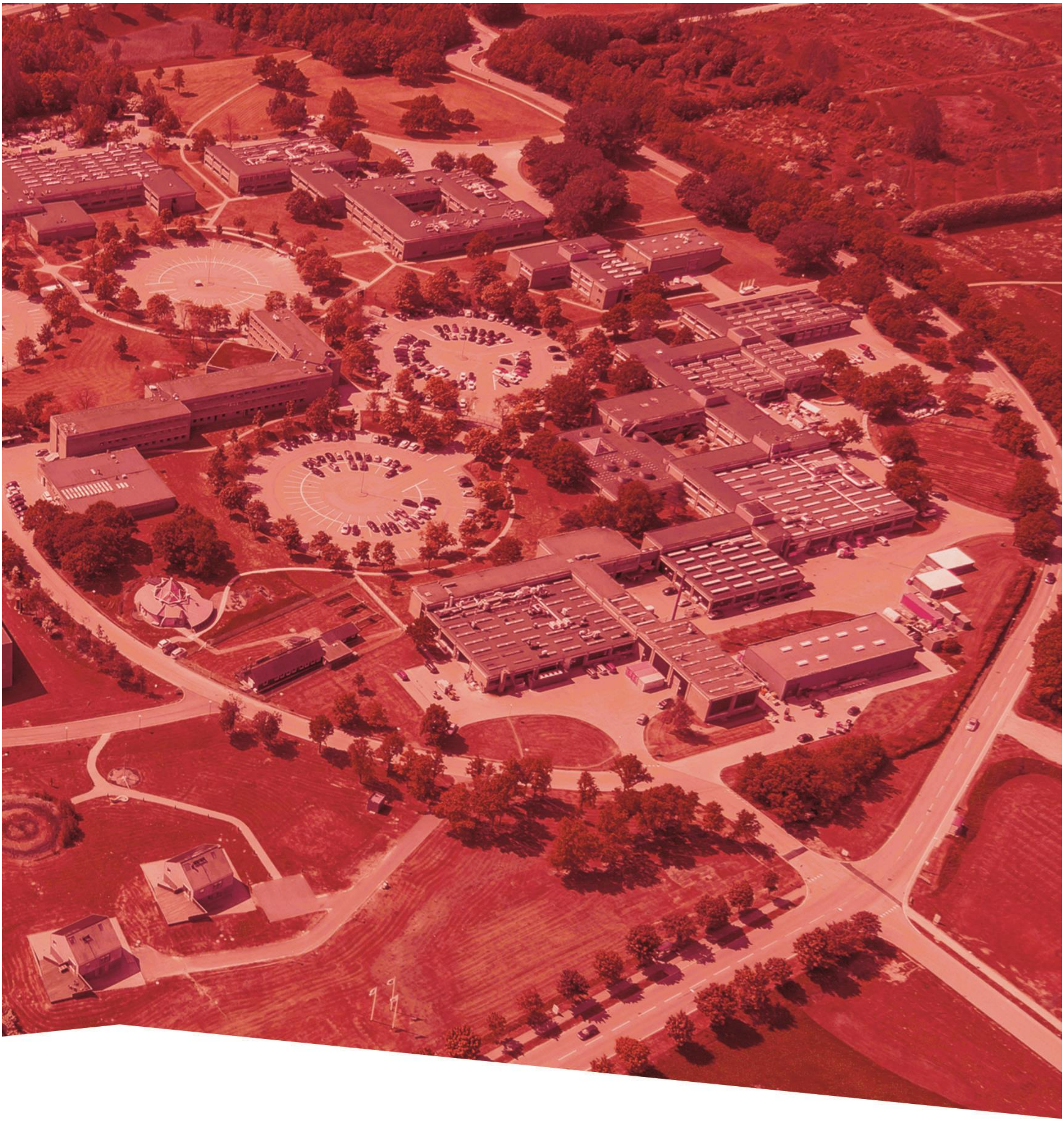

Test of Just-Measure (JMAR)

