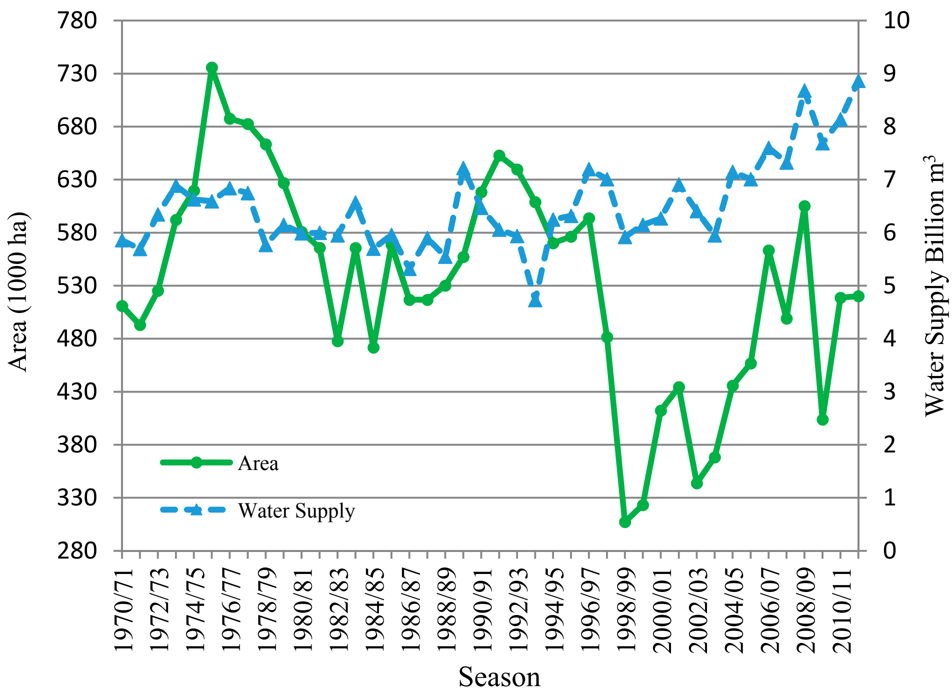

Figure 3. Variations in seasonal water supply and cultivated area.

3. Results

1925–1994: Ministry of Irrigation and Water Resources (MOIWR)

The chart below gives information about the volume of water supply compared with Indent and CWR for 23 seasons from 1970 to 1994 (Figure 4).

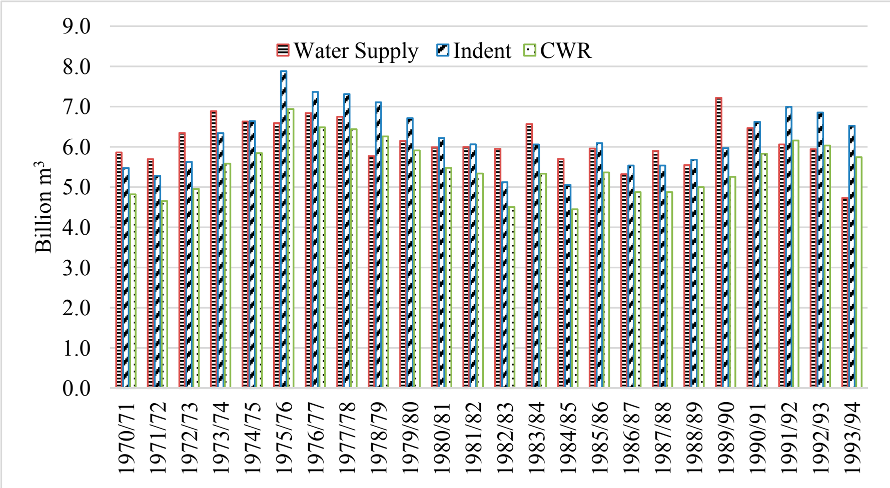

Figure 4. Water supply volume against Indent and CWR at MOIWR period.

