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Effect of Different Dyed Fabrics on the Adsorption of Air Pollution in Residential and Industrial Atmosphere in Cairo-Egypt

Ahmed G. Hassabo [1,*], Sahar Galal [2], Asmaa M. Elmekawy [3], Nadia M. El-Taieb [3], Naglaa S. Elshemy [2]

[1] National Research Centre (NRC, Scopus affiliation ID 60014618), Textile Research and Technology Institute, Pretreatment and Finishing of Cellulose-based Textiles Department, 33 El-Behouth St. (former El-Tahrir str.), Dokki, P.O. 12622, Giza, Egypt; aga.hassabo@hotmail.com (A.G.H.)
[2] National Research Centre (NRC, Scopus affiliation ID 60014618), Textile Research and Technology Institute, Dyeing, Printing and Textile Intermediate Department (DPTID), El-Behouth St. (former El-Tahrir str.), Dokki, P.O. 12622, Giza, Egypt
[3] National Research Centre (NRC, Scopus affiliation ID 60014618), Environmental Research Division, Air Pollution Department, El-Behouth St. (former El-Tahrir str.), Dokki, P.O. 12622, Giza, Egypt
* Correspondence: aga.hassabo@hotmail.com (A.G.H.);

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Abstract: Various dyed natural and synthetic textiles (silk, wool, cotton, nylon, polyester), as well as their blends (wool/polyester, nylon/polyester, and nylon/polyester), were on display for four months at two designated locations in the Cairo city neighborhoods of Dokki and Helwan. Both locations evaluated the changes in the exposed fabrics' color strength and mechanical characteristics. Utilizing delta E values over exposed fabrics for various times, an isothermal study was estimated.

Keywords: air pollution; different dyed fabrics; residential and industrial atmosphere.

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1. Introduction

As the natural ecosystem becomes more populated and contaminated without using renewable energy or technology, the air we breathe becomes dangerously polluted and every year causes mortality for millions of people worldwide due to stroke, lung cancer, and heart disease. Air pollution will directly reach our respiratory and circulatory systems, causing lung, cardiac, and brain damage [1-7]. Industrial processes and traffic constitute one of the main reasons for air pollution. There are significant economic advantages to reducing air pollution. Moreover, if we see the lack of visible smog, it’s not an indication that the air is good, not polluted, and healthy [8-11].

Furthermore, textile fabrics are destroyed by air pollution. Air pollution's most significant effects are weight loss, color fading, and tensile strength loss [12-15]. Additionally, harmful gases like sulfur and nitrogen oxides, which are present in the atmosphere as pollutants, affect the destruction of natural and synthetic textiles [12,16-18]. Therefore, one of the main causes of the deterioration of cellulosic materials is air pollution [17,19-21].

Cotton, silk, wool, flax, hemp, and jute make up the majority of natural textiles. Due to natural fiber usage as a workhorse in the textile industry and its multiple uses with a low resistance to environmental degradation, the effects of air pollution particles on natural textiles

have traditionally been limited, especially on cotton. The photochemical degradation of wool is affected by air pollution, like how exposure to cotton is affected [22-24].

Since synthetic fibers are now more often utilized in the textile business than natural ones, air pollution and soiling problems are becoming more significant. Additionally, synthetic fibers are tough to clean due to their nature. Furthermore, because synthetic fibers are often chemically stable, little has been explored regarding how air pollution affects synthetic fabrics. However, given the potential for synergistic effects, this theory could be incorrect [25-27].

The chemical structure of dyes plays an important role in saving the textile material from degradation, especially against bacteria as well as air pollution, which contains many organisms. The dyeing process provides chemical action between dyes and textile polymer backbone, which helps against air pollution degradation, as they react with the functional groups in the textile surface, which are attacked by organisms [28,29]. Mechanical properties exposed to industrial or residential atmospheres provide a way to track occurred changes and gauge how the environment affects textiles.

Additionally, the pollution-filled air in Cairo causes severe degradation and weakening of the textile fibers [21,30]. The main consequences of air pollution on textiles are soiling, tensile strength loss, and weight degradation. In addition, sulfur oxides (SOx and NOx) can deteriorate natural and synthetic fibers [31,32]. On the other hand, data on the impact of air pollution on textiles is few. To ascertain the impact of air pollutants and climate on the stability of cotton and synthetic textiles exposed to Cairo's environment, this portion of the current investigation was carried out.

For the duration of this study, textile samples (natural, synthetic, and certain mixes between them) were exposed to various air pollutants at two sites in Cairo City: El-Dokki residential district and Helwan industrial region (from October to January). Heavy smog days with high concentrations of pollutants, which depend on the stability of the atmosphere due to factors like temperature inversion and the predominant winds, were more common in Cairo during this time period between October and January [33-36]. However, in this research, the physical characteristics of various textiles exposed over a 120-day period were examined to determine the impact of air pollutants on the stability of natural and synthetic fabrics exposed in Egypt's industrial or residential atmosphere. Additionally, its isothermal model has been examined to determine how well these materials can adsorb air pollutants.

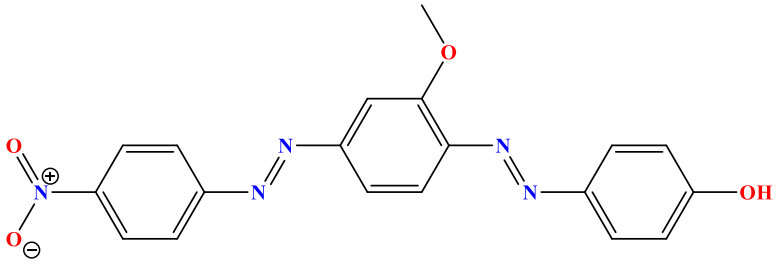
2. Materials and Methods

2.1. Materials.

Natural fabrics (silk (165 g/m^2), wool (210 g/m^2) and cotton (158 g/m^2) fabrics), Synthetic fabrics (nylon (145 g/m^2) and polyester (160 g/m^2)) and Blended fabrics (nylon/polyester (50/50, 165 g/m^2) and wool/polyester (45/55, 165 g/m^2)) were used during this study. All used fabrics have been found in the local market.

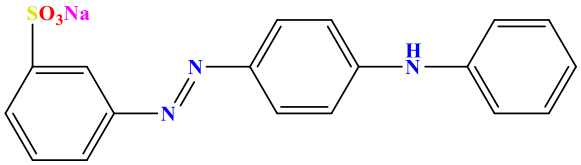
C.I. Reactive Blue 171 (sodium 4-amino-3,6-bis((E)-(5-((4-chloro-6-((3-sulfonatophenyl) amino)-1,3,5-triazin-2-yl)amino)-2-sulfonatophenyl)diazenyl)-5-hydroxynaphthalene-2,7-disulfonate, chemical formula: $C_{40}H_{23}C_{l2}N_{15}Na_6O_{19}S_6$) for dyeing cotton fabric. C.I. Acid Yellow 36 (sodium-3-((4-(phenylamino)phenyl)diazenyl) benzenesulfonate, chemical formula: $C_{18}H_{14}N_3NaO_3S$) for dyeing wool, silk, and nylon fabrics. C.I. Disperse Orange 29 (4-[[2-methoxy-4-[(4-nitrophenyl)azo]phenyl]azo]-phenol, chemical

formula $C_{19}H_{15}N_5O_4$) for dyeing polyester, wool/polyester and nylon/polyester fabrics. The chemical structure of used dyes is illustrated in Figure 1.