Test of measuring platform for measuring nitrate in Danish water wells

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1. Background

Just-measure has developed a measuring platform JMAR (Just-measure robotic remote control) for the purpose of measuring nitrate levels in Danish water wells. The platform is based on an optical sensor (UV) developed by TriOS Mess- und Datentechnik GmbH (Rastede, Germany). The Danish Technological Institute's task was to assess the practical implementation of the platform, as well as determine the accuracy of measurements performed with it, in collaboration with Just-measure, Aalborg Forsyning, WSP. A test protocol was prepared to test the platform in water wells designated by Aalborg Forsyning.

This report will review how these measurements were performed, how data was processed, what the results of these measurements were, and what recommendations we would give for implementing the platform based on the results.

2. Metode

Seven wells were selected in collaboration with Aalborg Forsyning for the test. During sampling, these wells were not in active use as drinking water wells. For each borehole, 4 to 11 depths were selected for sampling and measurements (see Table 1).

Table 1 Overview of wells from which samples were collected, when samples were collected from each well, who collected samples from the well and at what depths measurements and samples were collected from at each well.

WELL	DATE	COLLECTED BY	SAMPLING DEPTH [M]	SAMLING NUMBERS
34.1769	10. March 2023	Teknologisk Institut	3, 10, 20, 30, 40, 60, 80 og 95	8
34.1770	17. April 2023	Teknologisk Institut	5, 10, 20, 30, 40, 50, 60, 70, 80, 90 og 96	11
34.1777	17. April 2023	Teknologisk Institut	3, 7, 11, 15, 19, 23, 27 og 30	8
34.1656	8. May 2023	Just-measure	3, 10, 20, 30, 40, 50, 60, 70, 80 og 90	10
34.2908-2	8. May 2023	Just-measure	3, 6, 9 og 12	4
34.2908-1	8. May 2023	Just-measure	3, 7, 11, 15 og 19	5
34.1656	4. July 2023	Just-measure	10, 20, 30, 40, 50, 60, 70, 80 og 90	9
34.511	4. July 2023	Just-measure	5, 10, 15, 20, 25, 30 og 35	7

Over four measurement days, measurements were made in these wells with Just-measure JMAR. A pump for water sampling was installed on the measuring unit (see Figure 1). The measuring unit was hoisted into the borehole to a predetermined depth where measurements were made, and water samples taken. For each water sample, twice the volume of the hose to the water pump, in water was pumped out of the 100-metre-long pipe to the water pump, to ensure measurements were made from water at the desired depth and there was no contamination from other water layers. Water samples were collected in 250ml or 500ml bottles and refrigerated until analysis.

