TOWARDS THE EFFECTIVE MANAGEMENT OF GROUNDWATER RESOURCES DURING UNCONVENTIONAL GAS MINING

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Abstract:

Unconventional gas mining is a new and unprecedented activity in South Africa that may pose various risks to groundwater resources. According to legal experts, South Africa does not currently have the capacity to manage this activity effectively due to various lacunae that exist in the South African legislation. An analysis of the possible impacts of unconventional gas mining on groundwater as well as governance strategies that are used in countries where unconventional gas mining is performed; have been analysed and will be discussed. Based on possible impacts and strategies to manage and protect groundwater internationally, possible governance options for the management of South Africa's groundwater resources are proposed.

1. INTRODUCTION

Recently, South Africa received various applications for unconventional gas mining. Due to the uncertainty surrounding this mining activity in South Africa, the government currently allows for exploration of unconventional gas mining without hydraulic fracturing (HF). South Africa does not have legislative and regulatory instruments in place yet to effectively manage unconventional gas mining by means of hydraulic fracturing (1,2).

In order to effectively manage unconventional gas mining and ensure proper protection and future sustainability of groundwater resources, the recognition of the following issues is important:

- The risk posed by all the different phases and activities related to unconventional mining, and not only the impacts of hydraulic fracturing, should be recognised (3).
- Unconventional gas mining is a regional scale activity and is not localised as is often the case in conventional gas resources (3,4), necessitating the monitoring of land-use activities in conjunction with groundwater regulation.
- Impacts associated with unconventional gas mining are cumulative and should be managed as such (3,5).

Due to the above-mentioned facts, it is important that management of groundwater during mining of unconventional resources should take into account the following:

- Integrated management of this activity should be implemented (departments should control licensing and monitoring of the process in a coordinated manner and ideally strategic environmental assessments should be performed instead of environmental impact assessments).

- License applications should be managed centrally, so that cumulative impacts could be identified and managed.
- Upon awarding exploration or mining licenses, relevant departments should ensure that licence conditions are implemented. License condition data (e.g. monitoring data) should be stored with relevant regulatory bodies and such data should be made available to all relevant departments. Data obtained from operators as part of their license conditions should regularly be evaluated. Based on these evaluations, license requirements should be adjusted, if required, during review periods. Review periods of operating licenses could be shortened, if required.
- Licencing and monitoring could be performed by an independent body with sufficient and applicable human resource capacity.
- Relevant legislative amendments and drafting of regulations is required to ensure proper management of groundwater resources.
- Groundwater should be protected in an integrated manner together with surface water, to adhere to the principles of integrated water resource management.

Lastly it is extremely important that South Africa find the political will to manage this activity responsibly, to ensure adherence to the constitution and ensure the safety of groundwater resources for future use. This paper highlights the concerns associated with each phase of unconventional gas mining and also lists possible regulatory instruments that may be implemented during each mining phase.

2. INTERNATIONAL GROUNDWATER RELATED REGULATION OF UNCONVENTIONAL GAS ACTIVITIES

This section briefly describes some of the important aspects that need be taken into account for regulation of groundwater, based on international practice. During the different phases of mining different aspects of water management becomes important. During exploration baseline monitoring is important, while during mining the regulation of water abstraction, emergency event control, various drilling regulations and wastewater disposal are important. After mining the effective regulation of wastewater management and possible associated underground injection is required.

In Europe and the USA, aspects that receive research attention include the establishment of baseline water monitoring information necessary for assessing the impacts of hydraulic fracturing on groundwater reservoirs in different geological formations, including potential leakage and cumulative impacts. The lack of baseline data prior to oil and gas development often lead to cases where alleged groundwater contamination in the USA could not be proven because officials cannot link changes in groundwater quality to oil and gas activities, and can thus take no legal action (6,7).

Water abstraction for unconventional gas mining in the case of shale gas mining**,** is regulated in most countries (8,9) since the water requirement of full scale shale gas mining may be quite significant (5). The regulation of groundwater abstraction in a water-scarce country such as

South Africa is very important (10). Coalbed methane (CBM) by comparison may not require as large amounts of water, but rather generates large amounts of saline water that need to be managed (11,12). Various regulations can protect groundwater during the mining phase. These relate to drilling, casing, cementing, hydraulic fracturing operations and well plugging (6), which are activities that should also be closely monitored (13).