In the early 1970s, the water supply was slightly more than the Indent value (by 0.5 billion m^3) for the period from 1970 to 1975. Over the following years, until 1982, the volume of water supply was less than Indent. For this period, in general, the water supply values were fluctuating around the Indent value (with a variation of around 1 billion m^3).

1995–1998: Irrigation Water Corporation (IWC)

The chart below provides the analysis for water supply, Indent, and CWR volumes for the IWC period from 1995 until 1998.

This is period had witnessed a significant increase in the water supply volume, which jumped from 0.14 billion m^3 in 1994/95 to 1.85 billion m^3 in 1997/98 (Figure 5). In the seasons of 1995/96 and 1996/97, the excess water reached 0.14 billion m^3 and 0.84 billion m^3 respectively.

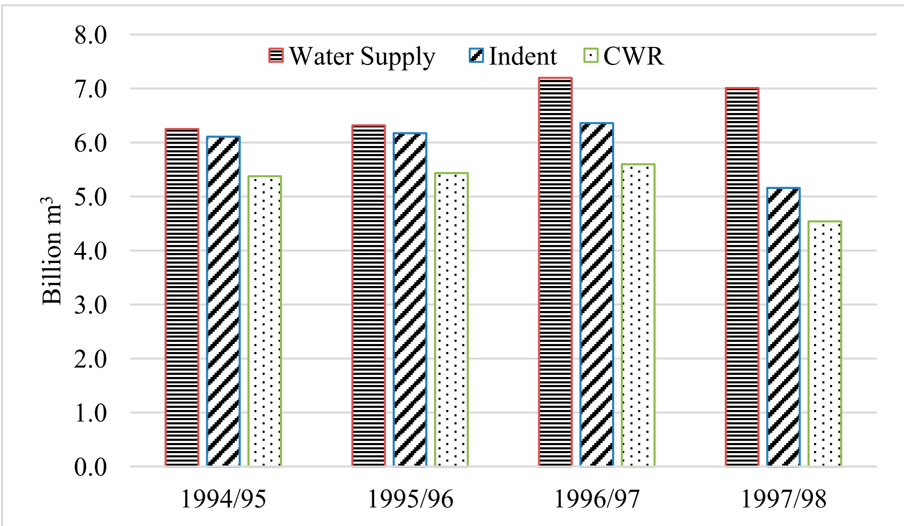

Figure 5. Water supply volume against Indent and CWR at IWC period.

1999–2005: SGB and MOIWR

In this stage, the operation and maintenance of the Minor canals were transferred to SGB, while the Main and Major canals were kept under the MOIWR supervision. The bar chart below illustrates the water supply, Indent, and CWR volumes generated from 1999 to 2005 (Figure 6).

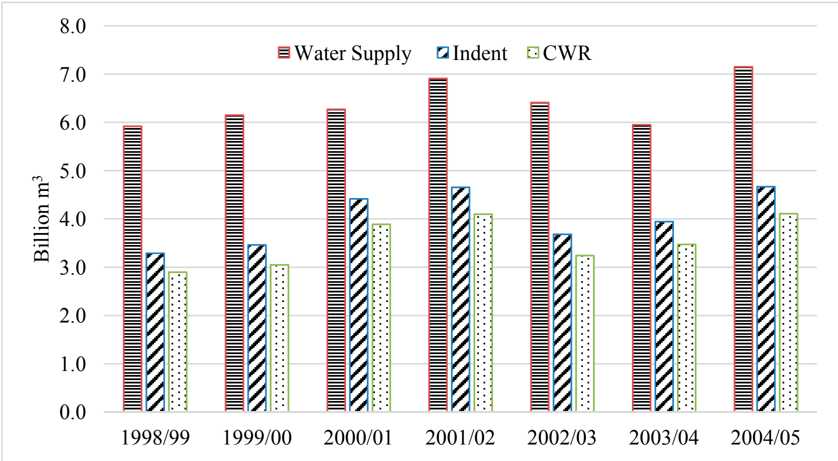

Figure 6. Water supply volume against Indent and CWR at SGB and MOIWR period.

