Sewage Sludge Management in Egypt: Current Status and Perspectives towards a Sustainable Agricultural Use

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***Abstract*—**The present disposal routes of sewage sludge represent a critical environmental issue in Egypt. Recently, there has been an increasing concern about sewage sludge management due to the environmental risks, which resulted from the fast expansion of wastewater treatment plants without equal attention in dealing with the produced sludge. This paper discusses the current situation of sewage sludge management in Egypt presenting a brief overview of the existing wastewater treatment plants, sludge production and characteristics as well as options of beneficial use and potential demand of sewage sludge under Egyptian conditions. The characteristics of sewage sludge are discussed considering the results of own sampling and analysis as well as previous studies. Furthermore, alternative treatment scenarios for sewage sludge, which have been recently developed in Egypt, are discussed and perspectives for a sustainable agricultural use are outlined.

***Keywords*—**Beneficial use, Egypt, Monetary value, Stabilization processes, Sewage sludge, Sludge management.

I. Introduction

SEWAGE sludge is composed of constituents collected or produced at different stages of the wastewater treatment process. It contains compounds of agricultural value (including organic matter, nitrogen, phosphorus and potassium) and a lesser amount of calcium, sulphur and magnesium. Moreover, it may also contain pollutants such as heavy metals, organic pollutants and pathogens. The handling of sewage sludge is one of the most significant challenges in wastewater management. In many countries, sewage sludge is a serious problem due to its high treatment costs and the risks to environment and human health. Although, the volume of the produced sewage sludge represents only 1 % to 2% of the treated wastewater volume, its management costs are usually ranging from 20% to 60% of the total operating costs of the wastewater treatment plant [1].

Due to the currently low capacities of wastewater treatment prevailing in many developing countries, a future increase in the number and capacities of wastewater treatment plants can be expected. As a consequence, the amount of produced sewage sludge is also expected to increase. The produced sludge from developing countries usually differs from which generated in developed ones due to divergent industrialization and public health levels. In developing countries, the metal and toxic content is usually much lower, while pathogens content is much higher [2]. These aspects show that, sewage sludge management is an increasing matter of concern in many countries due to the fast increases in sludge production, which increases the resulting environmental threats accordingly.

Sewage sludge is produced under different technical, economical and social contexts. Thus requiring different treatment approaches, which should be flexible enough to be applied under different circumstances, taking the different regulations as well as geographical, economical, social and cultural constrains into account [3]. It clearly appears, the development of optimal sludge management procedures requires adapted management routes capable of maximizing the recovery benefits. It also requires developing operational systems appropriate to local conditions. Moreover, it needs to develop realistic and enforceable regulations adapted to local situations and assuring long-term services and sustainable treatment processes [4].

Since a long period, Egypt has been concentrating its efforts on sanitation services mainly on wastewater treatment, while little priority has been given to sludge management in practice. The primary focus of investment has been addressed to water supply, sewerage networks and wastewater treatment. Until 2004, the percentage of population served by wastewater facilities was very low. More than 80 % of the rural areas and about 40 % of the urban areas are showing deficits in adequate sanitation facilities [5]. Currently, a quite small attention is given to sludge management, which is reflected in the local legislations that often simply depend on regulations of industrialized or more advanced countries without any attempt to adapt it to local situations.

II. Brief Overview of Wastewater Treatment Plants in Egypt

The Egyptian population has tripled during the last 50 years and still grows each year by approximately 1.5 million people. The total population increased from 22 millions in 1950 to 80

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millions in 2008, and is likely to increase to above 96 millions by 2026 [6]. With the rapidly growing population and industrial development, wastewater generation has been increased and is also expected to increase significantly in the future. The Egyptian sanitation sector is facing many difficulties to manage this wastewater mainly due to financial problems, which require huge investments far above the presently available national resources. The Government of Egypt has invested more than 24 billion US$ in development of water and wastewater services over the last 20 years and plans to invest about 20 billion US$ in the next 10 years [7].

More than 56 % of Egypt‘s population (45 million in 2007) live in rural areas, in 4600 villages, mainly concentrated in the Nile Valley and Delta [8]. Only less than 10 % of them have access to wastewater collection and treatment facilities, the wastewater from households in these rural areas are mainly primary treated in septic tanks [9]. On the other hand, 44 % of Egypt‘s population (35 million in 2007) live in urban areas, in 217 cities. Until 2004, only 57% of them had access to wastewater collection and treatment facilities.

During a site visit and field study of Egypt’s wastewater treatment plants (WWTPs) in 2008, a data survey from many sources such as the Holding Company for Water and Wastewater (HCWW), the National Organization for Potable Water & Sanitary Drainage (NOPWSD) and the WWTPs in Cairo and Alexandria was conducted. The total number of WWTPs in Egypt is 303 treating 11.85×10^6 m^3/day of wastewater. Table I shows the number and capacities of WWTPs in Egypt and the estimated amount of sewage sludge generated in 2008.

