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Investigating the Major Sources of $PM_{2.5}$ in Kuwait

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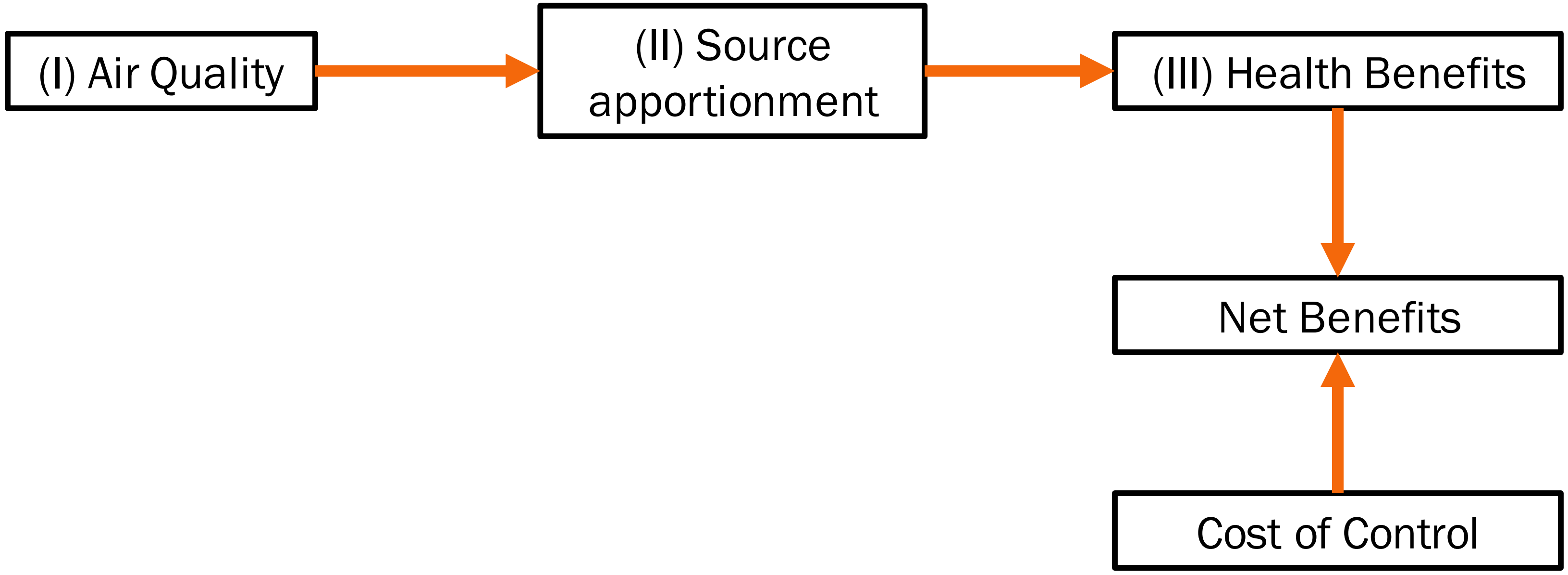
Objective

- To provide information to the decision makers in regard to air quality in Kuwait.
- One source was chosen to estimate the benefits of control.



Introduction

- PM is strongly associated with mortality and morbidity rates[1]
- The association has been shown to be stronger for $PM_{2.5}$ than for PM_{10} and $PM_{10\text{-}2.5}$[2]
- The benefits of improving outdoor air quality outweigh the cost of control
- Governments and environmental agencies are strictly enforcing regulation and monitor air quality

