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An Overview of Air-Pollution Terrain Nexus

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Terrain has been one of very significant impact factors of air pollution formation and distribution. The relationship between air-pollution and terrain has been studied for a long time. It is still a very hot topic, especially in the context of global environmental deterioration, being represented by severe haze, acid rain, local area air pollution and greenhouse gas emission as well. It is significant to obtain deeper insight into this relationship. This paper overviewed the mechanism of air-pollution terrain nexus, summarised some methods for modelling, monitoring and predicting the air pollutants distribution, flow and settling that influenced by terrain. The limitation and challenges of related studies were discussed. In conclusions, this paper aims at reviewing the nexus of terrain and air pollutions and the methods in this field, trying to highlight the current challenges.

1. Introduction

Terrain has always been one of the most significant impact factors of air-pollution formation and distribution (Saide et al., 2011). Different terrains and geographical conditions have been creating and influencing the atmosphere, hydrosphere, lithosphere and biosphere. The most concerned kinds of pollution, like air, water and land pollution, are all affected by this factor (Haldane and Kneese, 2015). In the context of increasingly serious air pollution worldwide (Carley and Spapens, 2017), the air pollution terrain nexus has been drawing increasingly social and environmental attention (Wang, 2017). The terrain influences on air-pollution are mainly caused by the impact on air flow (Haldane and Kneese, 2015). Air pollutants can either spread out or settle based on air flow influenced by terrain shape differences, it is not an easy task to make it clear or model the processes (Saide et al., 2011). Air pollutants varies, mainly by taking forms of gas, dust and particulate matters, such as PM_{10}, $PM_{2.5}$, PM_1, greenhouse gases (CO_2, CH_4, NOx etc.) and sulphur oxide (SO_x) (EPA, 2016). Air pollution can impair visibility and produce acidification, which brings negative influence world-wide, especially on global warming, human daily quality of life etc. The sources and types of air pollution and pollutants are various. Figure 1 shows the sources, type of air pollutants and pollutions (haze, sulphurous and photochemical smog).

Terrain can affect airflow and even the atmospheric circulation, consequently affecting the flow and distribution of air pollutants. Palau et al. (2005) studied the influence of complex terrain on the air convection, proposing that the valley/ridge circulations generate a significant impact on the regional air transport. This can decide the settlement and distribution of air pollutants. Sun et al. (2014) analysed that the stagnant meteorological conditions have been a significant factor for the periodic cycle haze generation of Beijing region, the capital of China. The meteorological conditions of Beijing, to an important degree, are controlled by the terrain of this region as the mountains at the northwest of Beijing hinder the airflow. The similar conclusion was also drawn by Guo et al. (2014), elucidating the severe urban haze formation in China.

There are used two strategies for studying air-pollution terrain nexus: 1) modelling and 2) experiments. Both are facing challenges. The relationship between air-pollution and terrain is highly variable over space and time and consequently difficult to experiment or model accurately, especially in the regions with complex terrain. It has been a pivotal element for comprehensive analysis of the environmentally sustainable development. Most of the current studies focus on monitoring the air pollutants in complex terrain or analysing the terrain's influences on kinds of main air pollutants basing on cases studies of certain regions. This study aims at reviewing the nexus

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of terrain and air pollutions and the methods in this field, trying to highlight the current challenges. The desired comprehensive perception of this field has been increasingly significant because of more serious pollution of the world-wide, especially the mechanism of air-pollution terrain nexus.

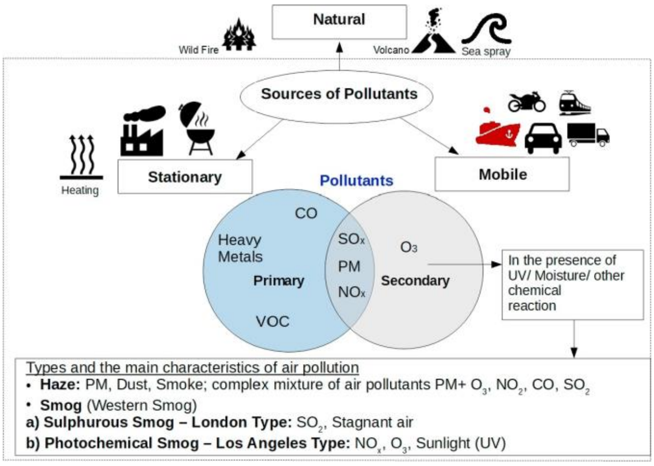

Figure 1: The sources and types of air pollutants and pollutions (Fan et al., 2018).

2. Mechanism of air-pollution terrain nexus

The air-pollution terrain nexus can be shown in simplified diagram (Figure 2). This is based on the detailed mechanism for terrain forced vertical and horizontal transport of air pollutants.

