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RAINWATER HARVESTING IN KHERLEN RIVER BASIN, EAST MONGOLIA

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ABSTRACT

Water resources of Mongolia are highly vulnerable to climatic conditions due to harsh climate with four distinct seasons, high annual temperature fluctuations, and low rainfall. Average annual temperature ranges between 8.5ºC in the Gobi and -7.8ºC in the high mountain region. Average annual precipitation is around 200-500 mm and total water resource is estimated at 599 km^3. About 64% is surface water and 36% is actually groundwater. Mining is rapidly changing the water consumption and landscape in Mongolia. In 2010, mining only consumed 13%, but the demand for water is projected to increase fivefold from 2012-2030. The future water resources are lacking, and will not be possible to satisfy by water from underground. One of the possible solutions is rainwater harvesting, to collect rainfall or snowfall. Objective of this study is to determine the feasibility of rainwater harvesting system in Kherlen River Basin, East Mongolia. Climate data, between 2000 and 2015, are obtained at three hydrological stations in the Kherlen River Basin. Results show that annual total precipitation ranges from 150-400 mm. About 90% of annual precipitation falls only in the warmer season. The lowest precipitation falls in winter months and the highest occurs in July. This study calculates possible water volume for collecting rainwater. Mungunmorit station is chosen as it is located at the upstream of the river. It will be possible to harvest on an average of 51 million m^3 of water in spring and summer seasons according to the last 10 years rainfall records. The collected water can be used for domestic and water consumption of Ulaanbaatar City. In the future, water level may decrease with increasing air temperature due to climate change. Avocation of rainwater harvesting system is urgently needed in the near future.

INTRODUCTION

Mongolia is a country located in central Asia. Geographically it can be divided into three main regions, including north, central and south (Fig. 1). The northern part of Mongolia is a conifer forest region - the Siberian taiga. The central region is steppes, and south part is all desert steppes (Sato, 2011). An ecological transition zone is considered to be highly vulnerable to future climatic change including global warming. Northeast Asia has indeed experienced one of the strongest warming signals on earth (Yamanaka *et al*., 2007). At present, due to global warming impact, Mongolia river basin ecosystems are changing dramatically. Because of the lowering groundwater table level, there are disrupted hydraulic connections between river and groundwater which often result in shrinking and disappearance of open water bodies during dry seasons and droughts. Usually, the humidity of Mongolia is extremely scarce.

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Dry season often occurs in spring and early summer every year. Drought occurs once in several years. According to recent studies, severe drought may become more frequent and may cause potential drastic consequences to central Asia. South of Gobi Desert, low precipitation and high climatic variability in dry land environment has altered the landscape and affected the pastoral dominant rural lifestyle. According to study based on standardized precipitation index (SPI) (Sternberg *et al*., 2013), drought occurs independently and is highly correlated with human population rather than natural factors. Water resources in Mongolia are limited and unevenly distributed within the country. There are three main hydrological basins: Arctic Ocean Basin, Pacific Ocean Basin, and Central Asian Internal Drainage Basin. The Central Asian Internal Drainage Basin is the largest and includes the Great Lakes Depression, Uvs Lake, Khar-Us Lake, Khar Lake and Khyargas Lake (Batnasan, 2003). There are 5,300 rivers, 7,800 springs, 3,600 lakes, and 362 mineral springs. Rivers are sparsely distributed; mostly flow from the mountains of the Siberian taiga forests towards the northwest, leaving the east and south regions dry with deserts (Sato, 2011).

Figure 1. Map of Mongolia

Figure 2. Kherlen River Basin

Table 1. Basic description of the Kherlen River Basin and the three main hydrological stations

