ARAB REPUBLIC OF EGYPT: COST OF ENVIRONMENTAL DEGRADATION

Air and Water Pollution

Korea Green Growth Trust Fund

PMEH POLLUTION MANAGEMENT & ENVIRONMENTAL HEALTH

WORLD BANK GROUP
Environment, Natural Resources & Blue Economy

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AIR AND WATER POLLUTION

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TABLE OF CONTENTS

FIGURES

TABLES

ACRONYMS

AAP	Ambient air pollution
AF	Attributable fraction
ALRI	Acute lower respiratory infection
CAIP	Cairo Air Improvement Project
CAPMAS	Central Agency for Public Mobilization and Statistics
CBV	Cerebrovascular disease
CDR	Crude death rate per 1,000 population
COI	Cost-of-illness
COPD	Chronic obstructive pulmonary disease
CP	Cardiopulmonary disease
DHS	Demographic and Health Survey
EEAA	Egyptian Environmental Affairs Agency
EIMP	Egyptian Information and Monitoring Program
EU	European Union
GBD	Global Burden of Disease
GDP	Gross domestic product
HFO	Heavy fuel oil
IER	Integrated exposure-response
IHD	Ischemic heart disease
JMP	Joint Monitoring Programme
KGGTF	Korean Green Growth Trust Fund
LC	Lung cancer
LE	Egyptian pound (currency)
$\mu g/m^3$	microgram per cubic meter
MOF	Ministry of Finance
OECD	Organisation for Economic Co-operation and Development
PM	Particulate matter
PMEH	Pollution Management and Environmental Health
PPP	Purchasing power parity
RR	Relative risk
SHS	Second hand smoking
UNICEF	United Nations Children's Fund
VSL	Value of statistical life
WASH	Water, sanitation, and hygiene
WHO	World Health Organization
WTP	Willingness-to-pay
YLD	Years lived with disability

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CHAPTER ONE

INTRODUCTION

Quantitative assessments of health impacts from environmental pollution are useful information for government and the general public. Such assessments can serve as an instrument to identify environmental priorities, mobilize support for their implementation, and, more broadly, to advance toward realizing environmental objectives.

This report provides estimates of health effects of ambient air pollution (AAP) in Greater Cairo, and inadequate household drinking water, sanitation, and hygiene (WASH) nationwide in Egypt. Monetized estimates are provided of the social and economic cost of these health effects in Egyptian pounds and as a percentage of Egypt's Gross Domestic Product (GDP) in 2016/17, using standard economic valuation techniques. The report utilizes the latest health risk assessment methodologies from the Global Burden of Disease (GBD) 2017, published in *The Lancet* in November 2018 (Stanaway et al., 2018).[1]

The report finds that 19,200 people died prematurely and over 3 billion days were lived with illness in Egypt in 2017 as a result of ambient $PM_{2.5}$ air pollution in Greater Cairo, and inadequate water, sanitation, and hygiene in all of Egypt. The estimated cost of these health effects was equivalent to 2.5% of Egypt's GDP in 2016/17. The cost of ambient $PM_{2.5}$ air pollution in Greater Cairo was highest, with a central estimate of LE 47 billion, equivalent to 1.35% of GDP. The cost of inadequate drinking water, sanitation, and hygiene nationwide was LE 39 billion, equivalent to 1.15% of GDP. However, water related costs are likely higher than suggested by this figure because of undetermined exposure to lead, other heavy metals, and chemicals through drinking water.

On a per capita basis, the cost of ambient air pollution in Greater Cairo was LE 2.7 billion per one million people. This is nearly seven times higher than the nationwide cost per million people of inadequate water, sanitation, and hygiene. While the report finds that air quality, in terms of $PM_{2.5}$ concentrations, improved in Greater Cairo over the period from 1999 to 2016, it was outpaced by population growth, resulting in an increase in annual deaths from ambient $PM_{2.5}$. Annual deaths from ambient $PM_{2.5}$ per 100,000 people did, however, decline by 8% from 79 to 73 from 1999 to 2017.

[1]The methodologies are available in Supplementary Appendix 1 to Stanaway et al. (2018), and in Annexes 1 and 2 in this report.

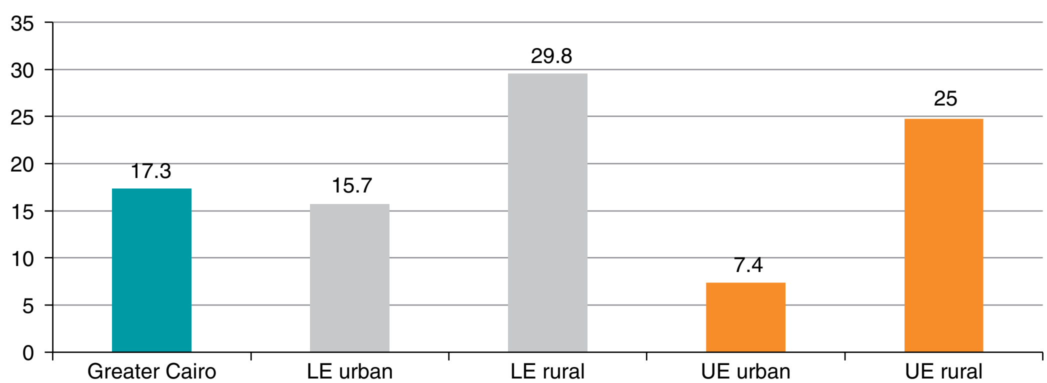
CHAPTER TWO

AMBIENT AIR POLLUTION

2.1 POPULATION

The population of Egypt reached 95 million in 2017 (CAPMAS, 2018). About 58% of the population or 55 million people lived in rural areas while 40 million lived in urban areas. The population of Greater Cairo was over 17 million.[2] The population in Lower Egypt (LE) and Upper Egypt (UE) was over 45 million and 32 million respectively (figure 2.1). Lower and Upper Egypt is here defined as governorates south and north of Greater Cairo, respectively.[3] GDP per capita in Egypt was LE 37,192 in 2016/17 (US$2,527) (MOF, 2018).

FIGURE 2.1: POPULATION OF EGYPT IN 2017 (MILLION)



Source: CAPMAS (2018).

2.2 AMBIENT PM AIR QUALITY

Particulate matter (PM) and especially $PM_{2.5}$ is the outdoor air pollutant that globally is associated with the largest health effects (Stanaway et al., 2018). The WHO reduced its guideline limits over a decade ago to an annual average ambient concentration of 10 micrograms per cubic meter ($\mu g/m^3$) of $PM_{2.5}$ and 20 $\mu g/m^3$ of PM_{10} in response to increased evidence of health effects at very low concentrations of PM.

[2] Greater Cairo includes Cairo governorate, the urban population of Giza and Kalyoubia, and 10th of Ramadan City in Sharkia governorate.
[3] This includes the 1.7 million population of the Western and Eastern Deserts and North and South Sinai.

TABLE 2.1: AIR QUALITY MONITORING STATIONS IN EGYPT

	Greater Cairo	Alexandria	Delta	Upper Egypt	Sinai and Canal Cities	Total
EIMP (1999)	14	8	10	9	1	42
CAIP (1998)	34					34
Other (2000+)			3	6	2	11
Total	**48**	**8**	**13**	**15**	**3**	**87**

Source: Sivertsen et al. (2000); Saffar and Labib (2010); EEAA (2015).

2.2.1 AIR QUALITY MONITORING NETWORK

Monitoring data of $PM_{2.5}$ ambient air quality of the Egyptian Environmental Affairs Agency (EEAA) are utilized in this report to provide estimates of health effects of ambient air pollution in Greater Cairo. Nationwide health effects are not presented due to insufficient air quality monitoring outside of Greater Cairo.

The national air quality monitoring network of EEAA consists of 87 stations (table 2.1). The monitoring sites are classified as 19 industrial, 21 urban, 11 residential, 11 traffic, 9 remote, and 16 mixed (EEAA, 2015).

Forty-two of the stations were designed and developed during 1997–1999 under the Egyptian Information and Monitoring Program (EIMP) (Sivertsen et al., 2000). These sites monitor PM_{10} and other criteria pollutants, but not $PM_{2.5}$. Thirty-four stations were established under the Cairo Air Improvement Project (CAIP). Formal operation of the CAIP monitoring network began on October 1, 1998. Twenty-four of the stations monitor $PM_{2.5}$ while all monitor PM_{10} (Safar and Labib, 2010).[4] Additionally, 11 stations were developed at a later stage in the Delta, Upper Egypt, and Sinai and Canal Cities.

The air quality monitoring network in Greater Cairo consists of 48 sites. Thirty-four sites were established under CAIP in 1998 and 14 sites under EIMP in 1999. Twenty-four of the CAIP sites monitor $PM_{2.5}$ and all CAIP and EIMP monitor PM_{10}. The EIMP sites also monitor other criteria pollutants, but not $PM_{2.5}$ (Saffar and Labib, 2010).

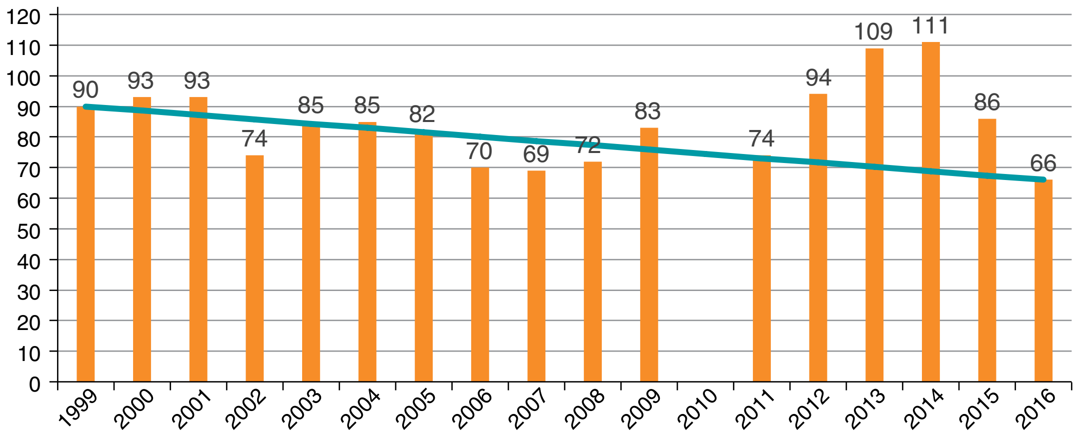
The 24 sites that monitor $PM_{2.5}$ in Cairo are classified as 1 traffic, 4 mixed, 9 residential, 7 industrial, and 1 "background" or rural/agricultural site (Kaha outside of Cairo), while 2 sites monitor source emissions in Shoubra El-Kheima and Tebbin (Saffar and Labib, 2010).

2.2.2 AMBIENT CONCENTRATIONS OF PM

Annual average ambient $PM_{2.5}$ in Greater Cairo is many times higher than WHO air quality guidelines. Annual $PM_{2.5}$ in Greater Cairo from 1999 to 2016 are presented in figure 2.2. Average concentrations over the 18-year period was 84 $\mu g/m^3$ with the lowest concentration of 66 $\mu g/m^3$ in 2016. Thus, ambient concentrations of $PM_{2.5}$ seem to have declined in Greater Cairo in the most recent years. This is also the case at Kaha (Qaha), 15 km north of urban Greater Cairo, but concentrations are not much lower than in urban Greater Cairo.

