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Article

Investigating the Change of Ash's Heavy Element Contents in Upper Egypt Electricity Power Company (UEEPC) In According to Egypt Vision 2030

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Abstract

The heavy fueled power plants produce solid waste as fly ash which contains heavy and trace elements. In this study the going in accordance with Egypt Vision 2030, effects and benefits in reducing the ash amount for produced MW will be studied, the change in ash contents of rare and heavy elements that can extracted and reused will be determined. As, the reduction in ash amount on the long run as it has a positive effect on the environment. The amount of ash produced will be defined, then the enrichment of its content of heavy and trace elements will studied. The results showed that fly ash amount reduced with application of Egypt vision 2030, and it has a valuable content that could be collected, treated and utilized. It was found that the pollution's indexes of these elements are extremely high, but on the other side ash has an economical value due to its contents of rare and heavy elements that can extracted and reused. Finally, this reduction in the long run has a positive effect on the environment and consequently, to the health.

Keywords: UEEPC, Heavy Fuel Oil, Ash, enrichment, Vanadium, Nickel, heavy.

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1. Introduction

Continuing to our work on environmental pollution[1], in Upper Egypt Electricity Production Company (UEEPC), in their way for applying the Egypt vision 2030 requirement they added a new 4 production units with a total 2600MW capacity, and as electric power generation emits a high amount of pollutants, as heavy fuel oil is still the largest source of electric energy production in Egypt needs, and its combustion produces; pollutant gases, fly and bottom ashes, and particulate matters (PM). Ashes from fuel oil combustion constitute the major solid wastes from power plants in Egypt, it is produced during normal operation and combustion and became a solid waste burden and contain toxic and hazardous wastes [1]. Fossil fuel combustion results in concentration increase for most trace elements in ash by approximately 10 times the concentration in the original fuel [2]. A power plant with 2300MW power generating capacity fueled with heavy fuel oil generates about 50-60 tons per day [3]. Also it was reported that the baseline discharges from steam electric power plants are estimated to be nearly three times the amount estimated for the pulp, paper, and paperboard industry, the petroleum refining industry and nonferrous metals manufacturing industry [4]. Ashes are classified into two categories; fly ash and bottom ash. Fly ash has been found to contain beside carbonaceous matrix a relatively high heavy metal content, as V, Ni, Cr, Zn, and Fe, in addition to Al, Ca, Mg, Si, and Na [5,6]. A bottom ash of oily fueled combustion power plant also contains, elements as V, Ni, Fe, Cr, Cu, Pb, Zn, Cd, and uranium [2,3,7]. Fly ashes contains heavy and trace elements, as these elements has a commercial value, it also may has hazardous effects.

II Pollution Calculations, Health Effect and Benefits

2.1. Ash's Elements Enrichment;

Enrichment Factor is a powerful factor used for processing, analyzing, and conveying raw environmental information to decision makers, managers, technicians, and the public. The partitioning of the metals is conventionally quantified by an enrichment factor EF, which is the ratio of the concentration of element in an ash from a combustor to its effective concentration in the ash content of the original fuel [8,9]. Fabian et al. studied the enrichment factor of copper and zinc during exploring the recovery of heavy metals from the fine fraction of solid waste incineration from wet-discharged bottom ash fine-fraction samples from full-scale treatment plants in Germany and

Sweden [10]. Latva-Somppi et al. [9,11] found significant enrichment of many metals in the fly ash.

2.1.1 Enrichment factor (EF); Eq. (1), has been used to calculate the degree of enrichment and accumulation of heavy elements in fly ashes relative to its content in heavy fuel oil. Enrichment factor classified as; deficiency to minimal enrichment (EF< 2), moderate enrichment (2≤ EF<5), significant enrichment (5≤ EF< 20),very high enrichment (20 ≤ EF<40) and extremely high enrichment (EF ≥ 40) [12].

$$\mathbf{EF} = (\mathbf{C_A}/\mathbf{C_F})/(\mathbf{C_F}/\mathbf{C_C}) \qquad (1)$$

Where: C_A is content of the examined element in the fly ash (mg/kg), and C_F is content of the element in the heavy fuel oil (mg/kg), Cc is the element in the crude oil.