TABLE I
SCALES OF WWTPS AND AMOUNT OF SLUDGE GENERATION IN EGYPT (YEAR 2008)

Range of WWTP capacities (10^3 m^3/day)	Number of WWTPs	Total treated wastewater capacity (10^3 m^3/day)	Amount of sewage sludge generation (ton DS /day)
>8	79	198	64
8 - 15	90	917	453
15 - 30	70	1425	683
30 - 100	44	2121	1010
100 - 500	15	2895	1445
500 - 1000	4	2600	1300
<1000	1	1700	845
Total	**303**	**11,856**	**5,800**

The wastewater treatment plant scale is directly proportional to the city scale. Generally more than 78 % of the WWTPs are relatively small ($<30 \times 10^3$ m^3/day) representing 21.5 % of the total wastewater treatment capacity. In this range there are 82 WWTPs with a treatment capacity of 10×10^3 m^3/day and 57 WWTPs of 20×10^3 m^3/day. The conventional activated sludge and oxidation ditch systems are representing about 63 % of the total treatment capacity, while the oxidation pond system is representing 11.5 % of the plant’s number and 2.24 % of the total wastewater treatment capacity.

III. SEWAGE SLUDGE TREATMENT AND DISPOSAL SCENARIOS

For many years, the methods and technologies for sewage sludge treatment, which are implemented in Egypt, were very limited. The main attention was devoted to the process of sludge drying, mainly through natural drying beds without any interest of the characteristics or quality of the produced sludge. Recently, there is an interest in expanding the use of new techniques and methods for sewage sludge treatment.

A. The Usually Applied Scenario for Sludge Treatment and Disposal in Egypt

The most common scenario for sewage sludge treatment and disposal that is applied in most of the existing WWTPs in Egypt is presented in Fig. 1 where, the primary and secondary sewage sludge produced from the WWTPs is pumped to thickening facilities, mainly gravity thickeners. Hence, the solids are concentrated to 4-6% DS, the thickened sludge is pumped to natural dewatering units (drying bed facilities) where it is drying to concentrations of 40-60 % DS. The dewatering time is usually 25 days in summer and 40 days in winter. After that, the sludge is stored for a period of 1.5 to 6 months according to the weather and available stacking area conditions before utilization. The dried sludge is mainly used for land application or it is rarely dumped into landfills.

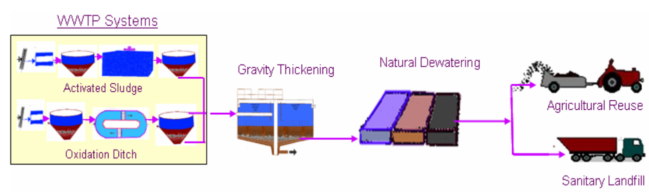

Fig. 1 The most common sewage sludge treatment scenario applied in Egypt

It is noted that, this scenario of sewage sludge treatment (Fig. 1) does not contain facilities for sludge stabilization processes. Moreover, the quality of the produced sludge in most of the WWTPs doesn’t fit with the Egyptian or international standards, especially pathogens limits. Therefore, additional alternative methods or scenarios have to be developed to meet the standards.

B. Recently Applied Scenarios

Recently, there are some new scenarios for sewage sludge treatment, which have been developed in some of WWTPs in Egypt, especially in Cairo and Alexandria governorates. The largest centralized wastewater treatment plants in Egypt are in this region and are producing more than 50% of the total dry sewage sludge produced in all Egypt’s WWTPs. Therefore, the amendment of sludge treatment processes at these plants is an urgent demand. These scenarios are mainly included stabilization processes during the sewage sludge treatment and are summarized as follow:

1. Stabilization Process by Using Anaerobic Digestion

This scenario has been applied in Al Gabel Asfer WWTP, which is the biggest wastewater treatment plant in Egypt. The current sewage treatment capacity is $1800x10^3$ m^3/day and will be increased to $3000x10^3$ m^3/day in 2020. The application of the anaerobic digestion technology for sludge stabilization and power generation in Al Gabel Asfer WWTP has achieved good results and many experiences in operation and maintenance have been gained. Thus, there is an interest in using such technology on large scale in Egypt, especially in big wastewater treatment plants in major cities. Fig. 2 shows the flow diagram of sewage sludge treatment and disposal scenario using the anaerobic digestion processes in Al Gabel Asfer WWTP.

