Integrated Performance Assessment of the Gezira Irrigation Scheme: Technical, Agricultural, Institutional, and Socio-economic Perspectives

by

Abdalla A. Ahmed

Professor of Water Resources, White Nile Centre for Scientific Research (WNCSR), White Nile University, Kosti, Sudan, Email: aaahmed55.aa@gmail.com

Abstract

The Gezira Scheme (GS) is considered one of the oldest irrigation systems in Africa and the Arab region. Moreover, it is the largest scheme (0.9 million ha) in the world under a single management. The irrigation network is 11,000 km long with 29,000 field channels. This paper evaluates the performance of the GS irrigation system after a century of operation, particularly given the serious deterioration over the past two decades, during which the system has failed to meet crop water requirements. The assessment draws on MOIWR sediment monitoring and desilting records for 1987-2005, HR Wallingford field measurements, and published technical efficiency and hydro-economic studies. This issue may be primarily attributed to the significant amounts of sediment entering the scheme each year and the mismanagement of the irrigation system. Inflowing sediment concentration rose from about 700 ppm in the 1930s to about 8,000 ppm in the 1990s; desilting now consumes more than 60% of O&M expenditure; and the scheme's debt grew from USD 34 million in 1999 to over USD 150 million by 2005. The consequence of this situation is water shortage in many areas of the scheme, while others experience flooding, leading to inequitable water distribution. This disparity leads to a decline in crop production and returns from the scheme. In light of these issues, a critical review of the irrigation system is warranted. The concept and procedure for designing and remodelling the silted canals to restore the original section are highlighted, based on the rich experience and performance of this irrigation system. It is concluded that aquatic weeds increase sedimentation, and the deposited sediment enhances aquatic weeds' growth, thereby reducing canal capacity. The impact of this on the socio-economic development of the scheme inhabitants is explained. The paper finally examines the possibility of maintaining stable regime conditions in the canals. It also reports on the future of irrigation system management and the possibility of achieving an efficient and effective system to improve crop production.

Keywords: *Sudan; canal regime design; irrigation; sediment management; performance; night storage system; aquatic weeds; water governance.*

1- Introduction

The Gezira irrigated scheme is considered the largest scheme in the world under a single management. It represents a major pillar of Sudan's economic support, food security and social stability. The main objective of this study is to assess how the deposition of cohesive sediment in the canals of the Gezira Scheme affects water delivery performance, institutional functioning and agricultural production. Three questions are addressed: (i) what are the patterns and rates of sediment accumulation through the canal hierarchy; (ii) how do these affect conveyance capacity and equity of supply; and (iii) how have the resulting operation and maintenance burdens interacted with governance and with crop productivity.

In 1925, after the construction of the Sennar Dam on the Blue Nile, the British developed the Gezira Scheme (GS) based on their experiences in India and Egypt. The scheme was established in the Central Clay Plain (CCP) between the Blue and White Niles. Currently, GS is the largest irrigation system in the world managed under a single administration, covering approximately 2.2 million feddans (about 0.9 million hectares, 1 feddan =0.42 ha). Therefore, its operation and maintenance are very complex and represent quite a challenge**.** The irrigation system comprises twin main canals running from the headworks at Sennar Dam to a common pool at the cross-regulator at km 57. In the early 1960s, the Managil Main Canal was constructed with a design capacity of 186 m^3/sec (16.0 million m^3/day), running parallel to the older Gezira Main Canal, which has a design capacity of 168 m^3/sec (14.5 million m^3/day). This construction aimed to serve the Managil extension. Together, the two main canals have a total length of 261 km, although their conveyance capacity decreases towards the tail end, reaching 10 m^3/sec. Fig. 1 and Table 1 provide a clear overview of the irrigation system in the Gezira Scheme (GS) (Plusquellec, 1990., Ahmed and Ahmed, 1993).

