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Towards Revitalizing Khartoum, Sudan Wastewater System

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Abstract: *Khartoum Metropolis Sewerage System is in crisis since it serves <5% of households while >30% of families use septic tank system, disposing effluents into groundwater instead of leaching fieldsand. Khartoum has no experience in water recycling although installed cluster wastewater systems are producing adequate-quality effluents at reasonable costs. Sudanese wastewater disposal standards into streams are exceptionally stringent despite the great flows of Nile Rivers. This paper, which is a result of several studies conducted by the author, stresses the crippling problems that retarded development of wastewater system and offers practical proposals for revitalisation. The major problem is Khartoum authorities' prejudice against disposal of treated effluents into River Nile and instead they prefer to pump wastewater from lower altitudes to higher altitudes areas located beyond the urban peripheries at excessively high costs. Khartoum wastewater system is discussed thoroughly and proposals are provided to streamline wastewater management plans, at first, by public enlightenment and engraving best wastewater practices in managing authorities and since Khartoum Metropolis is sprawling haphazardly it is economically feasible to install wastewater decentralized systems and reuse treated effluents or dispose them into River Nile. Establishment of an effective institutional framework is must to formulate new plans, undertake the mentioned tasks and restructure the existing networks*
Keywords: *Decentralized systems, Disposal standards, Khartoum, Reclamation, Restructuring, Wastewater,*

I. Introduction

1.1 Khartoum Metropolis

Khartoum Metropolis, Sudan tri-city capital (Khartoum, Omdurman and Khartoum North) has not maximised the benefited of the strong presence of the Nile Rivers that shape the three cities forming the Metropolis. It is a typical example for rapidly growing developing metropolises experiencing a significant population growth due to rural migration. It started in the Independence Day (1/1/1956) by less than 3% of the total Sudanese population and this figure jumped to 16.8% in 2010 while the physical block grew beyond imagination, refer to Table 1. The huge increasing demand for safe wastewater disposal facilities to serve this huge population is a great challenge and it is worrying Khartoum authorities putting in mind the evolving urbanisation trends Khartoum is subjected to and the continual urban transformation that requires restructuring and upgrading.

Table 1: Khartoum Physical Block Growth and Population Density

Year	1955	1970	1980	1998	2006	2010
Population in million	0.25	0.64	1.17	4.37	6.01	7.00
% of Sudan population	3.0	4.4	5.7	14.9	16.4	16.8
Total area in hectare	1680	3000	22840	80250	132300	165000
population density in person /ha	149	213	51	55	45	42

Source: Dr Bannaga, S.I.[2]

II. Methodology and Objectives

This paper is a result of several studies conducted by the author who gathered the relevant information through the years particularly during his term of office when he was Khartoum State Minister of Engineering Affairs and later Minister of Housing and Public Utilities. The processed data presented in the paper are collected from some of the wastewater cluster systems which were designed, installed and operated by the author in a number of Khartoum localities. Recent data were also collected to update the wastewater networks' existing conditions as part of an environmental assessment study. The paper as well sheds light on different standards on urban wastewater disposal and reuse in selected countries.

The Paper intends to:

Initiate a dialogue and enrich the discussions with the concerned people.

Highlight the main issues of wastewater disposal considering environmental sustainability and cost-effectiveness.

Help Khartoum authorities to streamline its integrated wastewater management plans by outlining the common engineering practices, , highlighting international regulations controlling wastewater disposal and reuse and identifying the relevant systems based on local conditions of the metropolis and providing practical proposals for revitalisation

III. Description of Khartoum Wastewater Disposal Facilities

3.1 The general Situation

Wastewater disposal remains a burdensome concern to all developing cities. They are the hardest hit since they are growing faster than services' development for their population. This public service is hampered by limited resources as compared to the extent of the problem and particularly the rising technical difficulties
Khartoum is a city in crisis with regard to wastewater disposal. The status of the wastewater system is currently posing the most serious problem facing Khartoum State. Epidemiology data show that gastroenteritis, typhoid and infectious hepatitis diseases are highly prevalent which are directly related to inadequate services of water supply and sanitation. In a recent study conducted by the author for the purpose of assessing Khartoum environment, the wastewater collection and disposal methods used by households are provided below in an order of sequence:
Use of dry pit latrines 56.1 %
Use of septic tanks + wells 30.8 %
Use of septic tank + soakaway or only soakaway pits 8.6 %
Use of waterborne sewerage network 4.3%
Use of open spaces 0.2 %

The recent study shows that the majority of people use the traditional method which depends on Pit Latrine construction and this method is unhygienic and associated with nasty smells, nuisance, flies and insects as well as unsafe structurally if it is not properly constructed.

Although waterborne systems drain the entire Khartoum wastewater budget they serve a very small percentage of households in parts of North Khartoum Locality and Khartoum North Industrial Area, the only parts of Khartoum Metropolis that are covered by these systems.