In this scenario, the mixed sewage sludge (primary and secondary sludge) is pumped to thickening facilities (16 gravity thickeners with a volume of 3,200 m^3 and 3 thickeners with a volume of 2,500 m^3 each). After the gravity thickening, the thickened sludge (12500 m^3/day, conc. 4 % DS) is pumped to primary digesters (20 anaerobic digesters with a volume of 11,000 m^3 and 8 digesters with a volume of 9,750 m^3 each) for a retention time of 20 days. Then, the sludge is transferred to secondary digesters (10 digesters with a volume of 7,550 m^3 and 2 digesters with a volume of 8,752 m^3 each) with a retention time of 7 days, where the decanting of liquors can be accomplished. After that, the digested sludge is pumped to mechanical dewatering facilities (30 belt filter press units with a capacity of 23 m^3/hr and 12 units with a capacity of 21 m^3/hr each) for dewatering. The total solids concentration in the dewatered sludge cake ranges between 23-30 %. Trucks transfer this cake (450 tons/day) for drying in a stacking area to a concentration of 40-60 % DS before its use in agriculture. The large portion of the produced biogas is currently used for the operation of hot water boilers, which are operated to heat the raw sewage sludge in the primary digesters. Dual fuel generators use the excess digested gas to generate electricity representing about (37-68%) of the power consumed by the WWTP.

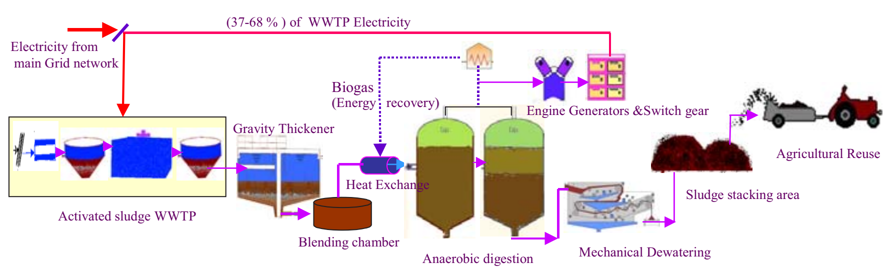

Fig. 2 Flow diagram of the sludge treatment scenario by using anaerobic digestion technology

2. Stabilization Process by Using Windrow Composting

The windrow composting of dried sewage sludge is another recently applied scenario for sludge treatment in Egypt, as already applied in the Al Berka WWTP in Cairo and the (9N) site in Alexandria. Fig. 3 shows the general flow diagram of the sludge treatment and disposal scenario using windrow composting in Al Berka WWTP and (9N) site.

The composting begins with collection of suitable organic materials that are mixed to achieve the desired C:N ratio, moisture content and pore space. Usually, sewage sludge is the primary material and one or more amendments are added to it such as rice straw as applied in Al Berka WWTP or old compost as applied in (9N) site. According to the Egyptian conditions (dry and warm weather mostly of the year) good bacteriological results were achieved in the produced compost as evaluated by several laboratory analyses [10].

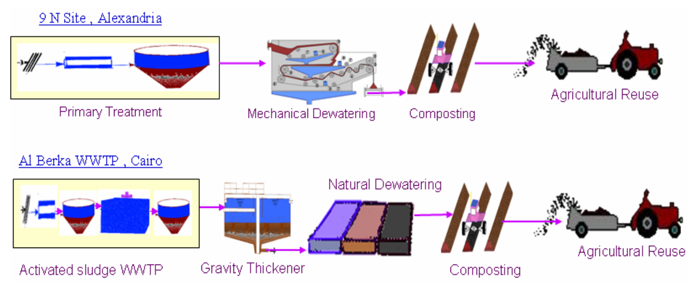

Fig. 3 Flow diagrams of the sludge treatment scenario by using windrow composting

a. AL Berka WWTP Compost Pilot Project

The pilot project in Al Berka WWTP is an experimental compost project that was initiated in 2007 to treat 140 m^3/day of dry sewage sludge produced from the drying beds in Al Berka WWTP using the windrow composting processes.

In this pilot project, a mixture of dried sludge produced at Al Berka WWTP drying beds and rice straw are composted in long parallel rows (stacking) or windrows. A total of 12 tested windrows have been formed. The ratio of dry sludge, old compost and rice straw are varied widely to select the best combination of ingredients (feed stocks). The composting time was about 3 months. The laboratory analyses of the tested windrows are attached. Some pathogens remained in certain windrows, while most of the pathogens could be removed. For the full-scale project, it is planed to construct larger windrows and the residence time will shorten to be 4-8 weeks followed by 30-60 days curing period. The most probable compost ratio by using a volumetric ratio was 4 parts sludge (25% DS): 1 part finished old compost (60% DS): 1 part shredded rice straw (85% DS). This ratio has given good results in the tested windrows.

The experimental composting project in Al Berka WWTP (2600 m^2) is now fully adequate to serve as a commercial project. The equipments and staff are adequate to sustain the production of about 70 tons of compost per day, which represents about 66% of the produced sludge from the drying beds in Al Berka WWTP.