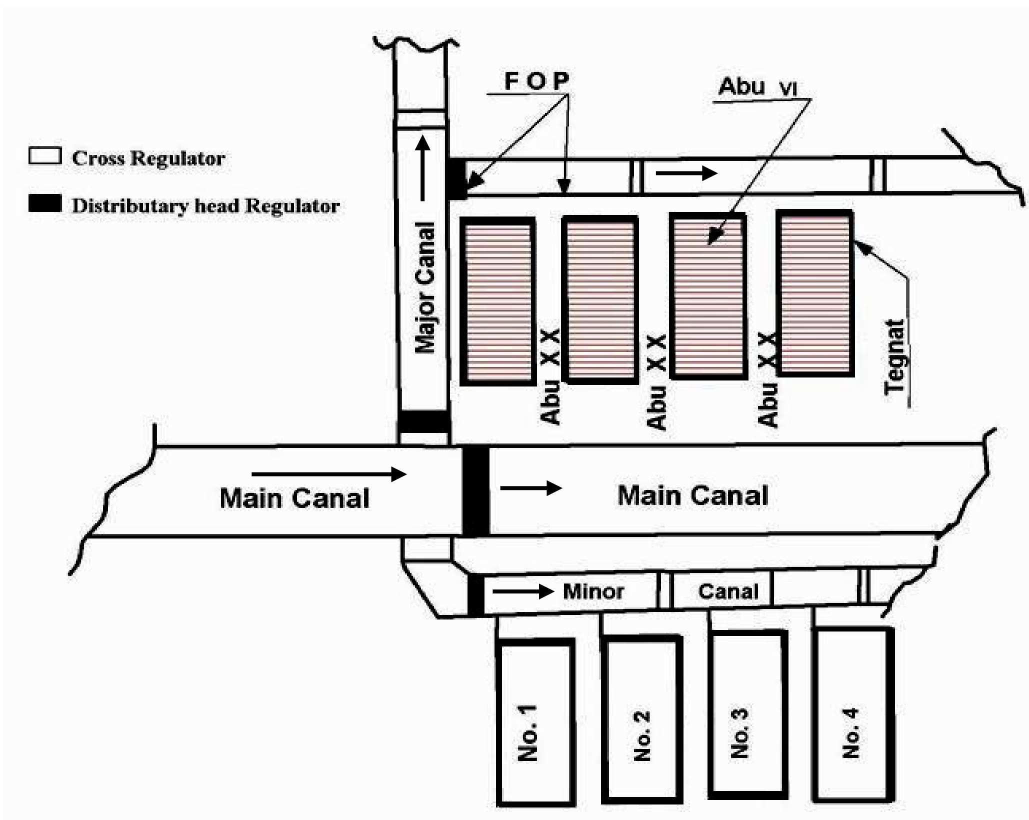

Fig. (1) General Layout of the GS Canalisation System. Source: after Plusquellec (1990).

Table (1) Detailed Information of the Irrigation System in GS. Source: after Plusquellec (1990), p. 18.

Canals	Number	Capacity(m^3/sec)	Length (km)	Av. width(m)	Area (ha)
Main	2	354	261	50	1315
Branches	11	25 to 120	651	30	1953
Majors	107	1.2 to 15	1652	20	3304
Minors	1498	0.5 to 1.5	8119	6.0	4872
Subtotal	1618	- - - - - - - - -	10683	- - - - - - - -	11444
Abu XXs	29000	0.116	40000	1.0	4000
Abu Vis	350000	0.05	100000	0.5	5000
Total	380618	- - - - - - - - - - -	150683	- - - - - -	20444

Downstream of the first common cross-regulator at km 57, the main canals are divided into reaches, each 5-22 km long, by additional cross-regulators. These regulators are the control points for the Branch and Major Distribution canal off-takes. The branch canals are similarly divided into reaches by cross-regulators, and major distributor canals are grouped at these regulators. The Main, Branch and Major canals are designed as regime conveyance channels, with water flowing continuously day and night. The minor canals were originally designed to be irrigated day and night. In the 1930s, the irrigation system was modified to operate only during daylight hours for practical reasons, because night irrigation proved impractical for tenants. Therefore, the Night Storage System (NSS) was introduced to store water in the canal reaches at night and release it during the day. The control structures are designed to maintain a constant upstream level. The system of water control throughout the distribution system relies on knowledge of the discharge characteristics of the regulator gates. The flow rate through the sluice gates is estimated using calibration charts that require measurements of gate openings and water levels upstream and downstream.

The standard distance between two successive Minors is 1.42 km. The total length of a minor canal can be up to 20 km, with a width of 6.0 m and a depth of 0.8-1.3 m. Each minor is divided into reaches (lengths from 1 to 4 km) depending on the land's slope. The reaches are divided by night-storage regulators. The main design criterion of the minor canals is a command of 20 cm above the highest parts of the field at full supply level (FSL).

2- Water Distribution Farm Level

The uniform slope of the land in the Gezira Scheme has permitted a very regular layout of fields. The field irrigation system (Abu XX) is designed to serve an area of 1,350 m x 280 m, locally known as a Number, at intervals of 292 m along the Minor Canal. Field Outlet Pipes take off at right angles (12 meters long and 0.35 m diameter). This unit is divided into eighteen 5-feddan plots, known as Hawasha, which are irrigated by secondary watercourses called Abu Sitta, or Abu VI, that draw from the main watercourse. In 1995, the area of the farm, locally known as Hawasha, was reduced to 4-feddan plots, which increased the total number of Hawashas to 22. The Abu XX has a command of approximately 0.20 m, and its theoretical capacity is 116 l/s (5,000 m^3 in 12 hours).

3- Drainage System

The drainage system in GS is designed to handle surface runoff from rainfall or excess irrigation. The present surface runoff drainage system consists of Minor Surface Drains (about 6,000 km) and Major Drains (about 1,500 km). Minor Drains run parallel to Minor Canals. These discharge into the Major or Collector Drains. The latter generally follow the lines of natural drainage and lead the runoff water to outfalls and back to the Blue and/or White Niles. However, in most of the GS this does not happen, since several drains terminate in large local depressions. Runoff water either has to be pumped into nearby canals or is allowed to pond and then evaporate, usually on land that is not suitable for agriculture. The lands so flooded are deliberately left uncultivated but are often used unofficially by labour settlements.