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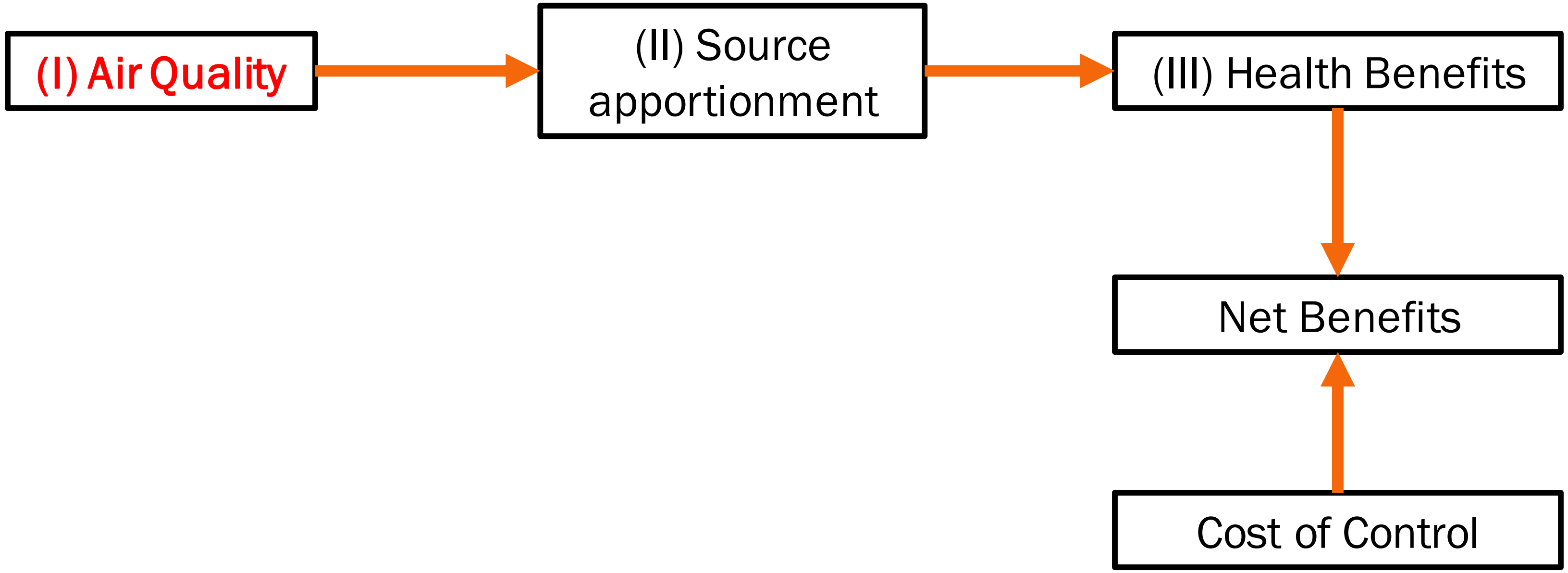