According to the Egyptian Government future plan, after the evaluation of the final results of each experimental and commercial pilot project, Al Berka composting pilot project may be expanded to a full-scale project to produce a compost of 720 tons per day from the dried sewage sludge accumulated from Al Berka, Shobera and Al Gabel Asfer WWTPs [10].

b. (9N) Site Sludge Treatment Scenario

The main WWTPs in Alexandria governorate are the East WWTP with a present sewage capacity of 490x10^3 m^3/day and the West WWTP with a capacity of 360x10^3 m^3/day. Both of them are still using only primary sewage treatment processes. The primary sludge produced at the Alexandria East and West WWTPs (3000 m^3/day, conc. of 3.8-5.25% DS) are mechanically dewatered by belt filter presses as applied in Al Gabel Asfer WWTP. Polymers (2-4 kg/ton DS) are used to produce a dry sludge cake of 580 tons/day with a solid concentration of 25-30 %. Trucks transfer this cake over a distance of 45 km to the central site for sludge treatment at (9N) site to complete the sludge treatment processes by using windrow composting facilities.

The (9N) site is a central sludge treatment place for all sludge produced from Alexandria's WWTPs. The site has been operating since 1997 with composting windrow processes. The site area is 1.51 km^2 and is located in the southwest of Alexandria city. The windrows are formed in two composting areas (each of 0.29 km^2), where the dry sludge is mixed with a bulking agent (old compost) with a ratio of 1.5:1 in long parallel rows (250 m length each). The width of a typical windrow is 2 to 4.5 m at the base and the height is 1 to 2 m. The composting period is about 1-2 months and the windrows are turned every 7 days by a special mechanical turning machine. The temperature in the central portion of the windrow reaches 55 to 70°C. Currently 112x10^3 tons of compost are produced each year [11].

3. Stabilization Process by Using Sludge Storage Lagoon

The third developed scenario for sewage sludge treatment in Egypt was applied in Abu Rawash area for treating the sewage sludge generated from Zenin and Abu Rawash WWTPs. Fig. 4 shows the flow diagram of sludge treatment and disposal scenario using a sludge storage lagoon. The storage lagoons hold the sewage sludge under anaerobic or aerobic conditions over a long period, typically 1 to 4 years. During storage, the sewage sludge is pretty decomposed and pathogens are destroyed [12].

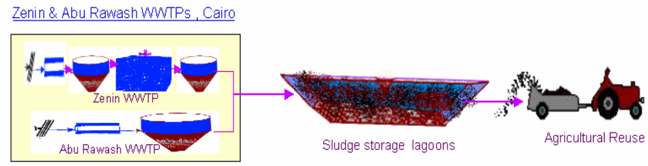

Fig. 4 Flow diagram for sludge treatment scenario using storage lagoons

In this scenario, the mixed sludge produced from the conventional activated sludge system in Zenin WWTP (20x10^3 m^3/day, conc. 0.5% DS) is pumped into a main sludge pump station in Abu Rawash WWTP. Then it is mixed with the primary sludge produced from the primary treatment facilities in Abu Rawash WWTP (1560 m^3/day, conc. 4.7 % DS). After that, the mixed sewage sludge is pumped through a force main pipe of 800 mm diameter over a distance of 33.3 km to the natural sludge storage lagoons (20 lagoons), which are situated at a desert area of 2.32 km^2 in Abu Rawash area.

IV. Sludge Production and Characteristics

Currently, except Cairo's WWTPs, there is very limited information about the actual sewage sludge production and characteristics for all Egypt's WWTPs.

A. Sludge Production and Quantities

TABLE II
Estimated Dry Sludge Produced from all WWTPs in Egypt, 2008

Type of WWTPs	No of WWTPs	Sludge production rate (kg/m^3)	Capacity of treated wastewater 10^3 m^3/day	Estimated dry sewage sludge (50 % DS) Amount tons/day	Volume m^3/day
Activated Sludge	97	0.225	6,703	1,508	2,793
Oxidation Ditch	47	0.225	833	187	347
Trickling Filter	9	0.22	291	64	119
Extended Aeration	17	0.1	170	17	31
Oxidation Ponds	35	0.05	266	13	25
Aerated Lagoon	4	0.1	197	20	36
Primary Treatment	22	0.15	2,021	303	561
Others*	72	0.2	1,372	274	508
Total	**303**		**11,853**	**2,387**	**4,421**

Assume: the dry solid content is 50 % and the average density of dry sludge 1.08 ton/ m^3.
Others*: types of WWTPs where the data about their system of treatment is missing.

