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Evaluation of the water quality at Bogdalen watershed near Kvitfjell and Raudfjell wind farm area

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Abstract. Wind energy is one of the important renewable energies that get fast development in recent years. The development of wind turbines can have potential environmental impact on the surrounding environment. Especially when the wind turbines are built near the watersheds, water quality in the watershed may be degraded. In this study, the water quality in Bogdalen watershed that in or surrounding Kvitfjell and Raudfjell wind farm, the biggest wind farm in the North of Norway was studied. The water was collected at 3 wind turbine points and one accumulation point in the watershed far from the wind turbine. The collected water samples were tested pH, the concentrations of Al, As, Cd, Cr, Cu, Fe, Ni, Pb, Zn and bacteria account of Intestinal enterococci, E.coli, clostridium perfringens and coliform. The results showed that the water in the watershed accumulation point has high bacteria account of Intestinal enterococci, E.coli, clostridum perfringens and coliform. The water has different degree of faecal pollution. The pollution is especially significant in the summer season. The water in the wind turbine point has high concentration of Al and Mn. However, the Al can easily remove by filtering the water through a filter paper. The Mn concentration didn't reduce much after the filtration. The concentration of Mn in the water is still higher than the limit values set by Ireland EPA.

1. Introduction

Of the different industries, renewable energy industry is becoming more and more popular. According to the estimation by International Energy Agency, the share of renewables in meeting global energy demand is expected to grow by one-fifth in the next five years to reach 12.4% in 2023 [1]. Norway is a country in Europe that are rich in different renewable energy resources, of which wind energy is one of the most important energy. 2017 was a record year for wind power development in Norway, with 324 MW of new wind power installed and an additional 1600 MW under construction at the end of the year [2].

In contrast to benefits from wind turbine development, there are increased concerns over the negative environmental impacts from wind turbine development, such as noise produced by the rotor blades, visual impacts and deaths of birds and bats that fly into the rotors [3]. If the wind turbines are built near the watersheds, it can also have effect on the water quality. Nordlys wind is the biggest wind power plants in the North of Norway. It consist of two wind farm areas Kvitfjell and Raudfjell. The wind farm is currently built in or surrounding several watercourses, and nearby communities such as Brennsholmen, Sjætun, and Buvik, that are using drinking water from Kvittfjell and Raudfjell mountain areas. The plant plans to build in total 67 wind turbines in the area. The construction of the wind turbines and later on operation of the wind turbines has the potential effect on the water quality in the nearby watersheds. It has already report on the drinking water degradation in the area in the local newspapers last year. Therefore, it is of great importance to study the water quality in the nearby watersheds since the water is used as drinking water sources by local people.

In this study, the water quality in the Bogdalen watershed that crosses both Kvitfjell and Raudfjell wind farm areas was investigated. The pH and concentrations of Al, As, Cd, Cr, Cu, Fe, Ni, Pb, Zn and bacteria account of Intestinal enterococci, E.coli, clostridum perfringens and coliform in the water were studied and the potential sources of the pollution were discussed.

2. Study area

Nordlys vind is one of the biggest wind farms in the North of Norway. It has two wind farm areas: Kvitfjell and Raudfjell. Kvitfjell and Raudfjell wind farm area is located in Tromsø municipality in Troms country in the North of Norway. The construction of wind farm project started in October 2017. It is expected that the wind turbine will be transported, installed and come into operation from April to September 2019.

