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Research paper

Groundwater resources monitoring during unconventional oil and gas extraction: South African laboratory analytical capabilities

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Groundwater resource quality monitoring before, during, and after unconventional oil and gas (UOG) extraction would assist in protecting groundwater resources. Limited laboratory analytical capacity may, however, hamper effective monitoring. We assessed South African (SA) laboratory analytical capabilities for specific groundwater monitoring parameters relevant to UOG extraction. We found a limited capacity to analyse for most of the UOG extraction–related groundwater monitoring parameters and that most of the surveyed laboratories are not planning to increase their analyses capacity to cater for UOG extraction. This issue must be addressed urgently if SA wants to proceed with UOG extraction. Policy recommendations include that South Africa should develop a specialised UOG extraction monitoring laboratory to cater for analytical needs. Such capacity could also address the analytical requirements for the rest of the African region during UOG extraction.

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INTRODUCTION

The Karoo Basin, South Africa, has been identified as a potential area for the extraction of UOG resources (De Kock et al., 2017; Rosewarne et al., 2013). Recent estimates for UOG resources in the Karoo Basin range from 13 to 390 trillion cubic feet (De Kock et al., 2017). While UOG development can benefit South Africa in many ways (economic growth, job opportunities, and increased electricity generation capacity), there currently exist serious concerns about negative impacts linked to UOG extraction, including contamination of groundwater resources (Botha, 2017; Esterhuyse, 2017), as well as possible competition amongst groundwater users in a water-scarce country (Hobbs et al., 2016). The Karoo Basin is a water-scarce region where groundwater is the main source of water supply, with most of the Karoo towns depending on groundwater for domestic and agricultural water use (Rosewarne et al., 2013). Contamination of these resources would be catastrophic for water security in South Africa. Groundwater can be contaminated during the fracking process, due to failure of the well casing, faulty well designs during well construction, migration of fracturing fluids via natural pathways, mismanagement of the fracking chemicals and due to the poor management of wastewater that is produced during UOG extraction (Esterhuyse, 2017; Bole-Rentel, 2015). To address water contamination concerns, it is recommended that South Africa ensure baseline monitoring of water resources to identify water pollution emanating from UOG extraction (Esterhuyse, 2017; Hobbs et al., 2016). The capacity of laboratories to analyse for specific contaminant parameters in groundwater resources during UOG extraction is however of concern and has been highlighted as an issue that needs attention in South Africa (Hobbs et al., 2016).

Groundwater monitoring during UOG extraction – the global and South African contexts

The global context

In the United States (US) and Canada, currently the leaders in UOG extraction (Downie and Drahos, 2017; Holding et al., 2017), the scientific understanding of its environmental impacts did not match the rapid development of UOG extraction (Brantley et al., 2018; Holding et al., 2017). Groundwater baseline monitoring was therefore not done before UOG extraction in most cases (Montcoudiol et al., 2017) and is only now viewed as important (Brantley et al., 2018; Susong et al., 2012). Despite its importance, very few published baseline studies have been carried out prior to hydraulic fracturing (McIntosh et al., 2019) and these mostly focused on dissolved methane concentrations (Bell et al., 2017; Humez et al., 2016; Schloemer et al., 2016; Moritz et al., 2015; Siegel et al., 2015). This is often insufficient for identifying contamination (Lefebvre, 2017) and for determining groundwater baseline conditions at a regional scale (Harkness et al., 2017; Rhodes and Horton, 2015; Eckhard and Sloto, 2012). The US reported certain monitoring and analytical challenges, including the fact that the chemistry of the flowback water is not well understood because analysing for the relevant parameters is expensive, no reference materials exist for testing, and the fact that there are no specific agreements on laboratory approaches and standards to use (National Academies of Sciences, Engineering, and Medicine, 2016). The high salinity and specific gravity of flowback and produced water also makes instrument calibration for analyses technically challenging (National Academies of Sciences, Engineering, and Medicine, 2016).