Currently, Egypt has 303 wastewater treatment plants that handle 11.85x10^6 m^3/day of sewage. The corresponding dry sewage sludge production was estimated to 5.8x10^3 tons/day (according to the NOPWSD and HCWW data) with a sludge production rate of 0.48 kg/m^3 of treated wastewater. Which seems relatively high compared to other typical values reported in some references [13]-[15]. In the current study, the results of some previous studies for sludge management in

Cairo are analyzed to evaluate and estimate a reliable amount of the produced sewage sludge from all Egypt's WWTPs [10], [11], [20]. Furthermore, the sewage sludge production rate has been also theoretical calculated according to the German standard and Metcalf & Eddy (2003) based on BOD and TSS concentrations [16]-[18]. Based on the results of previous calculations, the dry sludge production rate of the activated sludge treatment plant systems in Egypt is considered at 0.225 kg/m^3 of treated wastewater and the production rates of the others WWTP types are assumed at 0.05-0.22 kg/m^3 according to the literatures [18]. Table II Indicates the estimated amount of dry sewage sludge produced at all Egyptian WWTPs in 2008.

B. Sludge Quality and Characteristics

Currently, there are only a few wastewater treatment plants in Egypt that have information about their sludge characteristics. During the field study, dry sewage sludge samples were collected from the WWTPs in Cairo and Alexandria and were analyzed according to standard methods. The characterization of sewage sludge was focused on the following parameters:

1. Heavy Metals

TABLE III
CONCENTRATION OF HEAVY METALS (MG/KG) IN DRIED SEWAGE SLUDGE IN EGYPT

WWTP	Ref.	Zn	Cu	Pb	Cd	Cr	As	Hg	Ni
u Rawash	Field study	1,810	321	218					
	Others*	113-4,639	83-515	38-509	4,6-50	779	4-25	0,5-15	25-212
l Berka	Field study	1370	497	15,800					
	Others	112-6,298	257-2,640	26-1,119	2,5-40	333	0,4-30	3,7	5-645
l Gabel Asfer	Field study	1640	639	1,320					
	Others	132-1,176	339-747	51-1,724	0,9-6,21	312-993	0,2-28	0,1-10	43-215
) N) Site Alex.	Field study	804	220	384					
	Others	540-901	234-418	191-310	4-100	89	9	16	57-100
hobera	Others	232-604	63-322	195-1213	4,4	130	0,3	7,7	29
Ielwan	Others	155-8,097	119-988	50-302	15-312	172			23-188
gyptian standards		**2,800**	**1500**	**300**	**39**	**1,200**	**41**	**17**	**420**

Others*: results of sampling analysis of previous studies (METAP, 1999 [20], AFESD, 2007 [10], NOPWASD and HCWW data).

The level of heavy metal contamination is the first parameter that must be assessed to determine the overall quality of sewage sludge and is very important in case of using it for land application. Generally the Egyptian WWTPs don't have high heavy metal contamination in the produced sewage sludge. Although, high heavy metal contamination rates were detected in few isolated cases, those metal contaminations are related to irregular contributions from industrial areas. Table III lists the heavy metal contents in dry sewage sludge collected from Cairo and Alexandria WWTPs.

It is expected that the concentrations of the heavy metals in other WWTPs in Egypt are lower than the concentrations shown in Table III. The investigated WWTPs were in Cairo and Alexandria governorates where industrial activities are more concentrated. Recently, several new industrial zones are created in other cities, so that the concentration of industrial activities in Cairo and Alexandria governorates might be reduced in the future.

2. Nutrients Content

The sewage sludge contains nutrients including organic matter, nitrogen, phosphorus and potassium. These nutrients favour its agricultural use. According to the results of sample analysis and other previous studies, the nutrient contents in the dry sewage sludge in Egypt's WWTPS were as shown in Table IV.

TABLE IV
CONCENTRATION OF NUTRIENT RESOURCES IN THE DRIED SEWAGE SLUDGE IN EGYPT

Reference	Total organic mater (OM) %	Total nitrogen (TKN) %	Total Phosphorus (P) %	Potassium (K) %
Field study, 2008	57	3.16	1.13	0.28
AFESD, 2007	61	3.13	0.65	0.19
IIP, 2002		2.4	0.55	0.3
NOPWASD, 2000	61	4.11	1.6	0,55
METAP, 1999	45	1.7	0,8	0.3
Average	**56**	**2.90**	**0.95**	**0.32**

Sources: (IIP study, 2002[19], METAP, 1999 [20], AFESD, 2007 [10] and NOPWASD data).