From the chart, in the 1998/99 season, the water supply volume increased by 2.63 billion m^3, and continued growing to reach 2.73 billion m^3 by 2002/03. In the seasons of 2003/04 and 2004/05, the excess water had reached 2 and 2.48 billion m^3 respectively. In general, it seems that over the seven seasons, the water supply was much higher than the Indent and the CWR.

2006–2010: WUAs and MOIWR

The graph below shows how the water supply, the Indent, and CWR volume has changed from 2006 to 2010 at WUAs and MOIWR period.

According to the graph (Figure 7), the water supply volume was higher than the Indent value, for the seasons 2005/06, 2006/07, 2007/08, and 2008/09, where the excess water had reached 2.12, 1.56, 1.98, and 2.2 billion m^3 respectively. In the 2009/10 season, the water supply volume increased dramatically by 3.362 billion m^3, which represents an increase of 102% for Indent and 78% for CWR values.

During this period, over the whole five years, the water supply was higher than required with rising and falling trends from season to another. Throughout the period, the average water surplus value was 63% compared with Indent value.

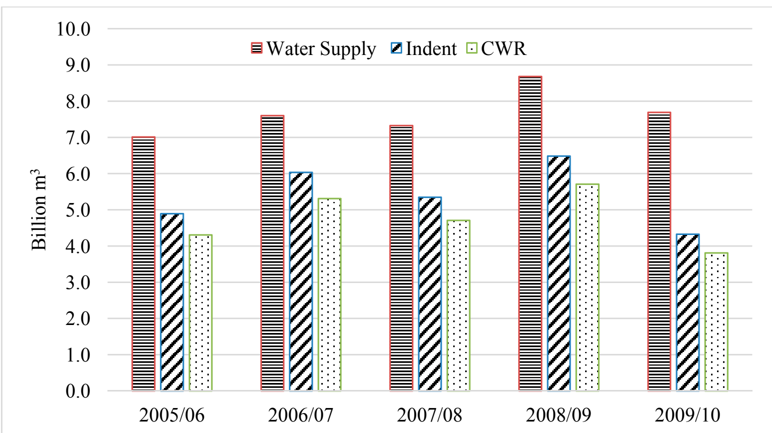

Figure 7. Water supply volume against Indent and CWR at WUAs and MOIWR period.

2011–2015: SGB and WUAs

The bar chart below illustrates the volume of water supply compared with Indent and CWR for SGB and WUAs period.

It is obvious that this period witnessed a significant increase in the water supply volume (Figure 8). For the seasons 2010/11, 2011/12, 2012/13, 2013/14, and 2014/15 the excess water had reached 2.59, 3.29, 3.65, 3.88, and 3.52 billion m^3 respectively.

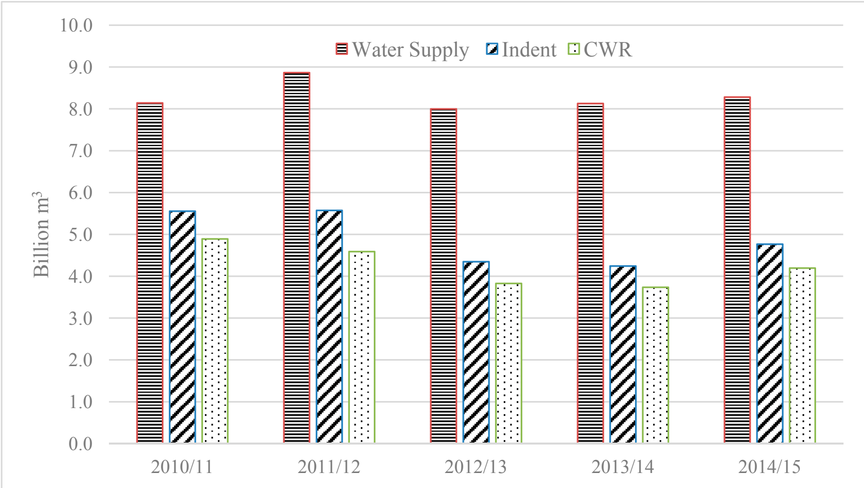

Figure 8. Water supply volume against Indent and CWR at SGB and WUAs period.

