Groundwater monitoring for evaluating the pasture carrying capacity and its vulnerability in arid and semi-arid regions: A case study of urban and mining areas in Mongolia

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Abstract. Arid and semi-arid regions cover 41% of the global land area and 2 billion people, 90% of which belong to developing countries, live there. Variation in precipitation due to climate change brings big large influences on ground and underground water resources, and especially it is predicted that arid and semi-arid regions are getting drier. Therefore, it is imperative to clarify impacts to environmental vulnerability caused by the variation of water cycle (VWC) due to climate change and consider options for its adaption. Mongolia is a typical country where environmental vulnerability is getting worse by VWC. Our previous studies revealed that the increase of evapotranspiration and permafrost degradation by global warming deteriorate the pasture carrying capacity (PCC) in semi-arid regions in Mongolia. In this manner, VWC is a key component of PCC, but VWC depends on not only climate change but also human activities. Recent mine development and urbanization, as well as growth of livestock, increase groundwater use, but their influences have not been clarified. To explore the influence of urbanization and mining, we have started groundwater monitoring of urban areas in semi-arid regions (Northern Mongolia) and mining areas in arid regions (Southern Mongolia) since May 2018. After investigating hundreds of wells in those areas, and finally selected 11 wells in urban areas and 7 wells in mining areas for groundwater monitoring. 22 Onset HOBO U20 Water Level Loggers (Forestry Suppliers, Inc.), including 5 Loggers for atmospheric correction, and a Water Flow Rate Sensor (Keyence Inc.) are working for measuring groundwater usage. Meanwhile, with data analyses of groundwater level at 875 wells from 2015 to 2017 measured by the local basin authority, it was found that the groundwater level of mining area had a tendency of decreasing widely comparing with that of non-mining area.

1. Introduction

Arid and semi-arid regions cover 41% of the global land area and 2 billion people, 90% of which belong to developing countries, live there [1]. Variation in precipitation due to climate change brings great influences on surface and underground water resources, and especially it is predicted that arid and semi-arid regions are getting drier [2,3]. Therefore, it is imperative to reveal impacts to environmental vulnerability caused by the variation of water cycle (VWC) due to climate change and consider options for its adaption.

Mongolia is a typical country where environmental vulnerability is getting worse by VWC. Our previous studies show the increase of evapotranspiration and permafrost degradation by global warming
deteriorate the steppe in semi-arid regions in Mongolia, and reduction of the pasture carrying capacity (PCC) widely affects food (livestock) supply in the nation [4]. In this manner, VWC is a key component of PCC, but VWC depends on not only climate change but also water use by human activities. However, our previous research has not yet taken account of the effects of VWC. Especially the rapid mine development and urbanization might increase groundwater use, but their influences have not been clarified.

This study aims to explore the groundwater usage of urban areas in semi-arid regions (Northern Mongolia; NM) and mining areas in arid regions (Southern Mongolia; SM). For this purpose, we have not only established a groundwater monitoring system network to obtain the data of groundwater level with higher temporal resolution (30 minutes) but lower spatial resolution (18 wells), but also collected the existing local data with lower temporal resolution (yearly) but higher spatial resolution (875 wells).

2. Material and method

In order to evaluate groundwater usage of urban and mining areas, we selected the study areas (Section 2.1), and then considered approaches to establish our own monitoring systems in NM and SM (Section 2.2). In addition, we analyzed variation of groundwater level based on the monitoring data measured by the local basin authorities in SM (Section 2.3).

2.1. Area classification and selection of study area

For evaluation of groundwater usage of urbanization and mine development, the study areas are categorized into four groups: urban area, mining area, non-urban area and non-mining area.

Urban area is defined as an area under urbanization and Ulaanbaatar, which is the capital of Mongolia and a half of the whole nation lives in, is selected. This is because urbanization is ongoing and the current population density has approximately doubled since 2000 [5] while many high residential and commercial buildings have actively been constructed recently.