3.2 Septic Tank Facilities

As revealed by the above data, the septic tank method, a small-scale sewage treatment system, represents a sizable percentage among the disposal methods and they are not restricted by local government regulations although the common practice in Khartoum is to dispose septic tank effluents into shallow groundwater instead of discharging them into leaching fields. The population who relies on septic tank facilities includes those who live in newly developed first and second class neighbourhoods and subdivisions and they afford to pay for installation of sustainable sewerage systems if motivated.

3.3 The Waterborne Sewerage System

Khartoum City sewerage system, displayed in Drawing 1, was constructed in 1953 to collect and treat foul wastewater. The system composed of the following: 146km of sewerage Network of sizes ranging from 175mm to 800mm of Asbestos Cement (AC) pipes together with 1186 manholes. The majority of pipe size was 175mm.

The serviced area comprises 13 drainage zones; each zone is served by a lifting or a pumping station. At present the total number of pumping/ lifting Stations has reached 16, (drawing 1). The sewerage network was extended for 303 Km, and the pressure mains lengths are 66km. The lifting and pumping stations are distributed within a small area of less than 15 km^2. The collection networks are in need of rehabilitation where the 16 pumping/lifting stations require major maintenance. This is in addition to replacement of 30 km of defective medium size sewer lines while replacement of small-diameter sewers in some parts of the sewerage network is a must to increase their pipe carrying capacities if blockage of sewers and flooding of raw wastewater are to be stopped.

Part of the sewerage network was Goz Treatment Plant which was completed in 1959 comprising conventional trickling filters' type. This treatment plant was abandoned two decades ago and instead a plant using a traditional oxidation ponding system of 28.000 M3/day capacity was constructed in the early nineties.
Furthermore, the discharge of the wastewater into the sewerage system has been increasing as new developments of the old city are added to the Network, the oxidation treatment ponds has also been expanded.

The Khartoum North City waterborne sewerage system was constructed in 1967 .The Network comprises 44KM of pipelines with one pump station and four lifting Stations. The wastewater is mainly of industrial source, pumped to the treatment plant through two pressure mains of 400mm and 450mm sizes, both running for a distance of 7 km. The treatment plant which is located at Haj Yousif and now out of order comprises primary treatment (screens, Aerated Grit Chamber, two clarifiers, 4 sludge digesters, 16 drying beds). The capacity of the STP is 28000m3/day. Lagoons system of three steps, anaerobic, aerobic and facultative ponds was adopted for the Biological Treatment.

Omdurman City has no sewerage network system till this moment.
The main projects which are under Construction and are of very high costs are:

1. Pressure Main from Wad Dafea STP to Hatab Area, 33KM North East
2. 900mm pressure main from Hizam STP to Soba running for 16KM length

Drawing (1): Khartoum City Existing Wastewater Networks

3.4 A Brief Assessment

It is noted that:

1. All networks are dependent on mechanical lifting of water through a series of lifting and pumping stations sited in a sequential order considering that their operation requires specialized technical personnel and the use of foreign equipment and pumping sets.
2. Collection networks are connected to very long trunk sewers helped by boosting facilities for conveying wastewater to distant overloaded treatment lagoons
3. The lagoons are functioning as impounding reservoirs rather than treatment facilities and they only retain wastewater as transient storage awaiting pumping to areas outside the urban boundaries. The objective of the projects under construction is to transport wastewater tens of kilometres further
4. The lagoons system failed even to perform as primary treatment process since the biodegradable component of the wastewater received by the lagoons from Khartoum North Industrial Area is very small because it contains high concentration of toxic and heavy metals.

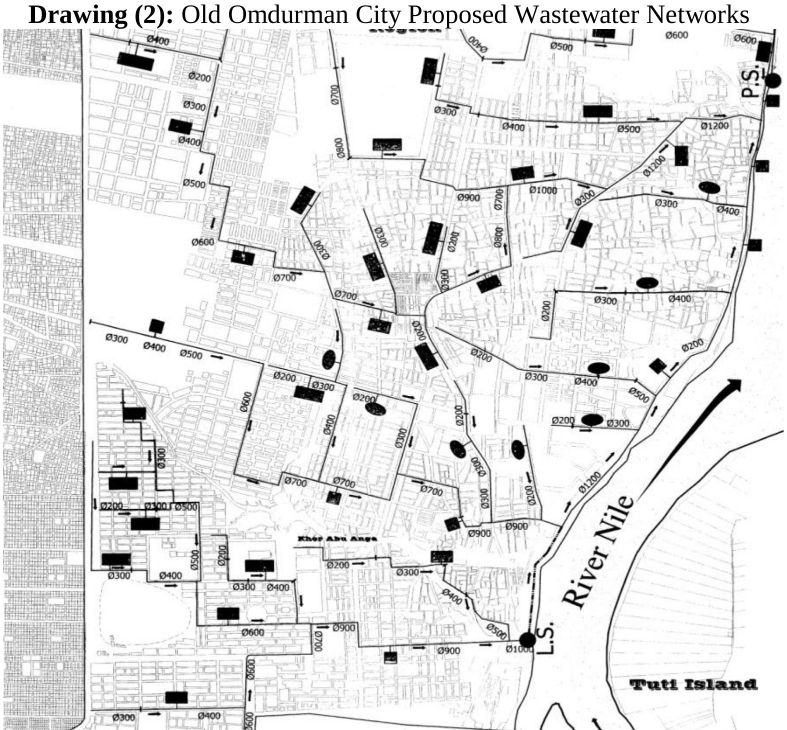
5. The majority resources allocated for wastewater services is consumed in maintaining pumping mains and rehabilitation of the pumping stations series and in paying the high cost of operation and energy. Maintaining the status quo of the existing network is exhausting all efforts
6. The current septic tank disposal methods pose health and environment risks. Poor quality septic tank effluents may mix with groundwater because effluents are discharged via wells into shallow unconfined groundwater basins. They pollute sub-surface water in certain areas and this may infiltrate in distribution systems of drinking water supply during periods of high demand when negative pressures exist in the system. Also leaks from failing septic tanks cause Khartoum expansive clayey soil to swell and consequently shrinks when dry causing major failures in building foundations. Foul water is seen flooding basement of buildings in certain localities, particularly in areas where septic tanks effluents accumulate on shallow sub-soil strata. Tap water was examined and 37.5% of samples tested were found polluted with bacteria and other pollutants.

