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# Air-quality assessment over the world's Most Ambitious Project, NEOM in Kingdom of Saudi Arabia

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**Abstract.** NEOM is an under-development transnational city and economic zone spreading over an area of 26,500 sq.km along the northern Red Sea coast of Saudi Arabia, bordering Jordan and Egypt. This work analyzes the meteorological parameters and air pollution dispersion over the NEOM region based on observations and air-quality dispersion modeling. The Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model was implemented to simulate air parcel trajectories, as well as transport, dispersion, chemical transformation, and deposition. To drive HYSPLIT, high-resolution meteorological data generated at 600 m resolution by downscaling ECMWF global reanalysis using the Weather Research and Forecasting (WRF) were used. The United States Environmental Protection Agency Air Pollutant Emission Factors 42 emission inventory was used to initialize HYSPLIT. A continuous three-year meteorological and air-quality data from WRF-HYSPLIT model is used to analyze the spatial and temporal distributions of air pollutants' concentration over the NEOM region. Strong land and sea breezes resulting from the differential heating dominates the diurnal dispersion and distribution of pollutants in the NEOM region. The spatial distributions of the mean seasonal ambient air pollution dispersion show similar patterns, with relatively higher concentrations in spring and winter. This is more pronounced in the spatial distributions of the maximum concentrations of different pollutants, which show the maximum concentrations in the spring and winter due to lower boundary layer heights. The predicted maximum concentrations of NO<sub>x</sub> (~40 µg/m<sup>3</sup>), SO<sub>2</sub> (~25 µg/m<sup>3</sup>), CO (~10 µg/m<sup>3</sup>), VOC (~0.05 µg/m<sup>3</sup>), and PMT (~4 µg/m<sup>3</sup>) over the study region remain well below the National Air Quality standards recommended by the Saudi General Authority for Meteorology and Environment Protection and the Royal commission. Our analysis provides needed information to understand the state of the air quality over the NEOM region, providing fundamental contribution to the environment impact assessment and planning in the region.

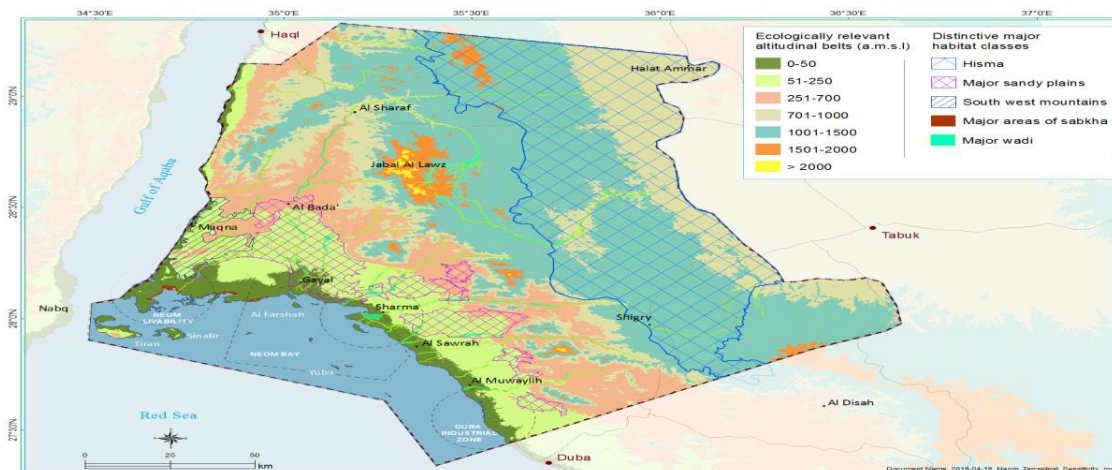
**Keyword:** NEOM, Red Sea coast of Saudi Arabia, HYSPLIT, high-resolution, Air-quality assessment, impact assessment

## 1. Introduction

NEOM is the prestigious project of the Kingdom of Saudi Arabia (KSA) to build a planned mega city along the northern Red Sea coast (Figure 1), bordering Jordan and Egypt. NEOM is proposed megacity with an estimated cost of \$500 billion to offer world-class education, healthcare, and culture by making use of



advanced, automated, zero-carbon infrastructure and forward-thinking, business-friendly governance. It is crucial to attain the ambient air-quality assessment using effective monitoring and associated modeling studies over any region. However, the air-quality studies over KSA are limited due to lack of observations and the few studies available for the region are mainly limited to the major urban areas such as Riyadh (El-Shobokshy, 1990; Rushdi et al., 2013; Alharbi et al., 2013; 2015), Makkah (Al-Jeelani, 2009), Yanbu (Al-Jeelani, 2014; Khalil et al., 2016), and Jeddah (Khoeir et al., 2012; Porter et al., 2014).