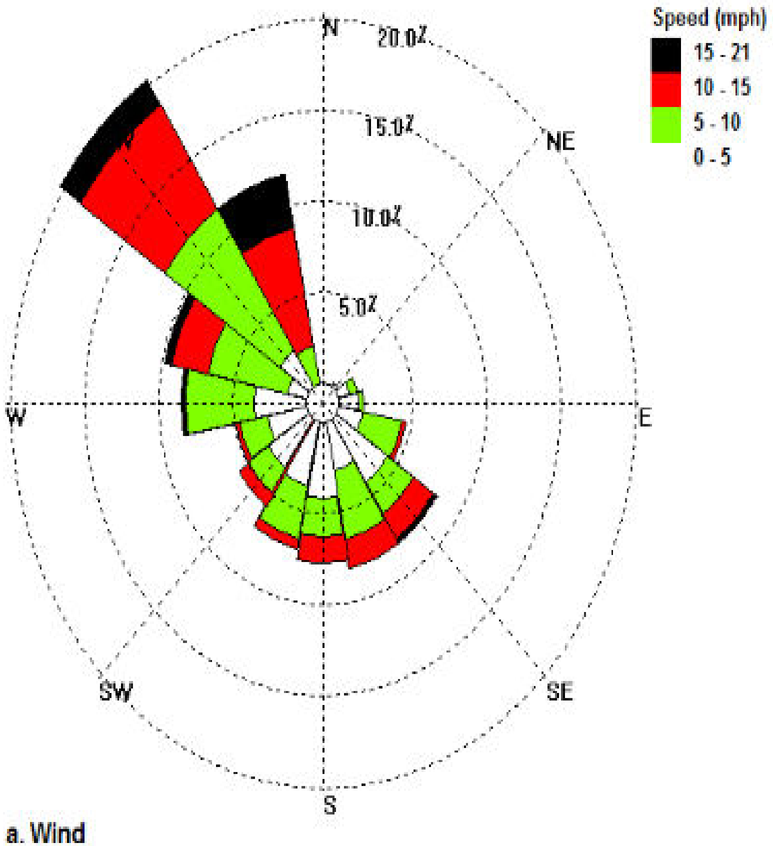
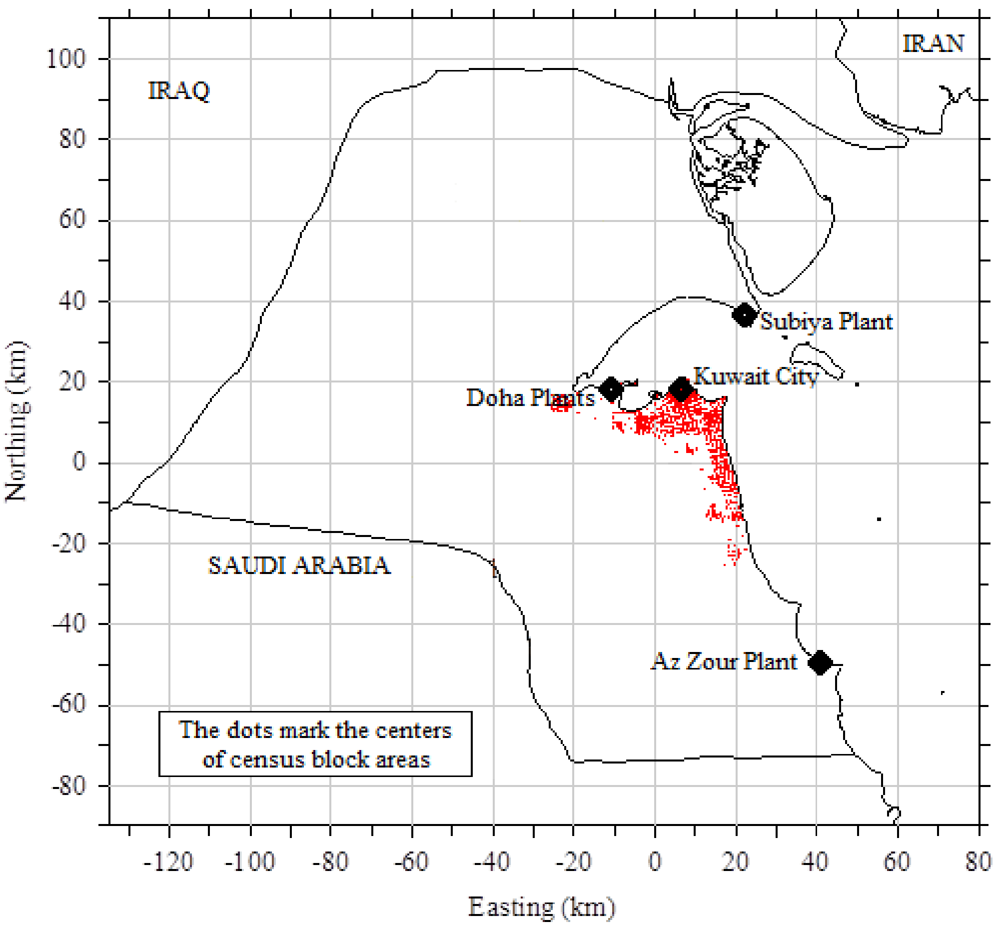


