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Review

Environmental contamination due to shale gas development

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HIGHLIGHTS

- Shale gas development potentially contaminates both air and water compartments
- Characterization of potential contamination pathways
- Measured concentrations from literature are compared with quality standards
- Concentrations of salts, metals, VOC's and hydrocarbons exceeded quality standards
- Future research must focus on aquatic toxicology and improved waste water treatment.

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ABSTRACT

Shale gas development potentially contaminates both air and water compartments. To assist in governmental decision-making on future explorations, we reviewed scattered information on activities, emissions and concentrations related to shale gas development. We compared concentrations from monitoring programmes to quality standards as a first indication of environmental risks. Emissions could not be estimated accurately because of incomparable and insufficient data. Air and water concentrations range widely. Poor wastewater treatment posed the highest risk with concentrations exceeding both Natural Background Values (NBVs) by a factor 1000–10,000 and Lowest Quality Standards (LQSs) by a factor 10–100. Concentrations of salts, metals, volatile organic compounds (VOCs) and hydrocarbons exceeded aquatic ecotoxicological water standards. Future research must focus on measuring aerial and aquatic emissions of toxic chemicals, generalisation of experimental setups and measurement technics and further human and ecological risk assessment.

Contents

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1. Introduction

Following depletion of oil and conventional gas, countries are beginning to turn to shale gas. Global shale gas reserves are estimated to be more than 200 trillion m^3 (Kuuskraa et al., 2013). Despite these large resources, only Canada, the U.S. and China produce shale gas at a commercial level (EIA, 2015). Other countries are reluctant because hydraulic fracturing, the method to retrieve shale gas, causes societal concern (Eaton, 2013; Hays et al., 2015; Hladik et al., 2014). Shale gas has a high economic value and a reduced greenhouse gas (GHG) potential when combusted, compared to coal (Burnham et al., 2011). Yet, there is a potential risk of contamination of groundwater, drinking water aquifers and ambient air (Bunch et al., 2014; Ferrar et al., 2013; Hladik et al., 2014; McKenzie et al., 2012; Osborn et al., 2011; Swarthout et al., 2015).

The extraction of shale gas is facilitated by a combination of horizontal drilling and hydraulic fracturing (King, 2012). Hydraulic fracturing requires large amounts of water, chemicals and suspended sand called proppants (Fracfocus, 2014). A well pad ranging from 15,000 to 30,000 m^2 is needed for connection of pipelines, transport and production waste materials. Waste mainly consists of drill cuttings, flow back fluids and other by-products emerged from the drill process (Lampe and Stolz, 2015). These activities may contaminate the environment, but the actual risks are unclear. By exploring contamination pathways, environmental risks can be better understood.

The lack of information on potential ecotoxicological risks and GHG emissions causes many countries to postpone shale gas activities (Jiang et al., 2015; Stamford and Azapagic, 2014; Vandecasteele et al., 2015). Conclusions are often tentative, based on a few measurements obtained by different techniques, at different sites and within different environmental compartments. Additionally, a comparison to natural background levels and environmental quality standards is lacking, hampering assessment of environmental impact (Vandecasteele et al., 2015). Therefore, the aim of the present review was to explore potential environmental impacts of shale gas development, with the intention to assist governments in future decision-making and priority setting for research needs.

2. Methods

In this review, environmental contamination pathways due to shale gas development are characterized. Hereby, studies with environmental pollution due to fossil fuel development other than shale gas or a combination of both, are excluded. We have collected information on 1) activities with their potential environmental risks, 2) estimated emissions of toxic substances, 3) measured concentrations of chemicals in air and water and 4) Natural Background Values (NBVs) and Lowest Quality Standards (LQSs). For the activities section, mostly recent and highly cited review articles have been consulted to give a brief overview of the known procedures and risks during shale gas development. For the emission and concentration section we relied on studies which provided an experimental setup with measured data to be further compared to NBVs and LQSs. NBVs in air represent background measurements which are taken from EPAs national database on ambient volatile organic compounds (VOCs) (IPCC, 2013; Mathesongas, 2005; NYSDH, 2006; Robinson, 1978). NBVs in water are obtained from European background measurements (INCHEM, 2015; Waterlaboratorium, 2015; WHO, 2015). LQSs represent Exposure Limits obtained from NIOSH based on U.S. air quality guidelines comprising time weighted average threshold limit values (TWA-TLV) (Mathesongas, 2005; NIOSH, 2015). LQSs for water refer to the Aquatic Toxicity Reference Values (TRVs) derived as Toxicological Benchmarks from different ecotoxicological studies (Suter and Tsao, 1996).

3. Results

3.1. Activities

During shale gas development, different types of activities can pose a direct or indirect risk to the environment (Fracfocus, 2014). Before exploratory drillings are allowed potential shale gas formations have to be located, and permits, legislations and drill rights have to be granted (SI Table S1).

Geological research helps determine if hydraulic fracturing activity in the target shale-formation can cause emissions of toxic chemicals or heavy seismic events. Aquifer formations close to shale gas production sites can get contaminated by chemicals that emerge from pre-existing or produced fractures (Reagan et al., 2015; Vengosh et al., 2014; Warner et al., 2012).

Some potential production areas are protected such as drinking water production sites and natural reserves. Legislation may impose a minimum distance to urban areas and buildings. A distance greater than 100 m to water bodies is required to prevent hazardous effects in case of leaks or spills (Vandecasteele et al., 2015).

3.1.1. Activities and potential risks

After locating the potential production areas, it is important to characterize the different activities involved in shale gas development and their respective potential effects to the environment. The activities can be divided into seven different stages: 1) drilling the borehole, 2) mixing of fracturing fluids, 3) hydraulic fracturing, 4) acquisition of flowback or produced water, 5) wastewater treatment 6) usage of transport and machinery and 7) sealing and abandoning the borehole (Vandecasteele et al., 2015) (Fig. 1).

3.1.1.1. Borehole drilling and construction. The first stage is the drilling of the borehole. At first, a vertical shaft is drilled until the depth of the shale gas formation has been reached. While drilling vertically, metal casings are being attached to the soil surrounding the well, along with sufficient amounts of cement to effectively isolate the well from the rest of the soil. Once the formation is reached, the drill head bends and drills a horizontal shaft through the shale gas containing layer that gets cemented as well (Fig. 2) (King, 2012).

After the well has been drilled, a well pad is constructed with an average size of 16,000 to 20,000 m^2 (Vandecasteele et al., 2015). This includes all machinery and pipeline structures needed for running the hydraulic fracturing process, and the infrastructure for transport of materials and chemicals from and to the well pad. A large area needs to be cleared and deforested so that a well pad can be constructed. Consequentially, the area becomes vulnerable to erosion during heavy