**Figure 1.** The study region NEOM for the air-quality assessment.

The ozone, nitrogen dioxide and carbon monoxide over KSA during 2007 are evaluated by Butenhoff et al. (2015). They collected observations at nine different locations and explained the ozone variability at monthly and seasonal scales. Khalil et al. (2016) analyzed the hourly measurements of oxides of nitrogen ( $\text{NO}_x$ ;  $\text{NO}$  and  $\text{NO}_2$ ), non-methane hydrocarbons (NMHCs), ozone ( $\text{O}_3$ ), sulfur dioxide ( $\text{SO}_2$ ),  $\text{PM}_{2.5}$  and  $\text{PM}_{10}$  collected at Yanbu and reported that the ozone concentrations are same and the precursors are significantly lower on the weekends, Eids, Ramadan and the Hajj periods. He further reported that substantial increase in the night time emissions are seen during Ramadhan due to the reversal of the human daily activities between night and day. Khalil et al. (2018) studied the net Ozone production rate for five urban regions (Riyadh, Hafouf, two cites in Damman, Yanbu and Makkah) of KSA using a continuous 1-hour data during 2007 and reported that the ozone concentrations in the cities are not high.

## 2. Model details and methodology:

This study provides a detailed air-quality assessment for the NEOM region using the specially collected air quality observations and dispersion modeling. The Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model (Draxler, 1997) was implemented to assess the dispersion of different pollutants. HYSPLIT computes the dispersion trajectories of the pollutants and their deposition, using puff or particle approaches. The dispersion computation is based on the transport of particles, by wind and turbulence, and air composition. High-resolution meteorological data generated at 600 m resolution by downscaling ECMWF global reanalysis using the Weather Research and Forecasting (WRF, Skamarock et al., 2008) and the United States Environmental Protection Agency Air Pollutant Emission Factors 42 emission inventory were used to initialize the HYSPLIT. The seasonal and diurnal variations in the emissions were not considered; the emissions from each source were considered, to assign pollutant mass to each virtual particle represented in the HYSPLIT model. A maximum of 10000 particles were permitted to be carried at any time during the simulation period, and about 500 particles or puffs were released every 30 min. Three-year meteorological and air-quality data from the state-of-art WRF-HYSPLIT model is generated and used to assess the spatial and temporal distributions of air pollutants' concentration over the NEOM.

This study provides a detailed air-quality assessment for the NEOM region using the specially collected air quality observations and dispersion modeling. The HYSPLIT model was implemented to assess the dispersion of different pollutants.

### 3. Results and discussions

The WRF and HYSPLIT model outputs are evaluated with the local available atmospheric and air-quality observations. Different statistical metrics computed between model and observed meteorological conditions such as wind speed, temperature and dew point temperature and are discussed (Figure 2).

Our results clearly indicate (Figure 2) that the model and observations are in good agreement with lower root mean square errors and with higher correlation coefficient and index of agreement. Similarly, the air-quality concentrations derived by the HYSPLIT are also in good agreement (not shown) with the specially collected observations over the region. After validation, we have utilized the atmospheric model outputs to explain the atmospheric conditions and associated circulation patterns that are important for the dispersion of pollutants over the NEOM region.

The temperature differences and associated heating over land and sea causing strong land and sea breezes, which allows the diurnal changes (Figure 3) in dispersion and distribution of pollutants in the NEOM region. Strong land and sea breezes, resulting from differential heating, dominate the diurnal dispersion and distribution of pollutants in the NEOM region. The distributions of mean diurnal variations of the ambient air pollution show higher concentrations in spring and winter because of lower boundary layer heights. Relatively, higher air-pollution concentrations with lower boundary layer heights in spring and winter are seen in the mean seasonal spatial distributions.