In Australia, methane migration (and the migration of certain other gases) is one of the main concerns during fracking (Eco Logical Australia, 2013). Continuous monitoring of UOG extraction well components over the lifetime of the project is required to minimise the risk of well failure and to gather groundwater quality information for identifying groundwater contamination after well decommissioning (Eco Logical Australia, 2013).

In Europe, Poland is the leader in shale gas exploration and exploitation (PGI-NRI, 2016). Here, the SHEER (Shale gas Exploration and Exploitation induced Risks) project was one of a small number of research projects investigating shale gas risks, funded by the EU Horizon 2020 programme. This programme conducted baseline and ongoing groundwater monitoring, as well as monitoring post UOG extraction (Montcoudiol et al., 2019; Montcoudiol et al., 2017). In the United Kingdom and Ireland, it is recommended that groundwater monitoring should be conducted before, during, and after the UOG extraction to inform risk assessments (Moe et al., 2016; Moore et al., 2014; Mair et al., 2012). As in Australia, methane has been identified as one of the main threats for groundwater contamination in the UK and must be monitored together with other gases, as monitoring of methane provides data to assess the carbon footprint of shale gas extraction (Mair et al., 2012).

Estimates of shale gas resources in China suggest that its gas deposits dwarf those of the US, with 1 115 trillion cubic feet (Tcf) of technically recoverable shale gas resources compared to 665 Tcf in the US (EIA, 2013). China wants to develop these vast deposits (Downie and Drahos, 2017) and places a high premium on the establishment of a groundwater baseline, as well as long-term monitoring to identify groundwater contamination (Li et al., 2016). Li et al. (2016) recommend that baseline groundwater monitoring for UOG production be carried out in China for 5 or 6 years before shale gas production.

The South African context

In South Africa, UOG extraction has not started yet and some specialized laboratory analytical services are not yet present. Scholes et al. (2016) reported that there are limited laboratories in South Africa that do the relevant analysis for water chemistry related to UOG extraction. Most South African commercial local laboratories are accredited and well equipped; however, the laboratories are designed to carry out water analysis for drinking water, for example, major cation and anions. Currently, there is limited water analyses capabilities for the following parameters: $\delta^{11}B$, $^{36}Cl/Cl$, ^{4}He, $^{3}He/^{4}He$, and CH_4 (Scholes et al., 2016). Enough time must, therefore, be allowed for laboratories to be set up before the development of the shale gas (Scholes et al., 2016). Currently, the main concern for groundwater baseline studies in South Africa is the limited available analytical resources for groundwater samples. Given the current analytical limitations in South Africa, these groundwater samples may need to be sent to internationally accredited laboratories (Scholes et al., 2016).

The Academy of Science of South Africa (ASSAF) indicated that there is currently no approved or agreed set of chemical parameters that are required for shale gas groundwater quality analysis. Groundwater specialists have compiled certain parameters which must be analysed for in academic studies, including: on-site electrical conductivity, pH, NO_3-N, alkalinity, CH_4; laboratory redox, TDS, Br, DOC, DOX, BTEX, naturally occurring radioactive materials (NORMS), major anions and cations, trace elements B, Ba, Cu, F, Fe, Hg, Li, Mn, Ni, NO_2, Pb, Sc, Si, Sr, U, Zn (McIntosh et al 2019; Luek and Gonsior, 2017; Rosenblum et al., 2017; ASSAf, 2016; Moe et al., 2016; Lester et al., 2015)

Hobbs et al. (2016) indicated that it may be important for South Africa to create an independent laboratory that specialises in UOG or 'shale gas' monitoring, especially for natural environmental stable and radiogenic isotopes, constituents of fracking fluids, and uncommon organic substances emanating from fracked wells and local groundwater. ASSAF (2016) also recommended that South Africa invest in academic and professional institutions to develop the necessary capacity, and to establish an applied and experimental 'Karoo Shale Gas Laboratory and Training College' where relevant skills development can be enhanced to address these shortcomings.

Because of the highlighted shortcomings, this study aimed to: (i) identify a complete set of parameters that need to be monitored in groundwater resources during unconventional oil and gas extraction, and (ii) to assess the capabilities of South African laboratories to meet the analytical needs for groundwater monitoring for UOG extraction.