Water surplus for the different periods

The figure below shows the percentage of excessive water supply compared with Indent and CWR for the different periods.

From the chart, it is clear that during the MOIWR period, the water surplus values were generally about the reference values, with average water surplus of 12% for Indent and 1% for CWR. For the other periods of (IWC), (SGB & MOIWR), (WUAs & MOIWR), and (WUAs & SGB) the average water surplus was 29%, 67%, 63%, and 80% for Indent and 13%, 61%, 44%, and 53% for CWR respectively.

According to the graph (Figure 9), the difference between the values of the Indent and the CWR is due to the fact that the Indent gives a fixed quantity of water for the different crops, while the CWR values consider the water requirement for each crop separately.

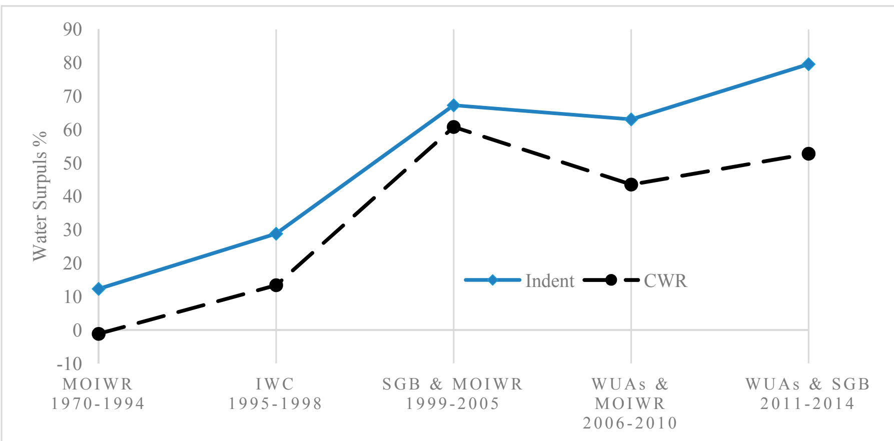

Figure 9. Water supply volume against Indent and CWR through the different periods.

4. Results Justification

From the analysis above, it is clear that there is a significant increase in water supply against water requirements for the different periods. However, a question may arise about whether the intensive water supply had a positive impact on crop productivity or not. Therefore, further analysis was done to investigate the impact of excessive water supply on crop productivity (Figure 10).

Figure 10 shows the relationship between water supply per hectare and crop productivity at the Gezira scheme. It is noted that, for all crops, the correlation values are very low (R^2 values: 0.005, 0.1238, 0.0665, and 0.1857 for Cotton, Wheat, Groundnuts, and Sorghum respectively). This indicates that the relationship between excessive water supply and crop productivity is weak, and hence, intensive water supply was not valuable for crop production.

On the other hand, climate conditions are of major importance to the irrigation process. The Gezira scheme is located in the semi-arid zone (see Section 2.2), and the annual volume of rainfall is extremely very low compared with irrigation water (e.g., in season 2000/01 the volume of water supply was about 6.27 Billion m^3, while the volume of rainfall over the cultivated area was 84,566 m^3, which represents only about 0.0013% from irrigation water).

From above, it can be concluded that large quantities of water have no effect on crop productivity, and the impact of rain and climate change is relatively low. Therefore, the large increase in water supply can be considered to be a result of poor water management.