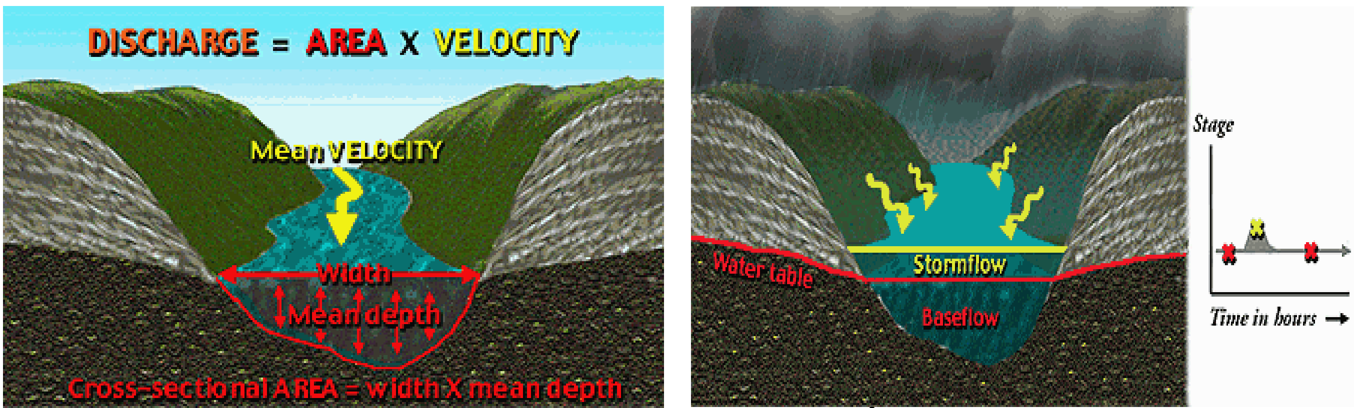
No.	Eco-region	River Station	Coordinates		River length km	Area (km²)	Elevation (m)	Record length
			Lat.	Long.				
1	Mountain forest	Mungunmorit	48.1	108.5	1000	5403	1405	Since 1999
2	Mongolian - Manchurian	Undurkhaan	47.2	110.4	829	39400	1280	1942
3	grassland	Choibalsan	48.1	114.5	390	71500	-	1942

Permafrost prevails over large areas (Natsagdorri *et al.*, 2011). Water resources of Mongolia are highly vulnerable to climatic conditions due to harsh climate with four distinct seasons, high annual temperature fluctuations, and low rainfall. Average annual temperature ranges between 8.5°C in the Gobi and -7.8°C in high mountain regions of Mongolian Altai, Khangai and Khentei.

Average annual precipitation is low (200-220 mm) and represents a range between 38.4 mm in the Gobi Desert and 389 mm in the North (Davgadorj *et al.*, 2009). Total water resource of Mongolia is estimated at about 599 km^3, from which 83.7% is located in 3,500 lakes, 10.5% in 262 glaciers and 5.8 % in 3,811 rivers. Of these resources, 63.5% is surface water and 36.5% is actually groundwater (Sato, 2011). In fact, more than 90% of the total population uses groundwater for daily necessities (Tsujimura, 2007). According to a 2009 report, water withdrawal totaled about 550 km^3, of which 38% by industries, 23% by irrigated crops, 21% by livestock cleaning and watering, 13% by municipal and 5% by cooling of thermoelectric plants. In recent years, the country is faced with the real situation of water deficit due to mining. Mining is rapidly changing the water consumption and energy landscape in Mongolia. Water resources are not enough and lack of water often occurs. The Mongolian government has planned to implement mega projects which include the Oyutolgoi, Tavantolgoi mining projects and many others. Before 2010, mining just consumes 13% of the total water use and the demand for water is projected to increase fivefold from 2012-2030. In the future the water resources are extremely lacking for mining projects, and it is impossible to obtain water from underground. Adequate water availability for the requirements of mining, despite climate change is a key challenge in the future. One of the possible solutions is rainwater harvesting (RWH). RWH has been practiced for different purposes in different manners and in many parts of the world for centuries. It is the collection of rain and snow from surfaces upon which it falls. A long standing practice of many countries still used as a means for solving water problems. It has been widely accepted around the world as one of the main alternative source of water (Islam *et al*., 2010; Mohammad *et al*., 2013). Harvested water is mostly used for non-drinking purposes such as crop irrigation and household cleaning use. The main objective of this study is to identify the past 15 year changes in the climate regimes, including precipitation, air temperature and water levels of Kherlen River Basin, East Mongolia and to develop the rainfall harvesting system model in this River Basin.