4- Irrigation Management in GS

Current water management in the GS departs substantially from the original design. The amount of water released from the Sennar Dam increased more than threefold, from 2.0 billion m^3 in 1957/1958 to 7.0 billion m^3 in 1997/1998. This increase in the water demand is attributed to the addition of the Managil Extension (about 900,000 feddans, ~378,000 ha) and the introduction of agricultural intensification in the 1960s. The additional water carries more silt, and irrigation begins a month earlier than before. The latter forces the peak crop water requirement to coincide with the peak of the silt concentration in the Blue Nile River. The irrigation management of the GS has always been divided between the Ministry of Irrigation and Water Resources (MOIWR) and the Sudan Gezira Board (SGB). The MOIWR is responsible for water supply and the maintenance of the canalization system, while the SGB distributes water to the farm fields. However, in 1999, the responsibility for the Minor Canals (maintenance and distribution of irrigation water) was transferred to the SGB, leaving the Main and Major Canals to the MOIWR. In 2006, following the introduction of the new GS Law (adopted in 2005), all irrigation management responsibilities were transferred back to the MOIWR after six years of the Sudan Gezira Board (SGB) management of the Minor Canal (1999–2005). During this time, the irrigation system experienced significant deterioration, marking the worst decline in its history, which will be discussed further in this paper.

5- Sedimentation in GS

The problem of sediment deposition in irrigation facilities represents a challenge to those responsible for operation and maintenance (O&M). It is not only seriously affecting the performance of these facilities, but also jeopardizing their sustainability. Fig. 2 shows the sediment loads entering the GS. There is a variation from year to year. However, the peak sediment concentration is about 1% by weight in the third ten-day period of July, then reduces to a few hundred parts per million in October (Fig 3). High sediment concentrations are typically sustained for only a few weeks during the rising phase of the Blue Nile flood hydrograph. According to HR Wallingford (1990), no clear relationship exists between sediment concentration and the Blue Nile discharge. This suggests that sediment loads are supply-controlled, a characteristic known as wash load sediment transport. The behaviour of sediment distribution in GS is closely related to sediment distribution in the Blue Nile, as shown in Figs. 2 and 3.

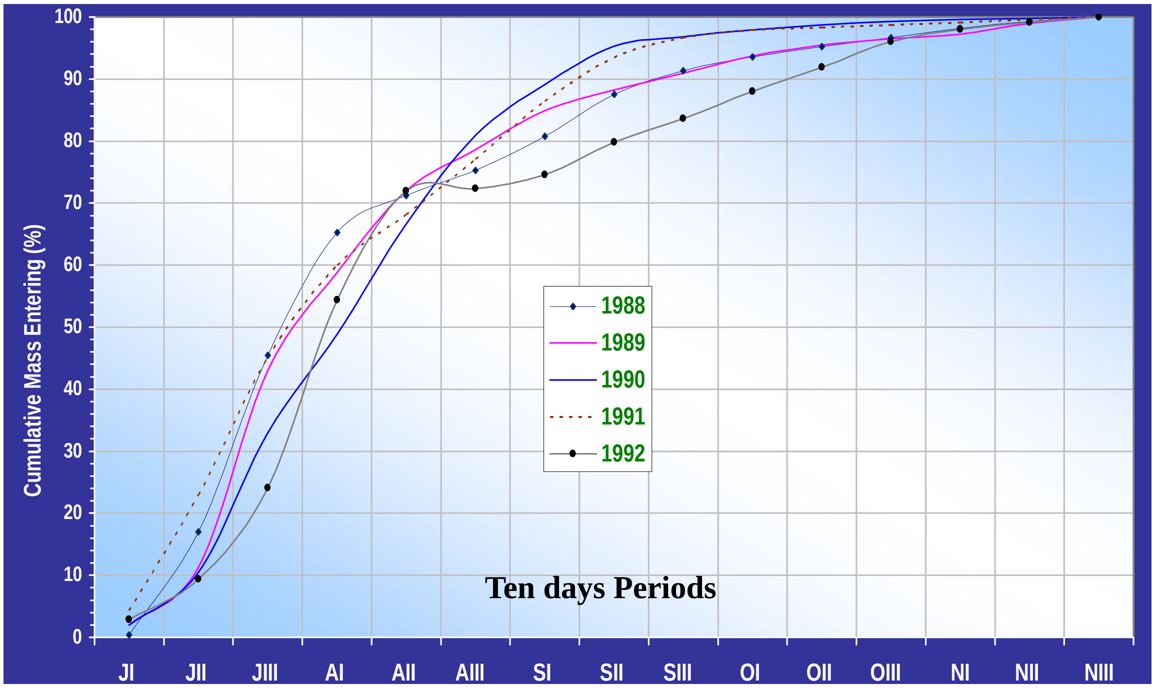

Fig. (2) Cumulative Sediment Load in GS (1988 – 1992)