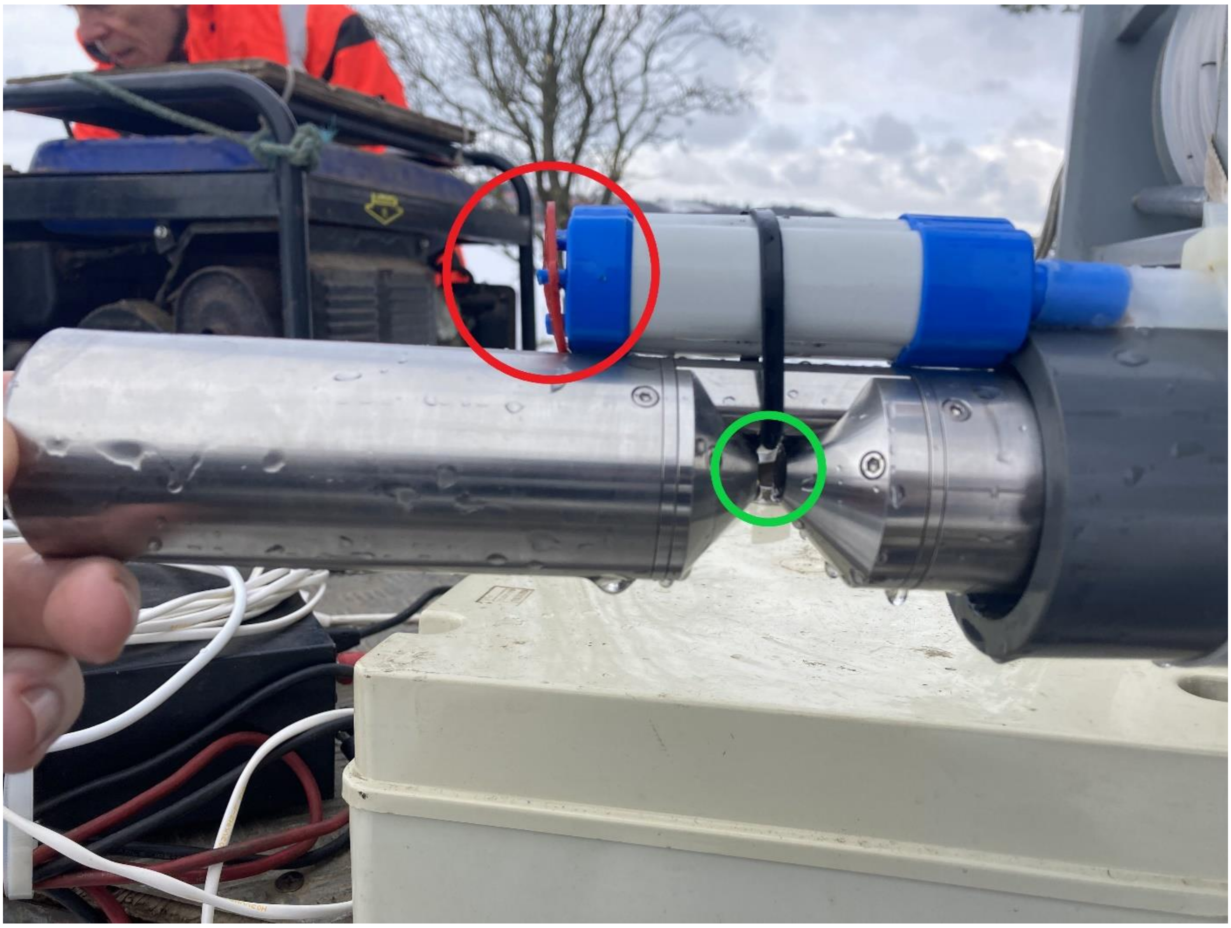

Figure 1 The water pump (intake red circle) was mounted on the JMAR measuring unit closest to the sensor (green circle), to ensure as far as possible that the same water layer measured by the JMAR meter would also be taken as a water sample for analysis with the reference method.

The water samples were analysed via chemical analysis method which served as the reference method of the test.

On two measurement days, the collection of samples was observed by a representative from the Danish Technological Institute, on the remaining measuring days, Just-measure performed data and sample collection (see Table 1).

For samples collected on it. On May 8 and July 4, turbidity was also noted for the water sample. This was not quantified, but described based on visual expression of visible substrate in the sample.

The water samples were analysed by Eurofins at ISO15923-1:2013.

Statistical tests were conducted in R (version 4.1.3).

3. Results

Der blev under forsøget målt nitrat koncentration ved 62 unikke punkter (forskellige boringer i varierende dybde). 13 målinger faldt udenfor måle området af enten af referencemetoden eller JMAR-måleren. Dette har resulteret i 49 observation der er blevet brugt i videre resultatbehandling (figur 2).