IV. Retarders of Khartoum Sewerage System Development

4.1 Main problem

The question that jumps to the mind is why the system is decaying despite the development boom witnessed by Khartoum State over the last couple of decades and enabled the metropolis to construct huge engineering infrastructures?. Many officials who have been tasked with the responsibility of sewerage networks are increasingly convinced that the primary reason for their slow pace of development is the excessively large amount of funds required. Most of them have the wrong perception of constructing massive networks to cover an expansive part of the city and install long trunk sewers to convey wastewater to remote treatment plants and dispose off the final effluent thereafter on the surface and not discharging it into the Nile Rivers even if there is a pressing need to do so. Despite the fact that funding is crucial but in reality financial resources can be available for implementation of decentralized systems when authorities abandon installing extensive networks that cover the whole city and served by a central treatment plant as exemplified by the lengthy pumping mains under construction. The idea of conveying wastewater against the natural gradient, a policy adopted by all consecutive managements, is the fundamental crucial problem that impeded sewerage system development. Wastewater officials resisted discharge of treated wastewater effluents into River Nile. Regrettably, this imperfect handling of the situation continues to persist and there is a present proposal in the pipeline, to adopt the concept of water lifting for Omdurman city, Drawing 2. In addition, the overarching tendency of authorities is to indirectly hamper any attempt to establish decentralized treatment facilities because of the delusional belief that such project is doomed to fail as far as there are no sufficient open spaces for the discharge of wastewater effluents. The other obstacle is lack of knowledge.

Drawing (2): Old Omdurman City Proposed Wastewater Networks



Source: Khartoum State Sanitary Corporation[7]

4.2 Lack of Scientific Knowledge

Lack of scientific knowledge of the majority of the involved actors is reflected by:

- Inefficient institutional setup
- Adoption of inappropriate legislations, policies and regulations for effluent disposal and negligence of wastewater reclamation.
- Lack of knowledge and experience on innovative cost effective technologies for wastewater treatment systems that best serve Khartoum Metropolis and absence of adequately trained technical cadre to operate, control and monitor sewerage systems
- Lack of the technical knowhow, courage and initiative to maximise limited funds utilisation for the improvement of wastewater system. Finance has continuously been falling short because of huge sums of money requested.

V. Regulations for Disposal of Treated Wastewater

5.1 Disposal into Surface Waters – a Common Practice

Waterborne sewerage systems collect wastewater from different sources and convey it to the point of eventual treatment for removal of contaminants, prior to disposal. It encompasses a wide range of potential contaminants such as suspend matters or solid materials, dissolved substances, living organisms (pathogenic and non-pathogenic), etc. The purposes for removal of water-carried pollutants are many but the main and of prime importance are:

1. Hazards related to public health.
2. Protection of water sources.
3. Protection of aquatic living creatures. Organic matter, micro-organisms, chemical pollutants, etc, consume dissolved oxygen in water and leave the aquatic and fish life with little or no oxygen. The other purpose is:
4. Recycling wastewater to utilize it for appropriate water-using activities including drinking water.

The common practice after wastewater treatment is the discharge of effluents into natural surface waters if wastewater is not needed for recycling. The self-purification or assimilative capacity of natural waters is thus utilized to provide the remaining treatment. The theory is that, when an effluent is discharged into a stream, a biochemical oxygen demand (BOD) is created and it decays exponentially in time and space. This oxygen demand causes an oxygen deficit. The greater the oxygen deficit, is the greater the rate of natural oxygen replenishment from the atmosphere into the stream. These two concurrent processes of oxygen consumption and oxygen replenishment explain the known phenomenon of the oxygen sag curve. The bacteria and other microorganisms living in water will do the job by disintegrating the organic matter. It is well known that biotic decomposition of organic matter is completed to a large extent because bacteria and other microorganisms feed on them by using oxygen in water and the atmosphere and the result is evolution of biological oxidation/ reduction processes. These processes are completed as wastewater flows through the receiving water body.