mountain section, and 1 m/sec in the steppe section. Surface runoff is generated from rainfall during the warm period and spring snow melt (about 56-76 %). Based on the flow regime classification, the Kherlen River belongs to the summer rainfall and spring snow melt flood type. Low winter temperature in the Kherlen Basin results in deep freezing of soils and even formation of permafrost pockets. Most river courses, including the Kherlen downstream from Baganuur, freeze down to the bottom. Fish has to seek refuge near groundwater release area at the river and lake bottom. The spring is cold, windy and dry. Most rainfall coincides with the highest annual temperature during the second half of summer. This leads to a highly intensive cycling of nutrients in the short summer period and, as a result, to the formation of primarily poor, shallow soils. According to recent research, 82.1- 90.7% of annual runoff along the Kherlen River is generated between April and September. Moreover, the high flood events in Kherlen River basin are observed in 1933, 1954, 1959, 1967, 1973, 1984, 1988, and 1990. In 1954, flood discharge at Baganuur Station reaches 1,320 m^3/sec (Oyunbaatar *et al*., 2014). There are 3 main hydrological stations in the Khelen River Basin, Mungunmorit, Undurkhaan and Choibalsan. Basic description of the Khelen River Basin and the hydrological stations is showed in Table 1.

The Mungunmorit Station is located in the Khentii Mountain area which is the source of river water. Undurkhaan and Choibalsan are located in the steppe and are in the middle stream and downstream of the Kherlen River, respectively. Precipitation, air temperature and water levels data of the three hydrological stations are obtained from the Institute of Meteorology and Hydrology (IMH), Mongolia from 2000 to 2015.



Discharge(m^3)=Cross-sectional area(m^2)*Velocity(m/sec)Cross-sectional area (m^2) = Width * Mean Depth

Figure 3. Formula for calculation of river discharge
Source: USGS science of water/ http://water.usgs.gov/edu/ streamflow2.html

MATERIALS AND METHODS

Kherlen River Basin is located approximately 120 km east of Ulaanbaatar, in Khentii Aimag between 48°44'N and 117°5'E. The river is in the south slope of the Khentii Mountain range at elevation about 1,750 m, near the Burkhan Khaldun Mountain in the Khan Khentii Strictly Protected Area. The river drains into Dalai Nuur in China (Fig. 2). The River Basin area within the territory of Mongolia is about 116,455 km^2 with length of 1,090 km (Oyunbaatar *et al*., 2004). The water depth and velocity as well as width are different at different parts of the river. In the upstream the river is about 30-50 m wide, in middle stream and downstream is about 150-200 m. Depth of river is about 0.8-1.5 m. The flow speed is 2 m/sec in the

Annual mean precipitation, air temperature and water levels are calculated. These data are then used to determine possibility of water harvesting from rainfall in the Kherlen River Basin. The discharge volume is calculated according to the schematic diagram and the formula listed in Fig. 3.

RESULTS AND DISCUSSIONS

Annual precipitation (PPT) in hydrological stations of Kherlen River Basin

Eastern Mongolian region has more humid climate compared to other regions. The annual precipitation ranges from 150 to 400 mm. Fig. 4 shows the annual precipitation on different parts (upstream, mid-stream and downstream) of Kherlen River's hydrological stations. The lowest precipitation (102.6 mm) is recorded at Choibalsan Station in 2004 and the highest precipitation (431 mm) also at the same station in 2013.

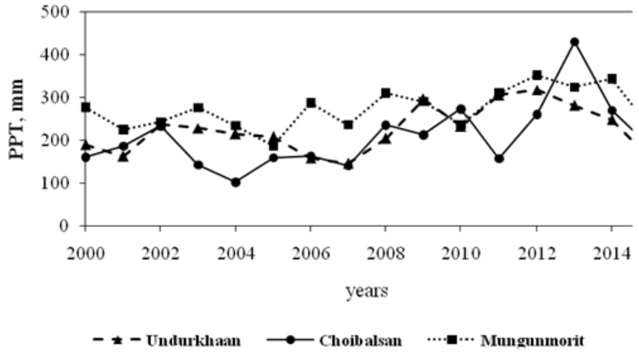


Figure 4. Annual precipitation (PPT) measured at the Undurkhaan, Choibalsan and Mungunmorit stations

Above 200 mm annual precipitation often occurs at Mungunmorit Station at the upstream of Kherlen River and located in forest area, close to Khentii Mountain. Figs. 5 to 8 show the PPT at three hydrological stations by seasons. About 90% of annual precipitation falls only in the warmer season, the lowest precipitation falls in winter and the highest occurs in July. In general, the annual precipitation in eastern Mongolian ranges from 250-400 mm during 1961-1990. Comparing to the current result findings, the amount of precipitation has decreased during 2000-2015. This is partly due to global warming impacts. Precipitation amount has reduced in the eastern and central part of Mongolia and increased in the Altai mountains and southeastern part of the country (Natsagdorj *et al*., 2011).