[4]There were originally 37 sites. Two sites were cancelled and one site relocated in 2001–2002.

FIGURE 2.2: ANNUAL AVERAGE $PM_{2.5}$ IN GREATER CAIRO 1999–2016 (μG/M³)



Source: Calculated by the author based on data provided by EEAA.

Ambient concentrations of PM_{10} also appear to be high at the monitoring locations in Lower and Upper Egypt. Concentrations in Lower Egypt (LE) are as high as in Greater Cairo (GC), with concentrations in Upper Egypt (UE) substantially higher. Concentrations of PM_{10} in Ras Mohammad at the southern tip of the Sinai Peninsula are less than half of concentrations in Kaha (Qaha) (see table 2.2).

Measurement data of PM_{10} and $PM_{2.5}$ from the same monitoring stations in Greater Cairo are available for the year 2016. The data demonstrates seasonal variations in both PM_{10} and $PM_{2.5}$ with the lowest concentrations in July and August and the highest in December to February (figure 2.3). The annual average $PM_{2.5}/PM_{10}$ ratio is 0.40. Annual average PM_{10} and $PM_{2.5}$ were 165 μg/m³ and 66 μg/m³ respectively.

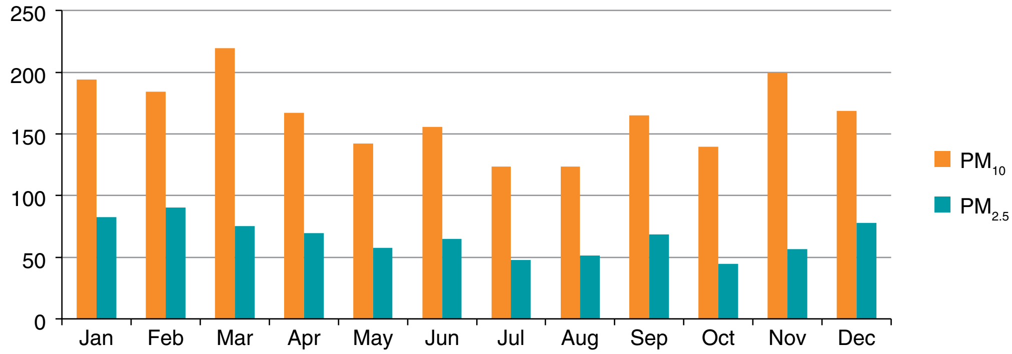
It should be mentioned that the monitoring data presented here may be influenced by the type of equipment, measurement procedures, equipment maintenance, and other factors.

TABLE 2.2: ANNUAL AVERAGE AMBIENT PM_{10} AND $PM_{2.5}$ IN EGYPT (μG/M³)

	PM_{10}							$PM_{2.5}$
	GC-1	**Qaha (GC-1)**	**GC-2**	**Qaha (GC-2)**	**LE**	**UE**	**Ras Mohammad**	**GC**
2017*			117	117	123	186		
2016	125	131	165	131	120	201	54	66
2015	132	127	197	180	136	178	66	86
2014	153	137	205	251	148	186		111
2013	161	181						109
2012	179	178						
2011	166	186						
2010	177	248						

Note: GC-1 = Greater Cairo (stations set 1), GC-2 = Greater Cairo (stations set 2), LE = Lower Egypt, UE = Upper Egypt.
* January–October. Source: Calculated by the author based on EEAA ambient $PM_{2.5}$ and PM_{10} monitoring data.

FIGURE 2.3: MONTHLY AVERAGE PM_{10} AND $PM_{2.5}$ IN GREATER CAIRO IN 2016 (μG/M^3)



Source: Calculated by the author based on EEAA daily ambient $PM_{2.5}$ and PM_{10} monitoring data.

2.3 POPULATION EXPOSURE TO AMBIENT $PM_{2.5}$

Ground monitoring data from EEAA for the years 2015 and 2016 are applied in this report to estimate ambient $PM_{2.5}$ exposure in Greater Cairo. The central estimate for Greater Cairo is 76 μg/m^3. This is the annual average $PM_{2.5}$ in 2015 and 2016. The lower bound estimate (66 μg/m^3) is the annual $PM_{2.5}$ in 2016, and the upper bound estimate (86 μg/m^3) is the annual $PM_{2.5}$ in 2015. $PM_{2.5}$ measurements for the year 2017 have not been made available.

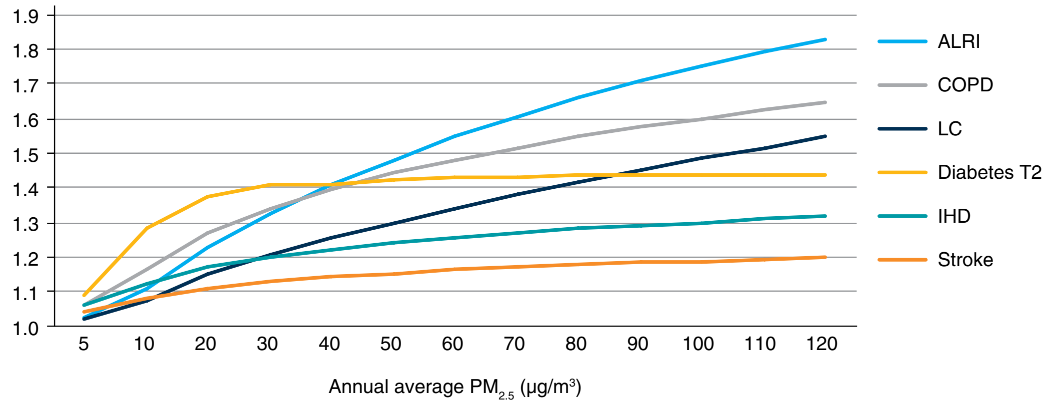
2.4 HEALTH RISKS OF AMBIENT $PM_{2.5}$ EXPOSURE

The main health risks of ambient $PM_{2.5}$ exposure assessed by WHO and the GBD Project are cardiovascular disease, pulmonary disease, and lung cancer mortality and morbidity. The risk of disease is expressed as relative risk (RR), or risk of disease from ambient $PM_{2.5}$ exposure relative to the risk if there is no $PM_{2.5}$ exposure. The risks normally reflect long-term exposure to ambient $PM_{2.5}$.

The health effects of ambient $PM_{2.5}$ exposure are estimated in this report using RR functions from the GBD 2017 (Stanaway et al., 2018). The health outcomes are ischemic heart disease (IHD), cerebrovascular disease (stroke) (CBV), chronic obstructive pulmonary disease (COPD), lung cancer, and diabetes Type II among adults (25+ years of age), and acute lower respiratory infections (ALRI) among children and adults (all ages) (figure 2.4).

An advantage of the "integrated exposure-response" (IER) or health risk function of the GBD Project is that it is age-specific for the two largest health outcomes (i.e., IHD and stroke) with a unique risk curve in relation to exposure level for each five-year population cohort. This is important because risk of health effects from $PM_{2.5}$ differs by age, and population age distribution and age-specific mortality rates differ from country to country. This development therefore provides increased confidence in applying the IER function across countries and regions.

FIGURE 2.4: RELATIVE RISKS OF MAJOR HEALTH OUTCOMES ASSOCIATED WITH $PM_{2.5}$ EXPOSURE, GBD 2017



Note: RRs of IHD and stroke are age-weighed.

Source: Produced from Stanaway et al. (2018) Supplement.

2.5 ESTIMATED HEALTH EFFECTS

Annual premature deaths from ambient $PM_{2.5}$ exposure in Greater Cairo are estimated at about 12,100 to 13,000 in 2017, with a central estimate of nearly 12,600 (table 2.3). About 59% of the estimated deaths from ambient $PM_{2.5}$ are due to ischemic heart disease (IHD), 14% due to acute lower respiratory infections (ALRI), 13% due to stroke, and 14% due to COPD, lung cancer and diabetes Type II. These estimates are based on annual ambient $PM_{2.5}$ exposure in the range of 66–86 $\mu g/m^3$ with a central estimate of 76 $\mu g/m^3$.

The step-by-step procedure to estimate annual deaths from ambient $PM_{2.5}$ in Greater Cairo is presented in table 2.4 for the central estimate of $PM_{2.5}$ exposure. This is summarized below with further details and data in annex 1.

Baseline deaths

Estimation of annual deaths from ambient $PM_{2.5}$ requires an estimate of annual baseline deaths in Greater Cairo for each of the six health outcomes associated with $PM_{2.5}$ exposure among the relevant age groups (i.e., among all age groups for ALRI, and among the population 25+ years of age for the other five health outcomes).

TABLE 2.3: ESTIMATED ANNUAL DEATHS FROM AMBIENT $PM_{2.5}$ AIR POLLUTION IN GREATER CAIRO, 2017

	Low	Central	High
IHD	7,176	7,437	7,666
Stroke	1,545	1,601	1,651
COPD	875	912	945
Lung cancer	244	262	278
ALRI	1,608	1,701	1,781
Diabetes Type II	654	655	655
Total	**12,103**	**12,569**	**12,976**

Source: Estimates by the author based on mortality data from CAPMAS (2018) and GBD 2017 (see www.healthdata.org), and RRs from GBD 2017.

TABLE 2.4: STEP-BY-STEP ESTIMATION OF ANNUAL DEATHS FROM AMBIENT $PM_{2.5}$ IN GREATER CAIRO, CENTRAL ESTIMATE 2017

	IHD	Stroke	COPD	Lung cancer	Diabetes II	ALRI	Other	Total
Baseline annual deaths (all ages)	34,655	10,966	2,692	927	2,160	4,370	49,283	105,053
Baseline annual deaths (25+ years)	34,480	10,805	2,623	914	2,146	4,370*		
$PM_{2.5}$ (ug/m^3)	76	76	76	76	76	76	76	76
Relative risk (RR)	1.275	1.174	1.534	1.402	1.439	1.637	1.000	
Attributable fraction (AF)	0.2157	0.1482	0.3479	0.2868	0.3053	0.3893	0.0000	
Annual deaths from $PM_{2.5}$	7,437	1,601	912	262	655	1,701	0	12,569

Source: Estimates by the author based on mortality data from CAPMAS (2018) and GBD 2017, and RRs from GBD 2017.
* All age-groups.

The GBD 2017 presents estimates of annual deaths in Egypt in 2017 by each cause of death and by age group, based on Egyptian vital registration, household surveys (e.g., Egypt Demographic and Health Survey), specialized surveys and reports, and the broader international evidence of the cause-specific structure of mortality by country income level, socioeconomic characteristics, and other determinants of cause-specific mortality rates.[5] According to GBD 2017, 52% of total deaths in Egypt in 2017 were from the six causes of death associated with ambient $PM_{2.5}$ exposure.[6]

These estimated deaths are first adjusted by the difference in the crude death rate (CDR) in GBD 2017 and the rate of 5.7 per 1,000 population reported by CAPMAS (2018). Secondly, the estimated deaths in GBD 2017 are adjusted for the difference in age distribution in Greater Cairo and in Egypt nationally reported by the Egypt Population Census 2017. The population in Greater Cairo is older than the rest of the Egyptian population. Death rates among older individuals are generally higher than among younger individuals. This results in a CDR of 6.05 in Greater Cairo. The estimated baseline annual deaths in Greater Cairo are presented in table 2.4. Deaths by age group are presented in annex 1.