2.2. Ash Pollution; The combustion of heavy fuel oil in electric power plants, concentrates a high content of; vanadium, calcium, magnesium, sulfur, sodium, zinc, iron, nickel, aluminum and manganese in the form of oxides, and radioactive one as uranium and thorium in the ashes [13]. As an example, average vanadium concentrations were from 117 to 15619 mg/kg in fly ash samples [14]. These elements enter the environment by different pathways, for example as an air pollutants (PM_1, $PM_{2.5}$, PM_5, and PM_{10})), generally PMs with size ≤10µm (PM_{10}), as it is an inhalable part, and effects on the general population [15], i.e has dangerous environmental impacts and produces adverse health effects on the quality of life, so reduction the amount to be discharged to the environment will go in accordance with Egyptian Environmental Legal Regulations and benefits man's welfare [4,13].

2.2.1 Quantification of Ash Pollution; Ash Pollution Index (API) may be used to quantify the degree of pollution of fuel and ash, where FPI and API could be calculated in two ways as given below:

2.2.1.1 Single Pollution Index; An assessment index is generally applied to measure environmental quality of ash is the single element pollution index (SEPI) which was used as evaluation methods and to identify single element contamination resulting in increased such metal toxicity, the Eq.(2) is used to calculate SEPI[16,17].

$$\boldsymbol{SEPI = metal\ content\ in\ fuel\ or\ ash/permissibl}$$

Where, each heavy metal was classified as low contamination (SEPI≤ 1), moderate contamination (1< SEPI ≤ 3) or high contamination (SEPI >3) [18].

2.2.1.2 Combined Pollution Index; As heavy metal contamination in the surface environment is associated with a mixture of contaminants rather than one metal contaminant [19], thus, the concept of a combined pollution index(CPI) was used as evaluation methods of heavy metal accumulation and to identify multi-element contamination resulting in increased over all metal toxicity, CPI is calculated by the average ratio of metal concentrations Eq.(3)[20], and was then classified as low(CPI≤1), middle(1< CPI≤2)or high(CPI>2) [18], the higher the CPI is the more serious heavy metal accumulation.

$$\mathbf{CPI = \sum SEPI\,/no.\,of\,metals} \quad (3)$$

2.2.1.3 Pollution Load; Pollution load Index(PLI) is a measures for quantity and concentration of various harmful metals in ashes. PLI was calculated as a ratio of each heavy metal's concentration in the ash to its concentration in fuel Eq.(4).

$$\mathbf{PLI = (EF_1\ X\ EF_2\ X\ EF_3\ X\ldots\ldots EF_n)^{\frac{1}{n}}} \quad (4)$$

Where n is number of metals, the index value PLI ≤1 shows that no pollution are present, whereas PLI>1 indicates a significant pollution load, and a prompt intervention is required to reduce pollution [21,22, 23].

2.3. HealthEffects; Exposure of humans and animals to particulate matter($PM_{2.5}$and PM_{10}) that carry heavy elements, leads to several diseases related to respiratory syndromes, $PM_{2.5}$ related premature deaths in London, associated with long-term exposure to $PM_{2.5}$ were 3,500 [24,25]. PMs may enhance the susceptibility to viral infection. It also serves as a transport vector for the virus [26]. Where the emitted PMs contain V and Ni; vanadium contamination can increase blood pressure and cause neurological effects in animals, while in humans, V exposure has been linked to the development of some neurological disorders and cardiovascular diseases; while humans exposure to high concentrations of nickel can cause gastrointestinal and kidney damage, also leaching of Ni to aquatic live, Nickel toxicity in fish and aquatic invertebrates varies among species and can damage the lungs, immune system, liver, and kidneys [4].