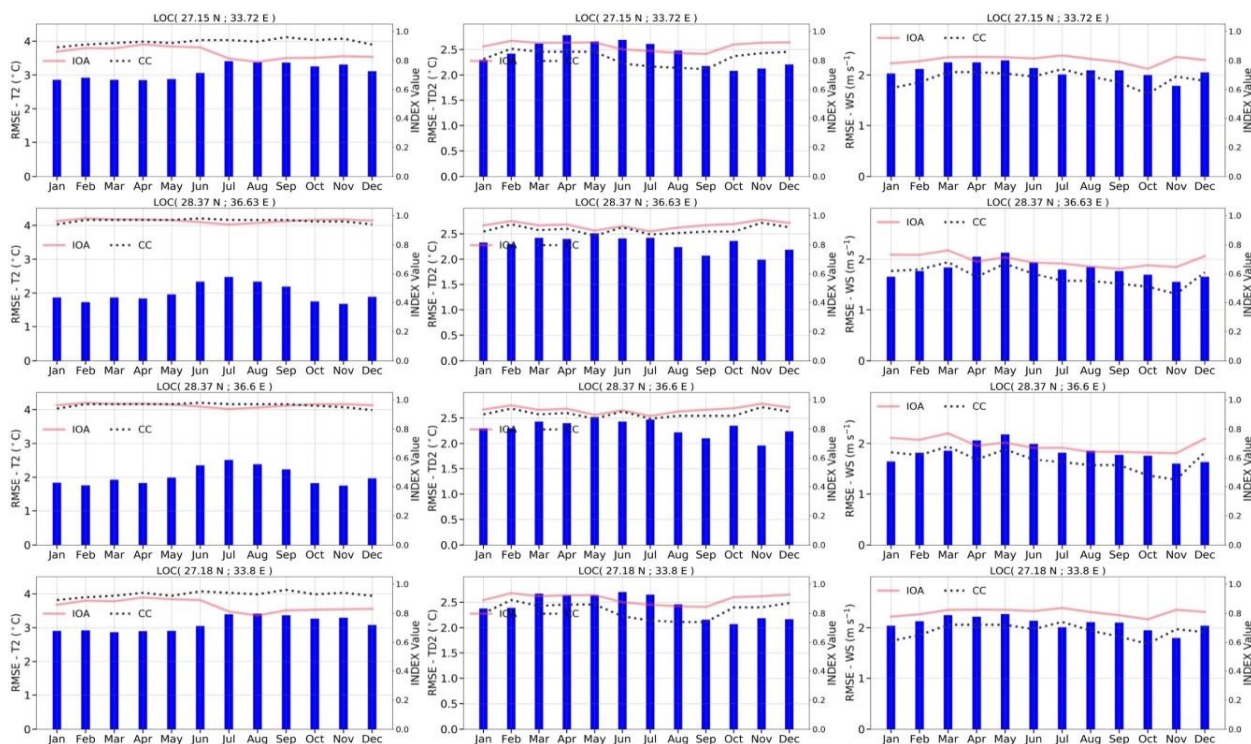
Finally, the predicted air-quality concentrations are well below (Table 1) the National Air Quality standards recommended by the Saudi General Authority for Meteorology and Environment Protection and the Royal commission. Maximum concentrations of NOX (~40  $\mu\text{g}/\text{m}^3$ ), SO<sub>2</sub> (~25  $\mu\text{g}/\text{m}^3$ ), CO (~10  $\mu\text{g}/\text{m}^3$ ), VOC (~0.05  $\mu\text{g}/\text{m}^3$ ), and PMT (~4  $\mu\text{g}/\text{m}^3$ ) are noticed over Duba region, which is located about 300 km south of NEOM in three years (2016-2018). This clearly suggest that the air-quality over NEOM is clean and well below the recommended standards. This study provides the state of the air quality over the NEOM region for the environment impact assessment and planning in the region.