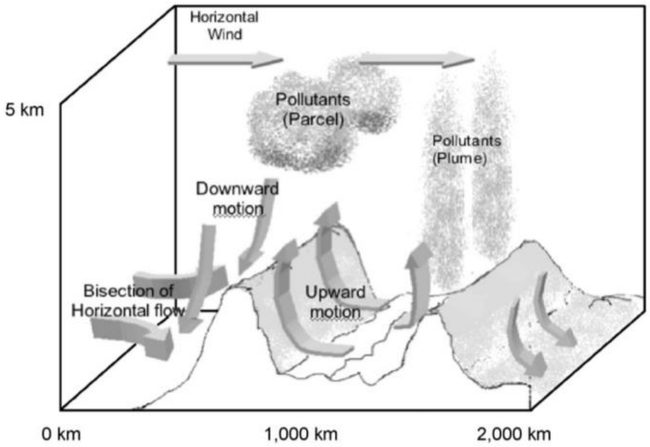

Figure 2: Schematic diagram of the vertical transport by terrain (Kim and Stockwell, 2007).

The mixing of air pollutants from the ground layer into the free troposphere can be influenced by several main factors. These include: (i) Airflow over mountainous regions forced by terrain difference; (ii) Weather systems resulted factors, such as wind, rain, low-pressure (Cairns and Corey, 2003); (iii) Boundary layer processes, troposphere and stratosphere (Kim and Stockwell, 2007); (iv) Orographic injection of pollutants (Barros et al., 2003); (v) Radiative heating resulted in atmospheric convection, such as that produced by thunderstorms (Darby et al., 2002).

Figure 2 mainly depict the interaction simplified schematic of air-pollution and terrain. The detailed mechanism of air-pollution terrain nexus can be much more complex than the schematic diagram, depending on the existing terrain construction, air pollutants properties, atmosphere conditions, hydrothermal conditions and so on. It also depends on the geographic scales and the influences from human beings. To address these challenges, experiments and sampling are mandatory. It is needed for obtaining and processing data, verified models are significant for simulating, predicting and even providing strategies for decision making.

3. Methods of monitoring air-pollution terrain nexus

Models and experiments are methods used for modelling, monitoring and predicting the air pollutants distribution, flow and settling influenced by terrain.

3.1 Modelling

Several models have been developed or improved for predicting the air-pollution terrain nexus, being highly important for the complex terrain. The neural networks, linear algorithms and clustering algorithms have been implemented to forecast PM_{10} (Perez and Reyes, 2006) and $PM_{2.5}$ (Perez and Salini, 2008). Those models are based on the measured parameters, such as terrain (slope, altitude, angle etc.), pollutants (PM, SO_2, NO_x, etc.), wind speed/direction, temperature, hydrothermal condition, rain. These models can also predict the air pollution episodes in the future.
As shown in Table 1, there are some models summarised from study results of some scholars, which have been verified for modelling and predicting air-pollution terrain nexus.

Table 1: Models for Air-pollution Terrain Nexus.

Tools/Models	PM_{10}	$PM_{2.5}$	RSPM	SPM	CO_x	Pb	SO_2	NO_x	VOC	Main Results
WRF–Chem Model (Saide et al., 2011)	√	√			√					(Verify the accuracy of the model)
Meteorological Model (Jazcilevich et al., 2005)					√		√	√	√	Maximum pollutant mixing ratios exist and follow the confluence line which crosses over the most populated areas.
k−ε Model (Huser et al., 1997)								√		Good at estimating ground pollution concentrations in a stable atmosphere over rough terrain.
Neural Network-based Method (Boznar et al., 1993)							√			Reliable for air pollution modelling in complex topography.
Air Pollution Model (TAPM) (Grigoras et al., 2012)	√					√	√			The complex terrain features and pollutions sources have an influence on the air pollutants concentration levels.
Lagrangian Particle Dispersion Model (FLEXPART) (Madala et al., 2015)			√	√			√	√		Low-level flow field is highly influenced by the topography and widely varies in different seasons.

VOC: volatile organic compounds; RSPM: respirable suspended particulate matter; SPM: suspended particulate matter.

The air pollutants most concerned have been PM ($PM_{2.5}$, PM_{10}, RSPM, SPM, etc.), CO_x (CO, CO_2), SO_2, NO_x. It is corresponding with the local, regional and global environmental issues. PM are both one of the key elements of haze and smog (Sun et al., 2014) and one of the most dangerous factors/mediums of diseases, like cardiovascular Disease (Brook et al., 2010). CO_2 is the key element of greenhouse gas (GHG), accounting for nearly than 2/3 of GHG (IPCC, 2014). CO_2 has been drawing increasing attention from human beings, especially in the context of global warming. NO_x is also one of the common air pollutants. N_2O is an atmospheric pollutant, which can both destroy ozonosphere and give rise to the atmospheric greenhouse effect. Although N_2O belongs to the trace gas, its global warming potential is 298 times more than CO_2 (IPCC, 2007). SO_2 is the key element of acid rain, which is a huge threat to plants, human respiratory tract and so on.

3.2 Experiments

Experiments are the main source of initial data and basis of models predicting (Soler et al., 2004). Experiments data can be used to verify the correction/ accuracy of models. Table 2 shows several experiments for air-pollution terrain nexus.

Table 2: Experiments for Air-pollution Terrain Nexus.