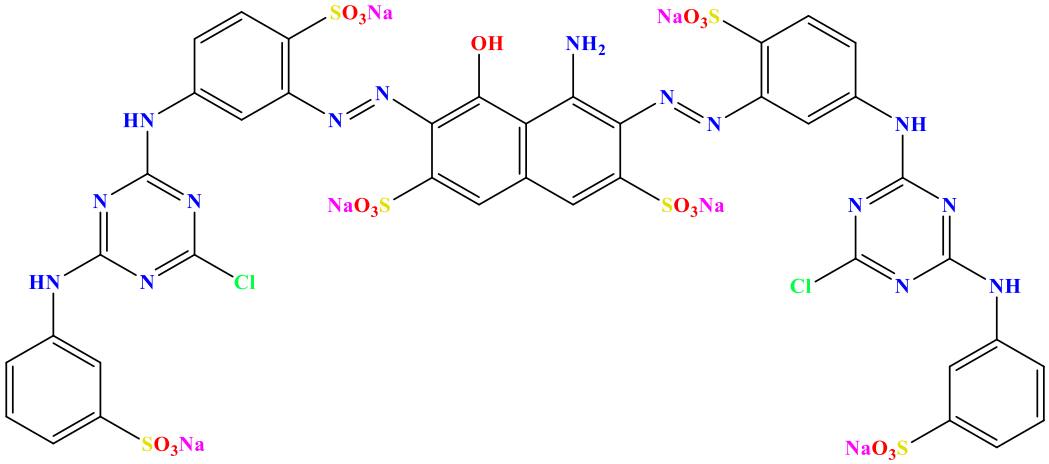
4-[[2-Methoxy-4-[(4-nitrophenyl)azo]phenyl]azo]phenol

Disperse Orang 29



sodium-3-((4-(phenylamino)phenyl)diazenyl)benzenesulfonate

Acid Yellow 36



sodium 4-amino-3,6-bis((*E*)-(5-((4-chloro-6-((3-sulfonatophenyl)amino)-1,3,5-triazin-2-yl)amino)-2-sulfonatophenyl)diazenyl)-5-hydroxynaphthalene-2,7-disulfonate

Reactive Blue 171

Figure 1. Chemical structure of used dyes.

2.2. Methods.

2.2.1. Dyeing of different textile fabrics.

2.2.1.1. Dyeing procedure for wool, silk, and nylon fabrics with an acid dye.

Dissolve the dye with a small amount of hot water; then add the appropriate volume of water based on the liquor ratio. Begin dyeing at around 40°C and stir thoroughly while raising the temperature to 90°C in 15 minutes, then continue dyeing at this temperature for 120 minutes. When dyeing is finished, the fabric should be removed, rinsed, washed, rinsed, and dried. During the dyeing process, the quantity of the dye bath should be kept constant by periodic tiny hot water additions.

2.2.1.2. Dyeing procedure for polyester, wool/polyester, and nylon/polyester fabrics with dispersed dye.

Begin the dyeing process at room temperature by putting the fabric samples and the predicted volume of wetting agent and water and stirring for 5 minutes. Next, add the dispersion agent, carrier, and acetic acid at room temperature and mix for 5 minutes. Then, for 5 minutes, add the dispersed dye and stir. Throughout the next 20 minutes, steadily raise the temperature to 95°C. Continue the dyeing at 95°C for another 60 minutes. After dyeing, the fabric is removed and placed in a reduction clearing bath containing caustic soda (NaOH) and sodium hydrosulfite for 15 minutes at 80°C. Cold water is used to rinse the sample. Finally, the fabric is immersed in a soaping wash containing non-ionic detergent for 15 minutes at 50°C.

2.2.1.3. Dyeing procedure for cotton fabrics with a reactive dye.

The dye heats in boiling water till thoroughly dissolved, then makes a dye bath at pH 9. Afterward, put the fabric in a blank dye solution at 40°C for 10-15 minutes. Then gradually increase the temperature to a boil and keep it for about an hour for the dying process to complete. Carefully cool the dye bath to 50-60°C once the dyeing is complete.

2.2.2. Exposed profile for fabrics to air pollution.

Dyed fabrics were exposed for 120 days at two different locations, first in the residential atmosphere in Cairo City (Dokki) and second in the industrial atmosphere in Cairo City (Helwan), which represents air pollutant loads. For 120 days, the dyed fabrics were hung over building roofs in both selected areas. Samples of each fabric were removed and measured after exposure for 30, 60, 90, and 120 days.

2.3. Characterisation.

2.3.1. Determination of Suspended Particulate Matter (SPM)

Due to safety orders, suspended dust was collected at the residence palace on a pre-weighted Whatman 42, open-face filter holder, and a vacuum pump set to draw 7 L/min for 24 hours. The filters were weighted, and concentration was measured and expressed as micrograms per cubic meter. ($\mu g/m^3$) [20].

2.3.2. Determination of Gaseous air pollutants.

Gas bubblers and vacuum pumps calibrated to draw air at a flow rate of 1 L/min were used to measure sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and ammonia (NH_3). The solution's absorbance was measured using a UV–Visible spectrophotometer (Novaspec–LKB model 4049 –Biochrom, Cambridge, England), and gaseous air pollutant concentration was expressed as $\mu g / m^3$ [20].

2.3.2.1. Sulphur dioxide.

SO_2 was collected using an absorbent solution of sodium tetra-chloromercurate (0.1 M) as an absorbent reagent, followed by the addition of para-rosaniline and formaldehyde to form the para-rosaniline methyl sulfonic acid. In the same way, the blank solution was formulated using an unexposed absorbent reagent [20].

2.3.2.2. Nitrogen dioxide.

NO_2 was collected using an absorbent solution of sodium hydroxide (0.1 N) as an absorbent reagent. The concentration of nitrite ions (NO_2-) was calorimetrically determined at 550 nm by the reaction of nitrite ions with phosphoric acid, sulfanilamide, and N-(1-naphthyl)-ethylenediamine di-hydrochloride. In the same way, the blank solution was formulated using an unexposed absorbent reagent [20].

2.3.2.3. Ammonia

NH_3 levels were measured using dilute sulfuric acid as an absorbent reagent, followed by a reaction with the Nessler reagent and colorimetric measured at 460 nm wavelength [37]. The blank solution was formulated similarly using an unexposed absorbent reagent [20].

2.3.3. Colour measurements.

The color strength of the dyed fabrics was evaluated by Hunter Lab Ultra Scan PRO [38-46].

2.3.4. Mechanical properties of exposed fabrics.

Tensile strength and elongation at break are carried out according to the ASTM Standard Test Method D–1682–2011 [47]. FMCW 500 tensile strength apparatus (Veb Thuringer Industrie Werk Rauenstein 11/2612 Germany) was used at 25°C and 65% relative humidity.

2.4. Isothermal studies.

Isotherm experiments for the sorption of air pollutants onto the exposed fabrics were conducted. Langmuir, Freundlich, and Dubinin – Radushkevich isothermal models with some modifications was used in this study [45,46,48]. Langmuir isotherm is the first isothermal method which is given by the following equation:

$$q_e = \frac{q_m C_e K_L}{1+C_e K_L} \quad \text{=====>} \frac{1}{q_e} = \frac{1}{q_m} + \left(\frac{1}{q_m K_L}\right)\left(\frac{1}{C_e}\right)$$

this isothermal model was converted to be:

$$\frac{1}{t} = \frac{1}{\Delta E_{max}} + \left(\frac{1}{\Delta E_{max} K_L}\right)\left(\frac{1}{\Delta E}\right)$$

Where t is the fabric's exposure time (days), ΔE is the difference between ΔE at 0 and 120 days of exposure, and KL is the constant Langmuir. A straight line with a slope of $1/1/\Delta E_{max}.KL$ and an intercept of $1/1/\Delta E_{max}$ are given from linearizing the Langmuir isotherm plotting of 1/t versus 1/ΔE.

Freundlich isotherm is the second isothermal method used in the analysis of heterogeneous systems, and their equation given below [48]

$$q_e = q_e C_e^{1/n} \text{=====>} \; ln(q_e) = ln(K_F) + \frac{1}{n} ln(C_e)$$

this isothermal model was converted to be:

$$ln(t) = ln(K_F) + \frac{1}{n} ln(\Delta E)$$

where t is the exposure time of fabrics (days), ΔE is the difference between ΔE at 0 and 120 days exposure time, K_F is the Freundlich constant, and n is the heterogeneity factor. The ln(t) versus ln(ΔE) plot gives a straight line with 1/n slope and ln(K_F) intercept.