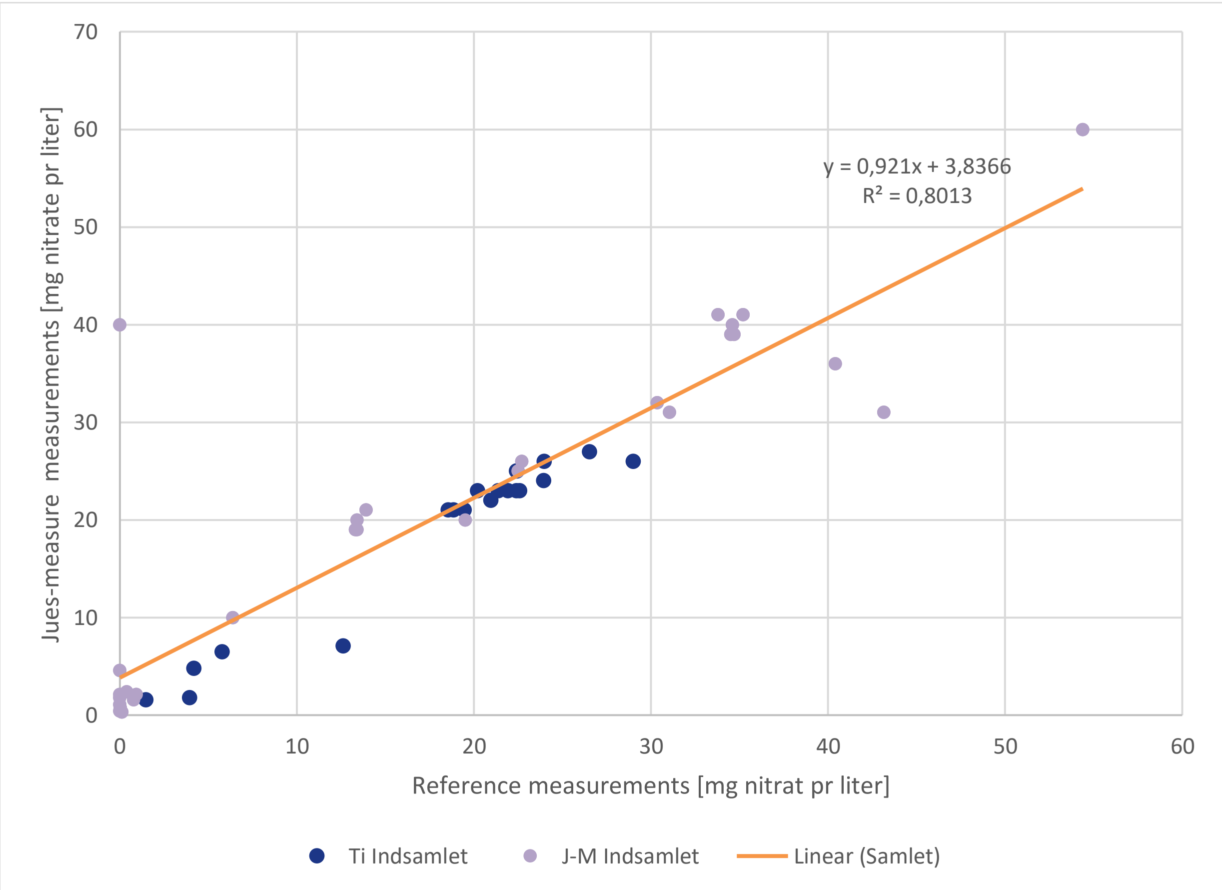

Figure 2 Nitrate content (mg per litre) for each measuring point measured with JMAR and the reference method (ISO15923-1:2013). The figure also indicates which samples were collected by the Danish Technological Institute (blue) and which were collected by Just-measure (violet).

Paired t-tests were used to assess whether there was a difference between data generated with Just-measure JMAR and the samples analyzed via the reference method. The mean difference was 2.4 mg/L (t=2.67, df=48, p=0.01) and therefore there was a statistically significant difference between the two methods.

We observed that at low concentrations (<5mg nitrate per litre) there was a high deviation (74%) between JMAR and the reference method compared to higher measurements (>5mg nitrate per litre) where the deviation averaged 17% (see Figure 3).