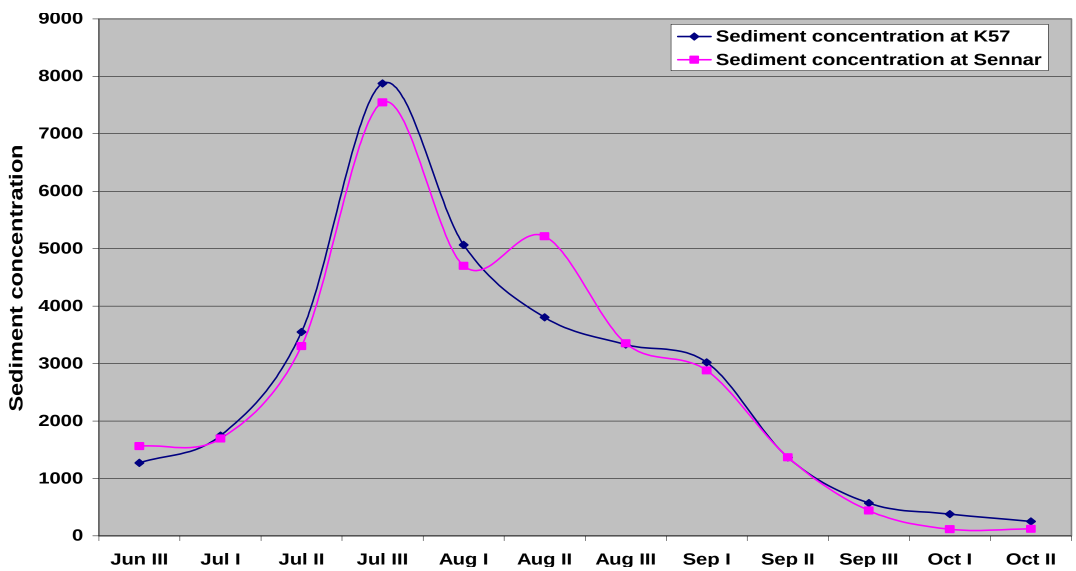

Fig. (3) Sediment Concentrations in Blue Nile and GS Main Canals 2002

The records from MOIWR indicate that between 1933 and 1938, the average sediment concentration entering the GS Main Canals in August was only 700 ppm (Ahmed & Ahmed, 1993). However, by August 1988 and 1989, this concentration had risen to 3,800 ppm, representing an increase of more than fivefold. In the Nineties, sediment concentration values increased significantly to around 8000 ppm, more than an 11-fold rise, indicating serious land degradation and soil erosion in the Blue Nile catchment area of the Ethiopian Highlands (Ahmed & Ahmed, 1993). This trend is compounded by the local seasonal streams upstream of the Roseires Reservoir inside Sudan, which usually carry high sediment concentrations.

Joint work by HR Wallingford and MOIWR, carried out in 1988 and reported in 1990, led to several conclusions that provide a solid foundation for sediment studies in the Gezira Scheme (HR Wallingford, 1990).

- 97% of the sediment entering GS during the flood season consists of silt and clays.
- About 70% of the sediment settles in the irrigation system over a short period from mid-July to the end of August (~three weeks). Fig. (3) gives similar results.
- The proportion of the sediments entering the Canal Reaches that settles increases as canal capacities reduce.
- The approximate distribution of sediment deposition is: 5% for the Main canals; 23% for Branch and Major canals; 33% for Minor canals and 39% passed to Farm Fields.

Subsequent research conducted by the Hydraulics Research Station of MOIWR indicated that the percentages were 5% for Mains, 22% for Branches and Majors, 33% for Minors, and 40% for Farm Fields. The latter results are close to those obtained by HR Wallingford (1990). The upper irrigation system (Main, Branch and Major canals) was designed to be non-scouring and non-silting, but has experienced sedimentation problems over the past four decades. This is quite different from the early stages of GS (before the fifties). The sediment distribution trend shows increased deposition downstream, indicating that the sediment type is wash load.

6- Impact of Aquatic Weeds on Sedimentation

The growth of aquatic weeds is a serious problem in GS, especially during winter when the irrigated water is clean and free of sediment. The growth of aquatic weeds increases the sedimentation rate, while sediment deposits create a favourable environment for weeds to thrive. Ahmed and Ahmed (1993) reported three types of aquatic weeds in GS, namely: submerged, emergent and floating. *Echinochloa stagnina* (emergent) is a common species responsible for most irrigation problems. These two issues lead to significant irrigation challenges, resulting in reduced crop yields and increased operational and maintenance costs. Despite many approaches implemented to address these issues, most have had limited success and numerous failures.

Manual labour was once used for weed removal, but this practice has been discontinued due to health risks, including bilharzia. Excavators with specialized weed-cutting equipment are used to remove weeds from the canals, but there is a lack of funds to keep them operating. Ahmed and Ahmed (1993) concluded that narrow, deep canals may reduce the growth of aquatic weeds by limiting sunlight from reaching submerged vegetation. Moreover, high velocities are created in the canals to increase water turbidity, which also prevents sunlight from reaching the vegetation. Therefore, the volume of weeds to be removed will decrease. Consequently, controlling aquatic weed growth would also reduce sediment deposition and lower operation and maintenance costs.

7- Sedimentation Impact on Farm Levels

The total magnitude of the sediment load entering the irrigation system is estimated to exceed 1000 Mm^3 since 1925 (the commissioned year of the scheme). The amount of sediment passed to the farm fields is estimated as 40% of the total sediment entering the irrigation system annually. If this amount is distributed evenly across the scheme, the expected average rise in the surface ground level of GS is 4.5 cm (about 0.45 mm per year). This rise, compared to the relatively gentle and flat slope of GS (approximately 5 to 15 cm/km), is likely creating significant irrigation challenges across many areas of the scheme. The situation will be exacerbated by a reported sedimentation rate of 3.5 mm per year at the farm-field level, as reported by Mahmoud (1999). This is attributed to the fact that a measurement was carried out in a sediment deposition near the farm inlet. Additionally, poor land preparation caused by the use of inappropriate machinery often leaves the farms uneven, resembling a dish, which further complicates an already difficult situation. This is one of the reasons for poor agricultural production and hence the scheme's financial difficulties.