(I) Air Quality

Prevailing Wind Direction



Sampling Sites



(I) Air Quality

- Sampling program was conducted in Kuwait by team from Harvard between February/2004 and October/2005 [3]
- Teflon filters were collected from three different sites (North, Central & South)
- PM_{10}, $PM_{2.5}$, Elemental composition, OC, EC, SO_4^- & NO_3^-

Parameter	Method
$PM_{2.5}$ & PM_{10}	Gravimetric microbalance
Elemental Composition	XRF
OC & EC	Thermal optical reflectance
$SO4^-$ & $NO3^-$	Ion Chromatography

(I) Air Quality

Parameter (µg/m^3)	Mean	Fall	Winter	Spring	Summer
OC	4.6	4.1	5.0	4.6	4.7
EC	3.1	3.4	4.0	3.1	2.6
NO_3^-	1.6	1.7	3.2	1.4	1.0
SO_4^-	10.0	14.9	7.2	8.7	8.6
Al	1.9	1.5	1.6	2.1	2.4
V	0.01	0.01	0.01	0.01	0.01
Zn	0.1	0.16	0.08	0.08	0.05

(I) Air Quality

- Levels for central site (3):

Parameter	$PM_{2.5}$	PM_{10}
Annual level (µg/m^3)	53	130
WHO guidance "annual" (µg/m^3)	10	50
WHO guidance "daily" (µg/m^3)	25	50
Daily samples violation (%)	91	78

- Coarse particles comprised 50 – 60% of PM_{10}
- There is claim of no sense of controlling air quality because of the sand storms
- Most of the emissions are from sources located out of the country's jurisdiction