METHODOLOGY

Physico-chemical parameters that need to be monitored in groundwater during UOG extraction have been identified via a literature survey of international and local publications and industry reports on chemicals that are most often used during the fracking process (that can return to the surface as flowback) as well as on chemicals that may be present in water produced by geological formations (or produced water, as it is termed in the petroleum industry) (Cai et al., 2019; Ferrer and Thurman, 2015; Anadarko Petroleum Corporation, 2015; Vidic et al., 2013). The chemicals in the wastewater may contaminate potable groundwater resources if it migrates to water supply aquifers.

The identified parameters were in turn used to assess the laboratory analytical capabilities in South Africa to monitor for groundwater contamination that may emanate from UOG extraction. To determine the laboratory analytical capabilities in South Africa, a self-administered questionnaire that assessed the analytical capabilities for the identified parameters was developed and distributed via email to 29 identified laboratories, and was followed up telephonically. Both commercial and government laboratories were located in different South African provinces, including Gauteng, Mpumalanga, North West, KwaZulu-Natal, Free State, Northern Cape, Eastern Cape, and Western Cape. A number of laboratories declined to complete the questionnaire because they did not have time to complete the questionnaire or cited confidentiality reasons.

The analytes for which analytical capacity was assessed, were grouped into 6 main groups, including (i) field parameters, (ii) major and minor elements, (iii) organics and dissolved gases in water, (iv) stable isotopes in water, (v) radiogenic isotopes in water, and (vi) naturally occurring radioactivity in water (which included gross alpha and gross beta radioactivity).

Firstly, the questionnaire gathered demographic information on the laboratory respondent to assess whether an appropriately qualified person completed the questionnaire. The questionnaire also assessed the knowledge, satisfaction with knowledge, and sources of knowledge on shale gas and fracking, for the respondent and the laboratory. To assess quality assurance and control at the laboratory, the laboratories were asked to specify whether they are South African National Accreditation System (SANAS) accredited and what they do to ensure data quality. Laboratory respondents were then asked to indicate which of the field parameters, major and minor elements, organics and dissolved gases in water, environmental stable isotopes in water, radiogenic isotopes in water, and radioactivity in water that they were able to analyse for. For the parameters that they could analyse, the laboratory was also asked to indicate their turnaround times for analysis, which would be important for planning field sampling activities. Lastly, respondents were asked to indicate whether their laboratory plans to expand on any of their analytical capabilities to cater for UOG extraction. If they indicated that they would, they had to specify which parameters they plan to include in the future. If not, they had to indicate why they would not consider expanding their analytical capabilities.

Completed questionnaires were given a case number and the data were analysed descriptively with the aid of IBM SPSS Statistics (version 25). Qualitative data were coded and analysed thematically.

RESULTS AND DISCUSSION

Groundwater parameters to monitor during UOG extraction

Groundwater parameters that must be monitored during UOG extraction have been divided into 6 different groups (see Table 1). Most of these parameters have been identified from international literature where UOG extraction groundwater monitoring already takes place (Envireau Water, 2017; Zolfaghari et al., 2016; Ferrer and Thurman, 2015; CWERC, 2014; Kroepsch and William, 2014), but are also based on the recommendation from the strategic environmental assessment that has been performed for shale gas extraction in South Africa (Hobbs et al., 2016), as well as some other South African studies (ASSAf, 2016; O'Brien et al., 2013). These parameters have been listed in the questionnaire that was distributed to the laboratories that assessed the analytical capabilities of the laboratories.

Laboratory analyses questionnaire results

Fourteen out of twenty-nine laboratories completed the questionnaire. Most of the targeted laboratories (48.3%) were based in Gauteng Province, with a response rate of 35.8%. KwaZulu-Natal and North West Provinces had the second-highest targeted number of the laboratories (10.8%). The targeted laboratories and response rates can be seen in Table 2.