Emergency event control is important for unconventional gas mining operations, as many road accidents or accidental spillages may occur. Emergency events may also constitute contamination of water wells or aquifers by methane or other fluids. Emergency control measures need to be in place to regulate cleanup of spillages and also for the provisioning of water in the case where water wells have been contaminated. Possible regulatory steps that can be included in such emergency instances of well contamination, may include: a) notification of incident, b) providing replacement of water resources, c) monitoring the fluid contamination in a well or in the case of gasses, monitoring explosive risk and d) conducting a survey of additional wells that may be affected in a given radius around the affected well. Lastly regulators can request that the responsible party conduct an investigation into how fluid / methane contaminated the well or aquifer in question (6).

South Africa would also have to develop a wastewater management strategy to manage flowback (typically consisting of returned fracturing fluids) and produced water (fluids displaced from the target geological formation). They must decide on whether to allow discharge of wastewater into surface streams after treatment, or to allow for deep underground injection with minimal discharge into streams. Geological complexity in South Africa may make deep well injection risky. If deep well injection is allowed, this activity should be properly regulated to ensure protection of groundwater resources. In the USA, approximately 115,000 wells are underground injection wells (6). There operators must obtain a permit from the EPA before operating, demonstrate that casing and cementing are adequate, pass a well integrity test prior to beginning operations and retest well integrity at least every 5 years. During the life of the underground injection well, the operator also has to comply with monitoring requirements, including tracking injection pressure, rate of injection and volumes of fluids injected (6).

Apart from the wastewater, brines produced during treatment of waste, should also be managed and disposed of. Factors that may complicate water treatment include the fact that the water contains high levels of non-aqueous phase liquids as well as naturally occurring radioactive materials (NORMs) (3,5,14). Larger volumes of water may be produced by CBM, which may require treatment and disposal (6). CBM wastewater management practices in the USA include land-based applications, but land-based applications may be limited depending on the type of wastewater and pre-treatment of the wastewater that may be required. The effectiveness of wastewater treatment plants (WWTPs) in South Africa is another aspect that would require attention (15).

A complication for regulation of this mining process is the fact that the characteristics of gas reservoirs dictate fracturing techniques, and heterogeneous geology thus makes the regulatory system highly variable and heavily dependent on regulators' local and regional of specific gas mining areas.

3. POSSIBLE REGULATORY INSTRUMENTS TO BE DEVELOPED DURING THE VARIOUS PHASES OF MINING

Various regulatory instruments may be required to protect groundwater and surface water resources during the different phases of mining. This section will describe concerns during each phase of mining as well as possible regulatory instruments that could be developed (Tables 1 - 4), based on international experience.

Table 1 describes regulatory instruments that should be developed during the pre-exploration phase, in anticipation of exploration. Such a course of action would ensure compliance with the precautionary principle as embodied in South Africa's National Environmental Management Act.

Table 1: Regulatory instruments and actions required during the pre-exploration phase

Pre-exploration phase	
Concerns	During the pre-exploration phase, there may not be any negative impacts on groundwater that are of specific concern, but certain regulations and rules to regulate and manage possible impacts during the exploration phase need to be developed before exploration.
Regulatory instruments	**Regulatory instruments that should be developed / actions to be implemented** • Baseline monitoring protocols specific to unconventional gas mining to be developed • Establishing setback rules (e.g. safe distances between oil and gas wells & storage tanks from waterbodies, public water supplies & property). [16,17] • Establishing storm water permitting requirements & management rules as well as spill prevention & control plans for unconventional mining areas [16] • Developing regulations on drilling, casing, cementing, hydraulic fracturing operations & well plugging [6] to ensure well integrity throughout all the mining phases. [13] • Developing regulations on real-time monitoring of drilling and HF operations, data capture and dissemination to relevant institutions. [13] • Ensure inclusion in license conditions of interim measures for wastewater and solid waste management generated during exploration. • Developing regulations on data dissemination, chemical disclosures, notifications to authorities (e.g. notices to drill, hydraulically fracture, notices of spillages)[18;19] & certifications (e.g. pre-fracturing certification). [19] • Creating a model regulatory framework to ensure public acceptability and establish industry discipline [13], including integration of provincial or local level regulation with international level regulations and possibly registering unconventional gas mining as a controlled activity under the National Water Act. **Actions required** • Establishing or upgrading laboratories with relevant accreditations that can analyse unconventional gas samples adequately to ensure legal standing. • Possible establishment of a central management agency for implementation & monitoring of gas mining & related activities.