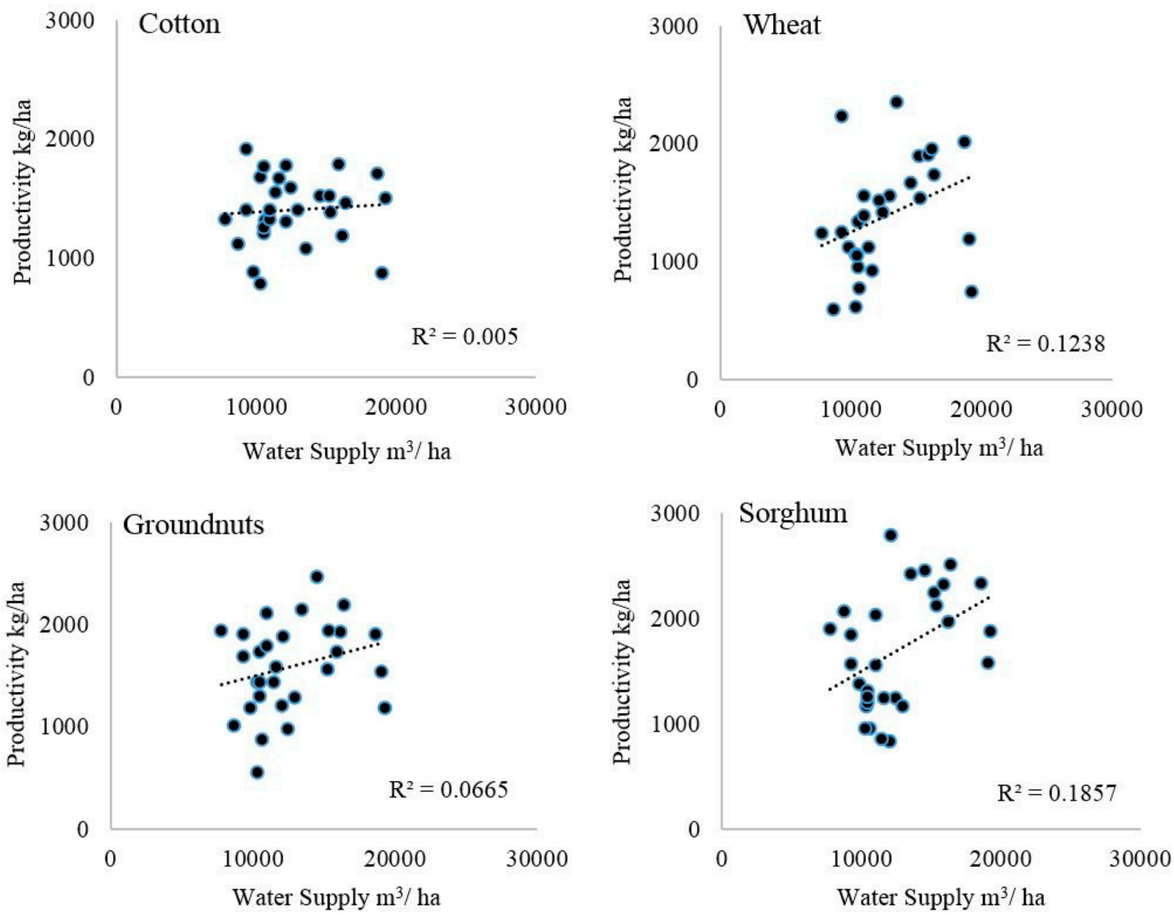

Figure 10. The relationship between water supply and crop productivity.

5. Discussion

In this part, the reasons that led to the different institutional changes in the Gezira scheme are discussed. The irrigation management at the Scheme was the responsibility of the MOIWR from 1925 until 1994. During this period, the irrigation management was running smoothly, and the water supply was generally based on the system requirements. The average water surplus was 12% compared with the Indent value.

The period of the IWC had witnessed an average increase in water supply of 29%. The main reason for this increase was an insufficient budget, which negatively affected water management performance. The task of water fees collection was the responsibility of the SGB, which failed in this mission, and due to its inadequate performance, the IWC was terminated in 1998 [25,36].

In 1998, the SGB requested full control of the irrigation system. The argument raised by the SGB was that they cannot hold responsibility for low productivity while irrigation water is not under their control [37]. The corresponding argument of MOIWR was that the irrigation system is complex and requires high technical knowledge and expertise to control [12]. To solve this conflict, the Minor canals were transferred to the SGB. Nevertheless, this period witnessed an average increase in water supply of 63%.

According to Ahmed [12], during this period, the system experienced the most serious deterioration throughout its long history. He stated that the inappropriate program of silt removal had negatively affected the hydraulic characteristics of canals, and consequently, the water distribution performance. This situation continued until the Gezira Act was introduced in 2005 [20,38].