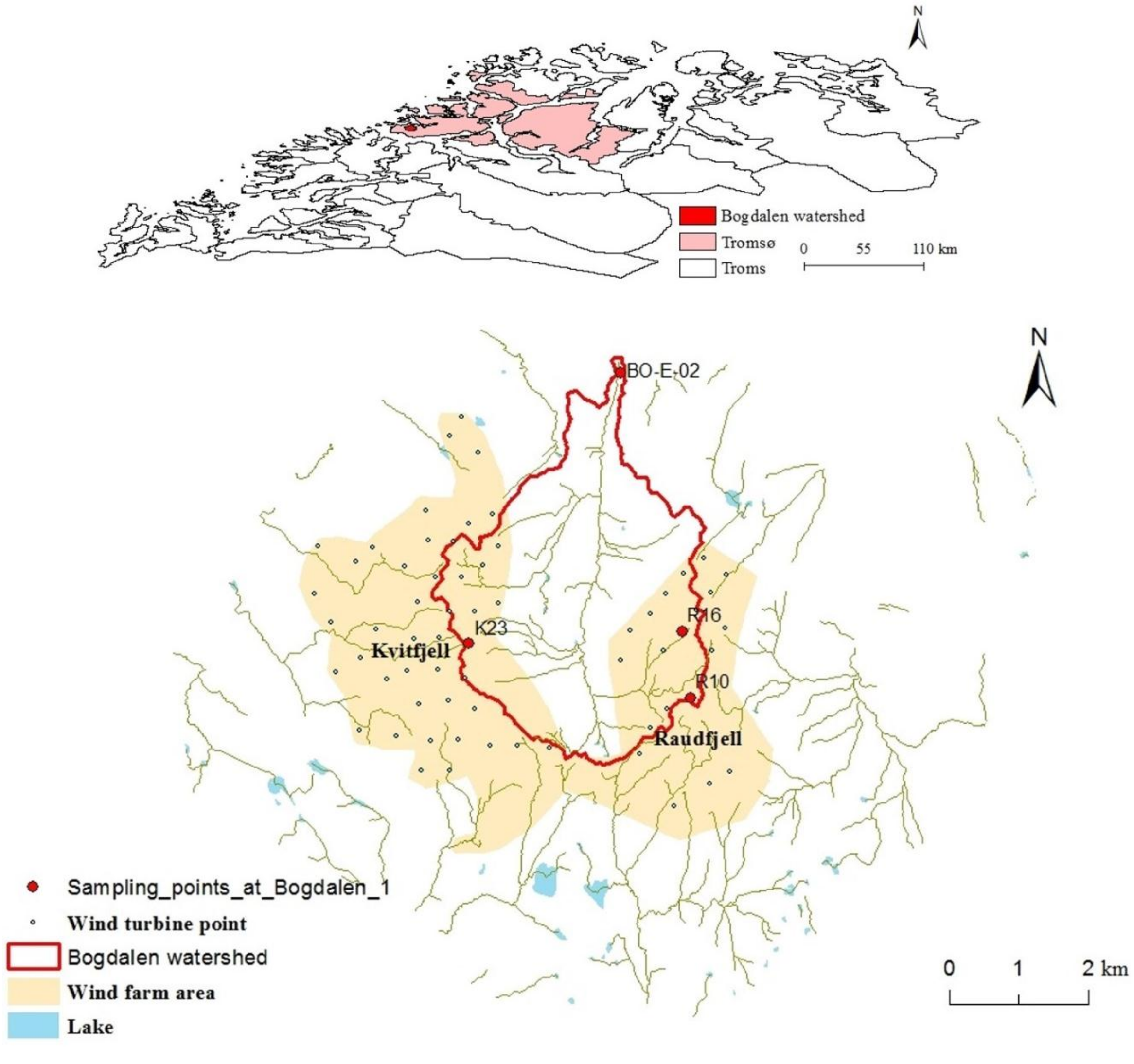

Figure 1. Study area and sampling locations.

There are many watersheds and lakes in or surrounding the wind farm area. Bogdalen is one watershed that crosses both wind farm areas. Therefore, Bogdalen was selected as the study area to investigate the effect of wind farm development on the water quality in the surrounding areas. The study area is shown in figure 1.

3. Materials and methods

3.1. Water sampling

The water samples were collected at four different points, of which three is in the wind turbine point, and one is in the Bogdalen watershed that is far from the wind turbine. The sampling points are shown in figure 1. The samples were collected into a polyethylene bottle every second week from the sampling points from March to November by Nordlys Vind company. The collected samples were stored at refrigerator at 4 ℃ until analysis. There are in total 13 sampling events performed at BO-E-02, of which one in March, 2 in April and May respectively, 3 in June, one in July, august and September respectively and 2 in November. One sample were collected at K23, R10 and R16 respectively in November.