2.4 Ash Uses; Fly-ash (FA) is the end residue from combustion of HFO in furnaces of thermal power plants in UEEPC, however, in many countries this industrial byproduct has not been properly utilized rather it has been neglected like a waste substance to be land filled [1]. The ash has a carbonaceous matrix and contains V, Ni, Zn, Cr, Cu and Pb with variable amounts, V was the most abundant heavy metal with enrichment factor of 277 in the (FA) [27]. The reuse of fly ash as an engineering material primarily stems from its pozzolanic nature, spherical shape, and relative uniformity. Fly ash recycling includes usage in;

(*) Portland cement and grout, embankments and structural fill, waste stabilization and solidification, raw feed for cement clinkers, mine reclamation, stabilization of soft soils to increase its strength,

(**) road sub-base, road bed and fill material, runways, aggregate, flowable fill and mineral filler in asphaltic concrete, construction sites, 40-70 percentages fly ash mixes in projects, include cellular concrete, roofing tiles, paints, metal castings, and filler in wood and plastic products, and it utilize in construction fields as in KSA (Saudi Arabia)[3,27,28,29]

(***) fly ash of burning of HFO has generally termed heavy fuel of anode grade calcined coke, of which "the majority" will be delivered to Emirates Global Aluminum, it sources up to 40% of its calcined coke requirement within the UAE [3]. Both ashes fly ash and boiler bottom ash are fed to the agriculture, where its minerals in these ashes are from the essential elements that could increase crop growth and thus the yield per acre[30]. Accordingly, the main objective of the current study is to assist from environmental point of view the effect of addition of new power plants in accordance with Egypt vision2030 on the ash's heavy elements' constituents, specially V, Ni and Mg emissions.

2.5. Studied Area;UEEPC zone area extends from south Giza to Qena governorate in south. With the electric power stations concentrate in three locations along the zone; Koraimat thermal power plant (1,2 units) Image(1), South Helwan thermal plant Image(2), and Assiut thermal power plant (1,2&3 units) Image(3) [1].

Koraimat thermal power plant (1,2 unit)2*625MW Image (1)

South Helwan thermal plant 3*650MW Image (2)

Assiut thermal power plant (units I,II (2*300MW) and unit III (1*650)) Image (3)

2.6. Materials And Methods; In this study oil and ash were analyzed in Holding Electricity Company Central Lab., Fuel characterization methods have been used extensively to quantify the presence of various components, including metals, in fuel oil, an Inductively Coupled Plasmas-Mass Spectrometer (Thermo-Elemental X7ICP/MS) was used. It uses high temperature plasma between 6000 K and 8000 K, connected to a high sensitivity mass spectrometer. The plasma is formed in the RF chamber, where the sample can be delivered as a solution, vapor, or even solid. The mass spectrometer is a quadruple mass-spec designed to rapidly measure ions at each mass unit. Detection limits are species dependent, and range from parts-per-trillion (ppt) to parts per billion (ppb), then the results were examined and taped. Where fuel used for electricity production in units that produce ashes consisted of 100% fuel from HFO, for Koraimat I and Walidia I,II, while it about 80% (HFO) of its required fuel for south Helwan and Walidia III. Expected fly ash production based on the station's capacity were calculated.

III Results and Discussions

3.1 Results; The following results are from lab analysis, and UEEPC's Energy reports

(UEEPC, 2022's, reports). Average heavy Fuel Oil (HFO) analysis for ash, sediments and trace elements and its corresponding value in crude oil (as standard value) is as in Table (1).

Table (1) ; HFO Analysis (average/year)

Item	**Year**	**Ash content**	**Mn**	**Cd**	**Ni**	**Pb**	**V**	Zn
		wt%	mg/kg					
Crude Oil Fuel	-	1[14]	0.05 [32]	0.001[27]	18.3[32]	1.57[32]	70[27]	2.55 [32]
Koraimat HFO	2014	0.125	0.063	0.02	42	1.7	133	1.45
	2022	0.09	0.05	-	46	1.3	102	1.0
Assiut HFO	2014	0.14	0.091	0.03	55.2	1.8	120	1.6
	2022	0.13	0.09	-	50	1.0	116	1.3

Average values of ashes content of trace elements (Cd, Mn, Ni, Pb,V, and Zn) are as shown in Table(2).