Mining area is an area where the mining industry is prospering. Mongolia has abundant mineral resources, which include copper, gold, coal, petroleum, and other resources, and it is estimated that the mining sector shares 20% of the GDP in Mongolia [6]. Especially Oyu Tolgoi in the South Gobi Desert is one the world’s largest mining sites of gold and copper, so Khanbogd Soum, Omnogovi Province, where Oyu Tolgoi LCC is located, is selected as the mining area.

In order to clarify influences by urbanization and mine development, non-urban and non-mining areas which are not influenced by urbanization and mine development are defined as reference areas. Furthermore, an area belonging to the same basin (Tuul River Basin or Galba-Uush, Dolood Gobi River Basin) around urban or mining areas is selected to set the same condition except for urbanization or mine development. Finally, Lun Soum and Altanbulag Soum, Tov Province are selected as non-urban area whereas Manlai Soum, Omnogovi Province,,as non-mining area. The location of these areas are shown as Figure 1.
2.2. Approaches for monitoring groundwater usage

2.2.1. Methods to measure groundwater usage. There are two approaches to measure groundwater usage. The first approach is a direct monitoring method to measure water flow rate from aquifers with a water flowmeter, and that has an advantage to collect reliable data. However, this method usually takes costs for a data logger as well as a flowmeter, and the pipe needs be cut to set a flowmeter according to a device. Another approach is an indirect monitoring method based on variation of groundwater level, which gets lower by pumping up groundwater. A device to measure groundwater level easily to set many wells due to low cost, but the results should be verified because groundwater level is influenced by other factors as well. Therefore, we adopted an indirect approach as the main method to measure groundwater usage for all monitoring wells, while a direct approach is utilized for verification of results of the main method at some reference wells. In addition, Onset HOBO U20 Water Level Loggers (Forestry Suppliers, Inc) and Clamp-and Clamp-on Flow Meter (Keyence Corporation) are selected as the main and supplemental monitoring devices respectively.

2.2.2. Selection of monitoring wells in the study areas. For the selection of monitoring wells, we collected locations and specification of wells in the study areas with literature review [7,8] and listed 145 wells first. 55 wells (38 wells in SM and 17 wells in NM) in the list were investigated in May 2018. In addition, test monitoring was started at 8 wells (7 wells in SM and a deep well in NM) whose owners or managers agree with our groundwater monitoring. With the second field survey, 18 wells (11 wells in NM and 7 wells in SM) are selected as groundwater monitoring sites, and 18 Onset HOBO U20 Water Level Loggers, as shown as Table 1, are installed. Meanwhile 5 loggers, the end of whose device code include “–a”, measure air pressure for atmospheric correction in the study area. A well of mining area is installed a flowmeter (device code as “M-f” in Table 1). Unfortunately, 2 water level loggers (M-b1 and –b2) were buried by huge flood occurred in the middle of July of 2018. The monitoring sites are shown in Figure 2 and 3.
Table 1. Status of groundwater monitoring systems of this study

| Monitoring target | Device code | Area classification | Depth of well (m) | Water-intake method |
|-------------------|-------------|---------------------|-------------------|---------------------|
| 01 Groundwater level | M-01 | Mining | 40 | Motor pump |
| 02 | M-02 | Mining | 200 | Motor pump |
| 03 | M-03 | Mining | 4.8 | Motor pump |
| 04 | M-04 | Mining | 3.5 | Retired |
| 05 | M-05 | Mining | 2.95 | Hand-pump |
| 06 | NM-01 | Non-mining | 2.7 | Hand-pump |
| 07 | NM-02 | Non-mining | 6 | Motor pump |
| 08 | U-01 | Urban | 25 | Motor pump |
| 09 | U-02 | Urban | 15 | Motor pump |
| 10 | U-03 | Urban | 80 ~ | Motor pump |
| 11 | U-04 | Urban | 2.75 | Motor pump |
| 12 | U-05 | Urban | 2.65 | Motor pump |
| 13 | U-06 | Urban | 4.9 | Well bucket |
| 14 | U-07 | Urban | No record | Well bucket |
| 15 | NU-01 | Non-urban | 60 | Motor pump |
| 16 | NU-02 | Non-urban | 70 ~ | Motor pump |
| 17 | NU-03 | Non-urban | 5.5 | Motor pump |
| 18 | NU-04 | Non-urban | No record | Well bucket |
| 19 | Atmospheric correction | M-a | Mining | |
| 20 | | NM-a | Non-mining | |
| 21 | | U-a | Urban | |
| 22 | | NU-a1 | Non-urban | |
| 23 | | NU-a2 | Non-urban | |
| 24 | Flow rate | M-f | Mining | Motor pump |
| 25 | (Buried by flood) | M-b1 | Mining | 5.7 | Motor pump |
| 26 | | M-b2 | Mining | 2.9 | Retired |
Figure 2. Location of the monitoring wells in urban and non-urban areas