(I) Air Quality

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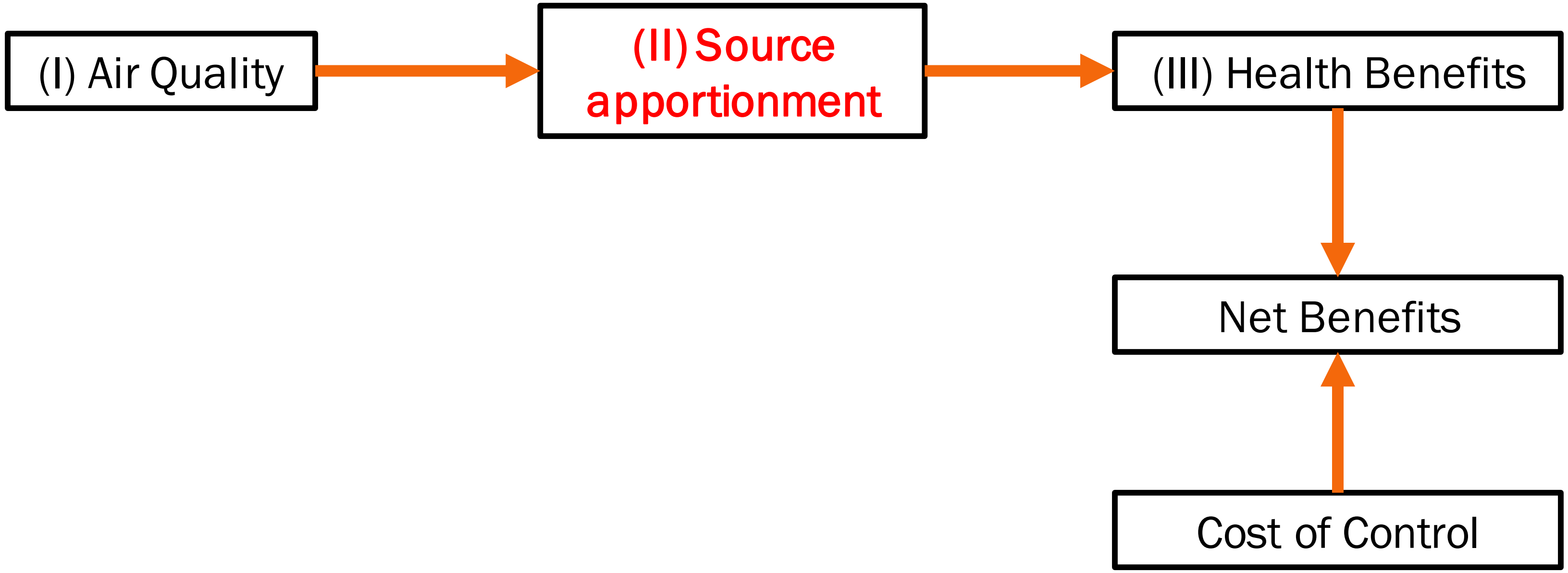


(II) Source Apportionment

- Investigating the major sources of $PM_{2.5}$ in Kuwait:
  - How many major sources are there?
  - What are the major sources' contributions?
  - What are the major sources' characteristics?
  - Where are the major sources located?

(II) Source Apportionment

- Conducting dispersion modeling for a source is the conventional way to estimate its contribution

- There is no inventories database neither an comprehensive concentration data

- Investigating the major sources for Kuwait is challenging:
  - No integrated monitoring network available in the region
  - Many small countries
  - Intense oil and gas industry in the region
  - Hot and dry weather condition

(II) Source Apportionment

- Similar study was conducted in the eastern Mediterranean part and estimated four major sources of PM; crustal, long range transport, marine, and local emissions (4)

- In UAE using aircraft satellite measurements fossil fuel combustion, mineral dust, and local vehicle emissions were found to be the major sources of PM (5)

(II) Source Apportionment

- Three analytical methods were used to estimate and characterize the major sources contribute to the $PM_{2.5}$ level in Kuwait:
  - Positive Matrix Factorization (PMF) model
  - Backward Trajectory (BT) profiles
  - Concertation Rose (CR) plots
- PMF model was used to estimate the number of the major sources as well as their contributions and profiles
- BT profiles were analyzed to identify whether each source is local or transported
- CR were plotted to examine which wind direction each source is associated with

(II) Source Apportionment

- PMF (6):

$$X_{ij} = \sum_{k=1}^{p} g_{ik} f_{kj} + e_{ij} \qquad (1)$$

$$Q = \sum_{i=1}^{n} \sum_{j=1}^{m} \left(\frac{X_{ij}^{*} - \sum_{k=1}^{p} g_{ik} f_{kj}}{U_{ij}} \right)^{2} \qquad (2)$$