Dubinin–Radushkevich is the third isothermal method was used in this study also. The liner form of this model is written as [49]:

$$lnQ_e = lnQ_m - \beta\,\varepsilon^2$$

this isothermal model was converted to be:

$$\ln(t) = \ln(\Delta E) - \beta\,\varepsilon^2$$

where t is the exposure time of fabrics (days), ΔE is the difference between ΔE at 0 to 120 days exposure time, β ($mol^2.kJ^{-2}$) is a constant related to adsorption energy while ε is the Polanyi sorption potential and can be calculated by

$$\varepsilon = RT \ln\left(1 + \frac{1}{\Delta E}\right)$$

where R is the gas constant 8.314 $J.mol^{-1}K^{-1}$and T is the temperature in Kelvin. The values of β and ΔE_{max} were calculated from the slope and intercept of the plot ln(ΔE*)* vs ε^2. The mean free energy of sorption E ($kJ.mol^{-1}$) required to transfer one mole of pollutant from the air pollution to the fabric surface can be determined using the following equation:

$$E = (-2\,\beta)^{-\frac{1}{2}}$$

In addition, certain error functions were used for the fitting nature [50-53]: the root mean square error (RMSE) was used to check the sufficiency and accuracy of the model fit with the results. The second analysis method is the sum of absolute errors (SAE), aggregating cumulative errors. The third statistical method is the average relative error (ARE) which attempts to limit the conveyance of fractional errors over the entire range. All the models of errors can be estimated using the following equations:

$$\mathrm{RMSE} = \sqrt{\frac{1}{n-2}\sum_{i=1}^{n}(\Delta E_i - \Delta E_e)^2}, \qquad \mathrm{SAE} = \sum_{i=1}^{n}|\Delta E_i - \Delta E_e|_i, \mathrm{ARE} = \frac{100}{n}\sum_{i=1}^{n}\left|\frac{\Delta E_t - \Delta E_e}{\Delta E_t}\right|$$

where ΔE is the test sorption limit from the batch analyzed i, ΔE_e is the sorption capacity evaluated from the sorption model for comparing ΔE_i and n is the number of perceptions in the batch experimental.

3. Results and Discussion

3.1. Estimation of gaseous air pollutants.

From a public health perspective, the origin and nature of air pollutants are the current major problem and result from multiple contamination and chemical reaction activity [54-57]. In addition, ozone (O_3), nitrogen dioxide (NO_2), volatile organic compounds, carbon monoxide (CO), carbon dioxide (CO_2), and sulfur dioxide (SO_2) are considered air pollutants. Some of the most violent contaminants that are produced with a high UV index during hot periods often contribute directly to global warming, which can thus affect cardiovascular health [58,59].

Concentrations of suspended particulate matter (SPM), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and ammonia (NH_3) as air pollutants in the either residential or industrial atmospheres; Dokki and Helwan; shown in Table 1. The concentrations of air pollutants in Table 1 represent the mean concentrations of four air pollutants (SPM, NO_2, SO_2, and NH_3) throughout the month and the mean concentration values of those pollutants in either residential (Dokki) or industrial atmosphere (Helwan) over the four months examined.

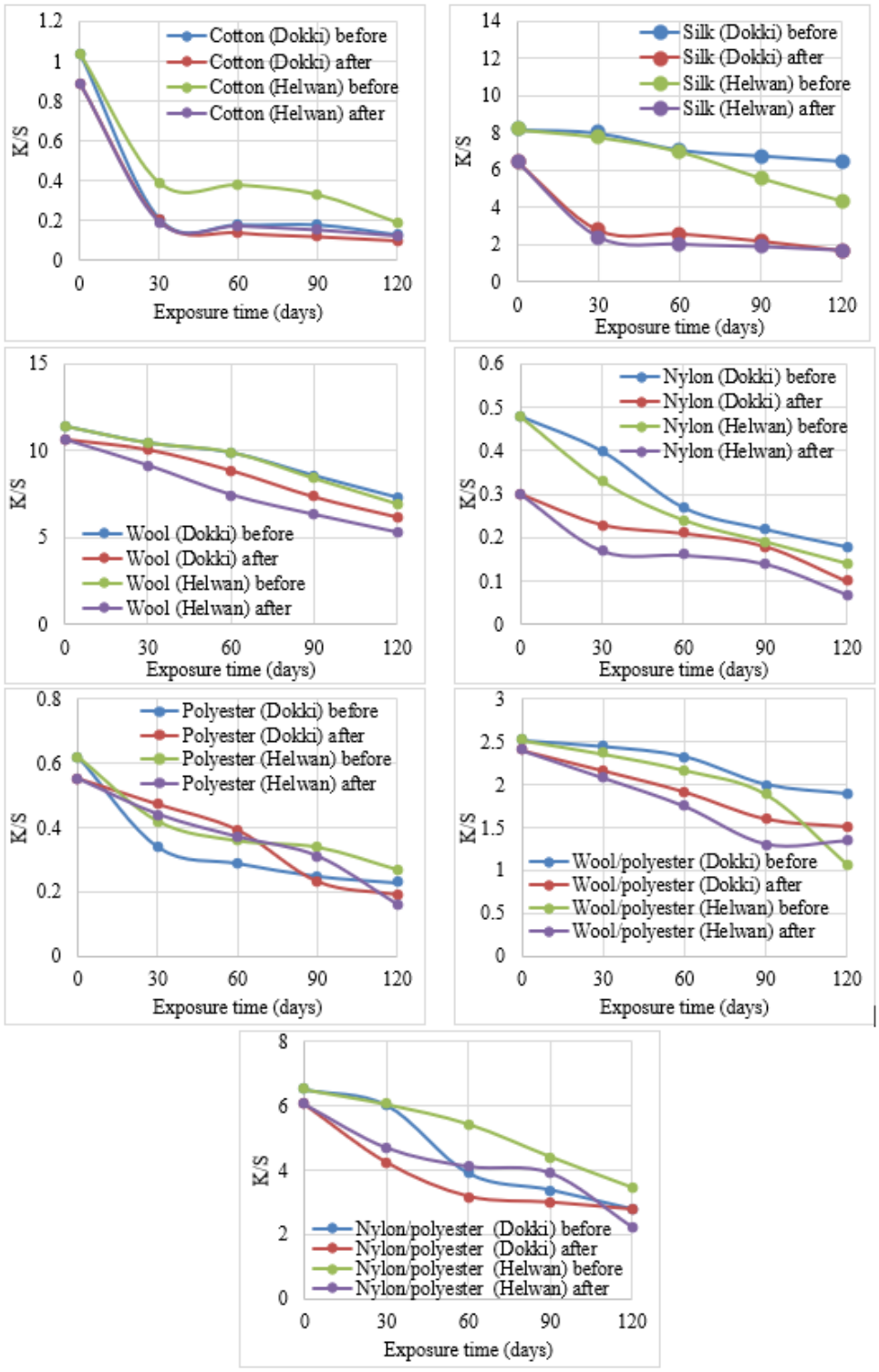


Figure 2. K/S over expressed days curves for different fabrics in industrial and residential atmospheres in Egypt before and after washing.

Table 1. Gaseous air pollutants concentration in both Helwan and Dokki destinations.

	SPM (μg/m³)		**NO_2 (μg/m³)**		**SO_2 (μg/m³)**		**NH_3 (μg/m³)**	
	Dokki	**Helwan**	**Dokki**	**Helwan**	**Dokki**	**Helwan**	**Dokki**	**Helwan**
October	336.51	417.12	32.95	39.38	50.42	56.88	37.45	40.81
November	232.31	500.81	35.67	40.48	52.92	57.88	39.3	41.48
December	242.33	355.08	36.56	44.87	55.77	61.45	41.06	41.73
January	226.01	359.25	39.32	49.38	57.51	65.64	43.55	42.48
Mean	**259.29**	**408.07**	**36.16**	**43.53**	**54.15**	**60.46**	**40.34**	**41.63**

From these results, it is clear that in a residential environment, the concentration of all air pollutants is greater than its value in an industrial environment. Furthermore, ammonia gas

is almost similar in both atmospheres. Still, two other gasses (NO_2 and SO_2) differ in gas concentration between the two atmospheres, which is a result of pollutants from the industrial output [20].