The most important regulations that need to be developed before exploration relates to baseline monitoring and management rules related to drilling operations and monitoring during drilling for exploration and mining. A regulatory framework that integrates regulation across different levels of government would also be required.

Table 2 describes regulatory instruments that should be developed during the exploration phase as well as regulations and actions that need to be implemented during the exploration phase.

Table 2: Regulatory instruments and actions required during the exploration phase

Exploration phase	
Concerns	• Artesian basin conditions [14,20] in the Karoo geological basin may cause upward migration of formation water. • Shales pose various problems during drilling (e.g swelling shale instability with associated borehole problems such as hole collapse, poor hole cleaning, plastic flow, lost circulation and poor well control). [21,22,23,24] • Large quantities of saline water possibly produced by CBM mining [11] and possible aquifer contamination from CBM mining if aquifers and coalbed formations co-occur [11,12] • Possible groundwater contamination if hydraulic fracturing is allowed during the exploration phase, both for coalbed methane and shale gas formations. [3,12,25]
Regulatory instruments	**Regulatory instruments that should be developed** • A strategy for regional scale integration of water use during unconventional gas mining (sourcing of water in water-scarce areas, enforcing closed-loop drilling & optimal water recycling). [16] • An unconventional gas wastewater management strategy (address and treatment of wastewater, brine management and deep well wastewater injection) and associated regulations / guidelines. Regulate pre-treatment requirements for WWTPs, recycling of water, solid waste disposal and hazardous waste disposal. [6] **Regulations that should be in place during exploration for groundwater management, and related required implementation:** • Baseline monitoring protocols for relevant aspects. • Drilling, casing, cementing, hydraulic fracturing operations and well plugging regulations. [6] • Regulations on real-time monitoring of drilling and HF operations, data capture and dissemination to relevant institutions. • Setback rules, storm water permitting requirements, data monitoring and dissemination requirements. • Regulations on data dissemination, disclosures & notifications to authorities. • Model regulatory framework with integration across different levels of government. **Actions required** • Development of a national centralised database to store fracking data. • Proper regional scale land-use planning. • Continuous upgrading laboratories with relevant accreditations that can analyse unconventional gas samples adequately to ensure legal standing. • Continuous development of technological solutions to better manage this mining activity. • Continuous development and implementation of amended legislation and developed regulations.

The most important regulatory instruments that need to be developed during exploration include the development of water use and sourcing strategy and a wastewater management strategy. The regulations regarding baseline monitoring as well as management rules related to drilling operations and monitoring during exploratory drilling, should be implemented during this phase.

Table 3 describes regulatory instruments that should be developed during the mining phase as well as regulations and actions that need to be implemented during the mining phase.

Table 3: Regulatory instruments to be developed and actions required during the mining phase