3.2. Water sample analysis

The collected water samples from BO-E-02 were sent to Toslab for analysis of pH and the concentrations of Al, As, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn, Clostridium perfringens, Presumptive E.Coli, Intestinal enterococci and coliform bacteria. Concentrations of Al, As, Cd, Cr, Cr, Fe, Mn, Ni, Pb and Zn were tested according to the method NS-EN ISO 17294-2. pH value was measured according to method NS-ISO 10523. The concentrations of the four bacteria parameters Clostridium perfringens, E.Coli, Intestinal enterococci, and coliform were tested according to the method NS-EN ISO 14189, NS4792, NS-EN ISO 7899-2 and NS4788 respectively. The water samples from K23, R10 and R16 were sent to ALS laboratory group Norway AS for chemical composition analysis. The concentrations of Al, As, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn in the water were analyzed before and after the filtration through a 0.45μm filter. The analysis results were provided by Nordlys Vind company.

4. Results

4.1. The test results at BO-E-02

The pH and concentrations of Al, As, Cd, Cu, Cr, Fe, Ni, Pb, Zn and the four bacteria parameters Clostridium perfringens, E.Coli, Intestinal enterococci, and coliform in the water samples from BO-E-02 were shown in figure 2. The results were compared with the drinking water guideline values set by world health organization (WHO) and Ireland Environmental Protection Agency (table 1) [4,5]. A guideline value normally represents the concentration of a constituent that does not result in any significant risk to health over a lifetime of consumption [4]. The results showed that concentrations of Al, As, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn are much lower than the guideline values set by both organizations (table 1, figure 2). The pH of the water is in the range of 6.4 to 7.4 during the test period, which are generally in the recommended pH range for the drinking water (table 1, figure 2). A pH range of 6.0 to 9.0 appears to provide protection for the life of fresh water fish and bottom dwelling invertebrates [6].

The test results on the four bacteria parameters showed that the water is polluted by the bacteria, especially in June and August. The highest concentrations of the four bacteria in water were observed in August, which are 101, 101, 101 and 74 CFU/100 ml of water for E.coli, Clostridium perfringens, Coliform and Intestinal enterococci respectively. The value is extremely higher than the limit values set for drinking water (table 1). The results indicate that the water has faecal pollution, especially during the summer. E.coli is considered the most suitable indicator of faecal contamination [4]. It provides conclusive evidence of recent faecal pollution and should not be present in drinking water [4]. Clostridium perfringens is a member of the normal intestinal flora of 13-35% of humans and other warm-blooded animals and is a highly specific indicator of faecal pollution [4]. The presence of