3.2. Colour measurements of exposed fabrics.

Figure 2 and Figure 3 show the color strength K/S and DK/S of exposed fabrics before and after washing at various exposed periods (0–120 days). K/S for the fabrics at exposed time 0 was reported as 1.04, 8.21, 100.33, 19.4, 111.08, 60.82, 60.24, and 46.8 for silk, nylon, linen, cotton, polyester, nylon/polyester, and wool/polyester respectively. From Figure 2 and Figure 3, the K/S of exposed fabrics decreased before and after washing as the exposure time increased.

In addition, it is clear that K/S of all types of exposed fabrics decreased as the exposure time increased even after washing in both sites (residential or industrial atmosphere). In addition, from K/S values, it is clear that natural fabrics have K/S values lower than synthetic or blended fabrics which provide the ability of natural fabrics type to adsorb the pollution from the atmosphere more than synthetic or blended ones.

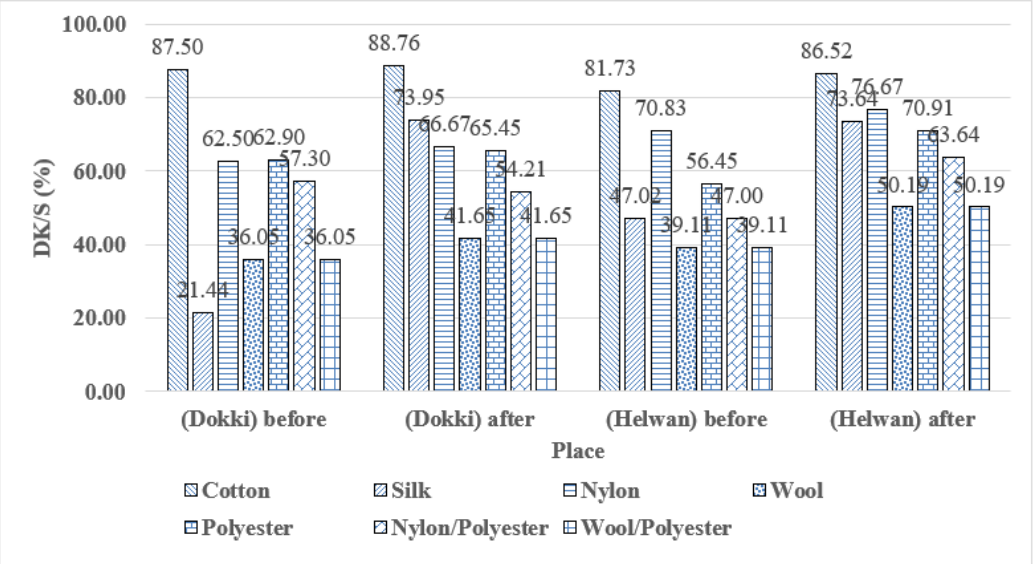


Figure 3. DK/S over expressed days curves for different fabrics in industrial and residential atmospheres in Egypt before and after washing.

3.3. Mechanical properties of exposed fabrics

Mechanical properties of the display fabrics have been studied regarding tensile strength and elongation during different periods (30, 60, 90, and 120 days). All findings for exposed fabrics (natural, synthetic, or mixed fabrics) are shown in Figure 4. Figure 4 shows that, as a function of the exposure time, the tensile strength and elongation (percent) of all exposed fabrics have been reduced at both locations. Therefore, in both analyzed mechanical properties, all exposed fabrics in the industrial atmosphere (Helwan Industrial Area) have decreased more than exposed fabrics in the residential atmosphere (Dokki residential area) as the exposure time increased.

It can be noted that the tensile strength of exposed fabrics decreased from the initial values of 33, 60, 51, 48, 60, and 55 kg (force) to approximately 8, 9, 30, 36, 36, and 33 kg in Dokki and 12, 9, 45, 38, 52, and 34 kg in Helwan after 120 days for silk, nylon, cotton, wool,

nylon/polyester and wool/polyester fabrics. Similarly, uncovered cloth elongation (percent) decreased from the initial values of 21, 74, 48, 43, 51, and 62 (percent) to about 14, 52, 15, 33, 29, and 30 (percent) at Dokki and 15, 35, 15, 33, 45 and 41 (percent) at Helwan after 120 days respectively for silk, nylon, cotton, wool, nylon/polyester and wool/polyester fabrics.

From another point of view, Figure 5 illustrates the tensile strength (percent)and elongation at a break (percent) after 120 days which provide that a) tensile strength (percent) between 0 and 120 exposure times for all fabrics in both places can be arranged in descending order as nylon, silk, cotton, nylon/polyester, and wool/polyester, wool. B) elongation at a break (%) between 0 and 120 exposure time for all fabrics in both places can be arranged in descending order as cotton, silk, nylon, wool, wool/polyester, and nylon/polyester.

From these data, we can conclude that, due to the presence of industrial pollutants, which includes many gasses pollutants and particulate matter, particularly heavy metals, air pollution affects the mechanical properties of the fabrics more than in residential, especially in industrial areas. These materials, which are also presented in the atmosphere of the Dokki residential area but with less due to traffic and other human activities, destroy more than synthetic the mechanical properties of the fabrics, particularly the natural ones. This disparity is, therefore, due to individual differences in the emission concentrations at each location.

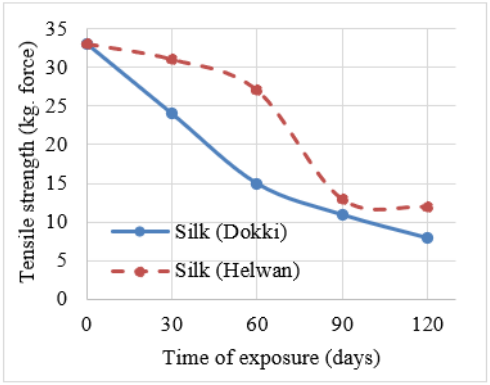
This decline in the tensile strength of natural fabrics at both sites studied is primarily due to the deterioration of the polymer chain of natural fibers under the influence of various contaminants with meteorological influences such as heat, temperature, and relative humidity, which induces a decrease in the average molecular weight and loss of tensile force. In addition, the number of pollutants depends on the degradation of the chain of biopolymers. When processing time increases, the fibers are raw, brittle, and easy to break. Substances of exposure to atmospheric pollutants will lead to significant degradation and weakening [60].

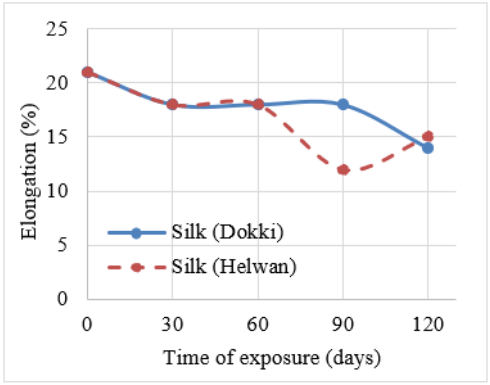
In addition, higher summer temperatures with relative humidity accelerate the action of acidic gasses such as SO_2, NO_2, and photochemical oxidants affecting the deterioration of the fabric. These results are in line with those of the claim that fabrics are damaged by industrial pollutant emissions [61-64].