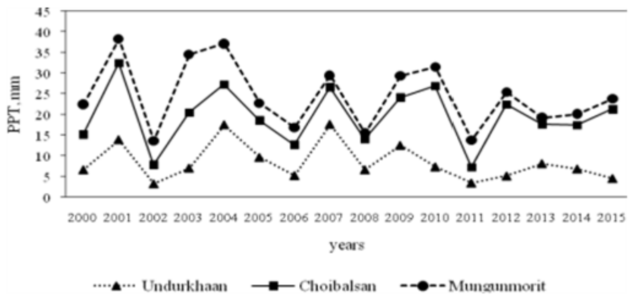


Figure 5. Winter season (December, January and February) PPT measured at the Undurkhaan, Choibalsan and Mungunmorit hydrological stations

Air temperature in hydrological stations of Kherlen River Basin

Fig. 9 shows the average air temperature on different parts (upstream, mid-stream and downstream) of the Kherlen River. The average temperature of Mungunmorit Station is -2.8±0.8°C, Undurkhaan Station 0.2±1°C and Choibalsan Station 1.7±1°C for the last 15 years. The lowest temperature (-22 to -26°C) is recorded in winter time at Mungunmorit Station. Tthe highest temperature (22 to 24.1°C) is at Choibalsan Station. Figs. 10 to 13 show the average temperature of different hydrological stations in Kherlen River by seasons. In winter months, the Mungunmorit Station reaches lower temperature than other stations. Temperature at Choibalsan Station is warmer than other stations. In summer months, the Mungunmorit Station has significantly higher temperature than other stations. During 1960-1990, annual mean temperature of the eastern part of Mongolia varies from -4.2°C to 1.1°C. But, according to the present results, average temperature has increased due to climate change and global warming, similar to many other studies (Natsagdorj *et al*., 2011).

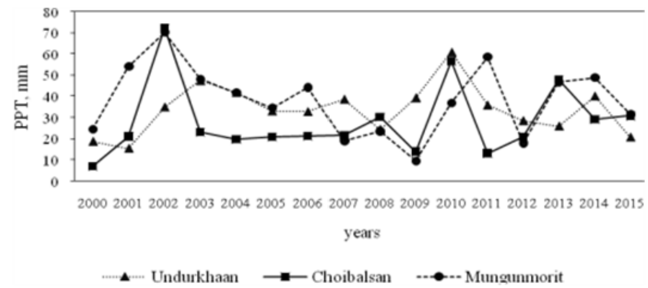


Figure 6. Spring season (March, April and May) PPT measured at the Undurkhaan, Choibalsan and Mungunmorit hydrological stations

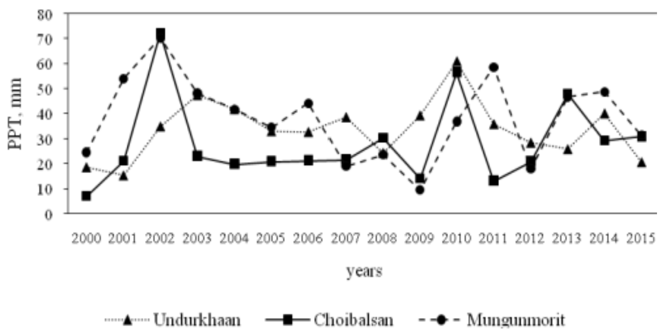


Figure 7. Summer season (June, July and August) PPT measured at the Undurkhaan, Choibalsan and Mungunmorit hydrological stations

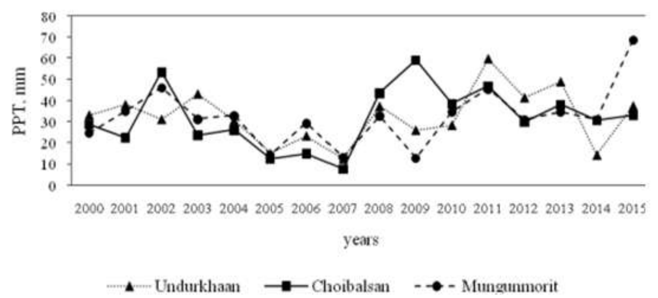


Figure 8. Autumn season (September, October and November) PPTs measured at the Undurkhaan, Choibalsan and Mungunmorit hydrological stations