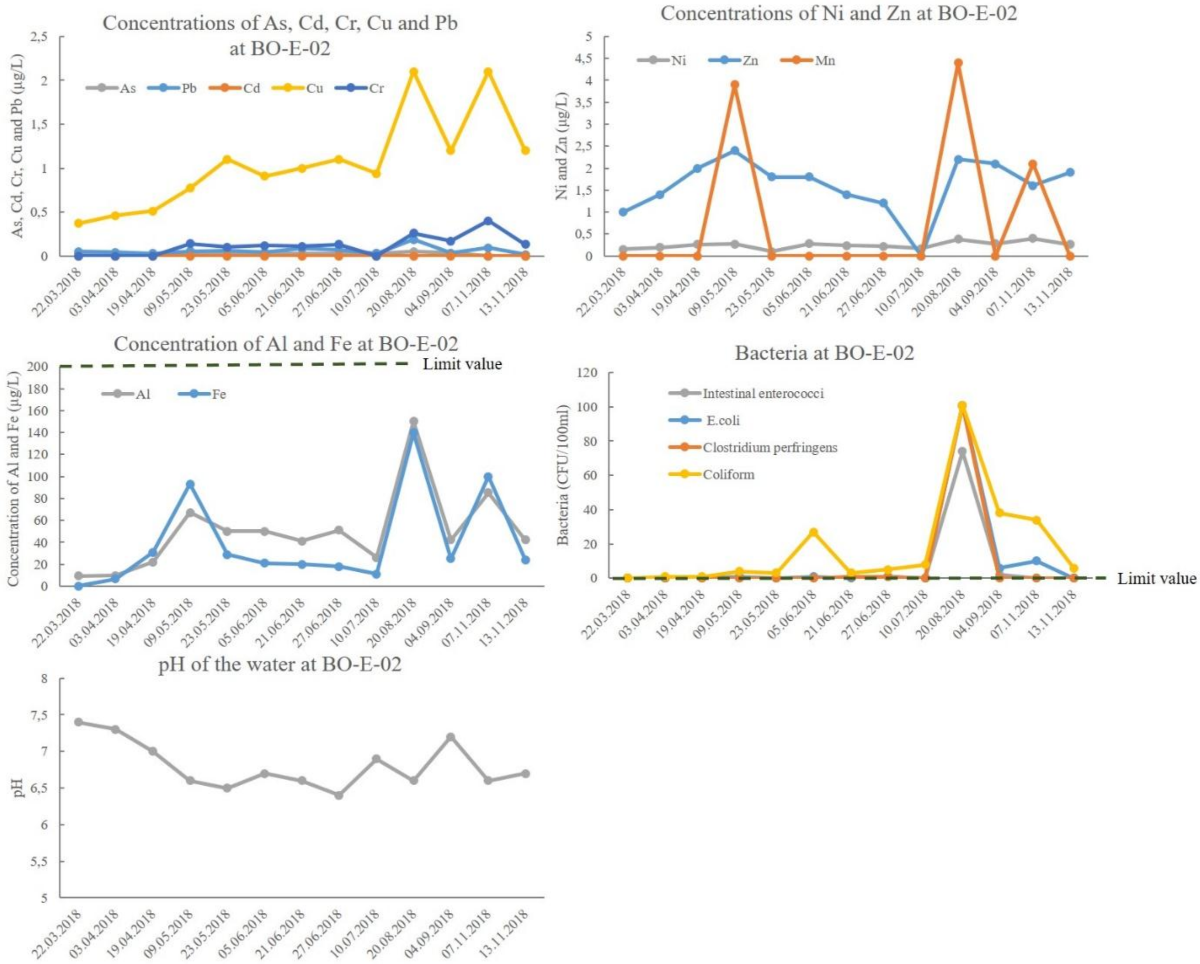

Figure 2. The results for the water samples at BO-E-02.

Table 1. Drinking water guideline values set by World Health Organization (WHO) and Ireland Environmental Protection Agency.

Element	WHO [4]	Ireland EPA [5]
pH	6.5-8.5	6.5-9.5
Al (µg/L)		200
As (µg/L)	10	10
Fe (µg/L)	-	200
Cr (µg/L)	50	50
Cd (µg/L)	3	5
Cu (µg/L)	2000	2000
Pb (µg/L)	10	10
Mn (µg/L)	400	50
Ni (µg/L)	70	20
Zn (mg/L)	-	-
Sulfate (mg/L)	-	250
Clostridium perfringens (No./100ml)		0
Coliform bacteria (No./100ml)		0
E.coli (No./100ml)		0
Intestinal Enterococci (No./100ml)		0

Clostridium perfringens in drinking-water can be an indicator of intermittent faecal contamination [4]. Fecal coliform bacteria are a collection of relatively harmless microorganisms that live in large number in the intestines of the warm and cold blooded animals [6]. The presence of fecal coliform bacteria in aquatic environmental indicate that the water has been contaminated with the fecal material of man or other animals [6]. The presence of fecal contamination is an indicator that a potential health risk exists for individuals exposed to the water [6].

4.2. The test results at wind turbine points K23, R10 and R16

The water samples were collected at the wind turbine K23, R10 and R16 at one occasion in November. The concentrations of Al, As, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn in the original water and water after filtered through the filter paper were analyzed. The results were shown in table 2. The results showed that the concentrations of all the tested elements in the water after filtration are reduced significantly compared with those in the original water. The reduction was most significant for Fe and Al, which reduced 99.5% and 94.1% after filtration. This indicates that most of the tested elements in the water attached to the fine particles in the water, which can be easily removed by filtering through a filtration paper. Contamination of Al was observed in the water from R10 and K23 before the filtration, which were 2230 µg/L and 1540 µg/L, much higher than the limit value set by the Ireland EPA [5]. However, the concentration of Al reduced to lower than the limit value after filtration. Contamination of Mn in the water from R10 was higher than the limit value set by Ireland EPA both before and after filtration. This indicates that Mn may have a different mechanisms compared with other elements.

Table 2. Test results at K23, R10 and R16.