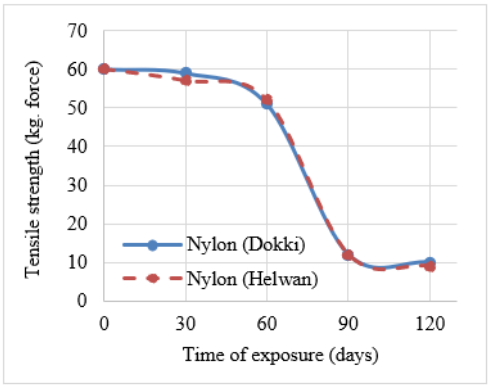
However, it is indicated that the natural fabrics at both sites were examined to provide a higher tensile strength loss relative to synthetic or blended fabrics. This disparity decreases with the rise in pollutant amounts in the atmosphere (more than the residential atmosphere in the industrial atmosphere).

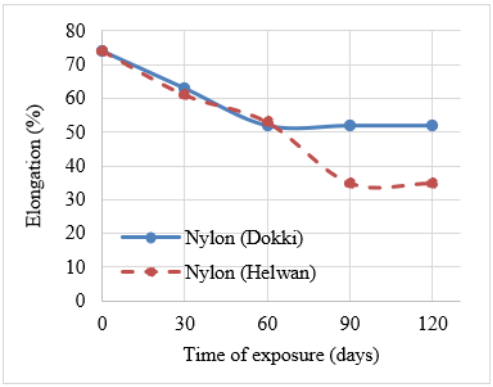
Changing the elongation at a break in textile fabrics after exposure, shown in Figure 5, shows that the percentage loss of elongation for natural, synthetic, or mixed fabrics increases as exposure time increases. Additionally, in the case of tensile strength, the change from a residential to an industrial atmosphere is discussed similarly.

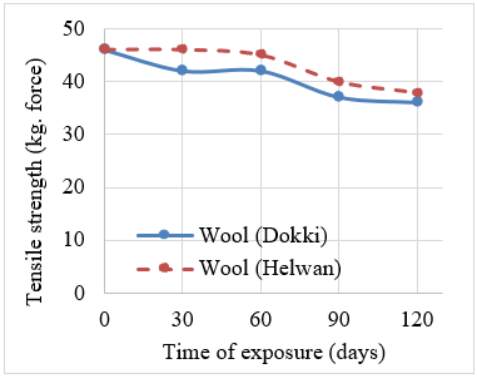
It is noteworthy because, after 30 days of exposure, the naturally dyed fabrics at both sites lost their elongation, while synthetic or mixed fabrics lost their elongation after 60 days of exposure. The decline in elongation for naturally dyed fabrics in both locations was due to the deterioration of the biopolymer chain arising from the impact of different toxins and other factors, such as temperature and relative humidity, causing dissolution and loss of the elasticity of the biopolymer chains [65,66].

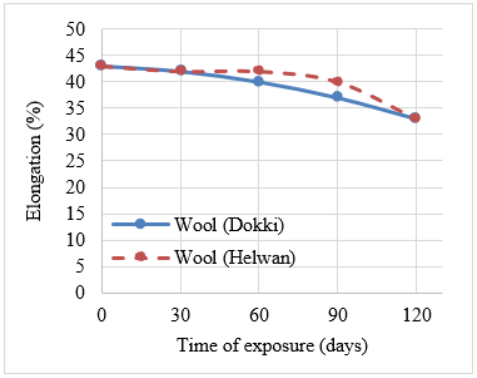

Tensile strength (kg. force)
Time of exposure (days)
Silk (Dokki)
Silk (Helwan)

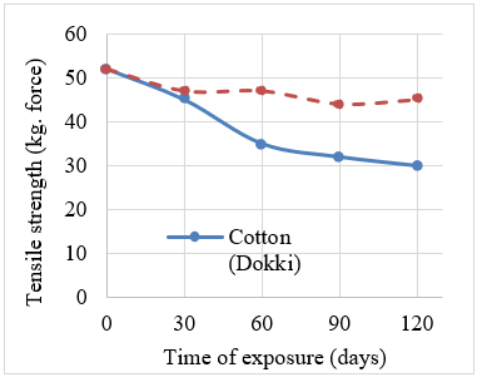

Elongation (%)
Time of exposure (days)
Silk (Dokki)
Silk (Helwan)

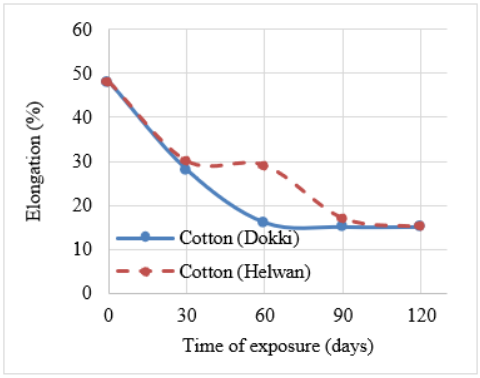

Tensile strength (kg. force)
Time of exposure (days)
Nylon (Dokki)
Nylon (Helwan)


Elongation (%)
Time of exposure (days)
Nylon (Dokki)
Nylon (Helwan)


Tensile strength (kg. force)
Time of exposure (days)
Wool (Dokki)
Wool (Helwan)


Elongation (%)
Time of exposure (days)
Wool (Dokki)
Wool (Helwan)


Tensile strength (kg. force)
Time of exposure (days)
Cotton
(Dokki)


Elongation (%)
Time of exposure (days)
Cotton (Dokki)
Cotton (Helwan)