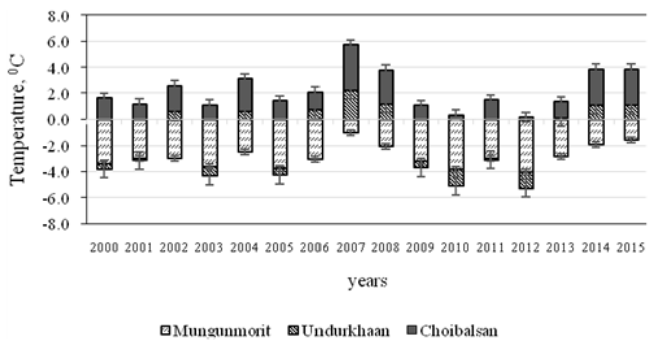


Figure 9. Annual mean air temperature from 2000 to 2015 years measured at the Undurkhaan, Choibalsan and Mungunmorit hydrological stations

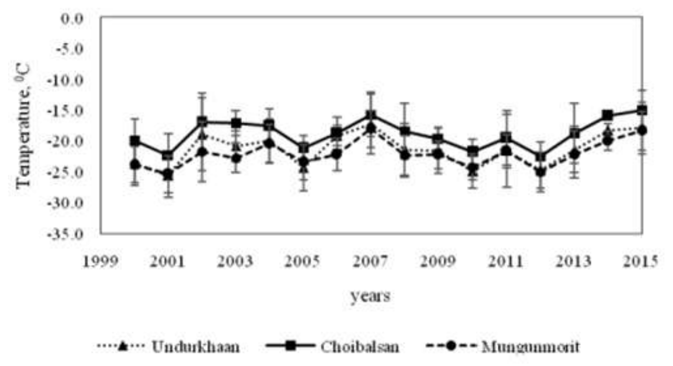


Figure 10. Mean air temperature of winter season (December, January and February) measured at the Undurkhaan, Choibalsan and Mungunmorit hydrological stations

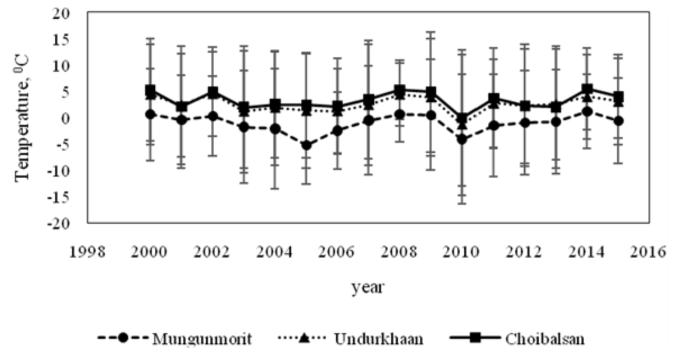


Figure 11. Mean air temperature of spring season (March, April and May) measured at the Undurkhaan,Choibalsan and Mungunmorit hydrological stations

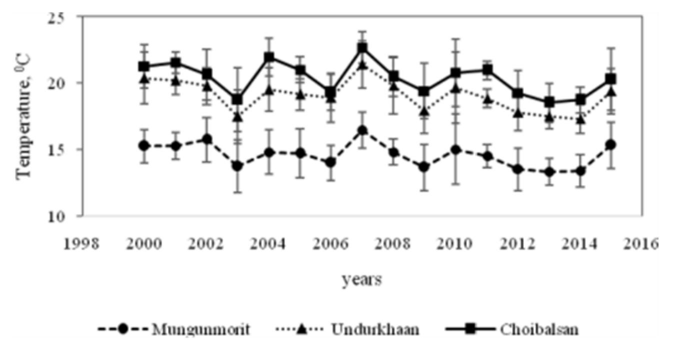


Figure 12. Mean air temperature of summer season (June, July and August) measured at the Undurkhaan,Choibalsan and Mungunmorit hydrological stations