Other various factors that determine the required level of wastewater treatment vary according to the type of wastewater, receiving waters, outfall characteristics and nature of the waste itself. For example, industrial waste requires high level of treatment to remove the hazardous toxic materials before being discharged into the sewerage system. On the other hand, waste materials discharged into seas may only require a primary treatment but in case of discharge into any body of fresh water the capacity of the water body should be determined to ensure that the pollutants are eliminated naturally.

5.2 Khartoum Experience in Disposing Treated Wastewater

Khartoum wastewater authorities have an erroneous perception which is well established among the environment protection officials who insist on conveying treated effluents to the city peripheries to avoid their discharge into the River Nile water which is a totally baseless idea and against common practice as shown above as well as it is against the natural topographic gradient. And this adequately explains the fact that nearly all the sewerage projects proposed for implementation are extensive collection networks employed to collect wastewater from the sources of generation and then convey it from areas of low altitudes to those of high altitudes starting from areas adjacent to the river and eventually wastewater is pumped via a series of pumping stations in a sequential order to far away high grounds. Such practice undermines any attempt to develop and upgrade the sewerage system in Khartoum Metropolis.

Surprisingly, Khartoum authorities allow disposal of septic tank effluents into groundwater aquifers despite of its inadequate quality. Nearly all effluents of septic tank installations in Khartoum find their way to the shallow depths of the unconfined aquifers of Khartoum groundwater through wells that are dug to penetrate the sub-soil layers before connection with the upper surface of the groundwater basins or the water table. Some localities are witnessing surface wastewater flooding and causing foundation problems to unprotected structures and especially to traditional buildings. However, mixing of wastewater with drinking water cannot be ruled out considering that water supply networks are in most cases not pressurized as pointed out earlier.

5.3 Standards for Effluents' Discharge into Surface Waters

Table 1: Selected Standards of Effluents Discharged into Surface Waters

Regulatory Body	Biochemical oxygen Demand BOD mg/l	Total Suspended Solids T.S.S mg\l	Chemical Oxygen Demands mg\l	PH
Canadian Wastewater System effluent Regulation [10]	25	25	-	
Irish Wastewater [19]	25	35	125	
Indian Standards [9]	30	100	250	5.5-9.0
EU Urban Wastewater Treatment Directive [4]	25	35	125	
Sudanese Wastewater Standards [16]	15	30	75	6-9
USEPA, Minimum Standards [17]	30	30		6-9

The quality standards for wastewater disposal in Sudan issued by Sudanese Standards and Metrological Organization, SSMO are much stricter than any standards in the world – this is largely attributable to the influence on SSMO by government officials who disagree with discharge of wastewater into rivers.

Table 1 above shows that the European and USA standards are apparently unified but in countries like India the standards are much more relaxed particularly in relation to suspended solids SS and Chemical Oxygen Demand (COD). The European standard measured in COD is 125 mg/l while the Indian standard is double the European standard or 250mg/l. Generally, the standards for effluent disposal into surface waters are more relaxed compared to standards of its reuse.

The Sudanese regulations are unnecessarily stringent with a COD standard of less than 1/3 of the Indian standard i.e. at 75 mg/l. Ironically, all the above countries have chosen reasonable standards based on B.O.D. measure as well as US standing at 30 mg/l except Sudan which has a standard of 15mg/l for BOD despite the huge capacity of the Nile rivers.

For more clarity the flow capacity of the River Nile and its tributaries (Blue Nile, White Nile, and River Nile) downstream Khartoum city may be compared with that of the Thames River that runs through London. It is needless to say that the British standards are the same as the European standards i.e. setting BOD limit of 25 mg/l. The fact is that River Nile flow capacity is much bigger than the Thames River as shown in table (2) which explains the huge difference in the daily rates of discharge conveyed by the two rivers. The variation in wastewater dilution rates simply emphasizes the erroneous position of the Sudanese officials when it comes to effluent discharge into Nile Rivers.

Table 2: Daily Discharges of the Nile Rivers and River Thames

River Gauging Location	Daily Minimum Flow on Record in million m³	Daily Average Flow in million m³	Daily Maximum Flow in million m³
River Nile (Gauge located Further downstream of Khartoum)*	40 M m³ or 463 m³/sec	185 M m³ Or 2141 m³/sec	910 M m³ or 10532 m³/sec
Blue Nile (Gauge located at Khartoum)*	0.25 Mm³ or 2.89m³/sec	119 Mm³ or 1377m³/sec	955 Mm³ or 11053m³/sec
White Nile (Gauge located at Khartoum)*	55 Mm³ or 637 m³/sec	75 Mm³ or 868 m³/sec	175 Mm³ or 2025 m³/sec
River Thames (Gauge located at Teddington)**	0.846Mm³ or 10 m³/sec	6.74Mm³ or 78 m³/sec (London:65.8 m³/s)	91.50 Mm³ or 1059 m³/sec