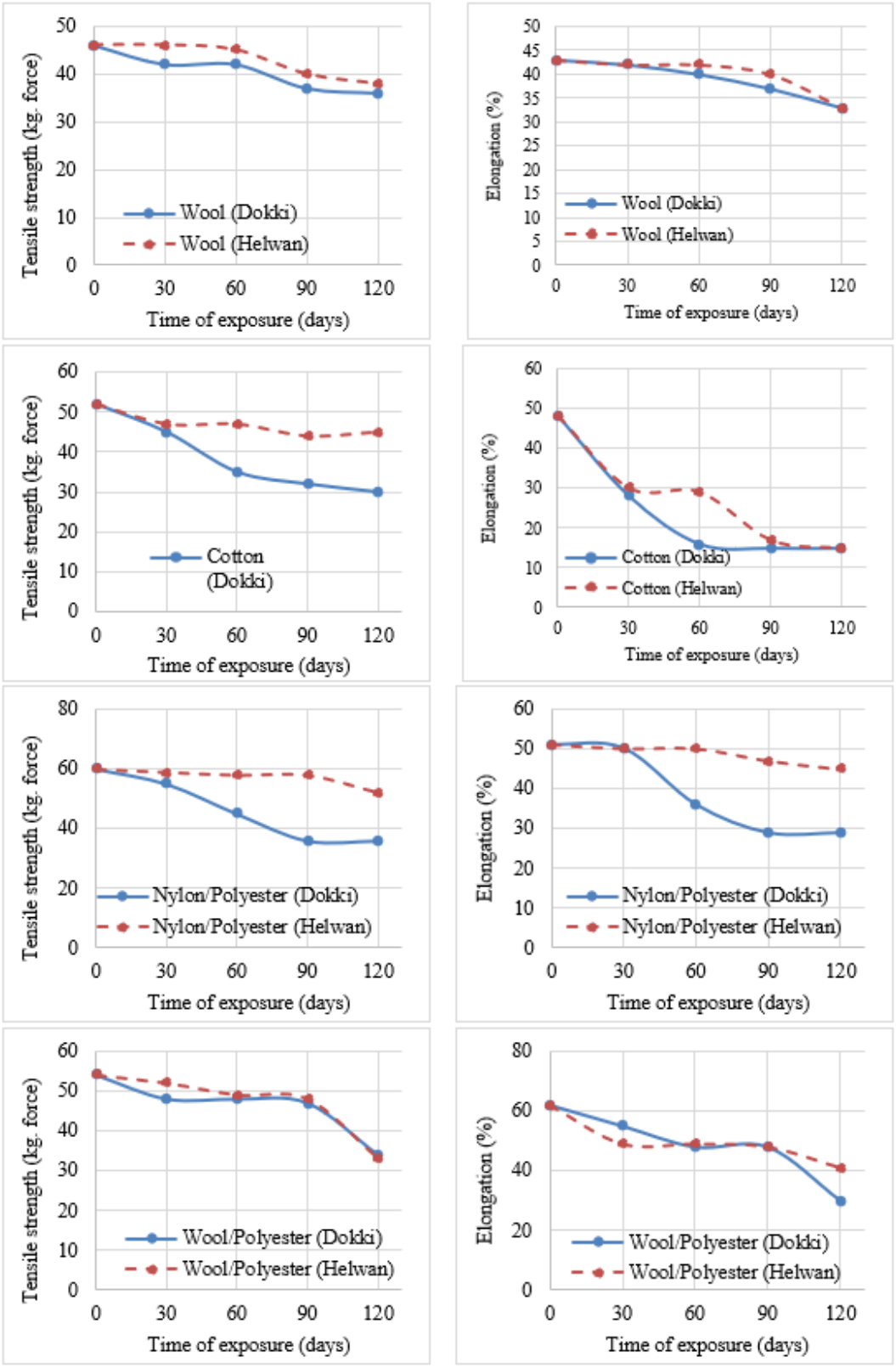


Figure 4. Tensile strength (kg. force) and elongation at a break (%) overexposure days for dyed fabrics in industrial and residential atmospheres in Cairo, Egypt.

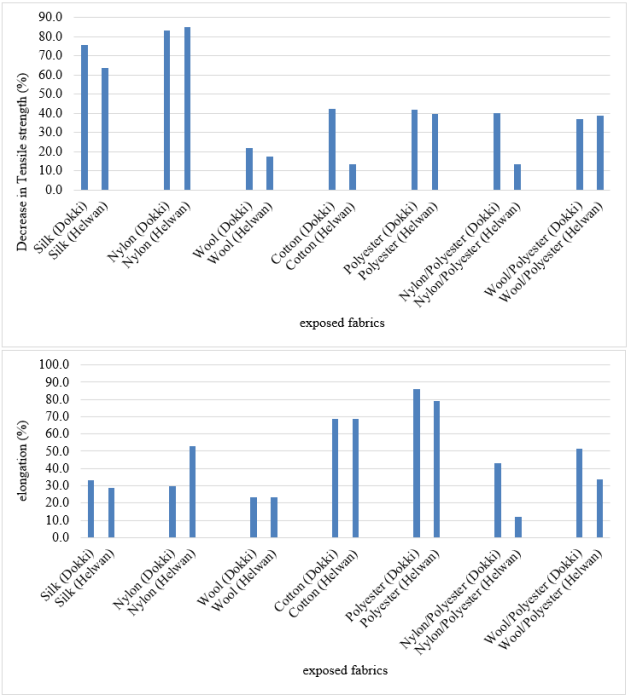


Figure 5. Decrease in tensile strength (%) and elongation at a break (%) after 120 exposure days for dyed fabrics at industrial and residential areas in Cairo, Egypt.

3.4. Isothermal studies.

Figure 6 shows the ΔE values over exposed fabrics for different time periods (0, 30, 60, 90, and 120 days) before and after washing. The ΔE rating for the fabrics at zero time before washing is 62.37, 17.09, 62.59, 27.73, 56.21, 40.49, 22.92, and after washing is 60.07, 15.11, 60.21, 24.73, 55.47, 24.58, 20.92 respectively for silk, nylon, wool, polyester, nylon/polyester, wool/polyester and cotton fabrics. From Figure 6, as the exposure time decreased, the ΔE values in both investigated sites (residential or industrial atmosphere) decreased before or after washing all exposed fabric.

However, natural fabrics have ΔE values higher than synthetic or mixed fabrics, providing more ability to adsorb air pollutants from the residential or industrial environment than synthetic or mixed fabrics.

Further investigation from the figure shows that, as the dye molecules on the fabric react with the air pollutant, especially heavy metals, which cause destruction in the bonds between them and fabrics, decreased the ΔE value. This decrease which is illustrated in Figure 6 and Figure 7, provided that dyed synthetic shows a better decrease in ΔE (%) than other fabrics. In addition, dyed cotton fabric confirms a better decrease in ΔE (%) than silk and wool fabrics. Blended fabrics provide the lowest decreased percentage in ΔE (%) of all investigated fabrics. These changes in the decreasing of ΔE (%) are attributed to the nature of the used fabric and the chemical structure of the dye molecule.

Various isothermal models were investigated to explain the actions of air pollution to adsorb on the surface of the dyed fabrics, the most commonly used models for textile fibers being Langmuir, Freundlich, and Dubinin–Radushkevich models [45,46]. At both investigated sites (Dokki and Helwan) before and after washing, the parameters of the isothermal models with different error features are described in Table 2 - Table 8 for each examined dyed fabric.

The isothermal Langmuir model explained the monolayer adsorbed emissions on the exposed fabric surface. As known, the assumption is that the intermolecular forces will decrease rapidly with separation with monolayer coating on the outer fabric surface with homogeneous distribution, using this model. Freundlich isothermal approach is a good model for characterizing pollutant heterogeneity adsorption onto the surface of the dyed fabric. The last isothermal model studied was the model Dubinin-Radushkevich [49].

The preceding models were generally applied during this research to provide physical and chemical adsorption of air pollution. It is clear that the Langmuir model gives the other models a better fit than the R^2. These results confirm that monolayer air pollution can be adsorbed onto the fabrics' active sites. In addition to this, it described the negative adsorption state from Freundlich's model as n value < 1 [67].

Based on this data, Langmuir, Freundlich, and Dubinin – Radushkevichmodels identified various isothermal models. This means that the air pollution in a homogeneous matrix is transported to the dyed fabric surface.