8- Management Situation in GS

To improve any irrigation scheme's performance, three main components are generally required:

1. capital investment and inputs;
2. building the capacity of the organization responsible for O&M; and
3. enabling individual farmer skills.

Instead of addressing these points, in 2005 Sudan's Parliament passed the Gezira Scheme Act to address the deteriorating conditions of the scheme based on the recommendations of the World Bank Report (2000). The law was aimed at giving farmers more autonomy in selecting crop patterns and rotations. Moreover, it created Water Users' Associations (WUAs), without regard to the different nature of the scheme. The WUAs in the new GS law are responsible for managing the irrigation system through the minor canals to the Abu Ashreen (Abu XX, the field channel). Hence, the farmers start irrigation from there through Abu Sitta (Abu VI, the small farm channel), (Fig. 1).

When this scheme was constructed in the first quarter of the last century, two important rules governing both the distribution of irrigation water and the agricultural side were established. The first one is the Canal Regulation Rule and the second is the Rule and Regulation (R&R). Since the seventies, many changes have taken place. However, most of them unfortunately failed to achieve their goals and have had negative impacts on the scheme, especially on the irrigation system. It is argued here that the GS layout and design are rigid. Therefore, any modifications or changes without careful and intensive study will lead to irreparable damage. To restore discipline in the scheme, the earlier regulations and rules should be reinstated and enforced, coupled with strict management and financial systems.

On the other hand, the Roseires Dam heightening on the Blue Nile (2012/2013) has provided enough water to GS for continuous irrigation throughout the year. However, this capacity has not been utilized to date. Therefore, productive crop rotation and crop intensity can be implemented in the scheme, leading to good crop production and returns.

9- **Mitigation of Irrigation System**

Desilting has always been necessary to restore the canalization system since the GS began in 1925. Plate 1 shows sediment removal from the GS canals, whereas Plate 2 shows sediment accumulation on the canal banks.

Plate 1. Canal Sediment Clearance

Plate 2. Accumulation of Sediment on Canal Banks

The amount of annual sediment removed and the cost of removal are shown in Fig. 4. In earlier years, when the irrigation canals were in good condition, removal of 5 to 7 million m^3 of sediment was considered satisfactory (World Bank, 2000).

The process itself was carried out using the scientific method and high professional practice; hence, the canals' L-sections were restored. Gismalla and Fadul (2006) argued that restoring the L-section of the canals in GS is an unsuitable solution, as it will increase sediment deposition. Ahmed (2003), on the other hand, argued that the regime condition is not always attainable in GS since the actual GS slope is 5 to 15 cm/km, while the regime canal design requires about 57 cm/km of land slope, which is not available.

In recent years, the condition of the canals has deteriorated to the point where they no longer meet the crop water requirements. In 1999, a substantial canal de-silting program was carried out. According to the MOIWR records and as shown in (Fig. 4), 41.0 million m^3 of sediment had been removed from the GS canalization system

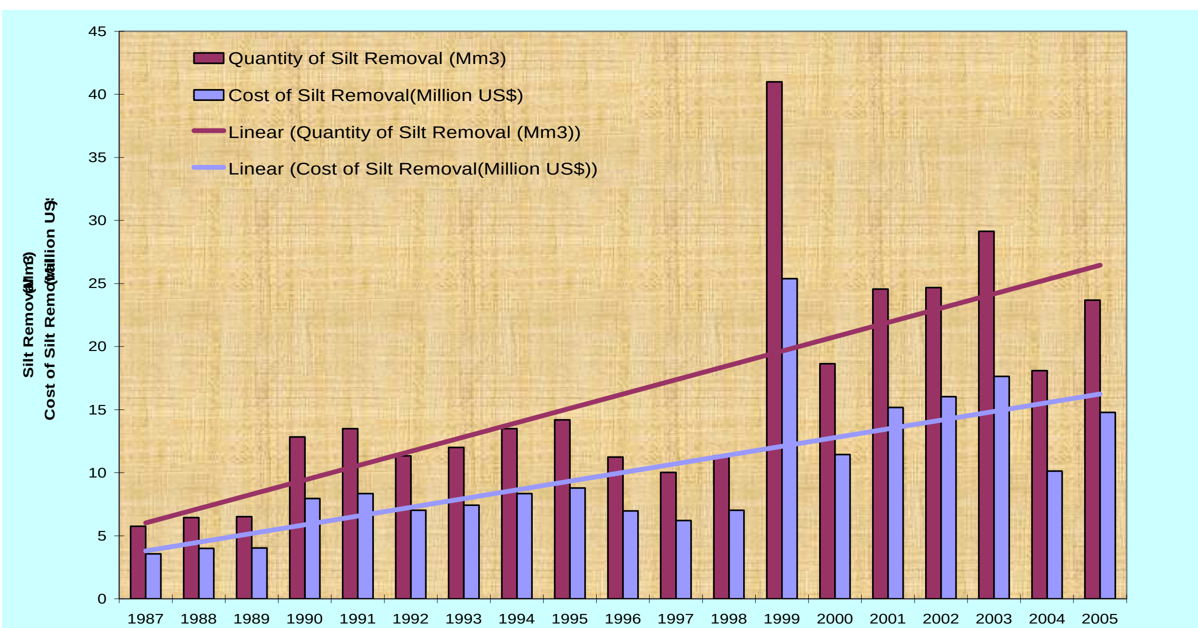

Fig. (4) Quantity and Cost of Sediment Removal in GS (1987 – 2005)