*Source: Sudanese Ministry of Irrigation [11]
**Source: E, Jones[6]

It is to be noted that in poor developing countries only a small proportion of the wastewater generated by communities and transported by sewerage networks is treated. In Latin America, for example, less than 15 per cent of the wastewater collected from cities and towns is treated prior to discharge, Pan America Health Organization, PAHO[14]. Some developing countries apart from Latin America also discharge raw sewage into surface waters and this although unwise and should be condemned but it is often practiced. According to Duncan Mara[8] and other practioners large water bodies such as seas or oceans as well as large receiving water courses may be used for dumping of wastewater when the dilution of discharged wastewater reaches more than 500 but this is governed by strict procedures and stringent selection of outfalls. For example, the city of Manaus (population in 2000: 1.4 million) in the Amazon region of Brazil discharges its wastewater untreated via a river outfall into the Rio Negro, a tributary of the river Amazon, which has a flow of 30,000 m³ per second. The available dilution is >>500 and therefore the pollution induced is considered negligible according to Mara[8]. Often the reason for the lack of wastewater treatment is financial, but it is also due to ignorance of adopting low-cost wastewater treatment technologies and to lack of knowledge of the economic benefits of recycled treated wastewater.

5.4 The Standards Used for Regulating Reuse of Wastewater

Wastewater contains valuable plant nutrients, and crop yields are higher when crops are irrigated with wastewater effluents than with freshwater. It is therefore too valuable to waste and fortunately reclaimed wastewater can be used for a number of options including agricultural irrigation. Many parts of the World use reclaimed wastewater for several purposes, Saudi Arabia, east neighbour of Sudan, uses over 70 % of its wastewater and determined to use up to 90% when the large projects under construction are completed, Al-Hagri[1]. India has been using wastewater for irrigation for nearly 100 years. Mexico City, the second largest city in the world, uses all its wastewater for irrigation, Mara[8]. Sudan has neither regulation governing reclaimed water use nor experience in this field despite the fact that a large portion of its land lies within the desert zone. Nearly all regulations adopted by countries recycling wastewater recommend treated water to achieve BOD and TSS at <30 mg/L level as well as receiving additional disinfection to ensure efficiency. The recommended values for each of the said indicators shown on Table 3 depends on the intended use of the reclaimed water considering four groups of water-using activities' classes (A, B, C and D). The table gives details of the reclaimed water standards set by some selected countries.

Table 3: Regulations for Treated Wastewater Effluent Reuse

Treated wastewater – using activity	Regulatory Body	Reclaimed Wastewater Quality					
		E. Coli CFU / 100 ml	BOD mg/l	S.S mg/l	Turbidity NTU	PH	Chlorine Residual
Class A Toilet flushing, outdoor hosing, garden watering, open space irrigation, Food crops eaten raw, root crops, fire fighting, water features, landscape irrigation Recreational lakes, groundwater recharge	1	<10	20	5	2	6-8.5	
	2	No fecal coliforms	<10		<2	6-9	1 mg/l
	4	2.2, 1 egg/l	<10	<10	<2		
	3	Disinfected tertiary treatment			<2		
Class B Irrigating pasture, fodder, none – food crops, soil compaction, mixing concrete, dust control on roads	1	<100	20	30		6-8.5	
	2	<200	<30	<30		6-9	1 mg/l
	3	Disinfected secondary treatment					
	4	<1000	<40	<40			
Class C Irrigation of "no public access "areas, water features for amenity purposes	1	<1000	20	30			6-8.5
Class D Silviculture, turf, cotton, wholesale nurseries	1	<10000				6-8.5	

1. State of Queensland (Australia) [15]
2. USEPA[18]
3. California Department of Public Health[3]
4. Ministry of Water and Electricity, KSA,[12]

Note: the WHO[20], main regulation for:
(1) Irrigation of crops eaten uncooked is <1 intestinal nematodes (eggs/litre) and
(2) Irrigation of cereal crops, fodder, pasture is <1 intestinal nematodes (eggs/litre)

VI. The Appropriate Wastewater System for Khartoum

Many systems now exist worldwide for safe wastewater treatment and disposal that serve rural and urban communities. Each system has advantages, as well as limitations. The appropriate system is selected in particular to meet site conditions and treatment objectives. The most influential factor that concerns the beneficial community is the cost of the selected facility in addition to physical and regulatory factors
The Following wastewater disposal systems are widely used for serving urban and suburban communities:

An Onsite System

It is used to collect, treat, and discharge or reclaim waste- water from an individual dwelling. A conventional onsite system includes a septic tank and a drain field. After leaving the septic tank, water is discharged into the leach field for further treatment by bacteria in the soil and filtering by the soil itself. The Sudanese practice disregards using a subsurface leach field and discharges septic tank effluents into a 20 m depth or a deeper well. This is not a recommended practice because wastewater may contaminate groundwater in case its water table is shallow. Fortunately this is not the case in most localities of Khartoum because it usually abstracts groundwater from a depth of 100-150 m. The other drawback of the applicability of septic tank systems is their relatively poor performance if a further treatment stage is not incorporated. Nonconventional additional onsite treatment units require more monitoring and maintenance.