Table (2); Ashes heavy elements' analysis (average/year)

Item	**Year**	**Unit**	**Mn**	**Cd**	**Ni**	**Pb**	**V**	**Zn**
Koraimat	**2014**	**%**	0.1	0.12	0.9	0.03	7.1	4.2
		mg/kg	1000	1200	9000	300	71000	42000
	2022	**%**	0.21	0.2	0.93	0.04	8.1	5.5
		mg/kg	2100	2000	9300	400	81000	55000
Assiut	**2014**	**%**	0.3	0.3	0.78	0.06	8.6	6.0
		mg/kg	3000	3000	7800	600	86000	60000
	2022	**%**	0.35	0.31	0.85	0.05	9.12	6.1
		mg/kg	3500	3100	8500	500	91200	61000

Koraimat (Koraimat I& South Helwan (I,III,III)) and Walidia (I,II,III), power generation (MW) max. load, HFO consumption rate for power generation (kg/MW) during year 2014 and 2022 are as in Table(3).

Table (3); Maximum Load, and average HFO consumption per MW

Item	**Year**	**Maximum Load** MW	**HFO consumption** kg/MW
Koraimat	**2014**	1250	213
	2022	3200	224
Assiut	**2014**	600	252
	2022	1250	233

3.2 Data analysis: The data of power generation MW, fuel oil and ash's analysis Tables (2,3 and 4), in Koraimat I, South Helwan (I,III,III)) and Walidia (I,II,III), were subjected to analyzing and processing for obtaining power production MW/month (at 85% of maximum load). Total HFO fuel consumption per month (ton/month), amount of ash produced and amount of individual elements content in ash during years 2014 & 2022 are as in Table (4;5) and Figs (1,2and 3).

Table (4) and Figs. (1;2) : MW/ month, Fuel and Ash *(g/MW)*

Item		**Max. L** MW/month	**Av. L** MW/month	**Av. L** MW/day	**HFO** kg/MW	**Av. Fuel** ton/month	**Av. Ash** ton/month	**Av. Ash** ton/day	**Ash** g/MW
Koraimat	**2014**	900000	765000	25500	213	162945	203.68	6.79	266.25
	2022	2304000	1958400	65280	224	438681.6	394.81	13.16	201.6
Assiut	**2014**	432000	367200	12240	252	92534.4	129.55	4.32	352.8
	2022	900000	765000	25500	233	178245	231.72	7.72	302.9