After the serious deterioration of the scheme's performance, the Sudanese government invited an international consultant agency to "assist in assessing the main factors which constrained the sustainable development of the Gezira Scheme" [17]. The consultant agency recommended that the farmers should have more participation in the irrigation process [18]. However, the MOIWR did not accept this recommendation, for the same objections raised previously against the SGB, which are the lack of both technical background and expert labors. Nevertheless, in 2005, the Gezira Act was issued, and ensured that the management of the Minor canals be transferred to the WUAs. However, the water performance did not show any progress, and the water supply had increased by 67% in this period.

An evaluation study was conducted by the same consultant agency in 2010 to evaluate the situation of the scheme after the Gezira Act. The study stated that the main reason for the failure was an incorrect application of the 2005 law. The agency argued that the transfer of irrigation responsibilities over from the MOIWR to the WUAs effectively ended any role for the MOIWR, and that this was why it did not cooperate. Therefore, in 2010 a decision was made to move the Gezira irrigation unit from MOIWR to SGB, and by 2012, the MOIWR was resolved [26]. However, the period of (SGB & WUAs) was the most critical period for water management at the scheme, since water supply increased by 80%.

Makadho and Ubels [39] stated that the approach of farmer participation in irrigation management seems very practical for small schemes; nevertheless, for larger schemes, i.e., several hundreds or thousands hectares (such as the Gezira scheme) it would require more elaborate investigation and study.

The irrigation engineers argued that the MOIWR have several departments which were involved in the irrigation process, such as (i) Irrigation operation department, (ii) Mechanical and electricity department, and (iii) Projects and planning department. The irrigation operation department is just one unit that works in coordination with other directories, and the absence of all these parties had a significant role in the failure of the irrigation system [25]. Finally, by the end of 2014, the Act 2005 was modified, whereas the WUAs was resolved and the irrigation management at Gezira Scheme returned again to the MOIWR [27].

6. Conclusions

The Gezira Scheme has witnessed vital changes in irrigation management responsibilities over the last three decades. These changes have significantly affected water management performance at the scheme. The period of MOIWR is considered to be the most efficient era, and then, gradually, the failure started at the period of IWC due to the limitation in financial resources and funding issues. In the third period, the contradicting interactions between SGB and MOIWR responsibilities, in addition to the SGB lack of knowledge and skilled labors, led to high damage in the irrigation system. The era of WUAs was slightly less damaging than the previous one; however, the situation had become more complicated due to the Gezira scheme Act arrangements. In the last period, the MOIWR was resolved, and the responsibility for irrigation was moved to the SGB & the WUAs; yet, the irrigation performance did not show any progress, and instead, the scheme faced further deterioration. During these periods, the water surplus had increased from 12% to 80%. It could be concluded that changes in policies and the institutional arrangements had negatively affected the irrigation performance in the Gezira scheme.

7. Recommendations

Suitable irrigation management institutions must comply with the design and operational standards of the irrigation project. When the operating system is changed, enough investigation and pilots are required to ensure that the new organization is qualified for system management. Furthermore, farmers' participation in water management requires efficient training to raise their awareness and skills, while the participation in system management should be implemented gradually. In conclusion, each irrigation project is a unique case, and any institutional modifications should take into account the technical, economic, and social needs that are commensurate with the system.