Relative risks

The relative risk of death from ambient $PM_{2.5}$ exposure for each of the six causes of death in table 2.4 is calculated based on the relative risk functions in the GBD 2017 presented in figure 2.4 and annual $PM_{2.5}$ exposure in Greater Cairo. For the average $PM_{2.5}$ concentration of Greater Cairo (76 ug/m^3), the relative risks range from 1.17 for stroke to 1.64 for ALRI. The relative risk is 1.00 (meaning no health effects from ambient $PM_{2.5}$) for health outcomes other than the six health outcomes associated with $PM_{2.5}$ exposure.

Attributable fractions

The attributable fractions indicate how large of a share of baseline deaths are caused by ambient $PM_{2.5}$ exposure. The attributable fractions are calculated from the relative risks

[5]See: http://ghdx.healthdata.org/gbd-2017/data-input-sources
[6]www.healthdata.org

and the share of the population exposed to a particular $PM_{2.5}$ concentration, as detailed in annex 1.[7]

Annual deaths from $PM_{2.5}$

Annual deaths from ambient $PM_{2.5}$ are then calculated by multiplying the attributable fractions with the baseline annual deaths. Annual deaths from $PM_{2.5}$ are 12% of all deaths in Greater Cairo in 2017 (table 2.4).

In addition to mortality, ambient $PM_{2.5}$ in Greater Cairo is estimated to cause about 59,800–61,800 "years lived with disability" (YLD), with a central estimate of nearly 61,000.[8] This translates to 246–253 million days lived with disease in 2017, with a central estimate of 250 million (tables 2.5–2.6). About 60% of YLDs and days lived with disease are from diabetes

TABLE 2.5: DAYS LIVED WITH DISEASE FROM AMBIENT $PM_{2.5}$ IN GREATER CAIRO, 2017 (MILLION)

	Low	Central	High
IHD	5.7	5.9	6.1
Stroke	8.3	8.6	8.8
COPD	74.7	77.8	80.6
Lung cancer	0.10	0.11	0.11
ALRI	5.9	6.2	6.5
Diabetes Type II	151.1	151.3	151.3
Total	**245.7**	**249.9**	**253.4**

Source: Estimates by the author based on YLDs per death and disability weights from GBD 2017 for Egypt.

TABLE 2.6: YLDS AND DAYS LIVED WITH DISEASE FROM AMBIENT $PM_{2.5}$ IN GREATER CAIRO, CENTRAL ESTIMATE, 2017

	YLDs per Death	Deaths	YLDs	Disability Weights	Days Lived with Disease (million)
IHD	0.08	7,437	558	0.035	5.9
Stroke	2.20	1,601	3,515	0.150	8.6
COPD	21.8	912	19,935	0.093	77.8
Lung cancer	0.25	262	65	0.226	0.1
ALRI	0.61	1,701	1,046	0.061	6.2
Diabetes Type II	54.6	655	35,762	0.086	151.3
Total from $PM_{2.5}$		**12,569**	**60,882**		**249.9**

Source: Estimates by the author based on YLDs per death and disability weights from GBD 2017 for Egypt.

[7]The whole population of 17.3 million in Greater Cairo is assumed to be exposed to the central estimate of $PM_{2.5}$. Therefore the attributable fraction formula is simply: AF = (RR – 1)/RR for each of the six health outcomes. The central estimate (76 $\mu g/m^3$) is the population weighed average exposure level. In reality some of the population is exposed to higher and some to lower concentrations than the central estimate. Due to the concavity of the risk functions (i.e., declining marginal increase in health effects at higher $PM_{2.5}$ exposure levels), the health effects are somewhat overestimated by applying the central estimate to the whole population. The overestimation is however very small. For instance, by assuming half of the population is exposed to $PM_{2.5}$ of +25% and half to –25% of the central estimate, results in only a 0.7% lower estimate of annual deaths from ambient $PM_{2.5}$.

[8]This is calculated as the number of deaths from $PM_{2.5}$ multiplied by YLDs per death. YLDs per death is from GBD 2017 for Egypt. YLD = M * d where M is number of days lived with disease and d is the disability weight ranging from 0 to 1 in severity.

Type II followed by 32% from COPD. Only about 8% of YLDs and days lived with disease are from IHD, stroke, lung cancer, and ALRI. The very large number of days lived with disease per year is due to the chronic nature of most of the health outcomes. A person that, for instance gets COPD or diabetes, lives with the disease all year.

2.6 COST OF HEALTH EFFECTS

The annual cost of the health effects of ambient $PM_{2.5}$ air pollution in Greater Cairo is estimated at LE 45-48 billion in 2016/17 with a central estimate of LE 47 billion. This is equivalent to 1.3% to 1.4% of GDP in 2016/17 with a central estimate of 1.35% (table 2.7).

TABLE 2.7: ESTIMATED ANNUAL COST OF HEALTH EFFECTS OF AMBIENT $PM_{2.5}$ IN GREATER CAIRO, 2016/17 (LE BILLION)

	Low	Central	High
Cost of mortality	36.9	38.3	39.5
Cost of morbidity	8.5	8.7	8.8
Total cost of health effects	**45.4**	**47.0**	**48.4**
% equivalent of GDP, 2016/17	1.31%	1.35%	1.39%

Source: Estimates by the author.

The cost of mortality is calculated as the value of statistical life (VSL), i.e., LE 3.0 million, multiplied by the estimated number of deaths. The cost of mortality accounts for 82% of total cost.[9] Cost of morbidity is calculated as a fraction of the average daily wages of LE 155 multiplied by the number of days lived with disease. The fraction of the wage rate is determined by the disability weight (severity) of the disease (see annex 3).

2.7 SOURCES OF $PM_{2.5}$ IN GREATER CAIRO

Gaining a perspective on what are the main sources of $PM_{2.5}$ and their relative contribution to ambient $PM_{2.5}$ is an important step toward assessing and identifying mitigation measures with lowest cost and highest benefit-cost ratios of improving air quality. There are three commonly applied methods available toward this aim:

1) Emission inventories;
2) Emission dispersion modeling;
3) Source apportionment studies.

Emission inventories are useful in order to understand the magnitude of emissions from various sources, such as traffic, industry, municipal waste burning, power plants, and residential fuel burning. However, emission inventories will have difficulties in portraying how much each of these sources contributes to ambient concentrations of a pollutant and do not capture the significance of secondary particulates (sulfates and nitrates) and area-wide sources such as resuspended dust, windblown dust from the desert, and long distance agricultural burning.

[9] The value of statistical life (VSL) is a welfare measure derived from individuals' willingness-to-pay (WTP) for a reduction in the risk of death. The VSL estimated for Egypt is LE 3.0 million based on a GDP per capita of LE 37,192 in 2016/17 according to MOF (2018) and the methodology for estimating the VSL in World Bank (2016) and World Bank and IHME (2016) (see annex 3).

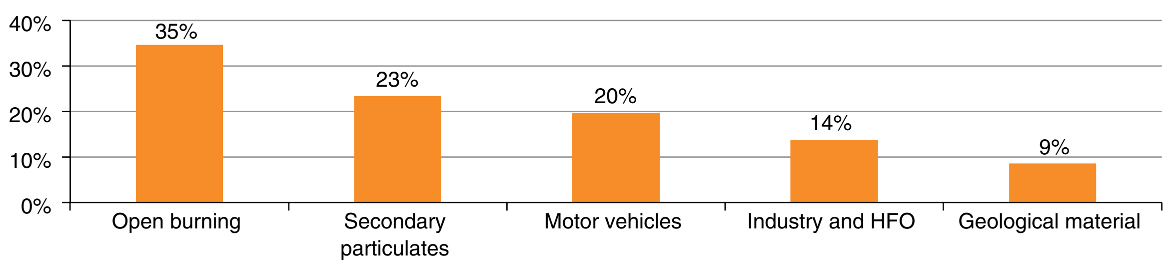
Emission dispersion modeling is very useful for estimating the contribution of large stationary point sources to ambient air quality. The results can therefore be used to estimate health effects per ton of emissions, which can be compared to the cost of emission control. Dispersion modeling is often applied to power plants and large industrial emission sources but can also be applied to emission from mobile sources. The results from dispersion modeling can also be used to estimate so-called emission intake fractions. The intake fraction tells us how much of a ton of emissions is eventually inhaled by the population and is therefore used for estimating health effects per ton of emissions.

Source apportionment studies analyze the chemical characteristics of ambient particulate matter such as $PM_{2.5}$ or PM_{10}. This analysis can therefore identify the likely sources of PM and apportion the PM to these sources, thus providing a perspective on the relative contribution of each source to ambient PM. Once a PM apportionment has been conducted, the results can be combined with an emission inventory to estimate the impact of a ton of emission on ambient concentrations from each source in the inventory. A cost-benefit analysis of mitigation options can then be undertaken. Apportionment studies in Egypt are discussed below.

The most comprehensive apportionment study in Egypt seems to be an assessment of $PM_{2.5}$ and PM_{10} in Greater Cairo in the winter (February 21 to March 3) and fall (October 27 to November 27) of 1999 and the summer (June 8 to June 26) of 2002 (Abu-Allaban et al., 2007). The study included five residential, industrial, and downtown monitoring sites, plus Kaha about 15 km north of urban Greater Cairo. These locations are a subset of EEAA's 24 locations with $PM_{2.5}$ monitoring stations.

The results of the study are summarized in figure 2.5. Open burning (including burning of agricultural waste in the Nile Delta), secondary particulates (sulfates, nitrates, chlorides), and motor vehicles were found to be the three most dominant sources of $PM_{2.5}$. Geological material (wind-blown natural dust) only contributed 9% of ambient $PM_{2.5}$ at the sites.

FIGURE 2.5: SOURCES OF AMBIENT $PM_{2.5}$ AT SIX SITES IN GREATER CAIRO, 1999 AND 2002



Note: HFO = heavy fuel oil.

Source: Produced from data in Abu-Allaban et al. (2007). The values are arithmetic averages of the six sites and three monitoring seasons.

There were large variations in importance of these sources to ambient $PM_{2.5}$ across sites over the monitoring periods (table 2.8):

- In *Kaha,* the highest contribution to ambient $PM_{2.5}$ was from open burning and secondary particulates, while geological material only contributed 4%. This is due to its agricultural location with relatively few motor vehicles and little industry.
- In *El-Qualaly* (downtown Cairo, close to road), *El-Zamalak* (residential with limited nearby point-sources of $PM_{2.5}$), *Helwan* (residential near industrial sources), and *El-Maassara* (near cement plants), the highest contribution was from open burning, motor vehicles, and secondary particulates, albeit with some variation across the sites.

TABLE 2.8: CONTRIBUTION TO AMBIENT $PM_{2.5}$ AT SIX SITES IN GREATER CAIRO, 1999 AND 2002

	Mean $PM_{2.5}$ ($\mu g/m^3$)	Open Burning	Motor Vehicles	Industry and HFO	Secondary Particulates	Geological Material
Kaha	65	53%	11%	3%	28%	4%
El-Qualaly	93	29%	35%	9%	24%	3%
El-Zamalek	78	34%	22%	9%	31%	4%
Helwan	59	40%	20%	6%	24%	11%
Shoubra El-Kheima	150	25%	15%	29%	17%	14%
El-Maassara	72	38%	16%	12%	22%	12%

Source: Produced from data in Abu-Allaban et al. (2007). The values are arithmetic averages of three monitoring seasons.