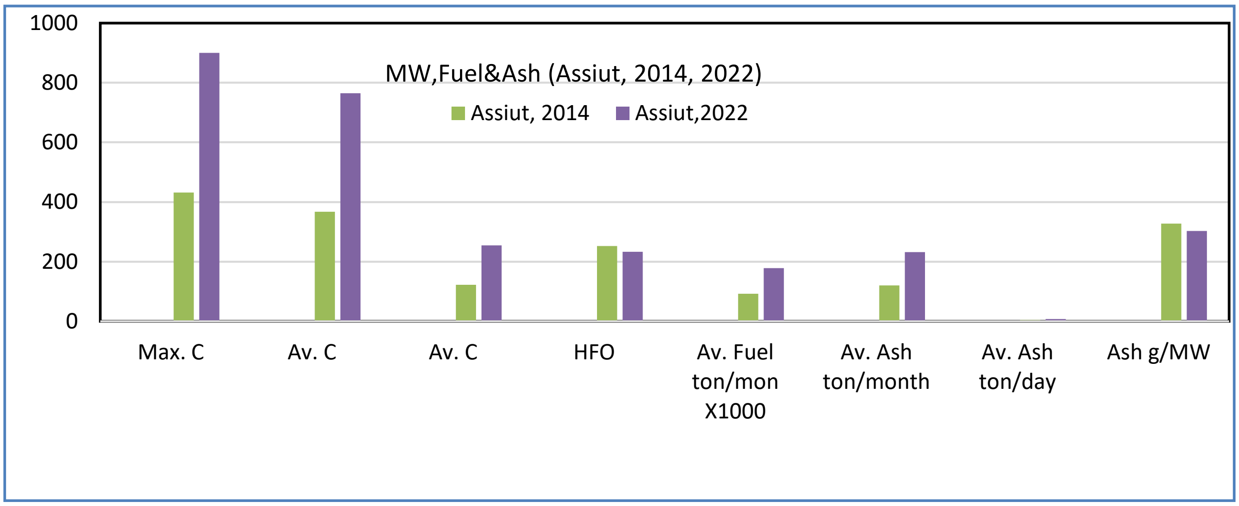

Figure (1); MW/ month, Fuel and Ash *(g/MW)* in Assiut during 2014 and 2022

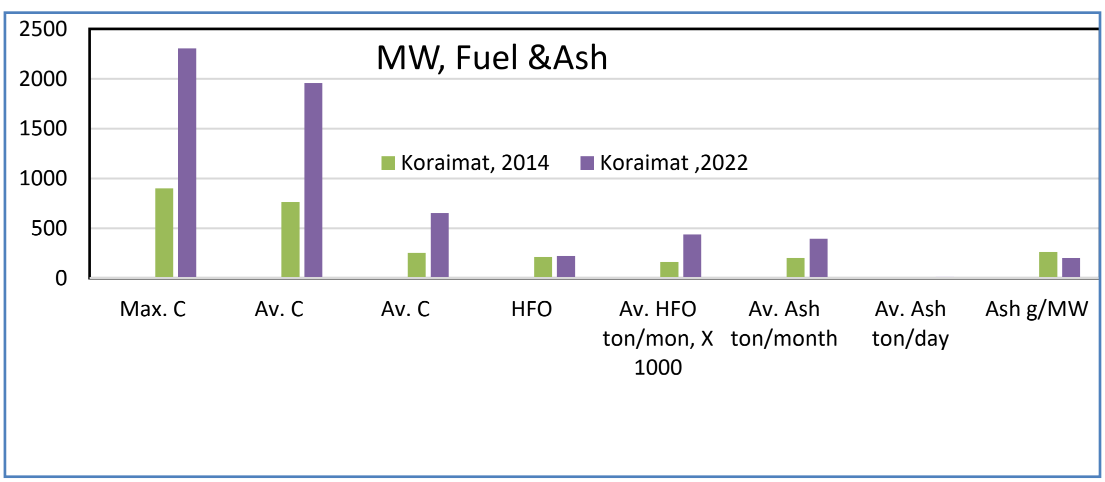

Figure (2); MW/ month, Fuel and Ash *(g/MW)* in Koraimat during 2014 and 2022

The results' data of oil and ash's analysis in Table (4) were subjected to analyzing and processing for obtaining the amount of heavy elements as in Table (5) and Figs. (3).

Table (5) : Heavy elements produced *ton/month*

Item	year	Mn	Cd	Ni	Pb	V	Zn
Koraimat	2014	0.2	0.24	1.83	0.06	14.46	8.55
	2022	0.83	0.79	3.67	0.16	31.98	21.71
Assiut	2014	0.39	0.39	1.01	0.08	11.14	7.77
	2022	0.81	0.72	1.97	0.12	21.13	14.13

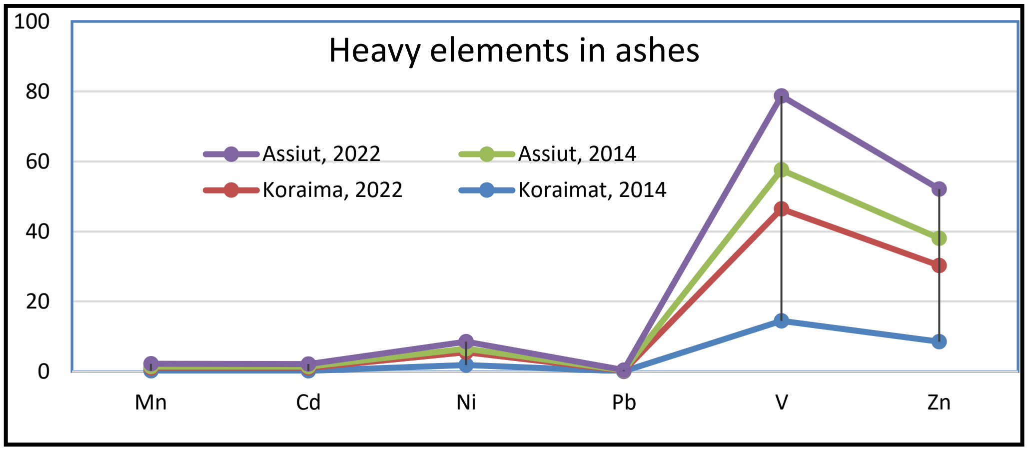

Figure (3); Heavy elements in fuel

Data of oil and ash's analysis in Table (1,2) were subjected to analyzing and processing for obtaining the enrichment factor, single element pollution index, combined pollution index, and pollution load index as in Tables (6;7 and 8) and Figs. (4,5 and 6).