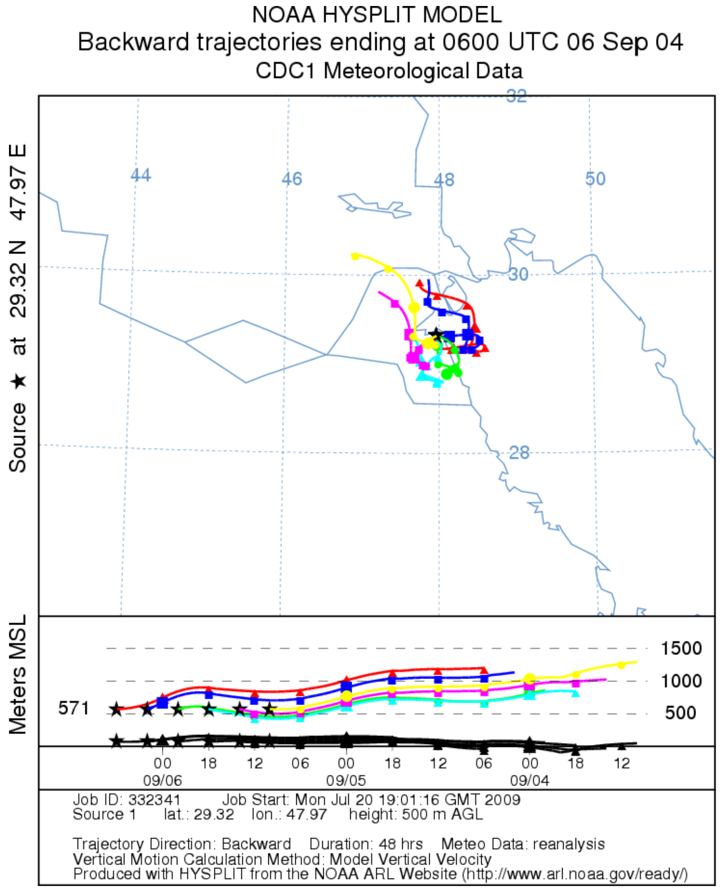
i is date of the measurement

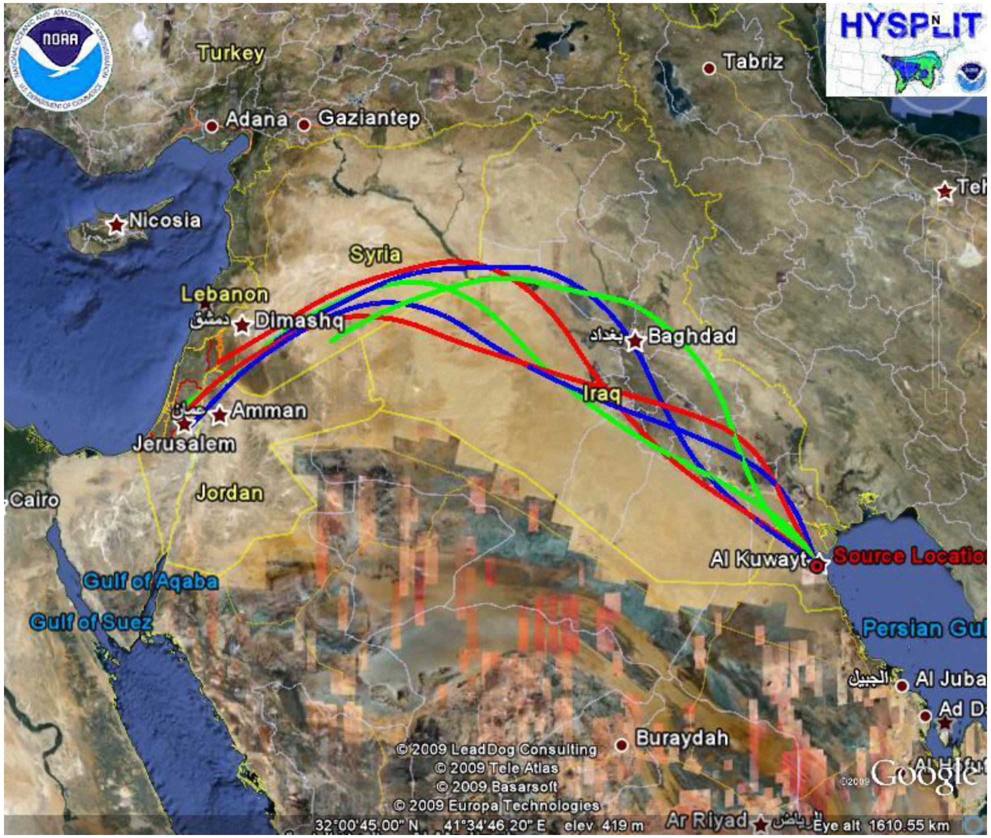
j is pollutant of the measurement

k is the source

(II) Source Apportionment

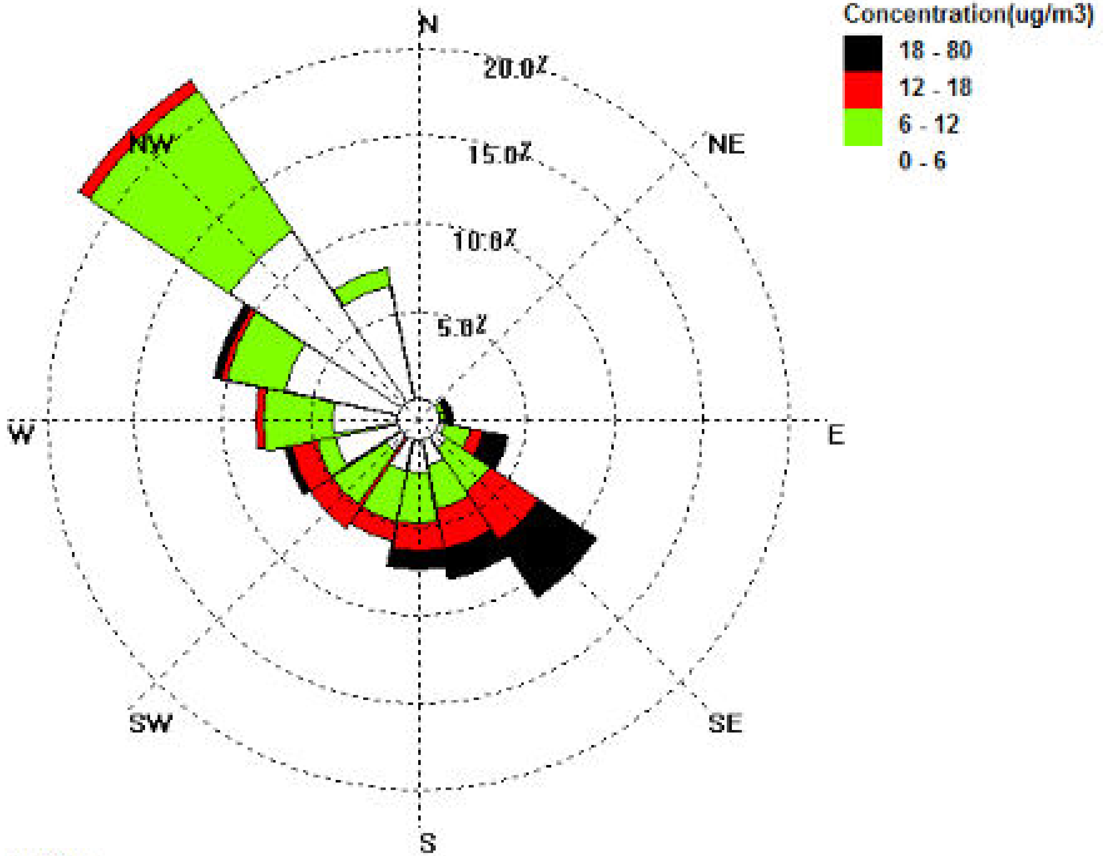
- BT (7):