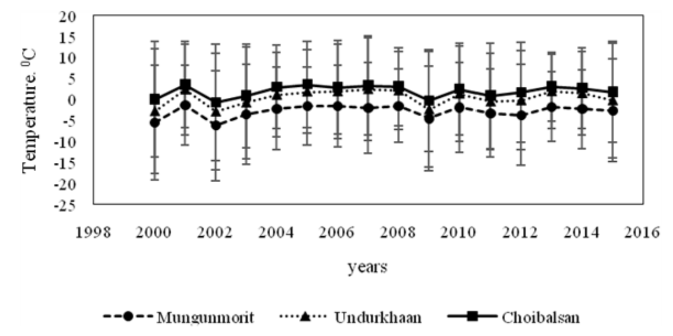


Figure 13. Mean air temperature of autumn season (September, October and November) measured at the Undurkhaan, Choibalsan and Mungunmorit hydrological stations

Fig. 14 shows the annual mean water levels at different parts (upstream, mid-stream and downstream) of the Kherlen River. The water level at upstream part of the river has the lowest level. Water level has increased at mid-stream and downstream of the river.

Water levels in hydrological stations of Kherlen River Basin

The average water level at Mungunmorit Station was 122.5±20.09 cm, Undurkhaan Station 153.6±16.6 cm and Choibalsan Station 203.7±54.38 cm for the past 12 years. In 2013, the water level at Choibalsan Station has decreased significantly. Figs. 15 to 18 show the annual mean river water levels of different hydrological stations in Kherlen River and by seasons. There are some missing data due to cold climate at the upstream and mid-stream part of the river. It is hard to record data in winter time because upper layer of the river has iced-up. But the highest river water level (259.5±44.68 cm) in winter time is recorded at Choibalsan Station in 2011. For warm seasons, the river water level increases at all hydrological stations. Higher level of water is recorded at Choibalsan Station for all the years.

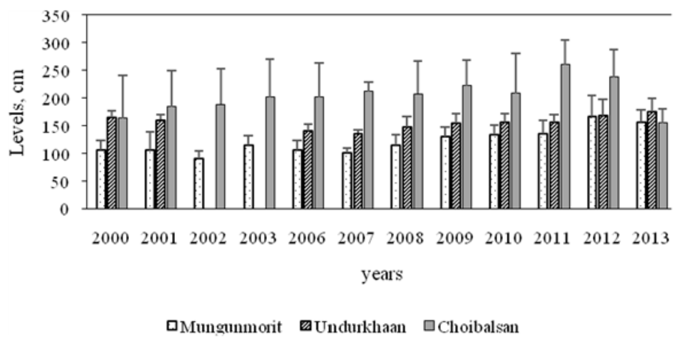


Figure 14. Annual mean river water levels measured at the Undurkhaan, Choibalsan and Mungunmorit hydrological stations

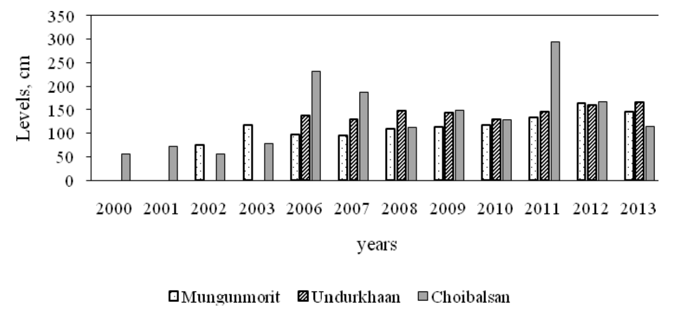


Figure 15. Mean river water levels of winter season (December, January and February) measured at the Undurkhaan,Choibalsan and Mungunmorit hydrological stations

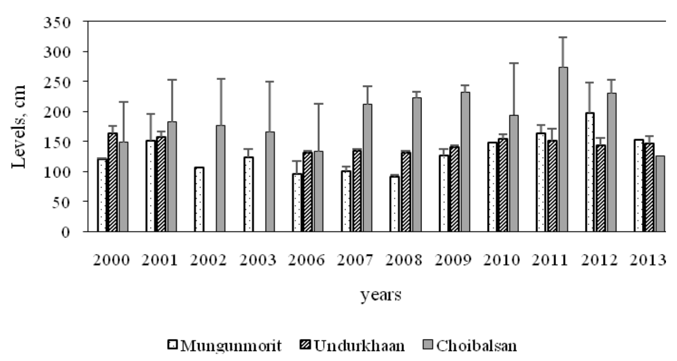


Figure 16. Mean river water levels in spring season (March, April and May) measured at the Undurkhaan, Choibalsan and Mungunmorit hydrological stations