The evidence suggests that the 1999 figure is not credible: the reported 41.0 million m^3 is inconsistent with the measured sediment inflow, reflecting mismanagement and dependence on unskilled personnel. If that figure is accurate, it indicates that the canals were over-excavated and their cross-sections were widened. This represents a significant waste of GS financial resources and has caused considerable damage to the entire canal system, which continues to suffer to this day. In the following season (2000), a further 17.5 million m^3 was removed, giving 58.5 million m^3 over two years. Spread over the 10,683 km of Main, Branch, Major and Minor canals listed in Table 1, this is about 5.5 m^3 per metre of canal. For a minor canal 6 m wide that corresponds to roughly 0.9 m of deposit removed across the full bed width — close to the entire design depth of 0.8-1.3 m. Removing that much material in two seasons is neither practical nor consistent with the measured sediment inflow.

Excessive sediment removal cost has added to the scheme's debt burden, following years of unprofitable performance. By the end of 1999, GS's total debt had reached USD 34 million, while the estimated annual revenue from Gezira's agricultural activities, excluding livestock, was approximately USD 46 million (World Bank, 2000). By 2005, the total accumulated debt of the Gezira Scheme exceeded USD 150 million. Fig. 4 shows a peculiar phenomenon: the average annual water usage in GS from 1987 to 1998 was 6.0 billion m^3, while the sediment amount never exceeded 14 million m^3 annually. In 1999, a significant turning point occurred when the GS Authority took responsibility for sediment removal from the GS canalization system. The result was drastic and damaging to GS. The average sediment removal from 1999 to 2005 was 25 million m^3 per year. However, no authorized personnel have provided a scientific explanation for this phenomenon. This amount is significantly higher than the average annual sediment inflow into the GS, which various studies indicate ranges from 6.0 to 10 million m^3 (Gismalla, 2003). Between 1999 and 2005, water usage in GS and the cultivated area was considerably lower than average, indicating a persistent decline in GS. Such situations, as shown in Figs. 4 and 5, raise a serious concern that involving non-professional personnel in highly technical matters can irreparably damage the irrigation system. Furthermore, the damage has persisted; the entire irrigation system is suffering and will continue to do so for years to come.

10- **Effective Solution for Sedimentation**

Sediment control through improved watershed management is viewed as a more sustainable and effective mitigation measure. Most of the Blue Nile's catchment lies outside Sudan, on the Ethiopian plateau. Sediment control must therefore be integrated into basin-wide development planning. Watershed erosion poses a significant challenge for Ethiopia, leading to substantial socio-economic and environmental consequences that impede rural development and contribute to food insecurity. Therefore, it is in the interest of both countries (Sudan and Ethiopia) to cooperate to alleviate the negative impacts of erosion and/or sediment deposition.

It is recommended to consider constructing a sediment control structure at the main water distribution point where the two Main Canals (Gezira and Managil) meet at the K57 regulator. This concept is consistent with the conclusion of the Hydraulics Research Station that, given the slope limitations of the scheme, sediment control options are limited to excluding sediment at the intake or trapping it in silting basins (Plusquellec, 1990, p. 43). Its feasibility, however, remains to be established: because more than 95% of the incoming load is clay and silt carried as wash load, the trap efficiency of a settling basin at the design discharge of 354 m^3/s cannot be assumed. Particle-size distribution, settling velocities, required detention time and basin volume, the land footprint at K57, a flushing and spoil-disposal route, and capital and operating costs all require investigation before the option can be recommended.

11- Socio-economic and Environmental Impacts

The accumulation of sediment in irrigation canals, along with the growth of aquatic weeds, leads to significant losses in agricultural production. Clearing sediment from the irrigation canal system accounts for more than 60% of the total operation and maintenance costs in this sector. The origins of this situation can be traced back to the droughts of the 1980s and the food security policies implemented in Sudan. This policy involved expanding irrigated areas without adequate measures to mitigate the negative impacts on reservoirs and irrigation canal networks. An intensive study conducted by Siyam (2006) examined the economic impact of sedimentation at Roseires on both agricultural production and hydropower generation. The economic loss is determined using the present value (PV) criterion and is expressed as a percentage of the total project cost. It is assumed that the water volume equal to the Roseires reservoir sediment volume will be available for irrigation each year. Fig. (6) shows the economic revenue loss in the agricultural and energy sectors, expressed as a percentage of the original dam cost, as a function of the discount rate. Irrigation management has become increasingly challenging due to the costs of sediment removal and aquatic weeds, along with significant sedimentation issues in reservoirs such as the Sennar and Roseires dams.