Table (6); EF, CPI, and PLI for fuel in Koraimat

Item	Mn	Cd	Ni	Pb	V	Zn
EF	**1.26**	**20.0**	**2.30**	**1.08**	**1.90**	**0.57**
CPI	**4.52**					
PLI ash	**2.02**					

Table (7) ; EF, CPI, and PLI for fuel in Assiut

Item	Mn	Cd	Ni	Pb	V	Zn
EF	**1.82**	**30.0**	**3.02**	**1.15**	**1.71**	**0.63**
CPI	**6.4**					
PLI ash	**2.42**					

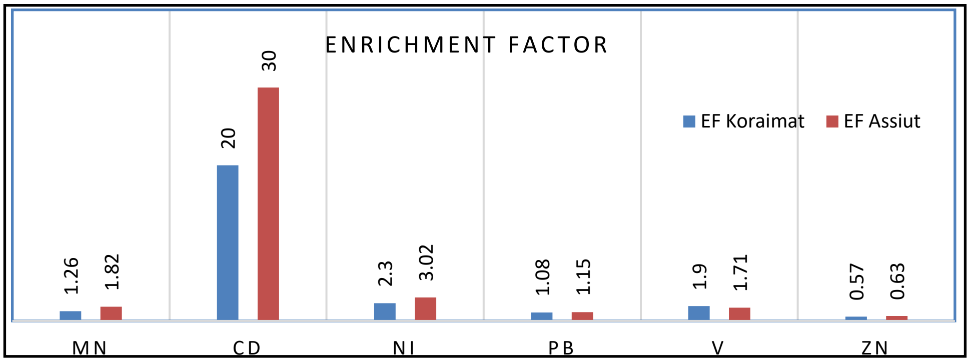

Figure (4); Enrichment Factor of Heavy elements in fuel (Koraimat&Assiut)

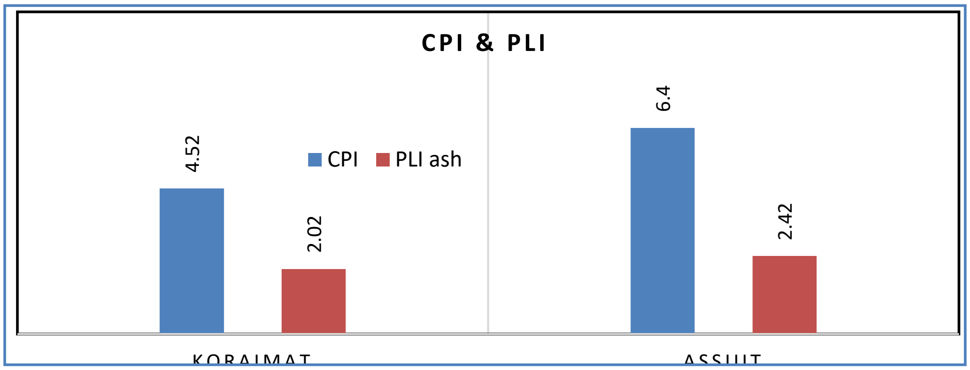

Figure (5); CPI and PLI of Heavy elements in fuel (Koraimat&Assiut)

Table (8); EF, CPI, SEPI, and PLI for ash in Koraimat

Item	Mn	Cd	Ni	Pb	V	Zn
EF	26455	5000	96.5	217.3	320.5	66706
SEPI	33333	100000	221	235.3	609	37931
CPI	28722					
PLI ash	3986					