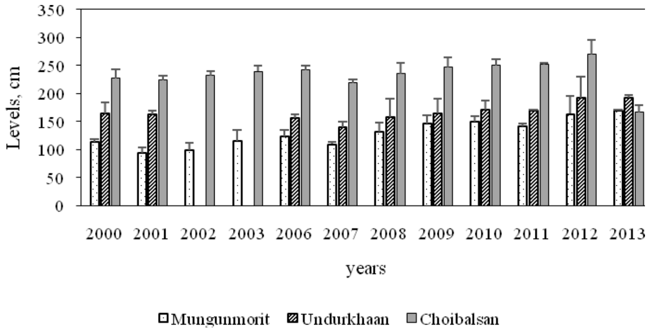


Figure 17. Mean river water levels in summer season (June, July and August) measured at the Undurkhaan, Choibalsan and Mungunmorit hydrological stations

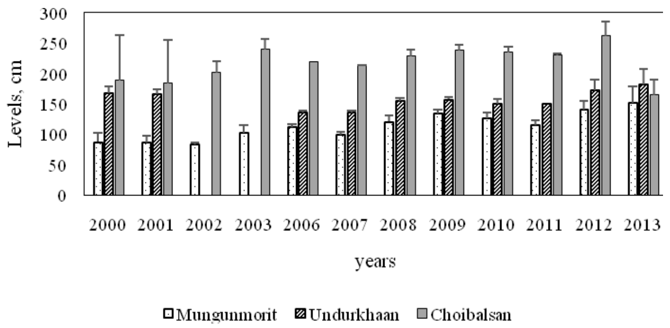


Figure 18. Mean river water levels in autumn season (September, October and November) measured at the Undurkhaan, Choibalsan and Mungunmorit hydrological stations

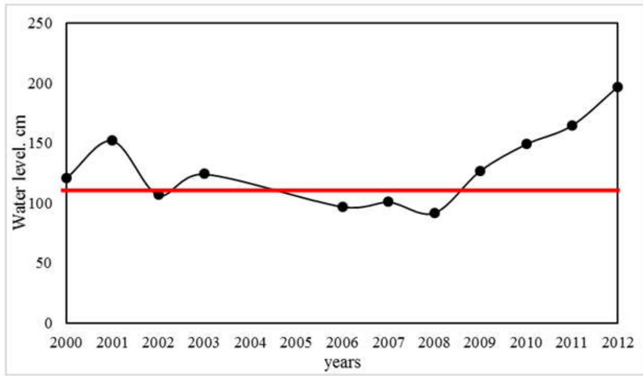


Figure 19. Water levels of Kherlen River in spring seasons at Mungunmorit Station (red line shows normal water level)

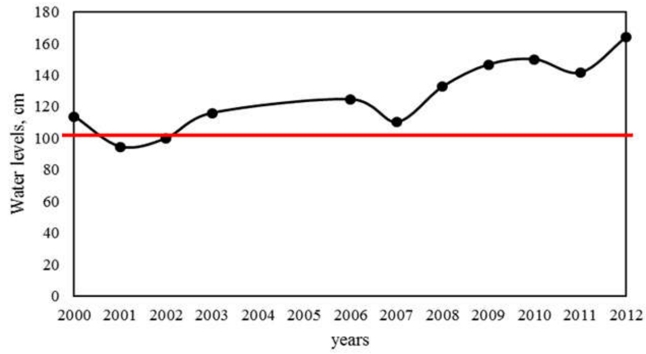


Figure 20. Water levels of Kherlen River in summer seasons at Mungunmorit Station (red line shows normal water level)