- In Shoubra El-Kheima (industrial site) the highest contribution was from industry followed by open burning.
- The highest contribution from geological material was at the sites with the most industry, that is *Shoubra El-Kheima*, *Helwan*, and *El-Massara*, perhaps suggesting that the main source of $PM_{2.5}$ geological material is not area-wide dust from desert winds, as dust from desert winds are mostly of coarse particle size (see below).

Source contribution to ambient $PM_{2.5}$ in Greater Cairo also varied substantially across seasons in 1999 and 2002 (table 2.9). Open burning and motor vehicles were the largest contributors in the summer season. Open burning was by far the largest contributor in the fall, with widespread burning of agricultural waste in the Nile Delta region. Industry and heavy fuel oil (HFO) and secondary particulates were the largest contributors in the winter. Geological material was the smallest source in all seasons, ranging from about 5 $\mu g/m^3$ (10%) in the summer to about 8–10 $\mu g/m^3$ in the fall and winter.

The PM apportionment study from 1999 and 2002 was repeated at five of the locations in the summer and fall of 2010, providing an opportunity for comparisons. The new study showed that open burning and motor vehicles continued to be the largest contributors to ambient $PM_{2.5}$ in Greater Cairo in the fall and summer, respectively, and that geological material continued to be a relatively minor source (table 2.10). However, the ambient levels of $PM_{2.5}$ reported by the study for the fall (52 $\mu g/m^3$) and summer (38 $\mu g/m^3$) of 2010 are substantially lower than EEAA reports for Greater Cairo. This makes it difficult to compare absolute changes in source specific and total ambient $PM_{2.5}$ across years.

TABLE 2.9: CONTRIBUTION TO AMBIENT $PM_{2.5}$ DURING THREE SEASONS IN GREATER CAIRO, 1999 AND 2002

	Mean $PM_{2.5}$ ($\mu g/m^3$)	Open Burning	Motor Vehicles	Industry and HFO	Secondary Particulates	Geological Material
Summer	49	30%	32%	10%	19%	10%
Fall	127	45%	16%	9%	23%	6%
Winter	84	18%	18%	26%	26%	12%

Source: Produced from data in Abu-Allaban et al. (2007). The values are arithmetic averages of the six monitoring sites.

TABLE 2.10: AMBIENT $PM_{2.5}$ CONTRIBUTIONS AT FIVE SITES IN GREATER CAIRO IN 1999/2002 AND 2010, % OF TOTAL $PM_{2.5}$

	Geological Material	Open Burning	Motor Vehicles	Secondary Particulates	Other	Total
Winter 1999	5.7%	22.0%	19.0%	33.1%	20.2%	100%
Fall 1999	5.1%	47.0%	17.0%	23.5%	7.4%	100%
Summer 2002	7.4%	28.0%	33.0%	18.8%	12.8%	100%
Summer 2010	17.0%	14.0%	36.0%	21.5%	11.5%	100%
Fall 2010	6.3%	39.0%	29.0%	13.1%	12.6%	100%

Source: Produced from Lowenthal, Gertler, and Labib (2014).

TABLE 2.11: AMBIENT CONCENTRATIONS OF PM_{10} AND $PM_{2.5}$ GEOLOGICAL MATERIAL μg/m^3

	Summer 2010		Fall 2010	
	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
El-Qualaly	52	5.1	29	3.0
Helwan	46	7.2	38	2.3
Kaha	54	8.6	39	3.9
Shobra	86	8.1	53	5.4
El-Zamalek	36	6.4	33	3.4
Average	55	7.1	38	3.6

Source: Produced from Lowenthal, Gertler, and Labib (2014).

An issue of interest is the non-anthropogenic contribution of natural dust from deserts (and marine particles) to ambient PM in Egypt in general and in Greater Cairo in particular. From the studies above, it seems that geological material (e.g., natural dust) only contributes a minor share. This is because geological material is largely of coarse particles of size 2.5–10 micrometers in diameter. In 2010 ambient geological material was in the range of 29–86 μg/m^3 of PM_{10} and 2.3–8.6 μg/m^3 of $PM_{2.5}$ at five sites in Greater Cairo (table 2.11). This disproportionate contribution of coarse particles from desert winds is also confirmed by assessment of satellite data over Cairo and the Nile Delta region (Marey et al., 2011).

The apportionment studies discussed above found that open burning and secondary particulates were the main sources of ambient $PM_{2.5}$ during all three seasons (fall, winter, summer), albeit of lower absolute magnitudes during summer and winter than the fall season.

A more recent study may suggest that natural sources may contribute more to ambient $PM_{2.5}$ in Greater Cairo than discussed above (Boman et al., 2013). The study monitored $PM_{2.5}$ from September 2010 to May 2011 at the National Research Center about 3 km east to southeast of the center of Cairo. Mean $PM_{2.5}$ was 51 μg/m^3. Mineral dust constituted 56% or 28.5 μg/m^3. However, monitoring took place only once a week for a period of 24 hours, and only at one site.

2.8 COMPARISON WITH PREVIOUS WORLD BANK ASSESSMENT

To allow for an assessment of the longer term trend in air quality and health effects in Greater Cairo, an analysis of 1999 (World Bank, 2002) and 2017 (this current study) is

TABLE 2.12: NON-COMPARABLE HEALTH EFFECTS AND COSTS OF AMBIENT AIR POLLUTION IN EGYPT, 1999–2017

Report	World Bank (this report)	World Bank (2002)
Year of assessment	2017	1999
Location coverage	Greater Cairo	Greater Cairo
Exposed population (million)	17.3	11.9
Annual ambient PM_{10} (μg/m^3)		270
Annual ambient $PM_{2.5}$ (μg/m^3)	76	110
Annual deaths from PM	12,569	18,924
Cost of ambient PM (% equivalent of GDP)	1.35%	2.1%*
Methodology for estimating annual deaths from PM	GBD, 2017	Ostro, 1994

* Cost of health effects only, and with valuation of mortality using VSL for consistency with this report for 2017.

presented in this section (table 2.12).[10] The cost of AAP in Greater Cairo ranged from an equivalent of 2.1% of GDP in 1999 to 1.35% of GDP in 2017.[11] The two studies can, however, not be directly compared for reasons discussed below:

1) *Ambient PM concentrations:* The study by World Bank (2002) applied higher ambient PM concentrations than subsequently available monitoring data indicates, contributing to a higher cost of ambient PM in 1999.
2) *Methodology for estimating health effects:* World Bank (2002) applied the methodology in Ostro (1994) for estimation of health effects with the assumption that health effects increase linearly or proportionately with increases in ambient PM. Recent research suggests, however, that the marginal increase in mortality from PM declines with increasing concentrations of $PM_{2.5}$ (Pope et al., 2009, 2011). This exposure-response relationship is featured in the GBD health risk assessment methodology used in the current study for 2017 for each of six health outcomes.

Health effects of ambient $PM_{2.5}$ in Greater Cairo in 1999 can be reassessed, and compared to 2017, using available $PM_{2.5}$ monitoring data from that time and the health risk assessment methodology from GBD 2017 applied in this report.

Published measurements of ambient PM_{10} and $PM_{2.5}$ in Greater Cairo in 1999 indicate lower concentrations of PM than applied in World Bank (2002) (i.e., lower than PM_{10} = 270 μg/m^3 or $PM_{2.5}$ = 110 μg/m^3 using a $PM_{2.5}/PM_{10}$ ratio of 0.4). EEAA reports PM_{10} concentrations of 234 μg/m^3 in Greater Cairo in 1999 (EEAA, 2015).[12] World Bank (2013) also reports PM_{10} of 234 μg/m^3 in 1999, as well as $PM_{2.5}$ of 90 μg/m^3 referring to data from EEAA. A $PM_{2.5}$ concentration of 90 μg/m^3 in 1999 is therefore applied in the reassessment.

Reassessment: In order to allow for a comparison of health impacts of air pollution over time, the current methodology (GBD 2017) is adopted to data from previous vintages (of the

[10]The third study undertook an assessment for the year 2009 (World Bank, 2013).
[11]These costs reflect the use of a value of statistical life (VSL) for valuation of the cost of mortality in both studies.
[12]EEAA (2015) reports $PM_{2.5}$ of 78 μg/m^3 in 1999. It seems, however, that this figure is from monitoring stations in all of Egypt.

TABLE 2.13: COMPARABLE ANNUAL MORTALITY FROM AMBIENT $PM_{2.5}$ IN GREATER CAIRO (GC) IN 1999 AND 2017

	1999 Reassessment	2017	Change 1999–2017
Exposed population (million)	11.9	17.3	+45%
Annual ambient $PM_{2.5}$ (μg/m^3)	90	76	–16%
Annual deaths from $PM_{2.5}$	9,400	12,569	+34%
Deaths from $PM_{2.5}$ per 100,000 population	79	73	–8%

Source: Annual ambient $PM_{2.5}$ is from EEAA (2015), World Bank (2013) and data presented in this current study. Annual deaths from $PM_{2.5}$ are estimates by the author using the GBD 2017 health risk functions.

reports from 1999) in order to guarantee the comparability across time. The reassessment of health effects in terms of annual mortality from ambient PM in 1999 with comparison to 2017 is presented in table 2.13. The reassessed estimate of mortality from PM in 1999 differs from the estimates in table 2.12. This is expected because of the difference in methodologies. The population of Greater Cairo (GC) increased by about 45% from 1999 to 2017 while ambient $PM_{2.5}$ declined by 16%. As a result, annual deaths from ambient $PM_{2.5}$ increased by 34% from 1999 to 2017. Deaths from ambient $PM_{2.5}$ per 100,000 population declined, however, by 8% from 1999 to 2017.

In order to achieve a reduction in the number of deaths from ambient $PM_{2.5}$ in Greater Cairo, the percent reductions in annual ambient $PM_{2.5}$ concentrations must be larger than the percent increase in the population. To speed up reductions in ambient $PM_{2.5}$, it would be very advantageous to undertake an updated $PM_{2.5}$ source apportionment study. This would contribute toward identification of cost-effective interventions for minimization of cost to achieve ambient $PM_{2.5}$ reduction targets.

CHAPTER THREE
DRINKING WATER, SANITATION, AND HYGIENE

3.1 WATER POLLUTION

Egypt receives over 55 billion m^3 of Nile water per year. This water is used and reused before a minimal amount of water needed for navigation enters the Mediterranean Sea. Nile water quality is considered of better quality in Upper Egypt than in the Nile Delta south of Greater Cairo.

Numerous studies have assessed Nile water quality in terms of parameters, such as dissolved oxygen (DO), total dissolved solids (TDS), chemical oxygen demand (COD), biological oxygen demand (BOD), turbidity, ammonia (NH_3), pH, chloride (Cl^-), phosphates (PO_4^{3-}), and nitrate (NO_3^-). Many studies have also assessed ground water quality in terms of parameters such as TDS, pH, nitrate (NO_3^-), sodium ion (Na^+), chloride ion (Cl^-), ferrous ion (Fe_2^+), manganese ion (Mn_2^+), zinc ion (Zn_2^+), copper ion (Cu_2^+), and nickel ion (Ni_2^+).

A report by COWI in collaboration with Chemonics Egypt prepared for the World Bank summarizes many of the studies of Nile and groundwater in the Delta, as well as the pollution status of the Northern Lakes (COWI, 2016).