A cluster system

It is a wastewater collection, treatment and disposal system that serves two or more dwelling units served by individual septic tanks or aerobic treatment units but the treatment unit is relatively small compared to decentralized systems.

A decentralized system

It is a wastewater system that is used to collect, treat and dispose relatively small volumes of wastewater. The wastewater system is generally originating from groups of dwellings and businesses or serving a number of neighbourhoods or subdivisions that are located relatively close to each other.

A Centralized system

It composes of a large network of collection pipes or sewers serving all town homes and businesses and these convey water to a central wastewater treatment plant.

Since Khartoum is witnessing an accelerated growth evolving scattered urban forms and haphazard development of a sprawled growth it may consider installing all forms of wastewater decentralized systems as appropriate. A decentralized system employs a combination of onsite and/or cluster systems that treat wastewater from a group of dwellings, clusters, neighbourhoods and businesses and its capacity may increase to include medium satellite treatment plants served by low-cost collection sewers or may decrease to include onsite systems located inside the buildings they serve. The decentralized systems offer flexibility in case of urban sprawl development made of scattered physical blocks. The wastewater that is collected from each dwelling or business throughout the decentralized network usually flows through smaller diameter collection pipes, buried at a shallower depth than extensive sewers of centralized network and they run relatively short distances before discharging into maintenance-intensive treatment and disposal facilities. The centralized system has an extensive (and expensive) network of trunk sewers to convey the entire city's wastewater to the central treatment plant, and this often involves pumping the wastewater from one drainage basin to another. The drainage lines of the decentralized networks require less maintenance and they are not subjected to the transfers of large volumes of water from one drainage zone to another that happens with centralized systems; therefore less expensive because it minimizes the costs of trunk sewers and avoids much, if not all, of the expenditure on pumping. Each decentralized plant serves a single drainage basin or small number of drainage sub-basins. Consideration should also be given to the susceptibility of effluent re-use.

However, central systems may be viable in case of a compact urban form characterized by dense development and when topography permits gravity flows.

In addition to being cost-effective the treatment units of the decentralized system can be installed according to the available budget and the desired priority while more units can be added in future when finance is availed. Also location of treatment units can be selected according to site conditions and this serves the purpose of Khartoum because of its flat topography and can be applied to neighbourhoods with onsite units already in operation or those which installed septic tanks facilities thus allowing homeowners to continue using their functioning systems if they desire.

It obvious that decentralized system is economically viable for Khartoum and fits perfectly with the flat topographical features of Khartoum Metropolis thus, avoidance of deep excavations is possible. The suitable sites for the construction of the wastewater treatment plants can easily be determine by considering essential factors such as the layout plan, natural topography and elevation, direction of the water flow, drainage zone boundaries, etc. Having addressed these essential inputs, there is no compelling reason to extend the sewerage networks beyond the downstream end of the drainage zone because this may increase the cost substantially and may require installation of large trunk sewers and use of a series of pumping stations to mechanically lift wastewater unless there are reasonable grounds to make such decision.

To follow are some examples provided in Table 4, three from Pegram, Tennessee, USA and the other three are from Khartoum which are serving student hostels - dense development. The cost of installing the cluster system as per household monthly payment is for the stated reason cheaper in Khartoum than in Pegram but in both localities the amount monthly paid in case of application of decentralized systems is reasonable and affordable to householders, standing at >$ 1.0/ m^3. The cost of the centralized system as expected is much higher. The cost of an onsite septic tank unit in Khartoum is higher in relatively impervious soils due to frequent well emptying.

Table 4: Comparison of Costs of Wastewater Disposal Systems, namely: Onsite, Cluster and Central Systems

Type of System	Total capital cost	Annual O&M operation and maintenance	Total annual cost (annualized capital plus O&M	Average monthly cost per household
Centralized System*	$2,585,600 $4,176,590	$33,110 $44,830	$241,480 $381,410	$149--$235 or $44,78-$70.51 perperson
Small Cluster System*	$666,040	$8,120	$61,800	$38 or $11.4 per person
Onsite System*	$567,940	$14,920	$60,690	$37 or $11.1 per person
Small Cluster System (Ali Abdelfattah Student Hostels-400 m^3/day))**	$ 380000	$ 51360	$ 124886	$ 3.1 per person or $0.86/$m^3$
Small Cluster System (Ribat University -600 m^3/day)**	$ 619000	$ 63600	$ 183370	$ 3.1 per person or $0.84/$m^3$
Small Cluster System (Islamic University - 600 m^3/day)**	$ 833000	$ 72000	$ 233177	$ 3.9 per person or $1.06/$m^3$

*Source: NSFC[13] The small community served consists of 450 people living in 135 home (3.33 members/home)

**Source: Plants constructed and operated by Author

Note: the design period considered in calculating the costs facility is 20 years and the cost of finance is 7% annually.