Methods	PM_{10}	$PM_{2.5}$	CO	SO_2	O_3	NO_2	MFF	Main Results
Doppler Sodar (FAS 64) (Soler et al., 2004)				√	√	√	√	Specific terrain results in the generation of main flow fields (MFF) and temperature change, which results in the pollutants concentrations and transmission.
Doppler Sodar (Reuten et al., 2005)	√	√						Air pollutants in lower valley can remain trapped within the convective boundary layer rather than being vented into the free atmosphere.
Sodar Sampling (Gustin et al., 2015)					√			Terrain complexity has a significant influence on the distribution and observation of air pollutant.
Sodar Sampling (Holmes et al., 2015)		√						Cloud and temperature have an influence on air pollutants flow.
Spatial Saturation Monitoring Study (Shmool et al., 2014)		√		√	√	√		Elevated concentrations of multiple pollutants are identified at lower-elevation sites.

As shown in Table 2, the most comment methods for air pollutants monitoring experiments are sodar detection and sampling. Sodar related methods can provide remote sensing of air pollutants without field monitoring (Soler et al., 2004), especially for the complex terrain, which can guarantee the safety of experimenter and minimise the cost of experiments. Besides, basing on the review of studies in Table 2, during the sodar monitoring process, it is significant to thoroughly monitor the experiments sites allocation, which must fully uniform cover of the region and all situations (Gustin et al., 2015).
Except sodar, Air-Monitoring-Site (AMS) is also an air pollutant monitoring method. The AMS is with good accuracy. It relatively restricted by terrains (Shmool et al., 2014). The experiments conducted by Shmool et al. (2014) as an example to show the spatial distribution of sites (Figure 3). In this experiment, they proposed a spatial saturation monitoring study for targeting the sources of air pollutions ($PM_{2.5}$, black carbon, NO_x, SO_x, O_3, etc.), understanding the influence of topography and temperature on air pollutants variation.

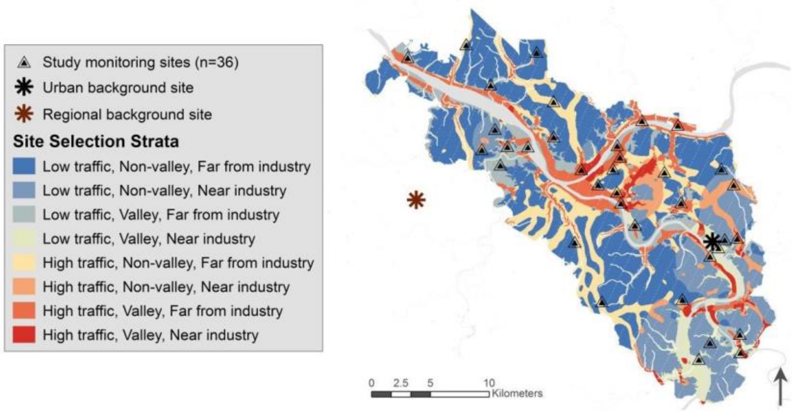

Figure 3: Air pollutants monitoring locations across source indicators and inversion-prone areas.

4. Limitations

The air-pollution terrain nexus is complex, depending on each specific region and its topography, atmosphere, temperature etc. Many limitations, challenges and different uncertainties limits the study of processes: a) Its inability for completely resolving or modelling the complex terrain, like WRF–Chem Model (Saide et al., 2011). The high accuracy topographic inversion is still a challenge for terrain modelling (Deng et al., 2017). Terrain complexity is a crucial feature in the field of terrain analysis; Unlike slope or aspect, terrain complexity is ambiguous that there is no optimal parameter to quantify it (Huaxing, 2008). The traditional indexes for monitoring terrain complexity are including geometrical, statistical and semantic parameters. These parameters are mainly from the perspective of geomorphometry, which will bring inaccuracy when modelling the real world (Huaxing, 2008); b) The modelling and experiments results are inaccuracy or even incorrect in meteorological initial and boundary conditions. The meteorological initial and boundary conditions are complex and unstable, changing all the time, which is difficult to monitoring and modelling precisions; c) The long-term and effective simulation and prediction need improvement and models have limited range of application. Meteorological condition changes all the time, depending on the certain terrain condition. Current models are difficult to be effectively implemented and obtain the long-term precise result in all scenarios.; d) The accurate monitoring of some air pollutants is complex, because the characteristics for air pollutants are different and some of them are difficult to capture. (Snyder et al., 2013).

5. Conclusions

This paper attempted to present the mechanism of air-pollution terrain nexus. Models and experiments are main methods selected for modelling, monitoring and predicting the air pollutants distribution, flow and settling that influenced by terrain. Some air pollutants, such as PM ($PM_{2.5}$, PM_{10}, RSPM, SPM, etc.), CO_x (CO, CO_2), SO_2, NO_x are most studied by the researchers. There are still some limitation and challenges in the study process of this topic, such as the inability for completely resolving or modelling the complex terrain, lacking long-term and effective simulation and prediction to mention at least a few.
In the future studies, more detailed state of the art, comprehensive impact factors, extended methods summary and research trend are going to be taken into consideration.

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