3. Pathogenic Micro Organisms

TABLE V
THE PATHOGENIC MICROORGANISMS PRESENCE AND LIMITS IN CAIRO WWTPs

WWTPs	Pathogenic microorganisms	Case of sewage sludge			
		Liquid		Dry	
		Units	Average value	Units	Average value
Abu Rawash	Total coliform	MPNx10^{10}/ 100 mL	38.5		No data
	Fecal coliform	MPNx10^{8}/ 100 mL	23	MPN/gm	5.3x10^{5}
	Salmonella	No/ 100 mL	0		50 % positive
Al Berka	Total coliform	MPNx10^{10}/ 100 mL	28.5		No data
	Fecal coliform	MPNx10^{8}/ 100 mL	5	MPN/gm	1.3x10^{6}
	Salmonella	No/ 100 mL	6		100 % positive
Helwan	Total coliform	MPNx10^{10}/ 100 mL	297.5		No data
	Salmonella	No/ 100 mL	12		100 % positive

Sources: (METAP, 1999 [20] and AFESD, 2007).

The third parameter for determining the sewage sludge quality is the presence or absence of pathogens. Usually, the dried sewage sludge produced at the Egyptian WWTPs contains a high rate of pathogenic concentrations, which represent the most important obstacles for a safe use in agriculture. Table V shows the pathogenic microorganism concentrations in sludge of three WWTPs in Cairo. The pathogenic were qualitative analysis in the dry samples.

V. Beneficial Uses of Sewage Sludge

Historically, most of the sewage sludge was disposed by land filling or applied directly to agricultural land. However there are several factors limiting the potential of expanding the beneficial use of treated sewage sludge. These factors include limited public acceptance, concerns of landowners, certain cost factors and types of crop grown. Furthermore, increasing problems that are related to an increased input of organic contaminants, heavy metals and pathogens into the soil and therefore into the food chain.

A. Options for the Beneficial Use of Sewage Sludge

Alternative beneficial uses of sewage sludge are receiving greater attention because of a decline in available landfill space and also an interest in conserving nutrients and other recoverable materials of sludge. Moreover, changes in public perception and legislation worldwide are likely to make disposal to landfill less popular. Furthermore, marine disposal has been stopped in almost all countries [13]. The future focus is likely to be incineration (and other forms of thermal processing) and agricultural use in many countries.

The beneficial use of sewage sludge in most of the developing countries as a soil conditioner or for land application can be considered as a good option. Especially, the land degradation problems and insufficient food production as well as the financial problems are considered. The land degradation costs between 5 to 10% of the agricultural production and 50 to 60 thousand km^2 per year of arable land are being lost through soil degradation [21]. The sewage sludge contains nutrients and organic matter, which are useful for soil conditioning to improve soil properties and to promote plant growth. Sewage sludge generally has lower nutrient contents than commercial fertilizers. Nevertheless, the use of sewage sludge in agriculture reduces the need for commercial fertilizers. Furthermore, it can reduce the costs of agriculture and the negative impacts of high levels of excess nutrients entering the environment. Moreover, the slow-release and long-term availability of nutrients in sewage sludge can enhance the efficiency compared to mineral fertilizers.

There is a debate on the use of sewage sludge in agriculture, originated mainly in Northern Europe, gaining in intensity from 1995 onwards. This is due to the fact that some concern was expressed about the potential risks for health and the environment when receiving sludge in agriculture. Nevertheless, there is still an increase in agricultural use in many other countries. The use of sewage sludge for land application in USA has changed from 20% in 1972 to 41% in 1998 [13], [22].

Based on the importance of agriculture in Egypt, as well as the degree of soil erosion and necessity of land reclamation, the land application is considered as the best and predominant method of beneficial uses of sewage sludge under the Egyptian conditions.

B. Sewage Sludge Agronomic Value

The agronomic value of sewage sludge depends on its nutrients, trace elements and organic matter content. The sludge contains agronomically valuable amounts of major plant nutrients including nitrogen, phosphorus, potassium as well as other macronutrients such as calcium, magnesium and iron. It is very difficult to place actual monetary values for the trace elements or organic matter that are applied to soil. The organic matter has an important role in maintaining and improving a wide range of soil properties that improve the plant root environment. Plants are better able to withstand drought conditions, extract water and utilize nutrients. Especially in sandy soils, the addition of organic matter increases the water holding capacity, soil aggregation and the cation exchange capacity, which is a very important property for supplying plant nutrients. Moreover, it reduces surface runoff, erosion and soil bulk density [23].

According to the results of sample analysis, which were collected from WWTPs in Cairo and Alexandria during the field study and other previous studies, as shown in Table IV, the average values of nutrients and organic resources in the dried sewage sludge in Egypt were as follows: 56 % organic matter, 2.9 % total nitrogen, 0.9 % phosphorus and 0.32 % potassium.

Theoretically, the monetary values of the resources contained in sewage sludge can be evaluated according to the current price of these relevant resources in the commercial market. To determine the economic values of the resources N, P, and K, the market prices of these elements in the commercial inorganic fertilizers are considered. While the monetary values of the organic matter can be estimated according to the market price of the generated electricity during the anaerobic digestion stabilization [24]. The theoretical electrical generation from 1 kg of dry sewage sludge can be calculated by 0.78 kWh/kg of dry sludge (assuming: the quantity of digested gas obtained during the anaerobic digestion is 1 m^3/kg of volatile solids destroyed and the lower heating value of the digested gas is approximately 6.22 kWh/m^3).