While the studies and parameters mentioned above are of importance in their own right, they are not first priority in terms of potential impacts on health. Parameters of first priority in terms of health effects include fecal coliforms (FC) and heavy metals such as lead (Pb), cadmium (Cd), mercury (Hg) and arsenic (As). High concentrations of FC have, for instance, been detected in various sections and locations of the Damietta and Rosetta branches in the Nile Delta (COWI, 2016).

3.2 HOUSEHOLD DRINKING WATER SUPPLY AND SANITATION

The Egypt Demographic and Health Survey 2014 (DHS 2014) reports that an estimated 98% of the Egyptian population had access to an improved drinking water source in 2014 (table 3.1). A method commonly used to protect against bacteriological contamination of drinking water is household point-of-use (POU) treatment. According to the Egypt DHS 2014 only 10% of the population lived in households practicing appropriate treatment of drinking water. The main method used was filtering of water.

TABLE 3.1: POPULATION ACCESS TO DRINKING WATER IN EGYPT, ESTIMATE 2014

	Urban	Rural	Total
Total improved sources			
Piped onto premises	96.0%	87.8%	90.9%
Other, improved source	2.7%	9.3%	6.8%
Total unimproved sources			
Unimproved	1.1%	2.3%	1.9%
Other	0.2%	0.6%	0.4%

Source: Egypt Demographic and Health Survey 2014.

TABLE 3.2: POPULATION ACCESS TO SANITATION IN EGYPT, ESTIMATE 2014

	Urban	Rural	Total
Improved, non-shared facility	**98.8%**	**84.9%**	**90.2%**
Flush/pour flush to sewage system	90.9%	34.3%	55.4%
Flush/pour flush to vault *(bayara)*	5.4%	22.5%	16.2%
Flush/pour flush to septic tank	2.5%	28.1%	18.6%
Unimproved, shared or no facility	**1.1%**	**15.1%**	**9.8%**
Shared facility (otherwise improved)	0.9%	2.8%	2.1%
Flush/pour flush to other	0.2%	12.1%	7.6%
Unimproved pit latrine	0.0%	0.0%	0.0%
No facility	0.0%	0.2%	0.1%

Source: Egypt Demographic and Health Survey 2014.

The Egypt DHS 2014 reports that an estimated 90% of the Egyptian population had access to an improved, non-shared sanitation facility in 2014 (table 3.2). Over 55% of the population was connected to a sewage system, while about 35% were connected to vault (*bayara*) or septic tank. The main sanitation facility classified as unimproved was flush/pour flush toilet draining to another place than a sewage network, vault, or septic tank. As of more recent, UNICEF/WHO (2019) reports that 67% of the population had sewer connection in 2017, and that 6% had unimproved, shared, or no sanitation facility.

In addition to good quality drinking water and sanitation, good hygiene practices are essential for infectious disease prevention, and especially hand washing with soap at critical times which have globally been found to substantially reduce diarrheal illness (Curtis and Cairncross, 2003; Fewtrell et al., 2005; Ejemot et al., 2009; Waddington et al., 2009; Cairncross et al., 2010; Freeman et al., 2014). UNICEF/WHO (2019) reports that 90% of the population in Egypt had a handwashing facility with soap and water in 2017. However, limited information is available on actial household and community hygiene practices and conditions.

3.3 HEALTH EFFECTS OF INADEQUATE DRINKING WATER, SANITATION, AND HYGIENE

Inadequate water supply, sanitation, and hygiene (WASH) causes diarrhea and other infectious diseases (Wolf et al., 2014; Pruss-Ustun et al., 2014). Poor sanitation and hygiene increases the risk of parasite infestation. And schistosomiasis is endemic in many parts of Egypt. Poor hand washing practices is a major contributor to diarrhea and respiratory infections in children in many countries (Rabie and Curtis, 2006). Repeated diarrheal infections in early childhood contribute to poor nutritional status (e.g., underweight), as evidenced by research studies in communities with a wide range of diarrheal infection rates in a diverse group of countries (World Bank, 2008).

Estimates of some of the health effects of inadequate WASH in Egypt can be provided. This includes diarrheal infections, typhoid/paratyphoid, schistosomiasis, acute lower respiratory infections (ALRI),[13] intestinal nematode infections, and trachoma, and child mortality from poor nutritional status caused by inadequate WASH.

Inadequate WASH caused an estimated 2.2 billion to 3.7 billion days lived with disease and 4,400 to 9,200 deaths in Egypt in 2017 (tables 3.3–3.4). The vast majority of the days lived with disease are from the high year-round prevalence of intestinal nematode infections and schistosomiasis among millions of people (see below).

TABLE 3.3: ESTIMATED DAYS LIVED WITH DISEASE FROM INADEQUATE WATER, SANITATION, AND HYGIENE (WASH) IN EGYPT, 2017 (MILLION DAYS)

	Low	Central	High
Diarrheal diseases	318	352	387
Typhoid/paratyphoid	0.29	0.34	0.41
Schistosomiasis	417	476	544
Intestinal nematode infections	1,400	1,950	2,725
Trachoma	12	20	31
ALRI	1.39	1.58	1.78
Total days of disease from WASH	**2,147**	**2,799**	**3,688**

Source: Estimates by the author.

TABLE 3.4: ESTIMATED DEATHS FROM INADEQUATE WATER, SANITATION, AND HYGIENE (WASH) IN EGYPT, 2017

	Low	Central	High
Diarrheal diseases	3,083	4,890	6,934
Typhoid/paratyphoid	98	193	335
Schistosomiasis	233	308	394
ALRI	366	433	509
Indirect from WASH	595	799	1,060
Total deaths from WASH	**4,374**	**6,624**	**9,231**

Source: Estimates by the author.

[13]ALRI from inadequate handwashing practices (Rabie and Curtis, 2006).

The health effects (D) from inadequate WASH are estimated as follows:

$$D = \Sigma D_i = \Sigma (B_i * AF_i) \qquad (3.1)$$

where B is the baseline number of deaths or days of disease, AF is the fraction of deaths or days of disease attributable to inadequate WASH, and *i* is type of disease. Baseline number of deaths, days of disease, and duration of disease are from the GBD 2017 for Egypt. Attributable fractions (AFs) are presented in table 3.5. The AF of 66.5% for diarrheal disease and typhoid/paratyphoid is estimated based on the status of household drinking water and sanitation (see annex 2). The same AF is also applied to the estimate of indirect deaths from diarrhea in young children associated with poor nutritional status (see annex 2).

TABLE 3.5: ATTRIBUTABLE FRACTIONS OF DISEASE DUE TO INADEQUATE WATER, SANITATION, AND HYGIENE IN EGYPT, 2017

Diarrheal disease	66.5%	Using GBD 2017 methodology
Typhoid/paratyphoid	66.5%	Using same as for diarrheal diseases
Shistosomiasis	100%	Fewtrell et al. (2007)
Intestinal nematode infections	100%	Fewtrell et al. (2007)
Trachoma	100%	Fewtrell et al. (2007)
ALRI	1.87%	Using GBD 2017 methodology

Days of diarrheal disease from inadequate WASH are based on a baseline diarrheal incidence rate of 0.9–1.2 cases per person per year and an average case duration of 5.5 days from GBD 2017 in Egypt, and an AF of 66.5%.

Days of typhoid/paratyphoid disease from inadequate WASH are based on a baseline incidence of 21,000 to 28,00 cases per year, an average case duration of 21 to 22 days, and an AF of 66.5%.

Days of disease from schistosomiasis due to inadequate WASH are estimates based on prevalence of 1.1 million to 1.5 million people with schistosomiasis at any time during the year, as reported by the GBD 2017 for Egypt. Annual days of disease from inadequate WASH are the prevalence multiplied by 365 days and an AF of 100%.

Days of disease from intestinal nematode infections due to inadequate WASH are estimates based on prevalence of 3.8 million to 7.5 million people with intestinal nematode infections at any time during the year, as reported by the GBD 2017 for Egypt. Annual days of disease from inadequate WASH are the prevalence multiplied by 365 days and an AF of 100%.

Days of ALRI disease from inadequate WASH are based on a baseline incidence rate of 0.1–0.13 cases per person per year as reported by GBD 2017, an average case duration of about 8.3 days, and an AF of 1.87%.

Days of trachoma disease from inadequate WASH are based on a baseline prevalence of 33,000 to 86,000 people with trachoma at any time during the year, as reported by GBD 2017 for Egypt. Annual days of disease from inadequate WASH are the prevalence multiplied by 365 days and an AF of 100%.

Deaths from inadequate WASH are estimated from the baseline deaths reported by the GBD 2017 for Egypt multiplied by the attributable fractions (AF) in table 3.5.

The estimated deaths and disease from inadequate WASH in this report are somewhat higher than reported by GBD 2017. The main reasons are:

1) The GBD 2017 is limited to attributing a share of diarrheal disease and ALRI to inadequate WASH, while this report also attributes typhoid/paratyphoid, schistosomiasis, intestinal nematode infections, and trachoma (see Fewtrell et al., 2007).
2) This report includes an estimate of the indirect effect of inadequate WASH through diarrheal infections on child nutritional status and consequent increase in risk of child mortality (see annex 2).

3.4 COST OF HEALTH EFFECTS

The annual cost of the health effects associated with inadequate drinking water, sanitation, and hygiene is estimated at LE 26 billion to 56 billion in 2016/17, with a central estimate of LE 39 billion (table 3.6). The cost is equivalent to about 0.75% to 1.61% of Egypt's GDP that year, with a central estimate of 1.14%.

Cost of mortality is calculated as VSL (LE 3.0 million) multiplied by the estimated number of deaths. Deaths from diarrheal disease account for 74% of deaths and cost of mortality.

Cost of morbidity is calculated as a fraction of the average daily wages of LE 155 multiplied by the number of days lived with disease. The fraction of the wage rate is determined by the disability weight (severity) of the disease (see annex 3). Cost of diarrheal disease accounts for 81% and schistosomiasis for 14% of the total cost of morbidity.

TABLE 3.6: ESTIMATED ANNUAL COST OF HEALTH EFFECTS OF INADEQUATE WATER, SANITATION, AND HYGIENE IN EGYPT, 2016/17 (LE BILLION)

	Low	Central	High
Cost of mortality	13.3	20.2	28.1
Cost of morbidity	12.8	19.2	27.9
Total cost of health effects	26.1	39.4	56.0
% equivalent of GDP, 2016/17	**0.75%**	**1.14%**	**1.61%**

Source: Estimates by the author.

CHAPTER FOUR

SUMMARY AND CONCLUSIONS

The report finds that 19,200 people died and over 3 billion days were lived with disease in Egypt in 2017 from ambient $PM_{2.5}$ air pollution in Greater Cairo and inadequate water, sanitation, and hygiene nationwide. The estimated cost of these health effects was equivalent to 2.5% of Egypt's GDP in 2016/17. The cost of ambient $PM_{2.5}$ air pollution in Greater Cairo was highest with a central estimate of LE 47 billion, equivalent to 1.35% of GDP. The cost of inadequate drinking water, sanitation, and hygiene was LE 39 billion, equivalent to 1.15% of GDP. However, water-related costs are likely higher than suggested by this figure because of undetermined exposure to lead, other heavy metals, and chemicals through drinking water.

On a per capita basis, the cost of ambient air pollution in Greater Cairo was LE 2.7 billion per million people. This is nearly seven times higher than the nationwide cost per million people of inadequate water, sanitation, and hygiene. While the report finds that air quality, in terms of $PM_{2.5}$ concentrations, improved in Greater Cairo over the period from 1999 to 2016, it was outpaced by population growth, resulting in an increase in annual deaths from ambient $PM_{2.5}$. Annual deaths from ambient $PM_{2.5}$ did, however, decline by 8% from 79 to 73 per 100,000 people from 1999 to 2017.