	Mining phase
Concerns	**Shale gas:** • Various impacts on aquifers for different water sourcing options: Large water volumes required for fracturing operations [3,5,25,26] may impact on aquifers, water users; freshwater or saline aquifer water abstraction may cause subsurface disturbance, fluid migration, triggered seismicity[12] possibly contaminating freshwater aquifers; wastewater reuse could introduce contaminants into aquifers.[12] • Uncertainties during drilling and mining shale gas may impact on aquifers: Poor well construction → migration of fluids / gas into aquifers[3,25,27]; contamination during drilling (poor storm water control, well blowouts)[11]; control of fracture zones & well bore placement [25,27] & cement setting behaviour[4] problematic; deep structures may cause aquifer connectivity & fluid migration.[14,28] • Shales pose various problems during drilling (shale instability with associated borehole problems such as hole collapse, poor hole cleaning, plastic flow, lost circulation and poor well control). [21,22,23,24] • Surface activities may contaminate aquifers via surface water–groundwater interaction. [12,29,30] • Wastewater treatment and disposal uncertainties put aquifers at risk[12]; re-injection of wastewater may cause geological / aquifer deformation with associated triggered seismicity [31,32,33] or fluid migration.[3,25] • Artesian basin conditions / deep structures[14] may facilitate fluid migration from shales to surface. • Poor well integrity may cause leakage of gas or fluids and groundwater contamination, also for CBM. [3,4,14,25,34,35] • Regulatory uncertainties (lack of fracking-specific legislation, regulations) may put groundwater resources at risk.[1,36] **Coalbed methane**: • Challenges with wastewater management due to saline water production from CBM. [11] • Extraction of water from CBM may lead to geology & aquifer deformation, subsidence, baseflow decreases & reduced springflow. [11,12] • Fluid migration from CBM to aquifers may occur due to induced aquifer connectivity [11,12,25] • Contamination of aquifers by HF fluids, saline water from CBM possible. [3,11,12.]
Regulatory instruments	**Regulatory instruments to be developed** • Post mining planning regulations: Long term monitoring plans & protocols for closed mining areas should be developed in anticipation of mine closure. Site reclamation regulations should be drafted for wellfield closure. **Regulations that should be in place during mining for groundwater management and related required implementation:** • Regulations on reporting requirements to relevant departments of aspects that should be monitored. • Regulations on well completion and drilling operations (siting & preparation, drilling, casing & cementing, hydraulic fracturing, well plugging). [6] • Wastewater management regulations / guidelines resorting under the wastewater strategy. **Actions required** • A monitoring entity for long term monitoring should be identified or founded. • Ensure that data obtained from licenses is fed into a national centralised database. • Continuous monitoring of water use and impacts as well as land-use. • Continuous development and implementation of amended legislation and developed regulations.

During the mining phase the most important regulations include regulations around integrated regional scale post mining closure planning that would include long term monitoring of various aspects. Early planning could ensure cost-effective mitigation of post closure impacts.

Table 4: Regulatory instruments to be developed and actions required during the post-mining phase

Post mining phase	
Concerns	• Aquifer pollution from deep shale layers may only surface years after a pollution incident. • South Africa not able to rehabilitate contaminated aquifers in complex geology (physically and economically). [37] • Well abandonment and long term monitoring may be problematic. [3,12] • Oil and gas well casing failure and leakage may pose long term legacy issues and lead to inevitable groundwater contamination. [12,34,38,39]
Regulatory instruments	**Regulations that should be in place post gas mining for groundwater management:** • Post mining water resource monitoring protocols, site reclamation & well abandonment regulations. [40] • Rules & regulations for continued data dissemination, storage and interpretation. **Actions** • Continuous development and implementation of amended legislation and developed regulations. • Continuous groundwater monitoring required to ensure that slow-onset contamination is identified and managed. • Continuous monitoring and evaluation of the mechanical integrity of wells. Well deformation is seen as the main contributor to slow-onset regional groundwater contamination. [13] • Ensuring data dissemination of unconventional gas mining monitoring data to national centralised database to store unconventional gas mining data. • Continuous monitoring of land-use and proper spatial and land-use planning. • Plans for site reclamation and waste management should be implemented during this phase. [6]

During the post mining phase most regulations for all the phases of exploration through to post mining closure should be in place, but revision of regulations based on monitoring outcomes or technological development may be necessary. During the post mining phase it is important to ensure implementation of regulations and required actions. Continuous monitoring of the mechanical integrity of abandoned wells and water resources in the areas of previous gas mining would be required (6,7,13). The long term monitoring and maintenance of decommissioned gas wells could be problematic, as is illustrated by various international cases (3,12,34,38,39).

4. CONCLUSION

This paper illustrates that various regulations and actions need to be developed and implemented to ensure proper groundwater protection during each phase of unconventional gas mining. If these regulations can be developed timeously, and implementation can be ensured, it may be possible to manage some of the risks posed by unconventional gas mining. Long term monitoring and maintenance of decommissioned gas wells could however be problematic, and could make ecologically sustainable development of this activity difficult to achieve in the long run.

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