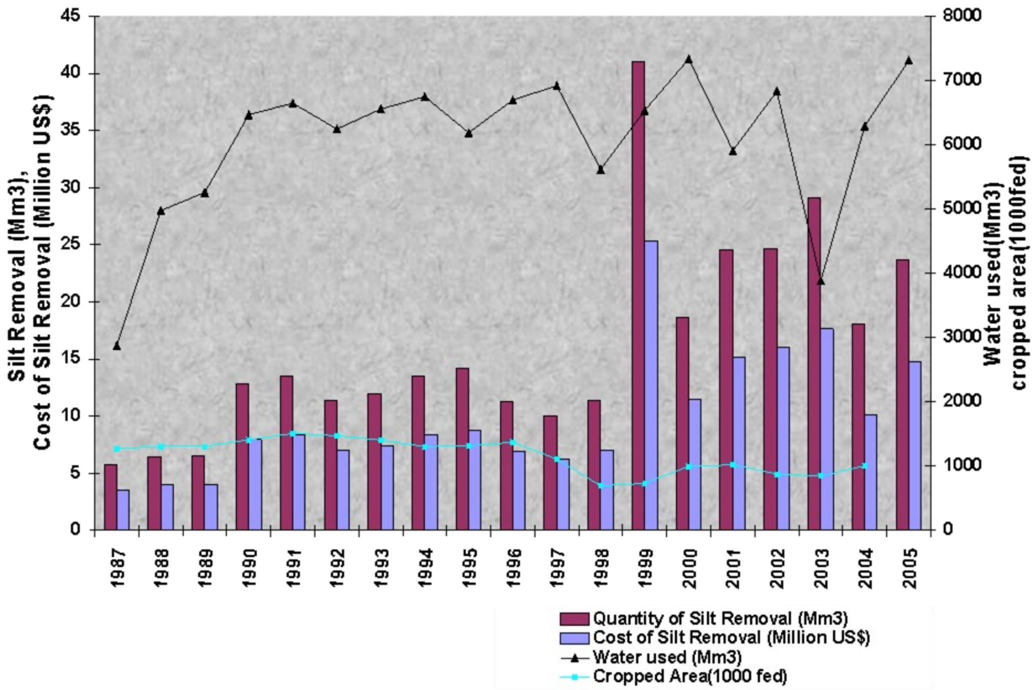

Fig. (5) Water Used, Cropped Area, Silt Removal and Cost in GS (1987 – 2005)

Sediment accumulation in the GS reduces canal flow velocity, creating shallow, stagnant zones that promote the proliferation of aquatic weeds such as *Vossia cuspidata and Cynodon dactylon*, which are documented as dominant species in Gezira canals throughout the year (Alhadari et al., 2023). This represents a shift in the dominant flora since the survey of Ahmed and Ahmed (1993), in which Echinochloa stagnina was the principal problem species, and may itself reflect the changed sediment and flow regime of the canals. These weeds trap additional silt and organic matter, further degrading water quality and increasing turbidity, conditions shown to be critical drivers of weed abundance in Gezira canals (Alhadari & Dafaallah, 2020). Stagnant, weed-infested water creates ideal habitats for disease vectors, including mosquitoes and schistosomiasis-carrying snails, as supported by ecological assessments indicating that Gezira canals host diverse biological communities (bacteria, fungi, algae, and aquatic fauna) conducive to pathogen and vector development (Alhadari et al., 2023). Farmers working barefoot or in direct contact with canal water are therefore exposed to higher risks of *malaria*, *schistosomiasis*, *and skin infections*, making sediment–weed interactions a significant driver of occupational disease vulnerability in the GS.

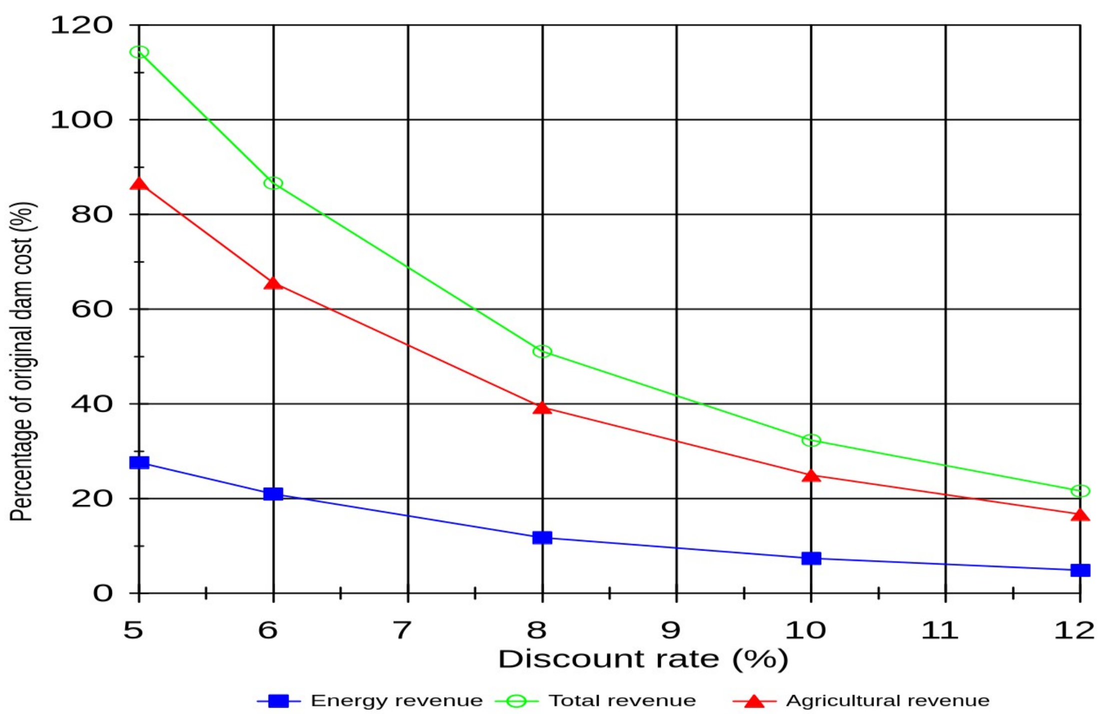

Fig. (6) Economic Revenues forgone in Agricultural and energy sectors as a percentage of original dam cost versus discount rate