The conclusions and recommendations that emerge in this report are:

- Environmental health risk exposure levels in Egypt are a concern, and aggregate health effects and their costs are substantial.
- Controlling and preventing outdoor PM pollution should continue to be a priority. The focus should be on $PM_{2.5}$, as these fine particulates have the largest health effects.
- Improvements should be continued in the water and sanitation sector, with emphasis on ensuring good quality drinking water, environmentally safe sanitation, and continuing efforts to improve hand washing practices and other hygiene dimensions.

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ANNEX 1
HEALTH EFFECTS OF PARTICULATE MATTER POLLUTION

Particulate matter (PM) is the outdoor air pollutant that globally is associated with the largest health effects. Health effects of PM exposure include both premature mortality and morbidity. The most substantial health effects of $PM_{2.5}$ are cardiovascular disease, chronic obstructive pulmonary disease (COPD), lung cancer, diabetes Type II, and acute lower respiratory infections (ALRI) (Pope et al., 2009, 2011; Lim et al., 2012; Mehta et al., 2013; Stanaway et al., 2018). The methodologies to estimate these health effects have evolved as the body of research evidence has increased.

A1.1 AMBIENT PARTICULATE MATTER AIR POLLUTION

Over a decade ago, Pope et al. (2002) found elevated risk of cardiopulmonary (CP) and lung cancer (LC) mortality from long-term exposure to outdoor $PM_{2.5}$ in a study of a large population of adults 30 or more years of age in the United States. CP mortality includes mortality from respiratory infections, cardiovascular disease, and chronic respiratory disease. The World Health Organization used the study by Pope et al. when estimating global mortality from outdoor air pollution (WHO, 2004). Since then, recent research suggests that the marginal increase in relative risk of mortality from $PM_{2.5}$ declines with increasing concentrations of $PM_{2.5}$ (Pope et al., 2009, 2011). Pope et al. (2009, 2011) derive a shape of the $PM_{2.5}$ exposure-response curve based on studies of mortality from active cigarette smoking, second-hand cigarette smoking (SHS), and outdoor $PM_{2.5}$ air pollution.

A1.2 AN INTEGRATED EXPOSURE-RESPONSE FUNCTION

The Global Burden of Disease Project takes Pope et al. (2009, 2011) some steps further by deriving an integrated exposure-response (IER) relative risk function (RR) for disease outcome, k, in age-group, l, associated with exposure to fine particulate matter pollution ($PM_{2.5}$) both in the outdoor and household environments:

$$RR(x)_{kl} = 1 \qquad \text{for } x < x_{cf} \qquad \text{(A1.1a)}$$

$$RR(x)_{kl} = 1 + \alpha_{kl}\left(1 - e^{-\beta_{kl}\left(x - x_{cf}\right)^{\rho_{kl}}}\right) \qquad \text{for } x \geq x_{cf} \qquad \text{(A1.1b)}$$

where x is the ambient concentration of $PM_{2.5}$ in μg/m^3 and x_{cf} is a counterfactual concentration below which it is assumed that no association exists. The function allows prediction of RR over a very large range of $PM_{2.5}$ concentrations, with $RR(x_{cf} + 1) \sim 1 + \alpha\beta$ and $RR(\infty) = 1 + \alpha$ being the maximum risk (Burnett et al., 2014; Shin et al., 2013).

The parameter values of the risk function are derived based on studies of health outcomes associated with long-term exposure to ambient particulate matter pollution, second hand tobacco smoking, household air pollution from solid cooking fuels, and active tobacco smoking (Burnett et al., 2014). This provides a risk function that can be applied to a wide range of ambient $PM_{2.5}$ concentrations around the world, as well as to high household air pollution levels of $PM_{2.5}$ from combustion of solid fuels.

The disease outcomes assessed in this report, as in GBD 2017, are ischemic heart disease (IHD), cerebrovascular disease (stroke), lung cancer, chronic obstructive pulmonary disease (COPD), diabetes Type II, and acute lower respiratory infections (ALRI). The risk functions for IHD and cerebrovascular disease are age specific with five-year age intervals from 25 years of age, while singular age-group risk functions are applied for lung cancer, COPD, and diabetes Type II from 25 years of age, and ALRI for all age groups (Stanaway et al., 2018).

The attributable fraction of disease from $PM_{2.5}$ exposure is calculated by the following expression:

$$AF = \sum\nolimits_{i=1}^{n} P_i \left[RR\left(\frac{x_i + x_{i-1}}{2} \right) - 1 \right] \Big/ \left(\sum\nolimits_{i=1}^{n} P_i \left[RR\left(\frac{x_i + x_{i-1}}{2} \right) - 1 \right] + 1 \right) \qquad \text{(A1.2)}$$

where P_i is the share of the population exposed to $PM_{2.5}$ concentrations in the range x_{i-1} to x_i. This attributable fraction is calculated for each disease outcome, k, and age group, l. The disease burden (B) in terms of annual cases of disease outcomes due to $PM_{2.5}$ exposure is then estimated by:

$$B = \sum\nolimits_{k=1}^{t} \sum\nolimits_{l=i}^{s} D_{kl} AF_{kl} \qquad \text{(A1.3)}$$

where D_{kl} is the total annual number of cases of disease, k, in age group, l, and AF_{kl} is the attributable fraction of these cases of disease, k, in age group, l, due to $PM_{2.5}$ exposure.

A1.3 BASELINE HEALTH DATA

Annual cases of premature deaths and disease (B) from ambient $PM_{2.5}$ are estimated by applying attributable fractions (AFs) to baseline numbers of deaths or cases of disease (D), as described in the previous section. This section presents the estimation of baseline deaths in Greater Cairo for each of the six health outcomes associated with ambient $PM_{2.5}$ exposure. This is undertaken in two main steps:

1) Cause-specific number of deaths from the GBD 2017 for Egypt in 2017 are adjusted to reflect the national crude death rate (CDR) reported by CAPMAS (2018); and
2) An additional adjustment is made to reflect that the population in Greater Cairo is older than the national average, and therefore has a higher death rate than the national average.

TABLE A1.1: POPULATION AND MORTALITY IN EGYPT

Year	Mid-Year Population (million)	CAPMAS Crude Death Rate (per 1,000 population)	CAPMAS Total Deaths (000)	GBD 2017 Total Deaths (000)*
1999	62.6	6.4	401	386
2009	76.9	6.2	477	449
2017	95.2	5.7	546	500

Source: Egypt in Figures 2018 (CAPMAS, 2018).
* http://www.healthdata.org/

Baseline crude death rates (CDR) per 1,000 population and total annual deaths in Egypt are reported in "Egypt in Figures 2018" by CAPMAS (2018).[14] The CDR declined by around 10% from 1999 to 2017, while total annual deaths increased by 36% as a result of population growth. The Global Burden of Disease 2017 (GBD 2017) also reports annual deaths in Egypt for the same years (table A1.1). These estimates are 4–8% lower than the number of cases reported by CAPMAS (2018). Number of deaths reported by GBD 2017 are therefore adjusted to reflect the CDR reported by CAPMAS.

CAPMAS (2018) reports CDRs for urban and rural areas nationwide and within each governorate in 2017. The CDRs vary substantially between urban (CDR = 7.9) and rural areas (CDR = 4.1) and across governorates (e.g., CDR = 9.0 in Cairo; CDR = 4.0 in Fayoum), compared to the national average of 5.7. According to Baseera/NPC/UNFPA (2016), a major reason for the high CDRs in urban areas (including Cairo) is the high demand for the higher quality of health services available in these areas. Many people in the rural areas therefore travel to the cities for treatment when they have serious health conditions. When deaths occur, they are registered in these cities, resulting in higher recorded CDRs. The CDRs for urban areas of each governorate are therefore not applied to estimate the baseline number of deaths in Greater Cairo.

An approach to estimating baseline deaths in Greater Cairo is therefore applied here based on the difference in age distribution in urban and rural areas, because death rates are higher among older individuals than among younger individuals. The population in Egypt is older in urban than in rural areas in Egypt (table A1.2). The population in Greater Cairo is also older than the national average (table A1.3). The cause-specific death rates for each age-group in GBD 2017 for Egypt are therefore adjusted to Greater Cairo to reflect these differences in age distribution.

TABLE A1.2: AGE DISTRIBUTION IN EGYPT ACCORDING TO THE POPULATION CENSUS 2017

Age Group	National	Urban	Rural
65+	3.86%	4.24%	3.58%
15–64	61.91%	64.99%	59.64%
0–14	34.23%	30.77%	36.78%
Total	**100.00%**	**100.00%**	**100.00%**

Source: Sayed (2018).

[14]Central Agency for Public Mobilization and Statistics (CAPMAS), Cairo, Egypt.

TABLE A1.3: AGE DISTRIBUTION IN GREATER CAIRO ACCORDING TO THE POPULATION CENSUS 2017

Age Group	Cairo	Giza Urban	Kalyoubia Urban	Greater Cairo
65+	4.84%	3.39%	2.97%	4.14%
15–64	68.32%	64.65%	64.82%	66.71%
0–14	26.84%	31.96%	32.21%	29.16%
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**

Source: Age distribution in Cairo, Giza, and Kalyoubia is from Census 2017 data in Sayed (2018). Age distribution in Greater Cairo is the population weighed average distribution of the former three.
Note: Age distribution in 10th of Ramadan city is not included here (not readily available). As its population is a very small fraction of the total population in Greater Cairo, this has minimal influence on the estimated age distribution in Greater Cairo.

TABLE A1.4: ESTIMATES OF CAUSE-SPECIFIC ANNUAL DEATHS IN EGYPT IN 2017

Age Group	IHD	Stroke	COPD	Lung Cancer	Diabetes Type II	ALRI
All Ages	158,822	50,841	12,449	4,208	9,724	23,097
25+	158,017	50,094	12,130	4,150	9,659	
25 to 29	860	323				
30 to 34	1,626	510				
35 to 39	2,971	919				
40 to 44	4,965	1,419				
45 to 49	8,305	2,181				
50 to 54	12,931	3,318				
55 to 59	17,055	4,529				
60 to 64	22,239	6,024				
65 to 69	25,060	7,575				
70 to 74	20,994	7,273				
75 to 79	16,973	6,493				
80+	24,035	9,530				

Source: GBD 2017 (http://www.healthdata.org/)

In order to estimate the health effects of ambient $PM_{2.5}$ air pollution annual deaths are required for each of the six causes for which the GBD 2017 provides exposure-risk functions. The GBD 2017 provides such estimates of cause-specific annual deaths based on Egyptian vital registration, household surveys (e.g., Egypt Demographic and Health Survey), specialized surveys and reports, and the broader international evidence of the cause-specific structure of mortality by country income level, socioeconomic characteristics, and other determinants of cause-specific mortality rates.[15]

The GBD 2017 baseline deaths in Egypt for the six relevant causes of deaths are presented in table A1.4. Deaths are presented by age group (ages 25+ years) for ischemic heart disease (IHD) and stroke, for aggregate age group 25+ years of age for COPD, lung cancer, and

[15]See: http://ghdx.healthdata.org/gbd-2017/data-input-sources

TABLE A1.5: ADJUSTMENT FACTORS FOR ANNUAL DEATHS IN GREATER CAIRO, 2017

		IHD	Stroke	COPD	LC	Diabetes II	ALRI
(1)	Adjustment to GBD 2017 to reflect the national CDR	1.094	1.106	1.100	1.066	1.070	1.108
(2)	Adjustment to Greater Cairo to reflect differences in age distribution	1.094	1.070	1.078	1.132	1.138	0.936
(3)	**Adjustment factors for Greater Cairo**	**1.197**	**1.183**	**1.186**	**1.208**	**1.218**	**1.038**

Source: Estimates by the author based on CAPMAS (2018), GBD 2017 for Egypt, and the Egypt Population Census 2018 age distributions.

diabetes Type II, and for all age groups for acute lower respiratory infections, as required by the GBD 2017 exposure-risk functions.