Most of the respondents who completed the questionnaire occupied posts at a senior level (66.7%), while 16.7% of respondents were from mid-level management; 8% of respondents were at an executive level while 8.3% did not indicate their job level. The respondents who completed the questionnaire were mostly scientists (41.7%), while 16.7% were laboratory technicians and 16.6% were directors; 25% of respondents did not indicate their specific job title. The position and job title of the respondents who completed the questionnaire is viewed as adequate since senior-level people would have institutional knowledge and would know future directions for a laboratory while scientists and laboratory technicians would know the analyses capabilities of the laboratory.

The extent of knowledge on shale gas and fracking and satisfaction levels with this knowledge base

The knowledge of the respondents on shale gas and fracking was tested, as well as the knowledge of the laboratory (as reported by the respondent who completed the questionnaire). Twelve out of fourteen laboratories completed this part of the questionnaire. Most respondents reported their own knowledge and the laboratory's knowledge on shale gas and fracking as fairly limited. Only 16.7% of respondents reported that they had extensive knowledge of shale gas and 8.4% reported extensive knowledge of fracking. Levels of satisfaction with knowledge were also tested for the respondent and the laboratory (as reported by the respondent). Satisfaction levels for the respondents and their laboratories were also reported as low (see Table 3).

The limited knowledge on shale gas and fracking in laboratories may be a symptom of the uncertainty on whether shale gas should be developed in South Africa, which could be preventing laboratories from investing resources into understanding this topic and preparing for possible shale gas extraction. The limited literature on the topic could also possibly contribute to limited knowledge (although this has been addressed in recent years in South Africa, see Esterhuyse, 2017; Scholes et al., 2016; ASSAf, 2014; Esterhuyse et al., 2014; Raviv, 2014; Esterhuyse et al., 2013). For this reason, we also gathered information on the knowledge sources of shale gas and fracking at laboratories.

Table 1. Recommended groundwater monitoring parameters during UOG extraction

Parameter group	Recommended monitoring parameter during UOG extraction
Field parameters	pH, temperature, electrical conductivity, dissolved oxygen, oxidation potential, reduction potential
Major ions	Na, Cl, Mg, Ca, HCO_3, SO_4, NH_4, DIC, DOC
Secondary ions	K, F, Sr, CO_3, NO_3-N, B
Minor and trace elements	Al, Pb Cd, CH4, Co, Cr, CN, Mn, Br, Si, PO_4 As, S, Se, B, Ba, Cu, Fe, Hg, Zn, Ni, Mo, U, V, Sb, M-ALK, P-ALK, $NO_3 + NO_2$, ORP, pH, TDS (total hardness), NH_3 (ammonia nitrogen), Pb, Sb
Organics	TOC, PAHs, VOCs, SVOCs, BTEX, glycols
Stable isotopes in water	$\delta^{13}C_{CH4}$, $\delta^{2}H_{CH4}$ in groundwater, $\delta^{13}C_{H2O}$, $\delta^{2}H_{H2O}$, $\delta^{18}O_{H2O}$, $\delta^{13}C_{DIC}$, $\delta^{13}C_{C2H6}$, $\delta^{2}H_{C2H6}$, $\delta^{34}S_{SO4}$, $\delta^{11}B$, ^{14}C
Radioactive isotopes in water	$^{235\,238}U$, ^{232}Th, $^{226\,228}Ra$, ^{222}Rn, ^{40}K, ^{210}Pb, $^{7}Sr/^{86}Sr$ ratio
Radioactivity in water	Gross alpha radioactivity, gross beta radioactivity

Table 2. Summary of the targeted and respondent laboratories

Province	Targeted number	Targeted labs (% of total)	Response number	Response rate (% of the total received)
Gauteng	14	48.3	5	35.8
Western Cape	2	6.9	2	14.3
North West	3	10.3	2	14.3
KwaZulu-Natal	3	10.3	1	7.1
Eastern Cape	2	6.9	1	7.1
Mpumalanga	2	6.9	0	0
Northern Cape	1	3.5	1	7.1
Free State	2	6.9	2	14.3
Total	29	100	14	100