12- **Critical Performance of the Gezira Scheme (2005–2025)**

This section presents a brief overview of the period 2005-2025; a fuller treatment is in preparation. The Gezira Scheme remains the largest gravity-fed irrigation project in the world under a single management, but it has declined markedly over the past two decades. The most persistent challenge has been *institutional deterioration*, driven by repeated restructuring and weakened governance. Responsibility is now divided between the Central Government, the Sudan Gezira Board and the Water Users' Associations created under the 2005 Act, with no clear line of accountability between them. The abolition of the Gezira Board's authority under the 1984 Act, followed by the liberalisation measures of the 2005 Gezira Act, weakened coordinated management, reduced accountability, and led to poorly coordinated water management, accelerating the deterioration of canals, pumps, and drainage infrastructure (Elshaikh et al., 2018; Goelnitz & Al-Saidi, 2020; Ahmed, 2018).

In 2014, changes were introduced to the GS Law of 2005; new Farmers Production Associations (FPAs) were created. The establishment of these FPAs is still under formulation to this date. This added further challenges to the management of the scheme.

Infrastructure degradation has further constrained performance. Ageing canals, siltation, pump failures, the collapse of the night-storage system throughout the GS, and weak irrigation management have reduced *water delivery efficiency*, especially for tail-end farmers. Studies using hydrological and economic modelling demonstrate that unreliable water distribution has increased production risk and reduced farmers' ability to follow recommended rotations (Elshaikh et al., 2018). The deterioration of the canal network has also increased conveyance losses, lowering effective water availability during critical crop stages (Osman et al., 2017).

Crop productivity has declined across most major crops. Technical efficiency analyses show farmers operating well below potential: cotton at *60–65%*, sorghum at *70–75%*, and groundnuts at *60–68%* efficiency (Mahgoub et al., 2017a). Wheat is the exception, achieving *85–90%* efficiency due to targeted government support and improved seed varieties. Potential yields are those established by the Sudan Agricultural Research Corporation. Overall, the Scheme's cropping intensity has fallen, and the traditional rotation system has become increasingly difficult to maintain.

Economically, the Scheme has struggled with rising input costs, declining cotton profit, and inconsistent government financing. Farm income simulations reveal that optimal cropping patterns—if water were reliably supplied—could increase incomes by *50–60%*, highlighting the gap between actual and potential performance (Mahgoub et al., 2017b). The withdrawal of state support for mechanization and extension services has further reduced farmers' capacity to adopt improved practices.

Environmental pressures have compounded these challenges. Climate studies indicate that irrigation in Gezira has altered local rainfall patterns, reducing precipitation over the Scheme while increasing it eastward (Alter et al., 2015). Combined with rising temperatures and more frequent dry spells, these changes have increased water stress and reduced yield stability. In summary, the Scheme's performance over the past two decades has been constrained by *institutional fragmentation, infrastructure decay, declining technical efficiency, and environmental stress*. While the Scheme retains enormous potential, meaningful recovery will require large-scale rehabilitation, governance reform, and proper water management systems.

The Grand Ethiopian Renaissance Dam (GERD) is expected to reduce sharply the sediment reaching the Gezira Scheme, since its reservoir traps most of the incoming load (Wheeler et al., 2020). Modelling of a 50% reduction in Blue Nile sediment concentration indicates that deposition in a Gezira major canal would fall by 74-81% (Osman, 2015). The benefit is not unqualified, however. Clearer water reduces turbidity, which by the mechanism described above should favour rather than suppress aquatic weed growth; sediment-starved flow tends to scour beds and undermine structures designed for a silt-laden regime, as observed downstream of the Aswan High Dam (Ahmed & Ismael, 2010); and the fields lose the nutrient-rich silt they have received for a century. However, the impact of GERD on the GS performance will be considered in a separate paper.

13- Conclusions

After a century of operation, the irrigation system faces significant management challenges, particularly regarding its infrastructure. The issue of sedimentation has been exacerbated by mismanagement, improper handling of irrigation practices, and a lack of timely maintenance. Sedimentation and aquatic weeds pose significant challenges for irrigation water management. A portion of the sediment issue can be addressed through collaborative efforts between Sudan and Ethiopia. A good suggestion for a sediment solution is the proposed settling basin at the junction of the two Main Canals (Gezira and Managil) at the K57 regulator. This may involve utilizing a sediment excluder, such as a settling basin or appropriate mechanical excavation methods. However, the most effective approach is to combine integrated sediment management with sound watershed management strategies at the national and regional levels. The current methods for sediment removal need to be improved by incorporating more scientific approaches. There is no doubt that the GS irrigation system is rigid; hence, adaptation of any changes and/or modifications requires careful handling. Many researchers and scholars conclude that the GS Act (2005) represents a turning point that led to the deterioration following its implementation, particularly in technical and institutional matters. Even the corrections introduced into the GS (2005) law in 2014 are not enough to improve the situation. Therefore, research studies are needed to have a better solution for the GS to improve its performance.

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