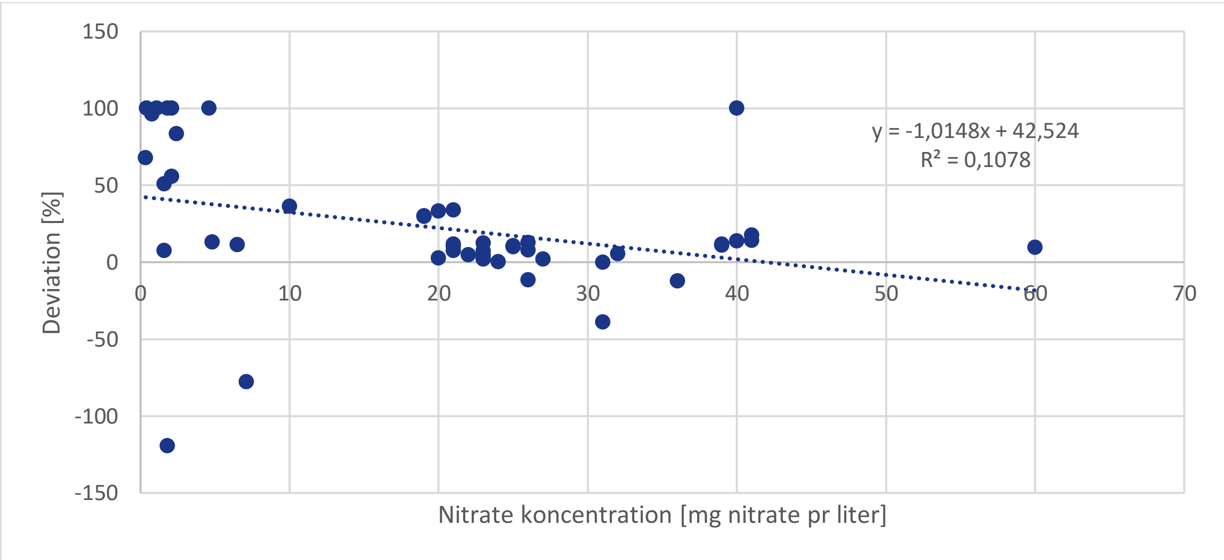

Figure 3 relative deviation (% deviation of nitrate in mg per litre) between JMAR and the reference method. A high deviation was observed at lower concentrations (<5mg nitrate per litre). The deviations here are mostly positive, indicating that the reference method measured a higher concentration than JMAR.

When samples below 5 mg nitrate per litre were omitted, there was no significant correlation to the relative deviation of the JMAR from the reference method relative to concentration. In Pearson's correlation test, the correlation coefficient between relative deviation [%] and measured concentration [mg nitrate per litre] was -0.20 (t=-1.71, df=32, p=0.10).