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References

1. FAO (Food and Agriculture Organization). *The Future of Food and Agriculture—Trends and Challenges*; FAO: Rome, Italy, 2017; ISBN 978-92-5-109551-5.
2. Darghouth, S. Modernizing public irrigation institutions: The top priority for the future of sustainable irrigation. In Proceedings of the Nineteenth Cogress on International Commision on Irrigation and Drainage, Beijing, China, 9–18 September 2005.
3. Biswas, A.K. Monitoring and evaluation of irrigation projects. *J. Irrig. Drain. Eng.* **1990**, *116*, 227–242. [CrossRef]
4. Elshaikh, A.E.; Jiao, X.; Yang, S. Performance evaluation of irrigation projects: Theories, methods, and techniques. *Agric. Water Manag.* **2018**, *203*, 87–96. [CrossRef]
5. Bos, M.G.; Burton, M.A.S.; Molden, D.J. *Irrigation and Drainage Performance Assessment: Practical Guidelines*; CABI: Wallingford, UK, 2005; ISBN 1845930207.
6. Valverde, P.; Serralheiro, R.; de Carvalho, M.; Maia, R.; Oliveira, B.; Ramos, V. Climate change impacts on irrigated agriculture in the Guadiana river basin (Portugal). *Agric. Water Manag.* **2015**, *152*, 17–30. [CrossRef]
7. Zhang, L.; Heerink, N.; Dries, L.; Shi, X. Water users associations and irrigation water productivity in northern China. *Ecol. Econ.* **2013**, *95*, 128–136. [CrossRef]
8. Huang, Q.; Wang, J.; Easter, K.W.; Rozelle, S. Empirical assessment of water management institutions in northern China. *Agric. Water Manag.* **2010**, *98*, 361–369. [CrossRef]
9. Lehmann, N.; Finger, R. Economic and environmental assessment of irrigation water policies: A bioeconomic simulation study. *Environ. Model. Softw.* **2014**, *51*, 112–122. [CrossRef]
10. Alcon, F.; García-Bastida, P.A.; Soto-García, M.; Martínez-Alvarez, V.; Martin-Gorriz, B.; Baille, A. Explaining the performance of irrigation communities in a water-scarce region. *Irrig. Sci.* **2017**, *35*, 193–230. [CrossRef]
11. Van Halsema, G.E.; Vincent, L. Efficiency and productivity terms for water management: A matter of contextual relativism versus general absolutism. *Agric. Water Manag.* **2012**, *108*, 9–15. [CrossRef]