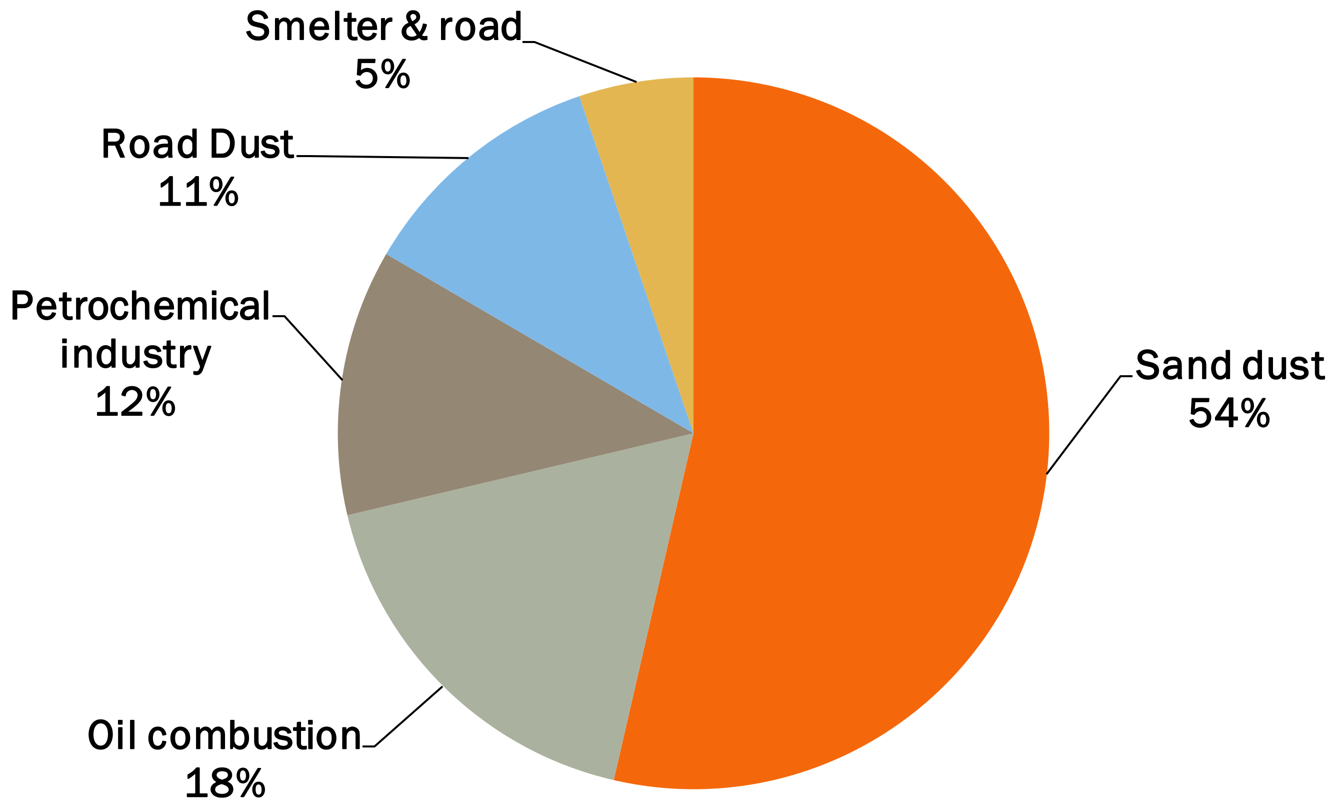
(II) Source Apportionment

- CR:



f. SO4

(II) Source Apportionment



(II) Source Apportionment

	PMF (%)					BT (%)		CR (%)				
	F 1	F 2	F 3	F 4	F 5	Local	Transported	SE	S	SW	W	NW
$PM_{2.5}$	54	18	12	11	5		69 from NW	17	10		15	45
Ca	86						82 from NW					64
K	73			14			82 from NW				14	59
Si	87						82 from NW					64
Ni	77						73 from NW		14			55
Mn	83						82 from NW					64
Fe	84						82 from NW					64
Al	87						82 from NW					64

(II) Source Apportionment

	PMF (%)					BT (%)		CR (%)				
	F 1	F 2	F 3	F 4	F 5	Local	Transported	SE	S	SW	W	NW
V	40	24		27		50	50 from NW	23	14		14	32
S		65	13	10		82		50	23	18		
NO_3^-			85	11		83		46	10			22
EC		14		65		96		19	27	31	15	
OC	32		14	45			54 from NW			25	29	29
Cu				52	29	27	59 from N	27	14	18	27	14
Zn					82	36	41 from N	32		23	18	23
Pb	10			63	24	27	45 from N	18		27	23	23

(II) Source Apportionment

- Factor 1: Sand Dust (%54) [8,9]
  - Associated with earth crust elements such as Al, Mg, Fe, Ca, … etc.
  - Highest in summer and lowest in winter
  - Northwestern wind
  - Not local " from west and north Africa"
  - Cr, Na, Mg and Cs Tracer elements

- Factor 2: Power Plants (%18)
  - Local source
  - Associated with S, V, and EC
  - Highest in summer and lowest in winter

- Factor 3: Petrochemical Industry (%12)
  - Local source in the southeast of the country
  - Associated with NO_3^-, OC and S
  - Highest in winter and lowest in summer

- Factor 4: Local Traffic (%11)
  - Local Source
  - Highest in winter and Lowest in summer
  - Associated with NO3-, EC, OC, Cu, K, and Pb

- Factor 5: Transported (%5)
  - Associated with Zn, Cu and Pb
  - Not Local "from north and within short distance"
  - Northern wind

(II) Source Apportionment

(II) Source Apportionment

- There is an opportunity to improve public health and outdoor air quality in Kuwait since non-anthropogenic sources contribute to the total level of $PM_{2.5}$ by %46

- Three out of the four anthropogenic sources are located inside the country and have total contribution of %41

- If inventories data is not available or in lack for budget and time, such analysis would provide valuable information to assess the major sources and any opportunity to improve outdoor air quality