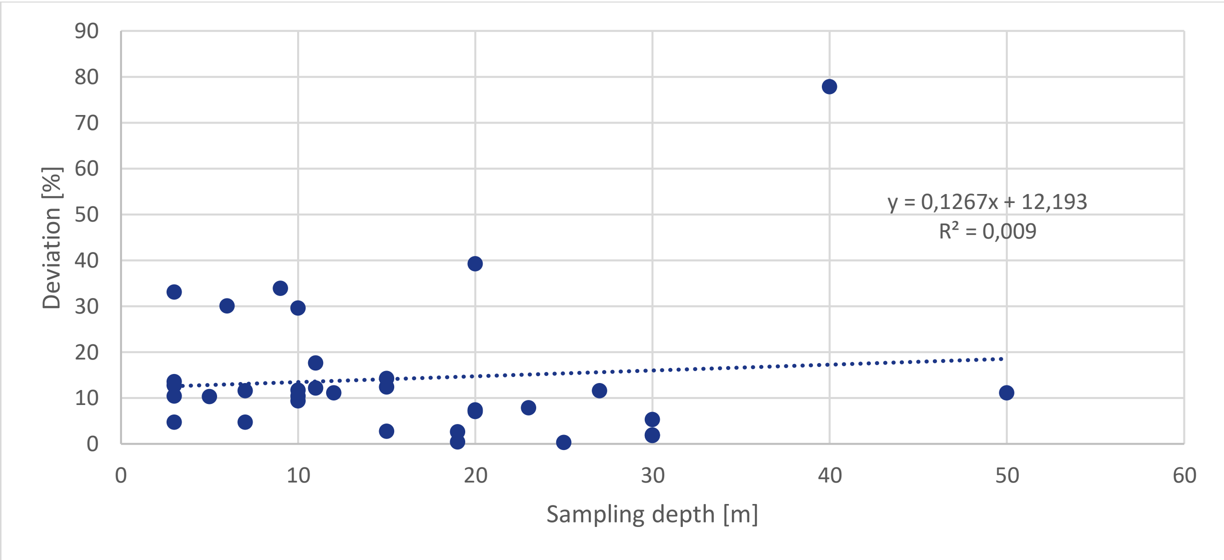

Figure 4 deviation (converted to positive percentage for all observations) of measured nitrate between JMAR and the reference method over depth. A weak positive correlation is observed between depth and deviation.

When samples below 5mg nitrate per litre were omitted, there was no significant correlation to the relative deviation between the JMAR and Reference method in relation to sampling depth. In Pearson's correlation test, the correlation coefficient between relative deviation [%] and depth was 0.12 [m] (t=0.70, df=32, p=0.48).

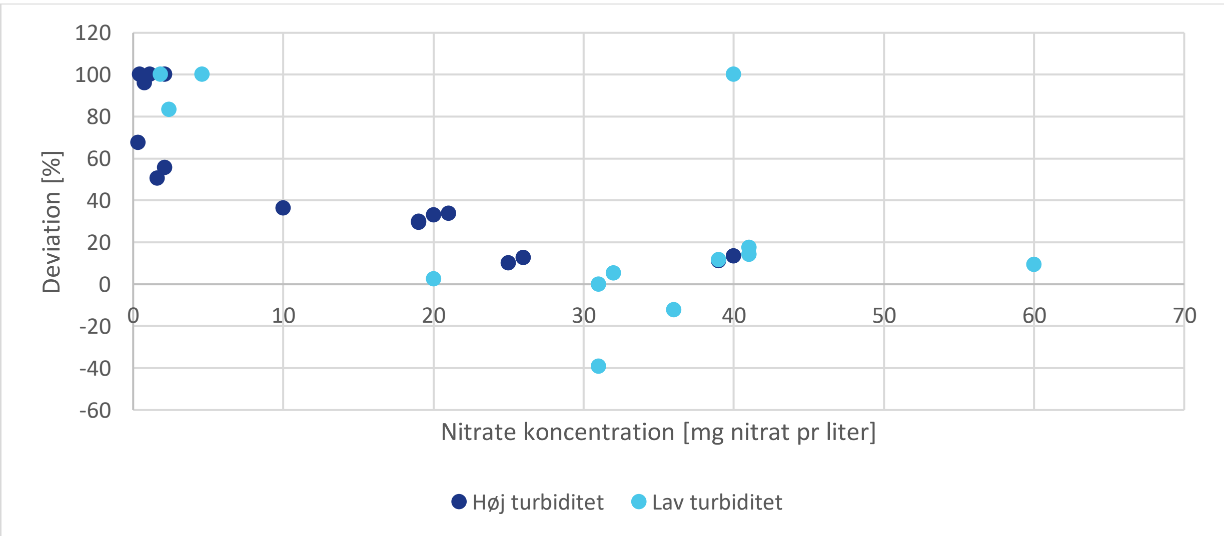

Figure 5 visible turbidity was noted in samples where this was visible. The observed turbidity in the water could not explain the measurement uncertainty we observed.