The effluents of the decentralized treatment units are often recycled rather than discharged into surface waters and this also suits the attitude of the Khartoum regulatory authorities who do not prefer treated wastewater effluents discharged directly into the Nile Rivers. Moreover, unlike the centralized system which requires a single-phased implementation resulting in high costs barely affordable by the city residents, decentralized systems can be implemented over different phases of implementation. Add to this the operational deficiency of the centralized system as it cannot become fully operational unless the entire components such as the main central treatment plant, the trunk sewer lines and the necessary pumping stations required for pumping of sewage to the processing site are installed, plus the need for huge initial funding for the phases of implementation in addition to the extended period of implementation.

However, what is important of all is attraction of finance; it is easier to avail the necessary finance resource for decentralized systems rather than for centralized systems because it is basically a small-scale enterprise and it could be implemented and operated with a limited period of time. And by so doing, the authorities will be able to proceed with their development plan and their priorities by using this model of phased implementation and of course with due consideration to the topographical and demographical characteristics of the city.

VII. Level of Wastewater Treatment Required for Wastewater Reclamation

No doubt advanced technology has taken a new seat and is playing the major role in people's lives considering that creative designs in wastewater have developed treatment packaging units that suit every purpose. Greywater recycling is now widely used for reclaimed water for domestic use and home irrigation. But when a decision is taken to recycle wastewater for municipal/industrial or agricultural use the characteristics of treated wastewater subjected to only secondary treatment may not comply with the strict regulations for reclaimed water adopted by the reputable regulatory authorities. This is because although primary and secondary treatment units remove the majority of BOD and Suspended Solids found in wastewaters, in an increasing number of cases this level of treatment has proved to be insufficient to protect low capacity receiving surface waters and of course it will not provide reusable water of the required higher quality. An average secondary effluent may have a BOD of 20 mg/L and a COD of 60 to 100 mg/L. In addition, effluents from secondary treatment plants contain both nitrogen (N) and phosphorous (P), ingredients in all fertilizers. When excess amounts of N and P are discharged, plant growth in the receiving waters may be accelerated. Algae growth may be stimulated causing blooms which are toxic to fish life as well as aesthetically unpleasing.

Thus, tertiary treatment units have to be added to wastewater treatment plants to improve the quality of wastewater effluent following the conventional secondary treatment. The author installed two advanced wastewater treatment plants post the secondary processes in student hostels in Khartoum city, one plant applies a pressure filter and the other uses MBR process, The described advanced treatment units operational in Khartoum are now producing quality of wastewater effluents satisfying the standards shown on table 3 for recycled wastewater to be used for irrigation purposes especially the effluents produced by MBR technology.

Table 5: Effluent Characteristics of Treated Domestic Wastewater

Test Results	Average BOD mg/l	Minimum BOD mg/l	Maximum BOD mg/l	Average SS mg/l	Minimum SS mg/l	Maximum SS mg/l
Ali Abdelfatah** 400 m^3/day,	11.0	3.6	41	12	8.0	30
Islamic University** 600 m^3/day	3.0	1.2	30	Nil	Nil	20

**Source: Plants designed, constructed and operated by Author

It is to be noted that advanced wastewater treatment plants are relatively expensive to install and run and their effluent quality is sensitive to the efficiency of operation. The cost of effluent produced involves the extra treatment needed to reach the reuse quality requirements and extra conveyance of the effluent to the sites where it is to be reused. On the other hand the benefit of reuse includes the value of fresh water saved but the most obvious benefits would be harvested by arid areas where scarcity of water is the main problem faced.

Many examples of the potential benefits of wastewater reuse in different countries have been presented by Hidalgo and Irusta[5] who provided a detailed study on main wastewater reuse in the Mediterranean region. They paid special attention to the cost associated to the total process of reclamation and reuse and calculated the cost of reclaimed wastewater per cubic metre as shown on Table 6 below together with the costs of reused wastewater in Khartoum. The table reveals that the cost per cubic metre for cluster system in Khartoum is around 1 USD while in Morocco it is nearly twice expensive and would definitely be more for Spain and Cyprus when the cost of wastewater collection and conveyance network is added to cost of water treatment.

The cost of reclaimed water estimated at 1 USD exceeds that of fresh water in Khartoum because sources of fresh water are plentiful. This is not the case in many regions of the world, where fresh water supplies are limited and what matter are sustainability and water conservation, in such circumstances the cost of reclamation would be economically feasible. Using reclaimed water for non-potable uses saves potable water for drinking. However, recycling wastewater in Khartoum, though terribly expensive, but will pave the way for decentralization of the sewerage networks and will satisfy the government higher executives who are not in favour of treated effluents' disposal into surface waters.