The monetary value of the dry sewage sludge can be calculated according to the current prices of the relevant resources at the Egyptian and international markets, as shown in Table VI. In general, the prices of commercial fertilizers in the Egyptian market are less than those at the international market due to the support of the Government to the fertilizer industry by about 32 % of the industry costs.

TABLE VI
THE MONETARY VALUES USED FOR THE RELEVANT RESOURCES IN DRY SEWAGE SLUDGE

Resourses	Egyptian market price (US$/kg)	USA Market price (US$/kg)
Nitrogen (N)	0.76	1.61
Phosphorus (P)	2.23	4.91
Potassium (K)	0.43	0.94
Organic matter	0.015	0.044

The average retail price of electricity in USA, 2008 was 10.13 Cent/kWh and in Egypt 3.4 Cent/kWh.
The exchange rate used in 2008 was US$ = 5.76 LE (Egyptian pound).

The theoretical calculated monetary value of the dried sewage sludge in Egypt is about 53 US$/ton (28.5 US$/m^3). This value probably indicates the maximum price of the dried sewage sludge that can be paid by farmers, including the transport costs in the Egyptian market.

C. Potential Demand of Sewage Sludge in Agriculture in Egypt

Egypt is an arid country, the dessert represents more than 95% of the total area and only 4% are occupied by overpopulation in a limited strip of the Nile valley and Delta. Due to the rapid increase in population, the cultivated land declined per capita from about 0.23 acre (acre = 4046.9 m^2) in 1960 to about 0.13 acre in 1996 and will be decreased to 0.09 acre by 2017 [25]. The sharp decline of the per capita cultivated land will also reduce the per capita crop production, which will directly affect food security for populations. An important issue in the future is to redistribute the population over a larger area. Therefore, the quest to bring new land under cultivation has been a cornerstone of Egyptian agricultural policy since the 1950s. Over the last 30 years, the Government of Egypt has undertaken a large programme of horizontal expansion of agricultural used land through the reclamation of desert areas. More than 3.29 million acres have been reclaimed and that will be increased in the future [5].

The soil in these reclaimed land are often saline, mild to moderately alkaline (pH 7.7-8.2), contain calcium carbonate in the range from 1-20% and appreciable concentrations of gypsum (hydrated calcium sulphate) [20]. Micronutrient element deficiencies are common, particularly manganese, iron and zinc due to the high pH [21]. Such soils derived under hot arid conditions are unlikely to cultivate and contain very little organic matter. Furthermore, the coarse nature of these soils, dominated by gravel and sand effects a low fertility and a low water holding capacity. There are considerable requirements for most plant nutrients as well as additional organic matters to improve water holding capacity, soil structure and aeration.

Some field pilot studies involved the establishment of a practical system for the safe use of sewage sludge in agriculture in Egypt had been done principally through a series of demonstration field trials and sludge quality sampling programmes. The results of these studies indicated that, the nutrients, trace elements and organic matter present in the sewage sludge have the potential to increase the yield and quality of crop and to improve the soil conditions for crop growth under Egyptian conditions. The crop response to sludge was equal to and often greater than that from an equivalent quantity of farmyard manure or inorganic fertilizers [19].

The climatic and soil conditions in Egypt strongly favour the use of sewage sludge for land application. This may be attributed to the following factors [20].

- Calcareous and clay soils limit crop uptake of heavy metals and potential toxicity
- Reclaimed land is deficient in Zn and Cu as well as other essential elements, which are required for plant growth and are present in sludge
- The extensive sunshine exposure, high temperature, and dry conditions provide aggressive and unfavorable conditions for the survival of microbial pathogens.

However, the quality of produced sewage sludge and conditions of sludge application in Egypt should be more controlled to ensure that the potential hazards to health and the environmental are avoided.

D. Sewage Sludge Market in Egypt

1. Potential Market Demand

The recommended application rate of dry sewage sludge for arable crops in Egypt ranges from 5 - 20 m^3 DS/acre/year depending on crop and soil types and frequency of application. For fruit crops the favour application rate is 8.7 m^3 DS/acre/year [19]. These values are also matching with the recommended application rates in Egyptian standards (Directive 254/2003) that ranged from 8-20 m^3 DS/acre/year according to the types of soil and cultivated plants [27].