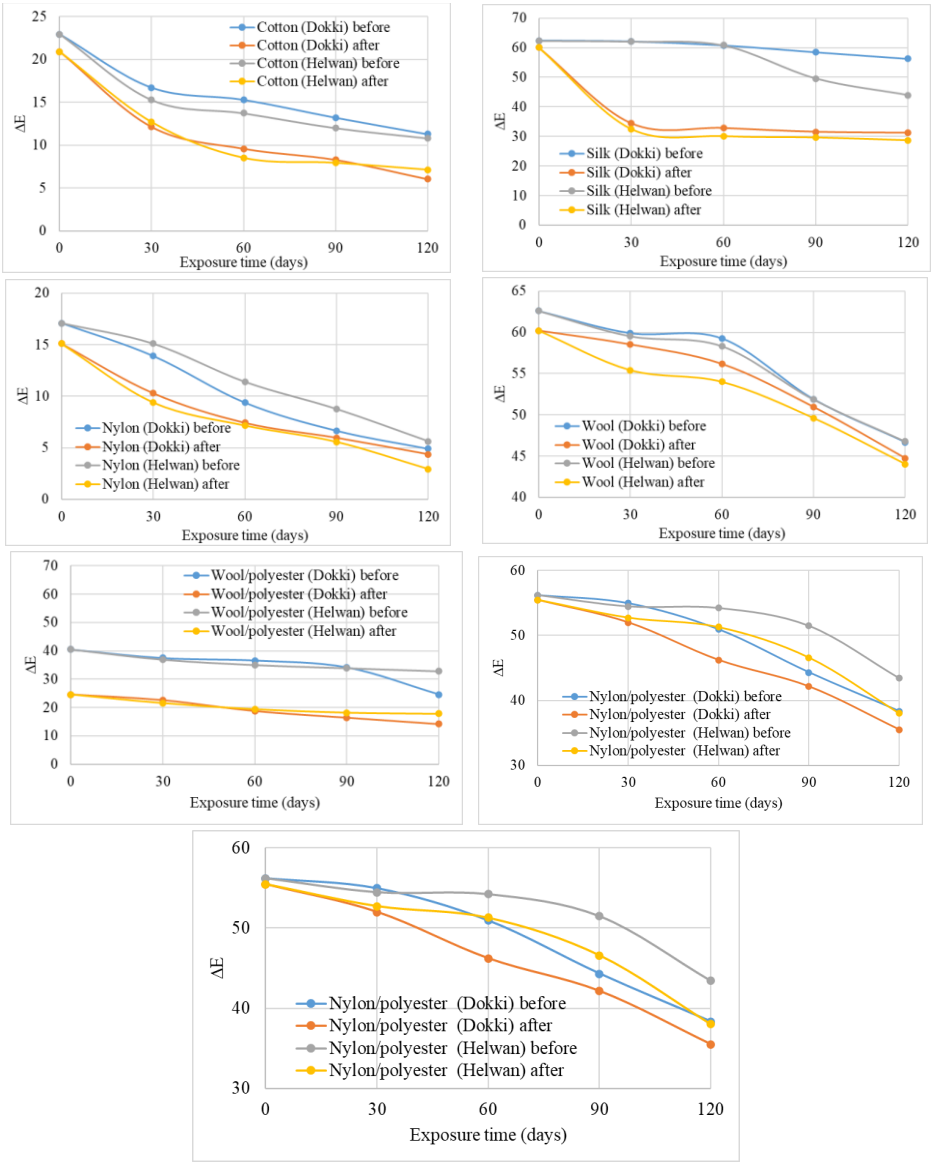


Figure 6. Values for (ΔE) overexpressed days for dyed fabrics at industrial and residential areas in Cairo, Egypt before and after washing.

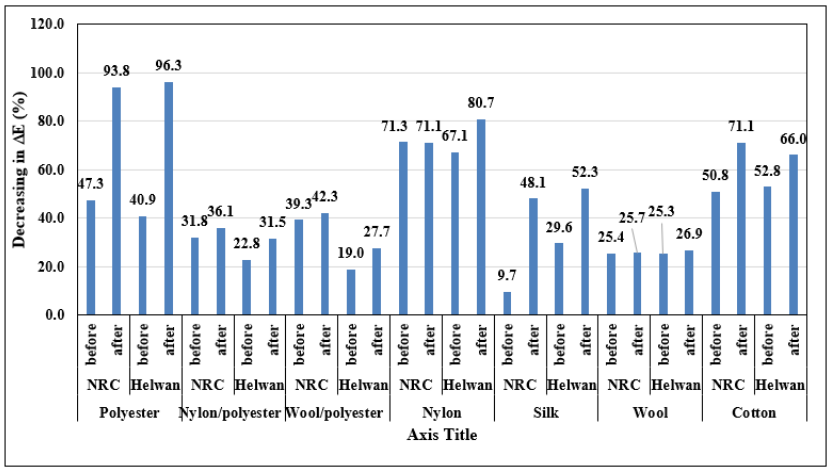


Figure 7. Decreased (ΔE) (%) for dyed fabrics after 120 days at industrial and residential areas in Cairo, Egypt, before and after washing.

Table 2. Isotherm parameters for different isotherm models for pollutants adsorbed onto dyed silk fabric with Acid Yellow 36.

	Silk (Dokki) before washing			Silk (Dokki) after washing		
	Langmuir model	**Freundlich model**	**Dubinin – Radushkevich model**	**Langmuir model**	**Freundlich model**	**Dubinin – Radushkevich model**
R^2	0.9604	0.9906	0.9995	0.9826	0.9485	0.9999
ΔE (mg/g)	5.291005	0.005324288	1.0013	2.95858	0.013619412	1.0037
K	-0.795238	94.9730		-0.579882	44.5349	
1/n		-0.1087			-0.0752	
β			-0.0007			-0.0022
E			26.73			15.08
RMSE	70.808	77.494	76.214	47.525	51.101	49.882
SAE	3.539	29.967	24.987	4.213	18.938	13.987
ARE	11.666	99.911	83.283	17.208	99.619	71.912
	Silk (Helwan) before washing			**Silk (Helwan) after washing**		
R^2	0.9924	0.9976	0.9924	0.8392	0.9042	0.9999
ΔE (mg/g)	3.472222	0.000906538	1.0016	2.770083	0.015786871	1.0043
K	-2.598958	420.4361		-0.498338	39.6369	
1/n		-0.4731			-0.0667	
β			-0.0008			-0.0026
E			25.00			13.87
RMSE	68.266	72.645	71.370	45.891	49.196	47.993
SAE	10.517	27.873	22.870	4.240	18.011	13.068
ARE	36.441	99.983	81.666	17.260	99.528	70.002

Table 3. Isotherm parameters for different isotherm models for pollutants adsorbed onto dyed cotton fabric with Navy Blue.

	Cotton (Dokki) before washing			Cotton (Dokki) after washing		
	Langmuir model	**Freundlich model**	**Dubinin – Radushkevich model**	**Langmuir model**	**Freundlich model**	**Dubinin – Radushkevich model**
R^2	0.9373	0.9863	0.9933	0.9612	0.908	0.9915
ΔE (mg/g)	0.919963	0.005597425	1.0167	0.738007	0.003322067	1.0398
K	-2.448758	91.1591		-1.198672	140.2168	
1/n		-0.4341			-0.6468	
β			-0.0122			-0.0349
E			6.40			3.79
RMSE	19.986	21.114	19.868	15.294	16.141	14.956
SAE	3.335	7.907	2.852	2.275	5.680	1.953
ARE	38.632	99.627	32.181	32.018	99.654	34.117
	Cotton (Helwan) before washing			**Cotton (Helwan) after washing**		
R^2	0.8629	0.9993	0.9959	0.995	0.9534	0.9981
ΔE (mg/g)	1.128668	0.010220181	1.0185	0.657895	0.030043797	1.0369

	Cotton (Dokki) before washing			Cotton (Dokki) after washing		
	Langmuir model	**Freundlich model**	**Dubinin – Radushkevich model**	**Langmuir model**	**Freundlich model**	**Dubinin – Radushkevich model**
K	-0.812867	55.9758		-1.432697	24.0880	
1/n		-0.343			-0.2521	
β			-0.0139			-0.0323
E			6.00			3.93
RMSE	18.689	20.050	18.821	15.404	16.130	14.978
SAE	1.924	7.421	2.380	2.424	5.563	2.044
ARE	20.986	99.269	27.108	32.734	96.928	33.482

Table 4. Isotherm parameters for different isotherm models for pollutants adsorbed onto dyed wool fabric with Acid Yellow 36.

	Wool (Dokki) before washing			Wool (Dokki) after washing		
	Langmuir model	**Freundlich model**	**Dubinin – Radushkevich model**	**Langmuir model**	**Freundlich model**	**Dubinin – Radushkevich model**
R^2	0.9748	0.9989	0.9955	0.9104	0.968	0.9962
ΔE (mg/g)	3.90625	0.001731639	1.0016	3.831418	0.002016792	1.0017
K	-2.069141	242.2144		-1.976628	212.9610	
1/n		-0.3434			-0.3231	
β			-0.0008			-0.0009
E			25.00			23.57
RMSE	67.845	72.781	71.502	65.397	70.237	68.958
SAE	8.504	28.026	23.027	7.900	27.047	22.048
ARE	29.507	99.969	81.925	28.361	99.962	81.270
	Wool (Helwan) before washing			**Wool (Helwan) after washing**		
R^2	0.9665	0.9964	0.9961	0.9037	0.9624	0.997
ΔE (mg/g)	3.968254	0.002006899	1.0016	3.816794	0.002497922	1.0018
K	-1.946825	213.8454		-1.807634	177.9099	
1/n		-0.3165			-0.2889	
β			-0.0008			-0.0010
E			25.00			22.36
RMSE	67.414	72.428	71.149	63.511	68.330	67.052
SAE	8.065	27.896	22.898	7.239	26.311	21.314
ARE	28.103	99.964	81.853	26.675	99.952	80.754

Table 5. Isotherm parameters for different isotherm models for pollutants adsorbed onto dyed nylon fabric with Acid Yellow 36.