The annual deaths in table A1.4 are in Egypt nationwide. They therefore need to be adjusted to Greater Cairo. This is undertaken in five steps:

1) Apply the age-specific death rates in Egypt in GBD 2017 to the age distribution in the Egypt Population Census 2017 (instead of using the age distribution in GBD 2017). This raises total annual baseline deaths from 500,000 in GBD 2017 to 520,000.
2) Adjust the deaths from step 1 (520,000) to the total annual deaths reported by CAPMAS in table A1.1 (546,000) and perform the same adjustment to the six health outcomes associated with $PM_{2.5}$ exposure. Steps 1 and 2 result in the adjustment factors in (1) in table A1.5.
3) Adjust the annual cause-specific deaths that result from Step 2 for the difference in age distribution between Greater Cairo and the national average. This results in the adjustment factors in (2) in table A1.5.
4) Multiply the adjustment factors in (1) and (2) in table A1.5 to get the total adjustment factors (3) for Greater Cairo.
5) Adjust by the population share of Greater Cairo, i.e., 17.36/95.2 = 0.182.

The adjustment factors for Greater Cairo are fairly similar for five of the health outcomes. The factor is substantially lower for ALRI. This is because a large share of deaths from ALRI are among young children, and young children are fewer as a percentage of the population in Greater Cairo than nationally.

The adjustment factors (3) in table A1.5 and the Greater Cairo population share (0.182) are multiplied by the annual deaths in table A1.4 to arrive at estimated deaths in Greater Cairo (table A1.6).

A1.4. ESTIMATING HEALTH EFFECTS

Estimating the health effects of ambient $PM_{2.5}$ concentrations is undertaken in three steps:

» The first step is to estimate the relative risk (RR) of death from each of the six health outcomes in table A1.6 associated with ambient $PM_{2.5}$ concentrations in Greater Cairo. This is performed by applying x = 76 (μg/m^3) and x_{cf} = 4.15 (μg/m^3) to equation A1.1b.[16]

[16]The parameter values of α, β, and ρ are estimated from the RR(x) reported by the GBD 2017 in Stanaway et al. (2018) Supplement 1 Appendix Table 6b.

TABLE A1.6: ESTIMATES OF CAUSE-SPECIFIC ANNUAL DEATHS IN GREATER CAIRO IN 2017

Age Group	IHD	Stroke	COPD	Lung Cancer	Diabetes Type II	ALRI
All Ages	34,655	10,966	2,692	927	2,160	4,370
25+	34,480	10,805	2,623	914	2,145	
25 to 29	188	70				
30 to 34	355	110				
35 to 39	648	198				
40 to 44	1,083	306				
45 to 49	1,812	470				
50 to 54	2,822	716				
55 to 59	3,722	977				
60 to 64	4,853	1,299				
65 to 69	5,468	1,634				
70 to 74	4,581	1,569				
75 to 79	3,704	1,400				
80+	5,244	2,056				

Source: Estimates by the author.

TABLE A1.7: ESTIMATED ANNUAL DEATHS FROM AMBIENT $PM_{2.5}$ AIR POLLUTION IN GREATER CAIRO, 2017

	IHD	Stroke	COPD	Lung Cancer	Diabetes Type II	ALRI	Total
$PM_{2.5}$ ($\mu g/m^3$)	76	76	76	76	76	76	76
Relative risk (RR)	1.275	1.174	1.534	1.402	1.439	1.637	
Attributable fraction (AF)	0.2157	0.1482	0.3479	0.2868	0.3053	0.3893	
Annual deaths from $PM_{2.5}$	**7,437**	**1,601**	**912**	**262**	**655**	**1,701**	**12,569**

Source: Estimates by author.

- The next step is to calculate the attributable fraction (AF) of deaths in table A1.6 that is due to ambient $PM_{2.5}$ concentrations. This is performed by equation A1.2, using $P = 1$ assuming that the whole population of Greater Cairo is exposed to the $PM_{2.5}$ concentrations of 76 $\mu g/m^3$.
- The final step is to multiply the AFs with the annual deaths in table A1.6.

Relative risks (RR) and attributable fractions (AFs) for ambient $PM_{2.5}$ air pollution in Greater Cairo are presented in table A1.7. The RR and AF for IHD and stroke are calculated by age group. The weighted average RR and AF are presented in the table.

ANNEX 2
HEALTH EFFECTS FROM WATER, SANITATION, AND HYGIENE

Inadequate water, sanitation, and hygiene (WASH) is directly and indirectly affecting population health. Directly, poor WASH causes diarrheal infections and other health effects which in turn lead to mortality especially in young children (Wolf et al., 2014; Pruss-Ustun et al., 2014; Fewtrell et al., 2007). Indirectly, poor WASH contributes to poor nutritional status in young children through the effect of diarrheal infections (World Bank, 2008; Fewtrell et al., 2007; Larsen, 2007).[17] Poor nutritional status in turn increases the risk of child mortality from disease (Fishman et al., 2004; Black et al., 2008; Olofin et al., 2013). Child underweight is the nutritional indicator most commonly used in assessing the risk of mortality from poor nutritional status (Fishman et al., 2004).

DIRECT HEALTH EFFECT

Estimating the direct health effect of inadequate WASH involves estimating the attributable fraction (AF) of diarrheal disease due to WASH. This is undertaken separately for drinking water, sanitation, and hygiene (handwashing) to estimate the joint attributable fraction. The relative risks of disease applied here are from the GBD 2017.

DRINKING WATER

The Joint Monitoring Programme for Water Supply and Sanitation (JMP) by WHO/UNICEF estimates that 98% of the population in Egypt had a piped water supply and 2% had another improved or unimproved water source in 2017 (UNICEF/WHO, 2019). Additionally the Egypt DHS 2014 reports that a little over 10% of the population filter their water prior to drinking. The drinking water population distribution and associated relative risks (RR) of diarrheal disease are presented in table A2.1. The relative risks are from the GBD 2017.

SANITATION

The Joint Monitoring Programme for Water Supply and Sanitation (JMP) by WHO/UNICEF estimates that 94% of the population in Egypt had improved, non-shared sanitation and 6% had unimproved or shared sanitation in 2017 (UNICEF/WHO, 2019). The

[17]Repeated infections, and especially diarrheal infections, have been found to significantly impair weight gains in young children. Studies documenting and quantifying this effect have been conducted in communities with a wide range of infection loads in a diverse group of countries. World Bank (2008) provides a review of these studies.

TABLE A2.1: RELATIVE RISK OF DIARRHEAL DISEASE FROM DRINKING WATER IN EGYPT, 2017

Type of Drinking Water	Treatment Status	RR	RR-1	Population Distribution
Unimproved water source	Untreated	11.501	10.501	0.9%
	Filtered	4.789	3.789	0.1%
Other improved	Untreated	9.428	8.428	0.9%
	Filtered	3.926	2.926	0.1%
Piped water supply	Chlorinated	1.653	0.653	88%
	Filtered	1.000	0.000	10%

Source: RRs are from GBD 2017 in Stanaway et al. (2018) Supplement. Population distribution is from UNICEF/WHO (2019).

TABLE A2.2: RELATIVE RISK OF DIARRHEAL DISEASE FROM SANITATION IN EGYPT, 2017

Type of Sanitation	RR	RR-1	Population Distribution
Unimproved sanitation	3.242	2.242	6%
Basic improved	2.595	1.595	27%
Sewage system	1.000	0.000	67%

Source: RRs are from GBD 2017 in Stanaway et al. (2018) Supplement. Population distribution is from UNICEF/WHO (2019).

same report states that 67% of the population had a sewer connection. The sanitation population distribution and associated relative risks (RR) of diarrheal disease are presented in table A2.2. The relative risks are from the GBD 2017.

HANDWASHING

The Joint Monitoring Programme for Water Supply and Sanitation (JMP) by WHO/UNICEF reports that 90% of the population in Egypt had a facility with soap and water for handwashing in 2017 (UNICEF/WHO, 2019). The population distribution with and without a facility and associated relative risks (RR) of diarrheal disease are presented in table A2.3. The relative risks are from the GBD 2017.

TABLE A2.3: RELATIVE RISK OF DIARRHEAL DISEASE FROM LACK OF HANDWASHING FACILITY IN EGYPT, 2017

Population with or without Handwashing Facility with Soap and Water	RR	RR-1	Population Distribution
With facility	1.000	0.000	90.0%
Without facility	1.908	0.908	10%

Source: RRs are from GBD 2017 in Stanaway et al. (2018) Supplement. Population distribution is from UNICEF/WHO (2019).

TABLE A2.4: ATTRIBUTABLE FRACTIONS OF DIARRHEAL DISEASE DUE TO INADEQUATE WASH IN EGYPT

	Attributable Fraction (AF)
Unsafe drinking water	42.9%
Unsafe sanitation	36.1%
Inadequate handwashing	8.3%
Joint AF due to inadequate WASH	**66.5%**

Source: Estimates by the author.

JOINT ATTRIBUTABLE FRACTION

Applying the standard AF formula (see eq. A2.1 below) to the relative risks (RR) and population distributions in tables A4.1–4.3 indicates that 43% of diarrheal disease in Egypt is due to unsafe drinking water, that 36% is due to inadequate sanitation, and that 8% is due to inadequate handwashing. Applying the joint attributable fraction formula in Gakidou et al. (2007) to these individual AFs indicates that 67% of diarrheal disease is due to inadequate WASH (table A2.4).[18] This joint AF is also applied to typhoid/paratyphoid as well as to the indirect effect discussed below.

INDIRECT HEALTH EFFECT

Estimating the indirect mortality effects of diarrhea from WASH is undertaken here in two stages. First, the fraction of under-five child mortality attributable to child underweight is estimated. This follows the methodology in Olofin et al. (2013). Second, a fraction of under-five child mortality from underweight is attributed to diarrheal infections from WASH in early childhood using the approach in Fewtrell et al. (2007).

An alternative approach to estimating the fraction of mortality attributable to diarrheal infections from WASH is the methodology developed in Larsen (2007) and World Bank (2008). This, however, requires estimation of counterfactual prevalence rates of child underweight (prevalence of underweight in the absence of diarrheal infections) from the original survey data of child nutritional status. As the original survey data are often not readily available, the approach in Fewtrell et al. is used here instead. The approach in Fewtrell et al. gives a somewhat lower estimate of indirect mortality from WASH than the Larsen and World Bank methodology.

Estimates of increased risk of cause-specific mortality in children under five years of age with mild, moderate, and severe underweight is presented in table A2.5 based on Olofin et al. (2013).