There is a controversy debate in Egypt about the suitable land that will be target for the sewage sludge application. The reclaimed desert land can be considered more preferably where the demand for sewage sludge on the reclaimed farms is likely to be high and any inputs of organic matter are valuable for water retention and nutrient supply. Moreover, the farm size and access to farms make the supply of sludge more practicable. Also, farm managers are often graduates or engineers and are able to realize the benefits of sludge and the needs for appropriate control of sludge application. At Delta Nile farms, sludge can be also used as an alternative to farm yard manure. But, this is likely to be constrained by the practicability of supplying and delivering relatively small quantities of sludge to small farms. The majority of farms in the Nile valley and Delta are small, less than 5 acres accounting for 96% of farms [20]. In addition, the access is likely to be difficult for large trucks; moreover, illiteracy is high amongst farmers that may cause hazards associated with the agricultural use of the sludge.

To evaluate the overall potential demand of sewage sludge on the Egyptian market, uniform average application rates have been assumed at 10 m^3/acre/year for field and fruit crops.

The reclaimed desert land was considered as the main target market where the use of sewage sludge is easier, more practical and fewer hazards to the human health than in the Nile valley and Delta areas. Furthermore, in general the estimated equivalencies of sewage sludge were higher than for clay soil. This may be attributed to factors such as a greater nitrogen release and mineralization from sludge in sandy soils than in clay because of their low organic matter status and poor physical conditions.

The theoretical quantity of dry sewage sludge which is required to satisfy the potential demand of the reclaimed desert land will exceed 32 million m^3/year. The current dry sludge production is estimated to be about 0.86 million tons per year (1.59 million m^3/year). This would represent only 4.9 % of the potential cropped land required within the reclaimed desert land only. Furthermore, the cultivated areas in the Nile Valley and Delta represent more than 5 million acres [13]. The theoretical need of these land is more than 50 million m^3/year of sewage sludge. Generally the use of sewage sludge in agriculture has a big and a good market in Egypt, but it must be environmentally and socially acceptable and cost-effective.

2. Sewage Sludge Market Price

In Egyptian market, the sewage sludge is highly valuable and the farmers are willing to pay up to around 6.4 US$/$m^3$ according to the result of some previous studies in 1995 [20]. The suggested sales price of converted sewage sludge is 4-10 US$/$m^3$ according to a study in 2002 [19]. Currently, the amount of dried sewage sludge produced at the drying beds of Al Berka WWTP is directly sold to farmers with a gate price of 8.20 US$/$m^3$. The sale price of the produced compost from the pilot compost project in Cairo ranges from 8 –13 US$/$m^3$ [10]. The Egyptian Holding Company for Water and Wastewater (HCWW) sells the produced dry sewage sludge to main contractors with a gate price ranging from 1.5-10.5 US$/$m^3$, with average prices of 6.1 US$/$m^3$. The contractors sell it after that to the farmers with a profit margin. This price is very suitable and a competitive price compared to other organic fertilizer in the Egyptian market, which are sold at about 17.76 US$/$m^3$ [10].

From the previous survey of the existing sale prices of dry sewage sludge in the Egyptian market and the study of the potential demand, it is noted that, there is still a big competition margin with other organic fertilizers on the market. The target price of sewage sludge in the Egyptian market can be estimated at about 20 US$/ton (10.8 US$/m^3).

VI. Conclusion

The sewage sludge production is continuously increasing in Egypt. Therefore, the main currently pressing needs are to find/develop more efficient and more sustainable technologies to allow a safe and suitable reuse of sewage sludge in agriculture. Furthermore, the legislations should be more adapted to the Egyptian conditions as well as improvement of the institutional capacity to guarantee the enforcement of their application.

For many years, the methods and technologies for sewage sludge treatment have been implemented in Egypt were very limited. The main attention was devoted to processes of drying sewage sludge, mainly through natural drying beds, without any interest in the characteristics or quality of the produced sludge. Recently, the application of the anaerobic digestion technology for sludge stabilization and power generation in Al Gabel Asfer WWTP and the windrow composting processes in (9N) site and Al Berka WWTP have achieved good results regarding to the produced sludge quality and also many experiences in operation and maintenance have been gained. There is a growing interest in using such technologies on large scale in the future.

The use of sewage sludge in agriculture in Egypt may offer the most sustainable and beneficial use of sewage sludge under Egyptian conditions. It may offer the most economical route of sludge disposal because the Egyptian farmers are prepared to pay for any source of organic manure. About 0.66 million tons of the dried sewage sludge have already been sold to farmers in 2007, which represent more than 85 % of the total produced sewage sludge from all WWTPs in Egypt according to HCWW data.

The treated sewage sludge has a good potential demand in the Egyptian market. The target price of municipalities is estimated at 20 US$/ton (10.8 US$/m^3) of dry sludge. This price has still a proper competition margin up to 5 US$/ton less than the present price of other organic fertilizers and also less than the estimated theoretical price (28.5 US$/$m^3$) of the relevant resources in the dry sewage sludge under Egyptian conditions. It must be emphasized that the sewage sludge, which doesn't fit the standards, must be disposed at controlled landfills and it should be prevented to use in agriculture.

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