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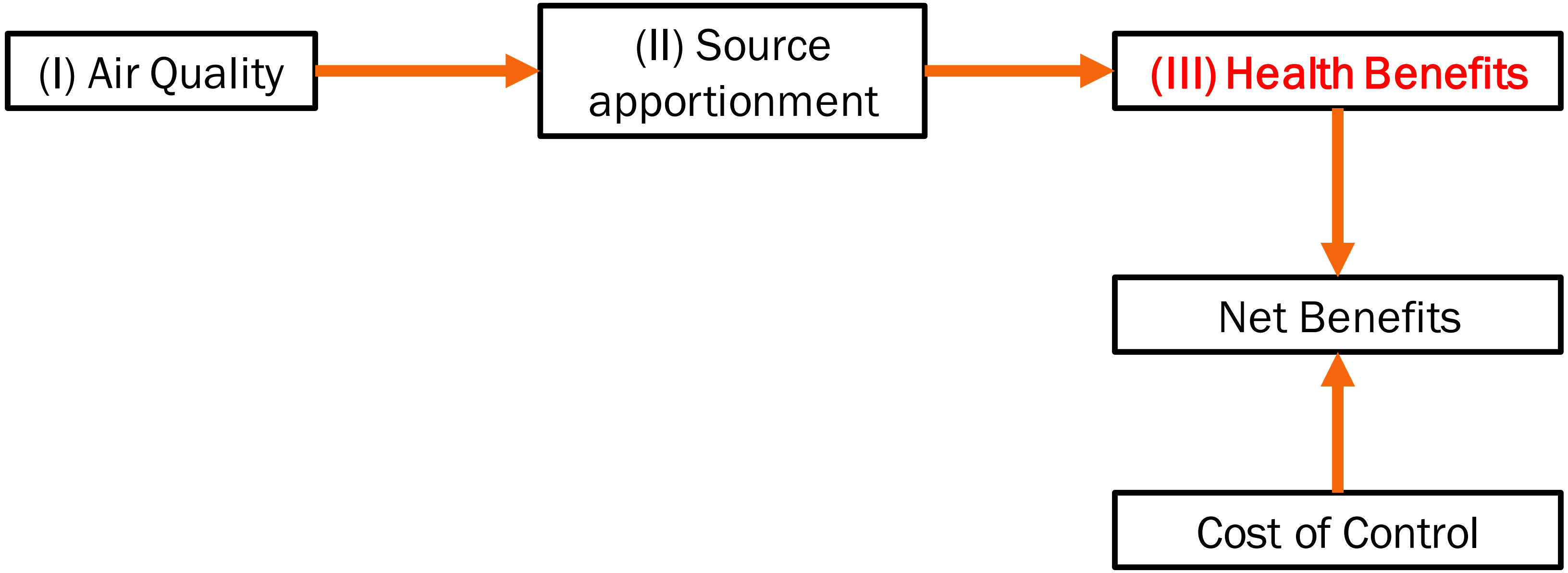

(III) Health benefits

- One Power plant in Kuwait was chosen to estimate the benefits of controlling the ammonium sulfate concentration through SO2 emissions.
- To monetize the benefits of mortality and morbidity the VSL was estimated for Kuwaitis so it can be compared with the cost of control.
- The VSL was estimated for Kuwaitis using contingent valuation study to be lognormally distributed with median of 21.7 million USD ($2011) based on a sample size of 623.
- The VSL in USA by EPA is 7.4 million USD ($2006).

(III) Health benefits

Switching from to		SO_2 Emissions Reduction (%)	Cost (USD/barrel)
Do Nothing		0.0	0
Fuel Oil	Gas Oil	87.5	20
Crude Oil	Gas Oil	80.0	10

(III) Health benefits

- Health benefits considered the reduction in mortality only as it has shown to dominate the others such as morbidity, welfare and recreation by around 80%.

- Three functions were used to estimate the health benefits:
  - Emission-exposure
  - Exposure-response
  - Response-monetization

(III) Health benefits

The analysis was conducted for two populations of interest Exposed Kuwaitis and 1000 km from the plant. 1,164,448 Kuwaitis and 110,705,971 in the entire region

All Kuwait
All Bahrain
All Qatar
All UAE
All Iraq
10% of Jordan
15% of Syria
67% of Iran
67% of KSA

(III) Health benefits

Control	Population	Concentration reduction ($\mu g/m^3$)				Lives saved (deaths-present value)			
		Expected	5%	50%	95%	Expected	5%	50%	95%
Fuel oil to gas oil	Entire region	0.015	0.005	0.013	0.032	196	25	138	561
	Kuwaitis only	2.551	0.869	2.206	5.475	108	10	70	333
Crude oil to gas oil	Entire region	0.002	0.001	0.002	0.004	23	3	17	64
	Kuwaitis only	0.308	0.105	0.266	0.662	13	1	8	39

(III) Health benefits

Population	Control	Cost (billion USD)				Health benefits (billion USD)				Net benefits (billion USD)			
		Expected	5%	50%	95%	Expected	5%	50%	95%	Expected	5%	50%	95%
Fuel oil to gas oil	Entire region	0.46	0.41	0.46	0.5	1.77	0.16	1.17	5.51	1.31	-0.30	0.70	5.08
	Kuwaitis only					1.54	0.12	0.96	4.60	1.09	-0.33	0.49	4.16
Crude oil to gas oil	Entire region	0.05	0.04	0.05	0.06	0.21	0.02	0.14	0.63	0.16	-0.03	0.08	0.59
	Kuwaitis only					0.18	0.01	0.12	0.54	0.13	-0.03	0.06	0.49

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Questions

- Thank you for your time and and attention:

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