No effect on measurement uncertainty as a result of turbidity was observed (see Figure 5). When samples below 5mg nitrate per litre were omitted, there was not a significant difference between samples with visible turbidity and samples without visible turbidity. High turbidity samples had a mean deviation of 12.4% whereas those with low turbidity had a deviation of 21.7% ($t=-1.72$, $df=14.95$, $p=0.11$) measured by a Welch's t-test.

1. Conclusion

During the test period, the use of Just-measure's JMAR measuring system for nitrate measurements in Danish drinking water wells and its accuracy was compared to water samples tested by chemical analysis. It is our assessment that the relative deviation between JMAR and the reference method ISO15923-1:2013 performed at Eurofins was too high (74%) for measurements below 5 mg nitrate per litre for the JMAR system to provide accurate measurements. It our evaluation that the measurement range where satisfactory accuracy of the JMAR system in the setup studied during this project can be observed is above 5mg nitrate per liter. Above this minimum threshold, we observed a relatively low deviation (17%). This compared to the reference method's own reported measurement uncertainty of 15% must be considered satisfactory despite the fact that the difference was statistically significant.
When omitting measurements taken at concentrations below 5mg nitrate per litre, no statistically significant association was observed between deviation between JMAR and the reference method and nitrate concentration, tubidity or depth of measurements. Thus, our conclusion is that under the parameters tested in this project (>5 mg nitrate per liter, <60 mg nitrate per liter and <50 meters) that the data does not give indications that the accuracy of the measurement system is negatively affected by turbidity, depth or higher concentrations of nitrate.

The JMAR system is an optical system. Accurate measurements during continuous operations with the system therefore require regular maintenance in the form of cleaning the sensor. We did not conduct studies to determine how frequently this cleaning should occur to ensure optimal operation of the system. With real use of the system, it would not be known what the turbidity of the water in the borehole is during operation. Therefore, the need for cleaning cannot be assessed on the basis of the observed turbidity of the water during operation. Recommendations on the cleaning of the equipment should therefore be conservative in nature. Flushing the sensor cover glass with demineralized water when a JMAR is removed from a borehole seems like a realistic, practical and safe approach to cleaning during daily use, with full cleaning occurring less frequently.
During the experiment, we did not observe an association between turbidity of the water and measuring uncertainty for JMAR. This observation is limited by the fact that we did not make objective measurements of turbidity but assessed this visually.
During the project, we only measured one well with concentrations above the limit value (50mg nitrate per litre). Measurements did not indicate that measurement uncertainty increased with increased concentration, but this limits whether it can be determined with certainty whether the system retains accuracy when measuring in wells with higher nitrate concentrations. Since we did not observe negative

effects of depth or turbidity, it is considered that this question of accuracy at higher concentrations could be satisfied with laboratory experiments.
In the wells used during the project, all wells had low concentrations of nitrate (<5 mg per litre) below 50 metres. This has limited our ability to comment on its accuracy in deeper drilling. However, we did not see any correlation between measurement accuracy and depth at the depths tested. The sensor supplier (TriOS) itself reports the max. pressure for operation of the sensor as being 30bar. We therefore do not expect measurements deeper than 50 meters to negatively affect the observed accuracy of the system.

According to the sensor supplier's (TriOS) specifications, the sensor can be adjusted to measure more accurately in certain concentrations by changing the "path length", which is the distance between the sensor glasses (the opening marked with green figure 1).
This distance may be increased to increase accuracy at low concentrations or decreased to increase accuracy at higher concentrations. The configuration tested as part of this report was with a path length of 10mm, as it was expected that this would provide optimal accuracy near the limit value for nitrate in drinking water (50mg/l).
As configurations other than 10mm path length have not been tested as part of this report, we cannot comment on the accuracy of these different configurations.

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