Table 6: Cost per cubic metre of Reclaimed Wastewater

Sewerage Facility	Total Construction Cost in $	Operation Cost in $/month	Total Annual Cost in $	Cost/m^3 in $
Ali Abdelfatah**400 m^3/day, operated in 2006	380000	$ 4280	124886	$ o.86 ,cost of plant + collection but negligible cost for reclamation
Ribat University**600 m^3/day , operated in 2008	619000	$ 5300	$ 183370	$ 0.84,cost of plant + collection but negligible cost for reclamation
Islamic University**600 m^3/day, operated in 2010, operated in 2006	833000	$ 6000	$ 233177	$ 1.06,cost of plant + collection but negligible cost for reclamation
Almería, South of Spain* 3200 m^3/day				0.65 €/m^3 or $ 0.85 Cost of plant + reuse network
Ville de Drargua, Morocco* 600 m^3/day 0perated in May 2001	2 million $	2,000 $ per month	387000 $	1.77 $
Larnaca, Cyprus* 8500 m^3/d. Operated in the year 2000	50 million €,			0.5 €/m^3 Or $ 0.66 Cost of plant + reuse network

*Source: D. Hidalgo and R. Irusta[5]

** Plants Designed, constructed and operated by Author

Note: the design period considered in calculating the costs of facility is 20 years and the cost of finance is 7% annually.

VIII. A Proposed Revitalization Programme

1. Public Awareness

To reform Khartoum wastewater system radical and drastic changes in people's attitude towards safe wastewater disposal is needed. Accordingly, the stakeholders ought to be publicly addressed to enlighten them and enrich their culture while the doctrinaire base on which the authorities stand should be shaken to engrave the new perceptions.

2. Institutional Reforms

Service Provision

A change in the concept of service provision should pave the way for a shift from serving the rich minority who enjoys waterborne collection services to serving the majority who lacks such services to achieve justice among all urban society layers. All wastewater projects under construction entertain the elite and the affluent of society. It is high time justice is seen to be done.

Framework

Strengthening Khartoum State Sanitary Corporation is a must. This is through professional development with all its technical and human resource requirements and through continuous capacity-building. The Corporation administration should be able to pursue an integrated approach focusing on implementation of supportive legislations and polices.

Regulations

Authorities ought to repeal the prevailing regulations and issue new ones that allow controlled discharge of treated wastewater into the River Nile and allow controlled reuse of final effluents in selected water-using activities.

Technology

- Measures to eliminate the practice of indiscriminate disposal of human wastes or soils must be considered as first priority. Properly designed communal latrines may be built and people must be encouraged to use them and maintain them properly.
- Introduction of affordable household wastewater disposal system should be sought to serve the majority of families which uses environmentally unsafe system.
- New methods for safe septic tank effluent discharge need to be developed. The current practice of disposing septic tank effluents is unacceptable sine it is environmentally unsafe
- Great attention should be given to development of compatible treatment technologies that optimizes in Khartoum capability, manpower and available materials.

Change of Conception

- The way forward is to revise all networks for the purpose of adopting gravity discharge systems, applying the technology that is making great strides day by day in similar local conditions and setting the priorities of developmental projects based on economic viability and public health requirements.
- Khartoum State Sanitary Corporation has to work actively to implement decentralized systems. The feasible approach is to build a treatment plant at the terminal of each of the gravity drainage zone.

3. Formulation of a Master Plan for Installation of New Sewerage Networks

- The reformation of the system starts with correction of the past errors and starting from square one by preparing contour maps for Khartoum Metropolis in order to identify zones of natural drainage to assist in preparing a master plan for the external networks comprising the plan layouts for the proposed decentralized networks and the location of each of the treatment plants serving the corresponding network

4. Restructuring the Existing Networks

Rehabilitation of the existing sewerage network is a must including upgrading of the treatment facilities and the networks of old Khartoum should be restructured for bad designs and lack of resilience to accommodate any new developments, it is practically impossible to construct high rise buildings in old areas. Restructuring the old existing Khartoum network means, abandoning the series of pumping arrangements by redirecting the flow and adopting network decentralization and recycling of treated effluents as much as possible. Most importantly is installation of a tertiary wastewater treatment unit at each pumping station location or wherever appropriate and recycling the effluent wherever possible. This eases the expansion of the local network and facilitates replacement of deficient and depreciated sewer pipelines with new ones. By so doing the series of pumping arrangement can gradually be put out of function. Drawing 3 provides the considered restructuring proposals that can easily be executed. The idea is to install a tertiary treatment plant at each of the lifting/pumping stations because each is sited at the end terminal of a drainage zone and fortunately nearly all of them are close to large open spaces or green parks where treated effluents be can reused for irrigation or let to flow through the nearest water course

System Development

- In areas where sewer lines are not expected to be installed in the near future the way out is to build onsite or cluster treatment plants and to use the treated wastewater to irrigate the open spaces left inside the residential neighbourhoods while discharging the surplus water into the local drain lines.
- Huge and high storey building compounds should be tempted to reuse part of their treated wastewater within their premises with State assistance.

Drawing 3: Khartoum Existing Networks' Restructuring

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