Table 3. Knowledge and knowledge satisfaction levels on shale gas and fracking

Knowledge and satisfaction of shale gas extraction and fracking		The extent to which respondents are satisfied with their knowledge		
		Limited	Average	Extensive
Knowledge on shale gas extraction and fracking	Your knowledge of shale gas extraction	n = 6 50%	n = 4 33.3%	n =2 16.7%
	Your knowledge of the fracking process itself	n = 7 58.4%	n = 4 33.3%	n = 1 8.3%
	Your laboratory's knowledge on shale gas extraction	n = 7 58.4%	n = 5 41.6%	n = 0 0%
	Your laboratory's knowledge the fracking process itself	n = 6 50%	n = 6 50%	n = 0 0%
Level of satisfaction on laboratory knowledge	Your level of satisfaction with your knowledge on shale gas extraction	n = 7 58.4%	n = 4 33.3%	n = 1 8.3%
	Your level of satisfaction with your knowledge on the fracking process itself	n = 6 50%	n = 6 50%	n = 0 0%
	Your level of satisfaction with your laboratory's knowledge on shale gas extraction	n = 7 58.4%	n = 5 41.6%	n = 0 0%
	Your level of satisfaction with your laboratory's knowledge on the fracking process itself	n = 7 58.4%	n = 5 41.6%	n = 0 0%

Table 4. Sources of knowledge on shale gas and fracking

Type of knowledge resource		The extent to which respondents regard various knowledge sources		
		Not important	Somewhat important	Very important
Scientific resources	Government reports	n = 6 50%	n = 3 25%	n = 3 25%
	Research reports	n = 5 41.7%	n =3 8.3%	n = 6 50%
	Scholarly articles	n = 4 33.3%	n = 2 16.7%	n = 6 50%
	Combined percentage of respondents who use Scientific sources	41.67%	16.67%	41.67%
Popular media sources	Internet sources	n = 4 33.4%	n = 4 33.3%	n = 4 33.3%
	Printed media	n = 6 50%	n = 3 25%	n = 3 25%
	Verbal media	n = 7 58.3%	n = 2 16.7%	n = 3 25%
	Visual media	n = 5 41.7%	n = 4 33.3%	n = 3 25%
	Talks and presentations	n = 4 33.3%	n = 3 25%	n = 5 41.7%
	Other	n = 5 83.3%	n = 0 0%	n = 1 16.7%
	Combined percentage of respondents who used Popular media sources	50.00%	22.22%	27.78%

Sources of knowledge on shale gas and fracking

Respondents were asked to share their main source of information on shale gas extraction and fracking. The scale ranged from 1 to 5, with 1 indicating that this source was not regarded to be an important information source and 5 indicating that the information source was regarded to be very important. The main sources of information can be seen in Table 4.

Under scientific resources, research reports and scholarly articles were viewed as the most important resources. These resources are peer-reviewed and therefore trustworthy, which may be why they are viewed as the most important resources. Government reports are not regarded to be as important a source of information for shale gas extraction and fracking processes as research reports and scholarly articles. The rated lower importance of government reports may be due to the lack of published government reports, due to issues regarding the accessibility of these government reports, or due to a lack of trust in government. In addition, more research reports and scholarly articles need to be published related to the shale gas extraction and fracking process in South Africa.

Popular media sources were rated as less important information sources on shale gas extraction and the fracking process, especially for printed media, verbal media, and visual media. Under popular media, talks and presentations were rated more important in providing information on shale gas extraction and the fracking process. It may be that respondents view talks as more trustworthy. Internet sources were rated as the second most important source of information on shale gas extraction and fracking processes.

Laboratory data quality assurance

Quality assurance is very important when considering that the data that will be generated by laboratories during shale gas water quality monitoring can eventually be used in court.