Table (9); EF, CPI, SEPI, and PLI for ash in Assiut

Item	Mn	Cd	Ni	Pb	V	Zn
EF	21133	3444.4	51.0	242.3	443.3	60762
SEPI	38461	103333	154	278	760	38125
PLI (ash)	4125					
CPI (ash)	30185					

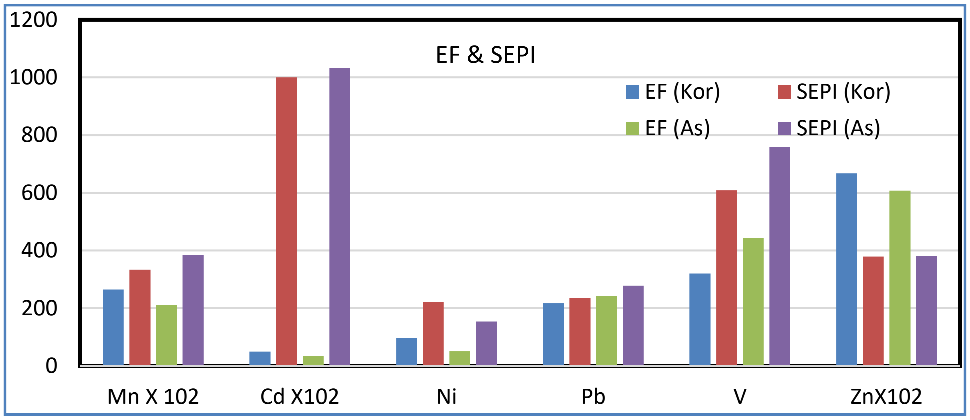

Figure (6); EF, SEPI in ash (Koraimat&Assiut)

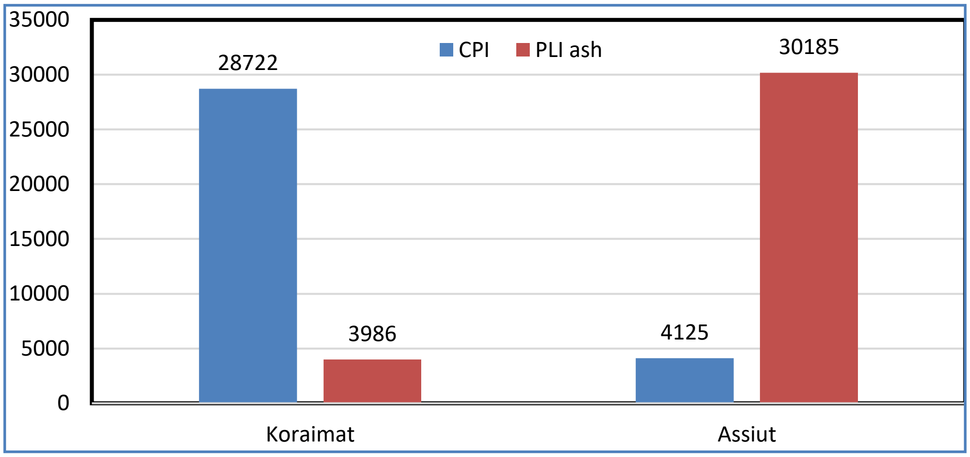

Figure (7); CPI and PLI for ash (Koraimat&Assiut)

3.3 Discussion

Upper Egypt Electricity Production Company (UEEPC) in 2014, had a production capacity 1850 MW that produces ashes, which had doubled in 2022 to about 4450MW. Includes El-Koraimat thermal power plant (1250 MW/h) uses heavy fuel oil and Assiut (600MW/h) a 100% heavy fuel oil (HFO) as the main fuel (UEEPC, 2014 & 2022, reports). In UEEPC they started new energy plan to face the sustainable plans for the nearest future, Egypt Vision 2030, according this vision a 2600 MW was added in the form of four units; Assiut III power plant (650MW), and South Helwan thermal power plant 3X650 MW. Each of them uses the HFO, as the main fuel, which has ash content ranges between 0.09 to 0.13 % Table (1), which contribute to a high ash emission during normal operation specially in the absence of dust eliminators devices. In 2014 the HFO was the most fuel used, with a gram fuel consumed for Kilo watt (KW) reach to 213g, and 252g in Koraimat and Assiut respectively, and the gram ash produced for MW were 266.25g and 352.8g in Koraimat and Assiut respectively, as in Table (4) Fig.(1;2).By 2022 the gram fuel used for