12. Ahmed, A.A. Gezira Scheme Irrigation System Performance after 80 Years of Operation. In Proceedings of the International Conference on Water, Environment, Energy and Society, New Delhi, India, 12–16 January 2009.
13. Tiffen, M. Variability in Water Supply, Incomes and Fees: Illustrations of Vicious Circles from Sudan and Zimbabwe. *ODI IIMI Irrigation Management Network Paper*. Available online: https://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/8164.pdf (accessed on 31 October 2018).
14. Jaujay, J. The Operation and Maintenance of a Pilot Rehabilitated Zone in the Office du Niger, Mali. *ODI IIMI Irrigation Management Network Paper*. Available online: https://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/8164.pdf (accessed on 31 October 2018).
15. Adam, H.S.; AW, A.; Hata, T. The Future of Participatory Water Management in Gezira Scheme, Sudan. In Proceedings of the International Workshop on Participatory Management of Irrigation Systems, Cairo, Egypt, 2–4 February 2003; Volume 1, pp. 10–11.
16. Abdelhadi, A.W.; Adam, H.S.; Hassan, M.A.; Hata, T. Participatory management: Would it be a turning point in the history of the Gezira scheme? *Irrig. Drain.* **2004**, *53*, 429–436. [CrossRef]
17. World Bank. *The World Bank and the Gezira Scheme in the Sudan Political Economy of Irrigation Reforms*; World Bank: Washington, DC, USA, 2010.
18. World Bank. *Options for Sustainable Development of Gezira Scheme*; World Bank: Washington, DC, USA, 2000.
19. Al Zayed, I.S.; Elagib, N.A.; Ribbe, L.; Heinrich, J. Spatio-temporal performance of large-scale Gezira Irrigation Scheme, Sudan. *Agric. Syst.* **2015**, *133*, 131–142. [CrossRef]
20. Osman, I.S.E. *Impact of Improved Operation and Maintenance on Cohesive Sediment Transport in Gezira Scheme, Sudan*; IHE Delft Institute for Water Education: Delft, The Netherlands, 2015.
21. Abdelgalil, E.E.B.; Adeeb, A.M. Impact of changing policies on agricultural productivity: A case of the Gezira scheme, Sudan. *Int. J. Sustain. Agric. Manag. Inform.* **2015**, *1*, 49–60. [CrossRef]
22. Osman, I.S.; Schultz, B.; Suryadi, F.X.; Mohamed, Y.; Osman, A.K. Improving the operation and maintenance for better sediment and water management in Gezira Scheme, Sudan. In Proceedings of the 21st International Congress on Irrigation and Drainage (ICID), Tehran, Iran, 15–23 October 2011; pp. 51–62.
23. Hussein, A.S.A.; El Daw, A.K. Evapotranspiration in Sudan Gezira irrigation scheme. *J. Irrig. Drain. Eng.* **1989**, *115*, 1018–1033. [CrossRef]
24. Mamad, N. Irrigation Performance of Gezira Scheme, Sudan: Assessment of Land and Water Productivity Using Satellite Data. Ph.D. Thesis, UNESCO-IHE, Delft, The Netherlands, 2010.
25. Babiker, A. Irrigation challenges in the Gezira Scheme (Arabic). In *Workshop of (Using Smart ICT Technology and Satellite Imagery to Improve Crop Productivity)*; Hydraulics Research Center: Wad Madani, Sudan, 2014.
26. Tajelsir, M. *Gezira Scheme Evaluation Report*; General Secretariat of the Agricultural Renaissance: Khartoum, Sudan, 2013.
27. Act. *The Gezira Scheme Act*; Ministry of Justice: Khartoum, Sudan, 2014.
28. Shaw, D.J. *The Managil South-Western Extension: An Extension to the Gezira Scheme: An Example of an Irrigation Development Project in the Republic of the Sudan*; Veenman: Rotterdam, The Netherlands, 1965.
29. Jensen, M.E.; Allen, R.G. *Evaporation, Evapotranspiration, and Irrigation Water Requirements*; American Society of Civil Engineers: Reston, VA, USA, 2016.
30. Jensen, M.E.; Burman, R.D.; Allen, R.G. *Evapotranspiration and Irrigation Water Requirements*; American Society of Civil Engineers: Reston, VA, USA, 1990.
31. Smajstrla, A.G.; Zazueta, F.S. *Estimating Crop Irrigation Requirements for Irrigation System Design and Consumptive Use Permitting*; University of Florida Cooperative Extension Service, Institute of Food and Agriculture Sciences, EDIS: Gainesville, FL, USA, 1998.
32. ENTRO (Eastern Nile Technical Regional Office). *Tool-Kit*; Eastern Nile Technical Regional Office: Addis Ababa, Ethiopia, 2009.
33. Farbrother, H.G. *Irrigation Practices in Gezira*; Research Momeries, Cotton Research Corporation: Khartoum, Sudan, 1974.
34. Abdelhadi, A.W.; Hata, T.; Tanakamaru, H.; Tada, A.; Tariq, M.A. Estimation of crop water requirements in arid region using Penman–Monteith equation with derived crop coefficients: A case study on Acala cotton in Sudan Gezira irrigated scheme. *Agric. Water Manag.* **2000**, *45*, 203–214. [CrossRef]
35. Farbrother, H.G. Modernization of indenting in the Gezira. In *Water Distribution in Sudanese Irrigated Agriculture, Productivity and Equity*; University of Gezira: Wad Medani, Sudan, 1984; pp. 78–93.

36. Eldaw, A.M.; Al-Jazīrah, J. *The Gezira Scheme: Perspectives for Sustainable Development*; German Development Institute: Bonn, Germany, 2004; Volume 2, ISBN 3889852629.
37. Ibrahim, Y.A. Participatory Approach in IWRM. In *Integrated Water Resources Principals*; The Ministry of Irrigation and Water Resources: Khartoum, Sudan, 2008.
38. Gismalla, Y.A. Sedimentation Problems in the Blue Nile Reservoirs and Gezira Scheme: A Review. Available online: http://journals.uofg.edu.sd/index.php/GJEAS/article/view/214 (accessed on 31 October 2018).
39. Makadho, J.M.; Ubels, J. The Design of Farmer Managed Irrigation Systems: Experiences from Zimbabwe. *Design Sustainable Farmer-Managed Irrigation Schemes Sub-Saharan Africa*. Available online: https://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/8164.pdf (accessed on 31 October 2018).