The laboratories were asked to report on data quality assurance practices at their laboratories. The most important data quality assurance techniques that laboratories reported include:

- Making use of the Laboratory Information Management System (LIMS) – software that allows you to effectively manage samples and associated data. LIMS is used to control, manage and record samples; the system allows the checking of sample results before authorising their release. The system can reduce human errors by, for example, processing some of the data automatically. This also saves time and enables real-time tracking of the samples.
- Using technical signatories to check reports and verifying that the results are correctly transcribed.
- Using proficiency testing from the South African Bureau Standards, the Bureau Interprofessionnel D'Etudes Analytiques, and the National Laboratory Association.
- Having and maintaining SANAS accreditation, according to the applicable standard ISO 17025, which assures the quality of the test results. For this study, we calculated the SANAS accreditation for the laboratories targeted in this survey for the different provinces, from their certification information (SANAS, 2018). All the targeted laboratories in Northern Cape Province are SANAS accredited. In Gauteng Province, 75% of the targeted laboratories had SANAS accreditation. In KwaZulu-Natal Province 67% of the laboratories were SANAS accredited, while of the laboratories in the Western Cape, Eastern Cape, North West, Free State, and Mpumalanga Provinces, 50% were SANAS accredited. In total, 62.1% of the surveyed laboratories had SANAS accreditation.
- Having a quality system with a quality policy and procedures manuals in place.
- Making sure that instruments are calibrated and well maintained according to the international primary standards (these are certified standards by different bodies in Europe and the USA).

The other techniques which the laboratories use to ensure quality data are: automated electronic data, using international reference standards, analysing quality control samples through the Customer Relationship Management System, duplicate analysis, blank analysis, and intralab testing. In comparison, international laboratories reported the following techniques to ensure data quality (Eurofins Lancaster Laboratories Environmental, 2018; SUEZ, 2018; ALS Water – Australia, 2016; Geochemical Testing, 2015):

- Data verification by dedicated technical and experienced data reviewers, using a full compound list, laboratory control samples, and matrix spike duplicates.
- Analysing method detection limits (MDLs) on every instrument and for each matrix and preparation method.
- Confirming MDL with each calibration to confirm the instruments' ability to 'detect' a concentration under specific conditions.
- Complying with stringent client- and program-specific technical specifications and implementing extensive documentation and data storage protocols.
- Conducting internal and external audits.
- Executing long-term national and international staff proficiency testing programmes.
- Final data checking and approval by a signatory.
- Instrument quality verification before use.
- Monitoring the fridges and the workplace to prevent contamination of the samples.
- Getting feedback from customers.
- Ensuring that laboratory instruments are calibrated and the laboratory is accredited.
- Running a quality control quality assurance programme and testing software performance to confirm data quality.

Laboratory analyses capabilities and turnaround times

The analytical capabilities of all the targeted laboratories are presented in Fig. 1, where the numbers in the pie charts indicate the number of laboratories that have been targeted in a specific province for a specific analyses group. There is a good spread of parameter analyses capabilities in the different provinces, especially in the Gauteng Province, since it had the largest availability of laboratories. Mpumalanga and Western Cape Provinces have fewer available laboratories and therefore also fewer parameter groups that can be analysed.