These relative risk ratios are applied to prevalence rates of child underweight to estimate attributable fractions (AF_j) of mortality by cause, j, from child underweight as follows:

$$AF_j = \frac{\sum_{i=1}^{n} P_i \left(RR_{ji} - 1 \right)}{\sum_{i=1}^{n} P_i \left(RR_{ji} - 1 \right) + 1} \qquad \text{(A2.1)}$$

[18] $AF_j = 1 - \Pi_{k=1}^{n} (1 - AF_k)$ for k risk factors.

TABLE A2.5: RELATIVE RISK OF MORTALITY FROM SEVERE, MODERATE, AND MILD UNDERWEIGHT IN CHILDREN UNDER FIVE

Cause of Mortality (j)/ Underweight Category (i)	Severe	Moderate	Mild	None
Diarrhea	11.56	2.86	1.73	1.00
Acute lower respiratory infections (ALRI)	10.10	3.11	1.85	1.00
Measles	7.73	3.12	1.00	1.00
Malaria	1.29	1.65	1.26	1.00
Other infectious diseases (meningitis, hepatitis)	8.28	1.58	1.54	1.00

Source: Olofin et al. (2013). ALRI is acute lower respiratory infections. Relative risks are in relation to underweight according to the WHO Child Growth Standards.

where RR_{ji} is relative risk of mortality from cause, j, for children in each of the underweight categories, i, in table A2.5; and P_i is the underweight prevalence rate.

Annual cases of mortality from child underweight (by cause, "j", in table A2.5) are estimated as follows:

$$M_j = C * U5MR * AF_j \beta_j \tag{A2.2}$$

where C is annual live child births (thousands), $U5MR$ is the under-five child mortality rate (per 1,000 live births), and β_j is the fraction of under-five mortality by cause "j".

Annual under-five child mortality from water, sanitation, and hygiene (W) is then estimated as follows:

$$W = \sum_{j=1}^{j=m} \gamma_j M_j \tag{A2.3}$$

where γ_j is the fraction of child underweight mortality (M_j) attributed to water, sanitation, and hygiene through diarrheal infections in early childhood. WHO (Fewtrell et al., 2007) uses γ_j = 0.5 for ALRI, measles, malaria and "other infectious diseases." This is adjusted here by the fraction of diarrheal disease attributed to water, sanitation, and hygiene, i.e., 0.665 in the case of Egypt (see table A2.4). Thus, the adjusted γ_j is 0.3325.

ANNEX 3

VALUATION OF HEALTH EFFECTS

A3.1 ILLNESS

Two valuation techniques are commonly used to estimate the cost of morbidity or illness. The cost-of-illness (COI) approach includes cost of medical treatment and value of income and time lost to illness. The second approach equates cost of illness to individuals' WTP for avoiding an episode of illness. Studies in many countries have found that individuals' WTP to avoid an episode of an acute illness is generally much higher than the cost of treatment and value of income and time losses (Alberini and Krupnick, 2000; Cropper and Oates, 1992; Dickie and Gerking, 2002; Wilson, 2003).

In most studies of the health effects and cost of ambient air pollution it is estimated that cost of mortality represent 70% to 90% of total cost, and cost of morbidity or illness represents 10% to 30%. It is therefore more important to reach a consensus on valuation of mortality risk than on incidence of morbidity. For infectious diseases from inadequate drinking water, sanitation, and hygiene, cost of morbidity can, however, be quite a substantial share, especially in countries with low fatality rates (but high non-fatal incidence rates) of these infectious diseases.

Estimating morbidity often requires much more and less accessible baseline health data than estimating mortality. One option is therefore to use the estimates of "years lived with disability" (YLD) from the relevant illnesses in Egypt from the GBD studies. YLD can then be converted to days lived with disease by applying the disability weights in the GBD studies. The cost of days lived with disease can then be estimated.

The approach applied in this report involve the following steps:

1) Estimates of YLDs are converted to days lived with disease by applying the disability weights in the GBD 2017 for Egypt.
2) The cost of a day lived with disease is then approximated as a fraction of the average daily wage rate to reflect income losses from illness, health expenditure, time losses, and the welfare cost of pain and suffering.
3) The cost of a day of illness is also applied to individuals without income, because illness prevents most of these individuals from undertaking household work and other activities with a social value, as well as involves all the non-income impacts of illness.

The cost of morbidity is thus estimated as follows. First, days lived with disease (M) are calculated as:

$$M = E_{i=1}^{n} M_i = E_{i=1}^{n}(YLD_i * 365/d_i) \quad \text{(A3.1)}$$

where YLD_i is years lived with disability from disease, i, and d_i is the disability weight for disease, i. The disability weight for each disease is calculated from the GBD 2017 for Egypt.

The disability weight is a measure used in GBD to calculate YLDs from days of illness, disease, or injury. The disability weights for the six diseases associated with exposure to ambient $PM_{2.5}$ in Egypt range from 0.035 for ischemic heart disease (IHD) to 0.226 for lung cancer (table A3.1). Disability weights for diseases associated with inadequate water, sanitation, and hygiene in this report in Egypt range from 0.0006 for intestinal nematode infections to 0.167 for typhoid/paratyphoid (table A3.2).

TABLE A3.1: DISABILITY WEIGHTS FOR EGYPT ASSOCIATED WITH AMBIENT $PM_{2.5}$ IN EGYPT

	Disability Weights
IHD	0.035
Stroke	0.150
COPD	0.093
Lung cancer	0.226
ALRI	0.061
Diabetes II	0.086

Source: Disability weights for Egypt are calculated from data at http://www.healthdata.org/

TABLE A3.2: DISABILITY WEIGHTS FOR EGYPT ASSOCIATED WITH INADEQUATE WATER, SANITATION, AND HYGIENE

	Disability Weights
Diarrheal disease	0.1130
Typhoid/paratyphoid	0.1670
Schistosomiasis	0.0140
Intestinal nematode infections	0.0006
Trachoma	0.0700
ALRI	0.0610

Source: Disability weights for Egypt are calculated from data at http://www.healthdata.org/

The cost of a day lived with disease, i, is thus:

$$c_i = w\, d_i / D \quad \text{(A3.2)}$$

where w is average daily wage rate and d_i disability weight for disease, i, and D is a disability weight that corresponds to a severity of disease for which the cost of a disease day is assumed equal to the average wage rate. D is here set at 0.4. This is a disability weight associated with severely restricted work and leisure activity from disease and substantial medical cost, e.g., severe COPD ($d = 0.41$), distance vision blindness ($d = 0.19$) and Stage V chronic kidney disease ($d = 0.57$) due to diabetes, and stroke with severity level 3 ($d = 0.32$) and 4 ($d = 0.55$).

Cost of morbidity (C) is calculated as follows:

$$C = \Sigma_{i=1}^{n} (c_i M_i) \tag{A3.3}$$

Average daily wage rate is estimated as follows:

$$w = GDP/L/250 * s \tag{A3.4}$$

where *GDP* is the country's total GDP, *L* is total labor force, *s* is labor compensation share of GDP, and annual working days is averaging 250. *S* = 0.35 for Egypt from PENN World Table, Version 9.

A3.2 MORTALITY

The predominant measure of the social cost of premature death used by economists is the value of statistical life (VSL). VSL is based on valuation of mortality risk. Everyone in society is constantly facing a certain risk of dying. Examples of such risks are occupational fatality risk, risk of traffic accident fatality, and environmental mortality risks. It has been observed that individuals adjust their behavior and decisions in relation to such risks. For instance, individuals demand a higher wage (a wage premium) for a job that involves a higher occupational risk of a fatal accident than in other jobs, individuals may purchase safety equipment to reduce the risk of death, and/or individuals and families may be willing to pay a premium or higher rent for properties (land and buildings) in a cleaner and less polluted neighborhood or city.

Through the observation of individuals' choices and willingness to pay for reducing mortality risk (or minimum amounts that individuals require to accept a higher mortality risk), it is possible to estimate the value to society of reducing mortality risk, or, equivalently, measure the social cost of a particular mortality risk. For instance, it may be observed that a certain health hazard has a mortality risk of 2.5/10,000. This means that 2.5 individuals die from this hazard for every 10,000 individuals exposed. If each individual on average is willing to pay US$40 for eliminating this mortality risk, then every 10,000 individuals are collectively willing to pay US$400,000. Dividing this amount by the risk gives the VSL of US$160,000. Mathematically it can be expressed as follows:

$$VSL = WTP_{Ave} * 1/R \tag{A3.5}$$

where WTP_{Ave} is the average willingness-to-pay per individual for a mortality risk reduction of magnitude R. In the illustration above, R = 2.5/10 000 (or R = 0.00025) and WTP_{Ave} = US$40. Thus, if 10 individuals die from the health risk illustrated above, the cost to society is 10 * *VSL* = 10 * US$0.16 million = US$1.6 million.

The main approaches to estimating VSL are through revealed preferences and stated preferences of people's WTP for a reduction in mortality risk or their willingness-to-accept (WTA) an increase in mortality risk. Most of the studies of revealed preferences are hedonic wage studies, which estimate labor market wage differentials associated with differences in occupational mortality risk. Most of the stated preference studies rely on contingent valuation methods (CVM), which in various forms asks individuals about their WTP for mortality risk reduction.

Studies of WTP for a reduction in risk of mortality have been carried out in numerous countries. A commonly used approach to estimate VSL in a specific country is therefore to use a benefit transfer (BT) based on meta-analyses of WTP studies from other countries. Several meta-analyses have been conducted in the last two decades (e.g., Mrozek and Taylor, 2002; Viscusi and Aldy, 2002; Kochi et al., 2006; Navrud and Lindhjem, 2010). Meta-analyses assess characteristics that determine VSL, such as household income, size of risk reduction, other individual and household characteristics, and often characteristics of the methodologies used in the original WTP studies.

Most of the meta-analyses of VSL are entirely or predominantly based on hedonic wage studies. The meta-analysis prepared for the OECD is, however, exclusively based on stated preference studies, arguably of greater relevance for valuation of mortality risk from environmental factors than hedonic wage studies (Navrud and Lindhjem, 2010; Lindhjem et al., 2011; OECD, 2012). These stated preference studies are from a database of more than 1,000 VSL estimates from multiple studies in over 30 countries, including in developing countries (www.oecd.org/env/policies/VSL).

The World Bank (2016) presents a benefit transfer methodology for valuing mortality from environmental health risks, drawing on the empirical literature of VSL, especially OECD (2012). The methodology is applied in the recent publication by the World Bank and IHME (2016) on the global cost of air pollution. The proposed benefit transfer function is:

$$VSL_{c,n} = VSL_{OECD} * \left(\frac{Y_{c,n}}{Y_{OECD}} \right)^{\in} \tag{A3.6}$$

where $VSL_{c,n}$ is the estimated VSL for country *c* in year *n*, VSL_{OECD} is the average base VSL in the sample of OECD countries with VSL studies (US$3.83 million), $Y_{c,n}$ is GDP per capita in country *c* in year *n*, and Y_{OECD} is the average GDP per capita for the sample of OECD countries (US$37,000), and $\in$ an income elasticity of 1.2 for low- and middle-income countries and 0.8 for high income countries. All values are in purchasing power parity (PPP) prices. $VSL_{c,n}$ must therefore be converted to local currency using PPP exchange rates, available in the World Development Indicators by the World Bank.

This approach provides a VSL for Egypt in the amount of LE 3.0 million in 2016/17, based on a GDP per capita of LE 37,192 in 2016/17 according to MOF (2018). The VSL is 82 times GDP per capita.

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