Table 2. Calculation of water harvesting

Year	Average water level (cm)	Normal water level (cm)	Above normal water level (cm)	Above normal water level (cm)	Average width, (m)	Velocity(m/s)	Volume of water (m^3/s)	Volume of water (m^3/hr)
Spring								
2000	121.2	115.0	6.18	0.06	40	2	4.94	17786.3
2001	152.1	115.0	37.07	0.37	40	2	29.65	106749.1
2002	106.8	115.0	-8.19	-0.08	40	2	-6.55	-23597.4
2003	124.3	115.0	9.31	0.09	40	2	7.45	26809.8
2006	97.1	115.0	-17.89	-0.18	40	2	-14.32	-51535.5
2007	101.0	115.0	-13.96	-0.14	40	2	-11.17	-40200.3
2008	92.0	115.0	-22.98	-0.23	40	2	-18.38	-66178.9
2009	127.0	115.0	11.97	0.12	40	2	9.58	34482.6
2010	149.2	115.0	34.23	0.34	40	2	27.39	98592.0
2011	164.9	115.0	49.87	0.50	40	2	39.90	143632.8
2012	197.2	115.0	82.17	0.82	40	2	65.74	236646.2
Summer								
2000	113.8	115.0	-1.19	0.00	40	2	-0.09	-341.6
2001	94.6	115.0	-20.36	-0.02	40	2	-1.63	-5863.5
2002	99.9	115.0	-15.10	-0.02	40	2	-1.21	-4348.7
2003	115.9	115.0	0.95	0.00	40	2	0.08	272.3
2006	124.6	115.0	9.56	0.01	40	2	0.77	2754.3
2007	110.2	115.0	-4.85	0.00	40	2	-0.39	-1396.8
2008	132.6	115.0	17.60	0.02	40	2	1.41	5069.9
2009	146.6	115.0	31.63	0.03	40	2	2.53	9108.1
2010	149.9	115.0	34.90	0.03	40	2	2.79	10050.7
2011	141.5	115.0	26.48	0.03	40	2	2.12	7625.4
2012	164.1	115.0	49.11	0.05	40	2	3.93	14143.6

Development of rainwater harvesting system at Kherlen River Basin

There have been estimated amount of water harvesting from river and precipitation of about 36 km^3 in Mongolia, only about 2.8% of the total water consumption. But in Russia, total possible water harvesting is estimated at 100 km^3 and there have been 150 km^3 water stored from rainwater harvesting system. Several studies have showed how to potentially use Kherlen River storage. But small cities such as Baganuur, Undurkhaan and Choibalsan people are using water supply from groundwater and flood plain.

River water is used for livestock for drinking. Undurkhaan city water supply is provided by underground water from three wells. The total daily water demand from one single underground well is about 0.14m^3/s. During flood of Kherlen River, more than 100 m^3/s water discharges for 8-10 days. Undurkhaan City water needs is only about 0.014% of the Kherlen River storm water size. Total water consumption in the three cities is only about 0.05% of the flood water. This water flows across the border and very little Kherlen River has been utilized. Possible water volume collected with rainwater harvesting is calculated. Mungunmorit Station is chosen because of:

- Landscape: mountain area, high elevation, valley
- Air temperature: lower air temperature, average annual temperature is negative
- Wind speed: low wind speed
- Transportation: close to city proximity

It is not possible to collect rainwater when river water is below normal level (Figs. 19 and 20). Therefore, only above normal water level is harvested and the computed results are listed in Table 2. It is possible to harvest on an average 51 million m^3 (approximately 51,080,127 m^3) river water both in spring and summer seasons according to the calculation for the past 10 years. Volume of water in spring season is much higher than summer season. It may be able to collect winter precipitation also for some years with high precipitation. Harvested water can then be used for domestic and other water consumption in Ulaanbaatar City.

Conclusions

The precipitation, air temperature and water level data of three hydrological stations in Kherlen River Basin are obtained from the Institute of Meteorology and Hydrology (IMN), from 2000 to 2015. The results show that annual total precipitation ranges from 150-400 mm. About 90 % of annual precipitation falls only in the warmer season. The lowest precipitation falls in winter and the highest one occurs in July. The average annual air temperature of Mungunmorit station is -2.8±0.8°C, Undurkhaan station's 0.2±1°C and Choibalsan 1.7±1°C. The river water level at river upstream areas is lowest, then increases at middle and downstream. The average river water level at Mungunmorit station is 122.5±20.09 cm, Undurkhaan station 153.6±16.6 cm and Choibalsan station 203.7±54.38 cm. This study calculates the possible water volume for collecting rainwater.

Mungunmorit Station is chosen due to its mountainous, high elevation and valley topography conditions; low air temperature; low wind speed; and its close proximity to city. It will be possible to harvest on an average of 51 million m^3 water in spring and summer seasons. It may also be able to collect increase volume of water in some year with high winter precipitation. The collected water can be used for domestic and water consumption of Ulaanbaatar City. However, water levels may decrease with increasing air temperature due to changes in climate condition. Therefore, development of rainwater harvesting system is necessary in the near future.

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