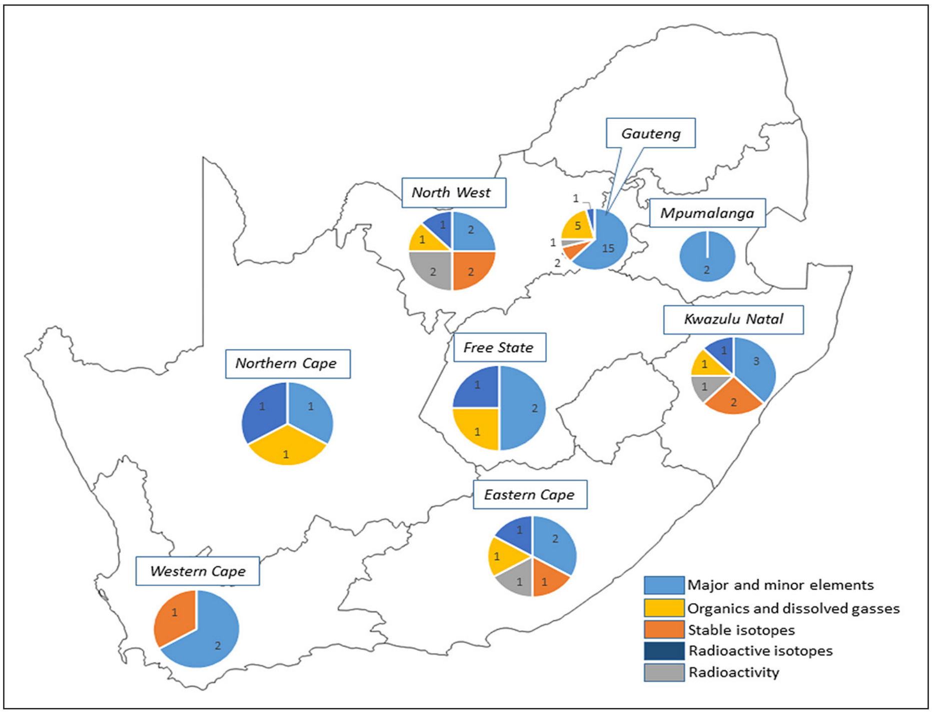

Figure 1. Laboratory analyses capabilities per province

Table 5. Analytical capabilities of South African laboratories

Parameter	Analytical capabilities
Field parameters	• South African surveyed laboratories can analyse most of the field parameters for water analyses • Based on the surveyed laboratories there is the limited capacity for analysing the following field parameters: CH_4, and CN
Major and minor elements	• South African surveyed laboratories can analyse most of the major and minor elements needed
Organics and dissolved gasses in water	• There is a somewhat limited capacity for analysing most organic compounds and dissolved gasses in water • Of the gases, methane and ethane analysis capabilities are especially limited, while none of the surveyed laboratories could analyse for radon • In terms of organics, none of the surveyed laboratories could analyse for total glycol
Stable isotopes in water	• For stable isotopes, analytical capabilities are limited in South Africa • Of the surveyed laboratories who responded, only two could analyse for the following stable isotopes: δ^2H_{H2O}, $\delta^{18}O_{H2O}$, $\delta^{13}C_{DIC}$, and ^{14}C • This is one aspect that can be expanded in South Africa due to a lack of laboratory capability and could be a niche area specifically for universities
Radiogenic isotopes in water	• South African surveyed laboratories have limited radiogenic analytical capabilities; only one of the surveyed laboratories could analyse for this
Radioactivity in water	• South African surveyed laboratories have limited analytical capabilities for most of the radioactive substances that may occur naturally in water or as a result of UOG extraction, especially $^{87}Sr/^{86}Sr$ ratio

The laboratory analytical capabilities of the laboratories who responded are discussed according to the 6 predefined groups: field parameters, major and minor elements, organic and dissolved gasses in water, stable isotopes in water, radioactive isotopes in water, and radioactivity in water. The survey results can be seen in Table 5.

The turnaround time for analysing field parameters is 1 day up to a maximum of 10 days, while major and minor elements range from 5–10 days. Organic and dissolved gases range from 5–10 days; except for radon analysis which takes a month. Stable isotopes can take up to 2 weeks for δ^2H_{H2O} and $\delta^{18}O_{H2O}$ parameters and up to 7 days for ^{14}C. Analysis of radiogenic isotopes has the longest turnaround times, ranging from 10 working days to up to 6 months, depending on the parameter. Analytical turnaround times for measuring alpha and beta radioactivity in water range from 2–4 weeks.

In the UK, the turnaround time for parameter analysis reported by Envireau Water was 3 working days for pH, EC, TDS, TSS, sodium, magnesium, calcium, potassium, chloride, bicarbonate alkalinity, sulphate, nitrate, nitrite, ammonium, iron and methane, while other analytical analysis required 10 working days (Envireau Water, 2017). Stable isotopes ($\delta^{13}CH_4$, $\delta^{13}CO_2$) usually take up to 20 days (Envireau Water, 2017). Most of the turnaround times for international versus local laboratories are comparable.