Parameter	Unit	R10		R16		K23	
		Before	After	Before	After	Before	After
Al	µg/L	2230	132	32	22.8	1540	153
As	µg/L	0,776	0.085	<0.5	<0.05	0.522	<0.05
Cd	µg/L	<0.05	0.004	<0.05	0.017	<0.05	0.012
Cr	µg/L	5.71	1.31	<0.9	0.825	6.88	1.03
Cu	µg/L	46	10.7	<1	0.728	9.93	2.24
Ni	µg/L	5.22	1.56	1.21	0.638	3.54	0.756
Pb	µg/L	1.12	0.211	<0.5	0.041	1.70	0.251
Zn	µg/L	10.5	1.32	<4	2.45	9.32	6.69
Fe	µg/L	3.53	0.168	0.044	0.012	2.1	0.095
Mn	µg/L	174	131	7.24	5.69	46.5	19.5

5. Discussions

5.1. Faecal pollution

Faecal contamination of water is a global public health problem [7]. Faecal contamination of drinking water has caused numerous disease outbreaks [8]. Tallon *et al* reviewed the history of different indicator organisms and the evolution of the analytical methods, and got the conclusion that E.coli appears to provide the best bacterial indication of faecal contamination in drinking water [8]. E.coli is a member of the faecal coliform group and is a more specific indicator of faecal pollution than other faecal coliforms [9]. The use of fecal indicators is a relatively fast, easy and inexpensive method to detect fecal contamination, and traditional indicators include coliforms, fecal coliforms, E.Coli, or enterococci [7]. For routine monitoring, faecal indicator bacteria (FIB) are usually enumerated to evaluate the level of microbial water contamination [10]. Total coliforms and faecal coliforms has been used as bacterial indicators for more than a century. E. coli and intestinal enterococci are the most frequently used indicators of faecal pollution nowadays [10]. E.coli and intestinal enterococci have been used to investigate the faecal contamination of water in the rivers of the Scheldt drainage network [10].

The test of the water at one accumulation point of Bogdalen watershed indicated that the water has high concentration of coliform, clostridium perfringens, E.coli, intestinal enterococci, especially in the summer. The results indicate that the water has different degree of fecal pollution. The pollution may be linked to local human and animal activity. The two wind farms are located in the Kvitfjell and Raudfjell mountain areas that are rich in wildlife, such as reindeer. The watershed area is used as grazing area for these animals in the summer. Afterwards the faecal excrement from the animals can be transported to local water system by surface runoff, and further down through the watershed to the accumulation point.

5.2. Accumulation mechanism of elements
The test results showed that the water has high concentration of Al and Mn at certain wind turbine point within the watershed. The concentration of Al is significantly reduced after filtering through a filter paper. This indicates that Al is probably mainly attached on the fine particles in the water. Al is the major chemical composition of clay minerals, and it is often used to reflect the variation characteristics of fine grain size [11]. Significant correlation between the aluminum concentration and %silt/clay and %<63µm fraction were observed, which indicated that Al mainly attached/bounded with fine particles [12]. Most of the metals have significant linear correlation with Al, indicating that a major portion of the heavy metals in the sediment were closely associated with fine grained clay minerals [12]. However, the concentration of Mn didn’t reduce much after filtration, which may indicates that Mn may have other source and accumulation mechanisms compared with other elements. Batch experiment was conducted to investigate the removal of Mn from water by contact with course solid material [13]. The results showed that limestone with a particle size of 3.35-4.76 mm could remove 95% of Mn from solution [13]. However, the filtration experiment in this study is through 0.45µm filter, which is too fine to filtrate out Mn from water.

6. Conclusions
The water at Bogdalen watershed is polluted by different parameters at different parts of the watershed. The water at the wind turbine point is polluted by Al and Mn. The Al can easily remove by filtration. However, concentration of Mn didn’t reduce much after filtration. An increase in filter size is suggested for Mn removal. The water in the accumulation point far from the wind farm has high concentration of the tested bacteria parameter, especially in the summer. The bacterial may originate from local reindeer grazing activity and other human activities. An investigation on the sources of bacteria pollution is suggested in the future. The results from this study indicate that a continuous monitoring of water quality is needed before, during and after the wind turbine construction.

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