	Nylon (Dokki) before washing			Nylon (Dokki) after washing		
	Langmuir model	**Freundlich model**	**Dubinin – Radushkevich model**	**Langmuir model**	**Freundlich model**	**Dubinin – Radushkevich model**
R^2	0.9393	0.996	0.9731	0.8733	0.9603	0.9852
ΔE (mg/g)	0.347343	0.00088681	1.0477	0.329381	0.00276706	1.0604
K	-3.87322	428.4499		-3.464097	163.3052	
1/n		-0.931			-0.7489	
β			-0.0430			-0.0588
E			3.41			2.92
RMSE	14.219	14.625	13.424	11.783	12.165	10.962
SAE	3.456	5.189	2.055	2.670	4.303	1.886
ARE	58.911	99.895	49.284	54.257	99.616	59.194
	Nylon (Helwan) before washing			**Nylon (Helwan) after washing**		
R^2	0.8309	0.9421	0.977	0.7477	0.8852	0.9807
ΔE (mg/g)	0.40568	0.000504385	1.0388	0.206612	0.00025243	1.0903
K	-4.037606	697.2684		-4.518182	1275.5574	
1/n		-0.9949			-1.2479	
β			-0.0332			-0.0935
E			3.88			2.31
RMSE	15.403	15.891	14.661	11.416	11.651	10.457
SAE	3.766	5.791	1.881	2.981	4.013	2.279
ARE	59.043	99.949	36.546	65.506	99.958	93.169

Table 6. Isotherm parameters for different isotherm models for pollutants adsorbed onto dyed polyester fabric with Disperse Orange.

	Polyester (Dokki) before washing			Polyester (Dokki) after washing		
	Langmuir model	**Freundlich model**	**Dubinin – Radushkevich model**	**Langmuir model**	**Freundlich model**	**Dubinin – Radushkevich model**
R^2	0.9997	0.9936	1	0.8535	0.9706	0.9481
ΔE (mg/g)	1.422475	0.045295496	1.0135	0.62422	0.005556643	1.0138
K	-0.31835	17.6929		-1.660112	91.7065	
1/n		-0.0403			-0.5605	
β			-0.0096			-0.0094
E			7.22			7.29
RMSE	22.567	24.246	23.058	17.032	17.677	16.641
SAE	1.959	8.845	4.003	3.470	5.621	2.975
ARE	16.729	97.348	40.670	96.843	98.875	138.368
	Polyester (Helwan) before washing			**Polyester (Helwan) after washing**		
R^2	0.9805	0.9998	0.9929	0.8026	0.9351	0.9601
ΔE (mg/g)	1.712329	0.017639728	1.0065	0.569801	0.010404033	1.0157
K	-0.628938	36.3329		-1.485242	55.1823	
1/n		-0.1534			-0.4716	
β			-0.0041			-0.0107
E			11.04			6.84
RMSE	25.014	27.121	25.881	16.196	16.754	15.770
SAE	1.912	10.241	5.296	3.245	5.086	2.980
ARE	16.180	99.118	49.693	137.413	96.890	229.509

Table 7. Isotherm parameters for different isotherm models for pollutants adsorbed onto dyed Nylon/polyester fabric with Disperse Orange.

	Nylon/Polyester (Dokki) before washing			Nylon/Polyester (Dokki) after washing		
	Langmuir model	**Freundlich model**	**Dubinin – Radushkevich model**	**Langmuir model**	**Freundlich model**	**Dubinin – Radushkevich model**
R^2	0.9422	0.9022	0.9997	0.9433	0.9937	0.998
ΔE (mg/g)	3.154574	0.004655515	1.0015	3.937008	0.005035159	1.0017
K	-2.336909	106.0474		-0.746063	99.4260	
1/n		-0.187			-0.1895	
β			-0.0008			-0.0009
E			25.00			23.57
RMSE	59.805	63.775	62.506	55.491	60.410	59.144
SAE	8.698	24.448	19.463	4.224	23.104	18.120
ARE	34.198	99.903	79.109	17.135	99.888	77.797
	Nylon/Polyester (Helwan) before washing			**Nylon/Polyester (Helwan) after washing**		
R^2	0.7627	0.6807	1	0.826	0.8064	0.9996
ΔE (mg/g)	3.802281	0.00859618	1.0015	3.184713	0.006966444	1.0015
K	-1.894677	64.3280		-2.388217	76.2606	
1/n		-0.0467			-0.1049	
β			-0.0007			0.0008
E			26.73			#NUM!
RMSE	62.516	67.317	66.045	59.502	63.513	62.245
SAE	6.966	25.934	20.969	8.487	24.376	19.403
ARE	26.188	99.833	80.558	33.598	99.855	79.119

Table 8. Isotherm parameters for different isotherm models for pollutants adsorbed onto dyed wool/polyester fabric with Disperse Orange.

	Wool/Polyester (Dokki) before washing			Wool/Polyester (Dokki) after washing		
	Langmuir model	**Freundlich model**	**Dubinin – Radushkevich model**	**Langmuir model**	**Freundlich model**	**Dubinin – Radushkevich model**
R^2	0.7008	0.8275	0.9996	0.947	0.9968	0.9965
ΔE (mg/g)	2.016129	0.011983794	1.0027	1.492537	0.009342236	1.0075
K	-2.871371	49.2947		-1.042239	60.1589	
1/n		-0.0783			-0.287	
β			-0.0015			-0.0048
E			18.26			10.21

	Wool/Polyester (Dokki) before washing			Wool/Polyester (Dokki) after washing		
	Langmuir model	**Freundlich model**	**Dubinin – Radushkevich model**	**Langmuir model**	**Freundlich model**	**Dubinin – Radushkevich model**
RMSE	42.754	45.276	44.021	23.559	25.402	24.154
SAE	7.249	17.270	12.316	2.339	9.608	4.617
ARE	40.055	99.644	70.187	21.600	99.496	45.677
	Wool/Polyester (Helwan) before washing			**Wool/Polyester (Helwan) after washing**		
R^2	0.9759	0.9998	0.9986	0.9722	0.9998	0.9957
ΔE (mg/g)	3.278689	0.012371594	1.0028	1.709402	0.017515575	1.0071
K	-0.340656	48.0618		-0.632479	36.5342	
1/n		-0.0775			-0.1549	
β			-0.0016			-0.0046
E			17.68			10.43
RMSE	42.242	46.361	45.094	24.259	26.385	25.131
SAE	1.518	17.849	12.897	1.603	10.062	5.114
ARE	7.974	99.653	71.853	14.578	99.125	49.671

4. Conclusions

Three different types of dyed fabrics with suitable dye, including natural (silk, wool, and cotton), synthetic (nylon and polyester), and some blends (wool/polyester and nylon/polyester), were exposed for 120 days in two locations, the first in a residential area of Cairo city (Dokki place), and the second in an industrial area of Cairo city (Helwan place), both of which represent high levels of air pollution. The color strength of exposed fabrics has been examined throughout a range of exposure times (0 to 120 days), and it is evident that dyed natural fabrics have lower color strength values than synthetic or mixed fabrics, which gives them a greater capacity to absorb air pollution than synthetic or blended fabrics. Tensile strength and elongation characteristics of exposed textiles after various times (30, 60, 90, and 120 days) have been studied. At each of the tested sites, it is evident that dyed natural textiles offer a greater loss in tensile strength than synthetic or mixed fabrics. This discrepancy gets bigger when the number of contaminants in the air worsens (in the industrial atmosphere more than in the residential atmosphere). The most popular models for textile fibers are Langmuir, Freundlich, and Dubinin-Radushevich models, and they all confirm that dyed fabric surfaces absorb air pollutants in a homogeneous layer. Various isothermal models have been investigated to describe the behavior of air pollution to adsorb on the fabric's surface.

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Conflicts of Interest

The authors declare no conflict of interest.

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