Plans by South African laboratories to increase analytical capabilities

Laboratory respondents had to indicate whether they plan to increase analytical capabilities in the laboratory to cater for future shale gas monitoring requirements. Of the laboratories surveyed, 35.7% indicated that they would consider increasing analytical capabilities. The increased capabilities included mostly DO, COD, O, H, PAH, VOC, SVOC, BTEX. TOC, total Kjeldahl nitrogen (TKN), dissolved ethane, dissolved methane, and gas components during gas analysis. However, 64.3% of laboratories indicated that they would not consider increasing their analyses capabilities. The main reasons for this decision included:

- The analytical facilities for the services that have been listed in the questionnaire operate within a different context from commercial laboratories that mainly focus on analysing water for drinking water purposes; the parameters listed in the questionnaire are very specialized.
- Setting up appropriate methods is feasible, but more research may be required for laboratories to determine whether investing in new capabilities is economically feasible.
- The laboratories are very complacent around the UOG market development (they are not sure whether shale gas extraction will happen in South Africa).
- For many years the laboratories conducting environmental stable and radiogenic isotope analyses have been offering services, unfortunately, with limited uptake by the community.
- There is a failure on the demand side because the services are typically commissioned through consultants with limited knowledge, and a limited budget.
- The laboratories will extend the scope of work if there is a need for a particular analysis.
- The laboratories do not have enough resources (human and financial).
- Has to be financially viable to diversity capabilities.

Since a high percentage of South African laboratories indicated that they would not consider increasing their analyses capabilities; the South African Government should consider the establishment of laboratories that will cater for UOG water resource monitoring analyses.

CONCLUSIONS

Various studies (Montcoudiol et al., 2017; Li et al., 2016; Scholes et al., 2016; Eco Logical Australia, 2012; Mair et al., 2012; Susong et al., 2012) have reported that groundwater resource quality monitoring before, during, and after UOG extraction is important to protect groundwater resources. Limited laboratory analytical capacity may, however, hamper effective monitoring.

In South Africa, UOG extraction has not started yet. In addition, some specialized laboratory analytical services are not yet available. This study aimed to identify a complete set of parameters that need to be monitored in groundwater resources during unconventional oil and gas extraction and to assess the capabilities of South African laboratories to meet the analyses needs for groundwater monitoring for UOG extraction. Identifying analytical capability gaps would enable South Africa to address these issues before UOG extraction commences.

The study identified 5 main groundwater parameter groups that must be monitored during UOG extraction, including field parameters, major and minor elements, organic and dissolved gases, environmental stable isotopes, radiogenic isotopes in water, and radioactivity in water. From the surveyed laboratories in SA, limited capacity was found for analysing organic and dissolved gases and radiogenic isotopes. Of the surveyed laboratories, 64.3% reported that they do not plan to increase their analyses capacity, because the analytical facilities required for UOG-related analyses in groundwater are based on a different context from that of current commercial South African water quality laboratories, which mainly focus on drinking water quality analyses. They also reported that the required analytical services are too specialised and that this may result in limited uptake of these services, which would make such a venture commercially unviable.

The survey also found that there is fairly limited knowledge on UOG extraction and fracking technology amongst South African water quality laboratories. The limited knowledge and the uncertainty in whether UOG resources would be developed in South Africa could be preventing laboratories from investing resources in understanding UOG development and in expanding their analyses capabilities in preparing for extraction.

We, therefore, recommend that a specialized UOG extraction laboratory that can cater for most of the analyses needs of the shale gas industry be established in Southern Africa. If shale gas extraction companies establish in-house laboratories to cater for their analyses needs, it would be prudent for the South African Government to perform an oversight function. South Africa is the country with the most analytical capacity on the African continent and increasing analytical capacity in South Africa would therefore be an important additional consideration to cater for Africa's governmental analytical needs in the oil and gas industry. South Africa should also invest in academic and professional institutions to develop the necessary capacity, and to establish an applied and experimental 'Karoo Shale Gas Laboratory and Training College' where relevant skills development can be enhanced to address these shortcomings. This will assist the government in planning for UOG extraction by guiding the regulator (the Department of Water and Sanitation) in monitoring the correct parameters and saving costs.

AUTHOR CONTRIBUTIONS

SE conceptualised the research, guided the research, checked data analyses for accuracy and finalised manuscript. AM executed the research, analysed the data and drafted the initial manuscript.

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