(KW) production were reduced, due to rehabilitation that was performed on both Walidia I and II boilers and addition of 650MW (Unit III) in Assiut, from 252g/KW to 233g/KW as in Table (3). Consequently, it has a positive effect on ash amount which has been reduced from 352.8 g/MW in year 2015, to 302g/MW in year 2022 as in Table (4) Fig.(1), with a reduction ratio 1.6%. While gram fuel used in Koraimat increased from 213 to 224g/KW as in Table (3) due to aging of the units and increase the ratio of HFO to natural gas used, despite of high adds on (1950MW) of new power plants constricted in South Helwan (3 units) that were put in service in year 2022. In contrast of this, ash amount has been reduced from 266.25 g/MW in 2015, to 201.6 g/MW in year 2022, as in Table (4), Fig. (2).which may due to the decrease in the average of ashes content in HFO (from 0.125% in 2014 to 0.09% in 2022) used in 2022.Ashes amounts are in Table (4) these ashes contain valuable elements (heavy and trace elements) as; Mn, Cd, Ni, Pb,V, and Zn in ash, the enrichment factor is used to calculate the degree of enrichment and accumulation of heavy elements in fly ashes relative to its content in heavy fuel oil. For fuel all elements are has minimal enrichment EF < 2, except Cd which has very high enrichment ≥ 20 for both of Koraimat and Assiut as shown in Tables (6;7) and Figs.(4). But for ashes all results are more than 40, meaning that extremely high enrichment of heavy elements in fly ashes as in Tables (8;9) and Fig. (6). Also, their weight was estimated, where the weight/mouth of valuable elements as Vanadium, and Nickel are 3.67, 1.97 and 31.98, 21.13 ton/month, in Koraimat and Assiut respectively and Zn was 21.71 and 14.13 ton/month in Koraimat and Assiut respectively, as in Table (5) and Fig. (3).

As UEEPC zone are highly polluted zone [33], HFO combustion in thermal power plants produces a lot of ashes as shown in Table (4), and there is chronic exposure to PM ≤ 10μm in UEEPC area [1]. As PMs carries the heavy elements, the SEPI, CPI and PLI for ash elements were calculated (in 2022); in fuel CPI for both Koraimat and Assiut are higher than (2) meaning a serious heavy metal accumulation, and PLI >1 for both also indicating that a significant pollution load as in Tables (6;7), and Figs.(4;5); in ashes SEPI, CPI and PLI are showing that there a very high heavy metal contamination, accumulation and high pollution load of elements in ashes in both Koraimat and Assiut as in Tables (8;9), and Figs. (6;7). Finally exposure of humans and animals to particulate matter ($PM_{2.5}$and

PM_{10}) that carry heavy elements, leads to several diseases related to respiratory syndromes.

3.4Conclusions;In this study, it was found that the went in accordance with sustainable plans Egypt Vision 2030, benefits in reducing ash amount for each produced MW, the change in ash amount is with new power load generation adds on and rehabilitation processes. But ash content of heavy metal revealed that the heavy metal concentrations (Mn, Cd, Ni,V, Pb, and Zn) in fly ash were enriched according to the concentrations in HFO.

3.5 Recommendations;The pollution's indexes of these elements are extremely high, but on the other side ash has an economical value due to its contents of rare and heavy elements that can extracted and reused. Finally, this reduction in the long run has a positive effect on the environment and consequently, to the health.

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List of abbreviation

Cd : Cadmium,
V : Vanadium
Zn : Zinc
Pb : Lead
Ni :Nickel
Mn :Manganese
CPI :Combined pollution index
EF :Enrichment Factor
FA : Fly Ash
HFO:Heavy Fuel Oil
MW :Mega Watt
PM : particulate matter
PLI : Pollution Load Index
SEPI : Single Element Pollution Index
UEEPC: Upper Egypt Electricity Production Company
PM : Particulate matter