Figure 3. Location of the monitoring wells in mining and non-mining areas
2.3. Data analysis of variation of groundwater level measured by local basin authorities
Mongolia has 29 basins and some basins are managed by the local basin authorities under the Ministry of Nature, Environmental and Tourism. Our study areas are just located in Tuul River Basin and Galba-Uush, Dolood Gobi River Basin, the local authorities constantly measure groundwater level by themselves. Thus, we collected the annual data measured by the Galba-Uush, Dolood Gobi River Basin Authority between 2015 and 2017, and analyzed variation of groundwater level of mining and non-mining area, based on the data of 875 wells in total, using Multilevel B-Splines methods [9].

3. Results and discussion

3.1. Changes of groundwater level by test monitoring
Only few data of our monitoring systems are available due to time limitation. Figure 4 shows depth of groundwater of M-04 and M-05. M-04 was set up in a retired well, which has the only positive behavior of peak values since no one pumps water up while M-05 shows not only positive but also negative change of peak values. Especially significant negative change is related to groundwater usage, 17 peaks (red-colored dotted circles in Figure 4) are observed. The results indicates that the depth of groundwater become lower in the range between 0.11 and 1.64 m (mean value and standard deviation: 0.50±0.41m). In addition, the depth gets lower with a pace of 0.45 m per hour averagely.

Since the middle of July when huge floods occurred due to heavy rainfall, it is considered that huge floods disturbed farmers’ access to the well because a few negative variations have been observed. In addition, the depth of groundwater has drastically become lower (1.49 and 1.65 m) for an hour twice in August, but it is presuming that farmers may pump groundwater up with portable motor.

![Figure 4. Changes of depth of groundwater at testing sites in mining area](image)

3.2. Variation of groundwater level by the past data analysis
Figure 5 shows the variation of groundwater level in mining and non-mining area. The results show that the groundwater level decreased in more than half of mining area, and especially north-eastern parts, whose maximum drawdown possibly reached at 3.4 m, are significant. On the other hand, groundwater
level of 74% of non-mining area increased and it is estimated that less than 2 m raise occurred in more than half area.

Figure 5. Variation of groundwater level in mining and non-mining area (2015-2017)

4. Conclusion
VWC depends on not only climate change but also human activities. In order to explore the groundwater usage of urbanization and mine development, we have not only established a groundwater monitoring systems network to obtain the data of groundwater level with higher temporal resolution (30 minutes) though lower spatial resolution (18 wells), but also analyzed the existing local data with lower temporal resolution (yearly) but higher spatial resolution (875 wells) groundwater levels.

The groundwater monitoring network to evaluate groundwater usage by urbanization and mine development has been established at 18 wells in Mongolia. As results of test monitoring in mining area, it is found that groundwater usage possibly makes the groundwater level lower by 0.50±0.41 m. In addition, the results indicate that groundwater level recovered for a relatively short time after water withdrawals. At the same time, with data analyses of groundwater level measured by the local basin
authority, it was found that the groundwater level decreased in more than half of mining area, while that of 74% of non-mining area rose in the past 2 years. We might come to a very primary conclusion that the mine development has made an influence on groundwater level. However, we are understanding that this result was based on only 3-year data, we need to make confirmation to our results with long-term datasets in the future. Of course, we may also focus on the study on the influence of urbanization on water use in the next stage.

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