**Table 1.** Results of different pollutants from the HYSPLIT predicted concentrations ( $\mu\text{g}/\text{m}^3$ ).

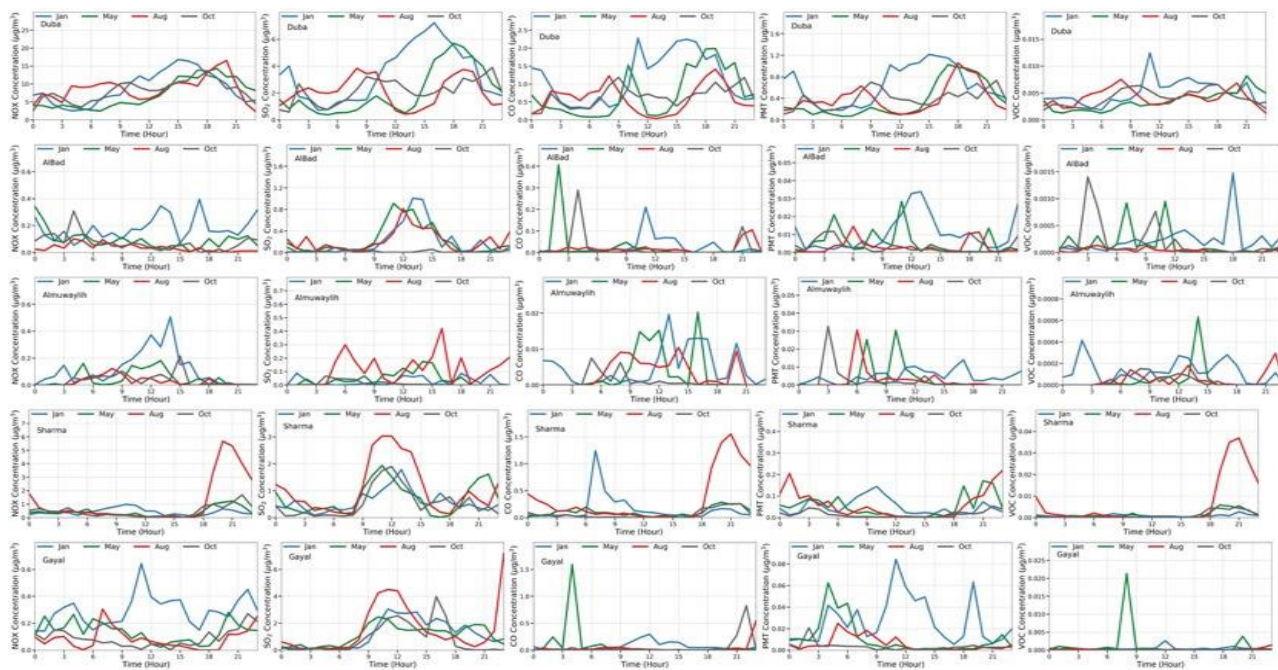
Pollutant Location		Duba	Albad	Almuway	Sharma	Gayal	GAMEP standard ( $\mu\text{g}/\text{m}^3$ )	RC standard ( $\mu\text{g}/\text{m}^3$ )
Sulphur Dioxide (SO <sub>2</sub> )	Annual average concentration	2.477	0.168	0.048	0.722	1.170	80	80
	No. of Exceedance of annual standard	None	None	None	None	None	None	None
	1-hour maximum concentration	41.759	11.767	3.376	20.399	104.251	730	730
	No. of Exceedance of 1-hour standard	None	None	None	None	None	2 times per year	Twice in 30 days

	24-hour maximum concentration	12.395	1.256	0.536	4.733	8.332	365	365
	No. of Exceedance of 24-hour standard	None	None	None	None	None	Once per year	Once per year
Oxides of Nitrogen (NO <sub>x</sub> )	Annual average concentration	8.143	0.100	0.057	0.586	0.156		
	No. of Exceedance of annual standard	None	None	None	None	None		
	1-hour maximum concentration	64.930	3.403	6.295	29.298	6.383		
Carbon Monoxide (CO)	Annual average concentration	0.794	0.022	0.003	0.160	0.064		
	1-hour maximum concentration	16.204	7.242	0.333	23.509	28.356	40,000	40,000
	No. of Exceedance of 1-hour standard	None	None	None	None	None	None	Twice in 30 days
	8-hour maximum concentration	4.469	0.322	0.041	1.212	1.034	10,000	10,000
	No. of Exceedance of 8-hour standard	None	None	None	None	None	None	Twice in 30days
Total Particulate Matter	Annual average concentration	0.456	0.006	0.003	0.044	0.012		
	No. of Exceedance of annual standard	None	None	None	None	None	80	50
	1-hour maximum concentration	7.109	0.474	0.588	2.633	1.090		
	24-hour maximum concentration	2.223	0.052	0.042	0.317	0.088	340	150
	No. of Exceedance of 24-hour standard	None	None	None	None	None	24 times per year	None
volatile organic compounds (VOC)	Annual average concentration	0.004	0.001	0.001	0.002	0.001		
	1-hour maximum concentration	0.131	0.028	0.010	0.135	0.379		
	No. of Exceedance of 1-hour standard	None	None	None	None	None		
	24-hour maximum concentration	0.016	0.002	0.001	0.017	0.008		
	No. of Exceedance of 24-hour standard	None	None	None	None	None		





**Figure 2.** Root mean square error (RMSE) of model and observed meteorological conditions for each month at four different locations. First, second, and third columns are for temperature (C) at 2m, dewpoint temperature (C) at 2m, and wind speed (m/sec) at 10m heights, respectively. The solid line is the Index of agreement and dotted line is the correlation coefficient between model and observations.



**Figure 3.** Model derived concentrations of different pollutants over five different locations.

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