A THESIS FOR THE MASTER DEGREE OF FOREST SCIENCE

Underlying Causes of Desertification in Mongolia

몽골 사막화의 근본 원인

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By

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Abstract

In the case of Mongolia, desertification is a rapidly growing environmental concern. It has been estimated that 78% of the total territory of Mongolia is at risk of desertification, of which nearly 60% is classified as highly vulnerable.

The goal of this study is to determine the factors that influence desertification and to estimate the impacts of each variable on desertification. The seven factors were selected as independent variables, and desertification ratio was chosen to be the dependent variable. For the purpose of finding relationships between independent variables, correlation analysis was conducted.

Stepwise regression analysis result suggest that the most influential factors on desertification in Mongolia are animal husbandry and overgrazing. The change in forestland is identified as a precursor of desertification in semi-desert, forest-steppe and steppe zones. The climate factor, represented as temperature, slightly contributes to the desertification in semi-desert region. In the steppe zone, the population growth has a moderate influence on desertification. In the forest-steppe zone, desertification was driven by road networks construction. Based on the elasticity of desertification ratio with respect to each of the seven variables, pastureland was found to be elastic in all regions, which means that desertification is predominantly induced by pastureland expansion in Mongolia. Eventually, the study proves that human activities are more influential than natural impacts on desertification.

Keywords: Desertification, underlying causes, Mongolia

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Chapter 1 Introduction

1.1 Background

The subject of desertification has been highly controversial in many countries. For instance, Merriam Webster's Collegiate Dictionary defines the term desertification as "the process of becoming a desert". However, the International Convention to Combat Desertification (CCD) characterized the desertification as following: 'land degradation in arid, semi-arid and dry humid areas resulting mainly from adverse human impact (Dregne et al. 1991). Human activities, in particular, unplanned development, human and livestock population pressure, urbanization, industrialization, and mining could be the reasons for acceleration of the desertification process (UNCCD, 2011). In addition, desertification appears when land degradation becomes irreversible or when loss of total productivity reaches 50% to 66% (Katyal and Vlek, 2000).

The country of Mongolia landlocked, and situated far from the oceans, is located in the center of the Eurasia continent. Mongolia is considered to be the driest country within the region, with an aridity index range between 0.05 and 0.65 (UNCCD 2007). This wide fluctuation relates to the dry ecosystems showing non-equilibrium behavior. Also, short-term rainfall variability imposes changes in vegetation cover, and it causes a downward trend in conditions, except in the most extreme cases (Behnke and Scoones, 1993, Ellis and Swift, 1988).

Furthermore, it is viewed that human-caused activities inflict on land degradation, more than climate impacts. These activities would include overgrazing, deforestation, overexploitation of land by outdated agricultural practices, and population growth. Developmental pressure and daily activities of the population in environmentally vulnerable areas dramatically accelerate soil erosion and land degradation, thus, the socioeconomic factors, such as population growth, urbanization, poverty, etc., are emerging as key additional factors of desertification.

On that note, Mongolia has been increasingly affected by desertification; more than 40% of the total area is degraded, 400 rivers and lakes have dried out and desertification rate has risen by 8-10% over the last ten years (Adyasuren and Dash, 2001). In addition, according to the desertification map and evaluation work, approximately 90% of Mongolia's pasturelands have been affected by desertification and land degradation, of which 5.0 % have been classified as a type of very extreme desertification (Figure 1), 18.0 % is strong desertification, 26 % is medium and 23.0% is low desertification (National Action Program for Combating Desertification, 2010).

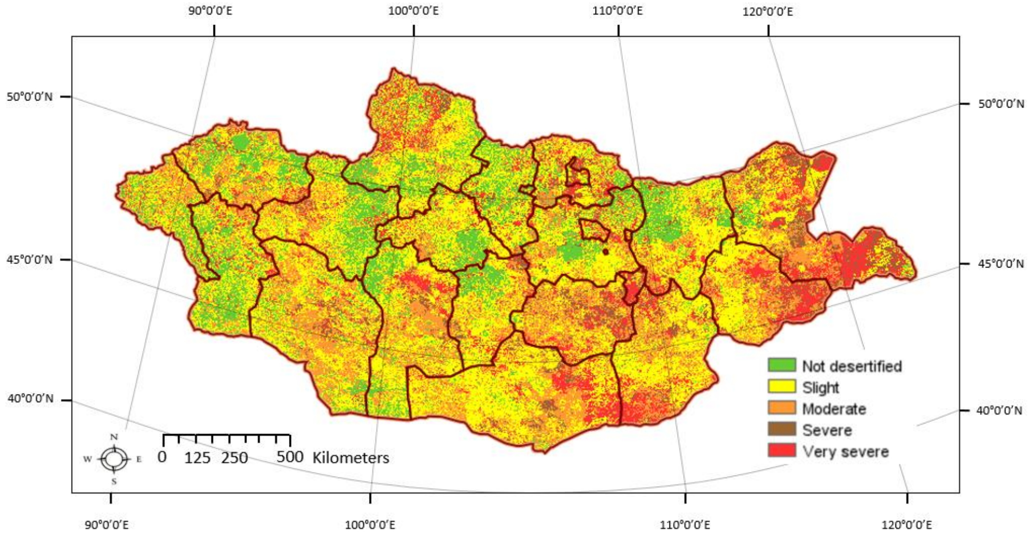


Figure 1. Desertification map of Mongolia 2010

1.2 Objective of the study

This research aims to identify the underlying causes of desertification and to evaluate the magnitude of impacts on desertification in Mongolia. Based on the literature review, the study investigates the key factors of desertification which are the human and natural impact. In essence, this research intends to compute the socioeconomic factors, especially human activities.

1.3 Research question

This study aspires to answer the following two research questions:

1. Among the predicted variables, what are the most significant causes of desertification? Why?
2. What is the magnitude of the impacts causing the desertification?

1.4 Hypothesis

1. In compliance with the desertification situation of Mongolia, among the predicted factors, the human-caused activities such as pastureland, forestland (timber logging), and livestock change are the major reasons of desertification.

2. With regard to natural and social conditions, the magnitude of each specific variable is expected to be different in each natural zone.

Chapter 2 LITERATURE REVIEW

2.1 Cause of desertification

Land degradation involves two interrelated, complex structures: the natural ecosystem and the human social system (Figure 2). Natural drivers include periodic strains from extreme and persistent climatic conditions, aridity, and droughts. Aridity limits biological productivity and results in poor quality soil (Stewart et al., 1992). Few rainy days are often associated with intensive dust storms. Those features make dryland regions climatically unstable and susceptible to desertification (Katyal and Vlek, 2000). Overgrazing, deforestation, over-cultivation, and damages to sensitive vulnerable ecosystems are commonly linked to unsustainable human land use. (Xiao et al., 2006). The edible plant species may be lost when pasturelands are overgrazed by too many animals, or unsuitable kinds of animals. (UNCCD, 2006). The causes of land degradation are not only biophysical. Moreover, the socioeconomic factors such as marketing, income, human health, institutional support, and poverty (undermining food production and political stability) also induce desertification. (UNCCD, 2004; WMO, 2006).

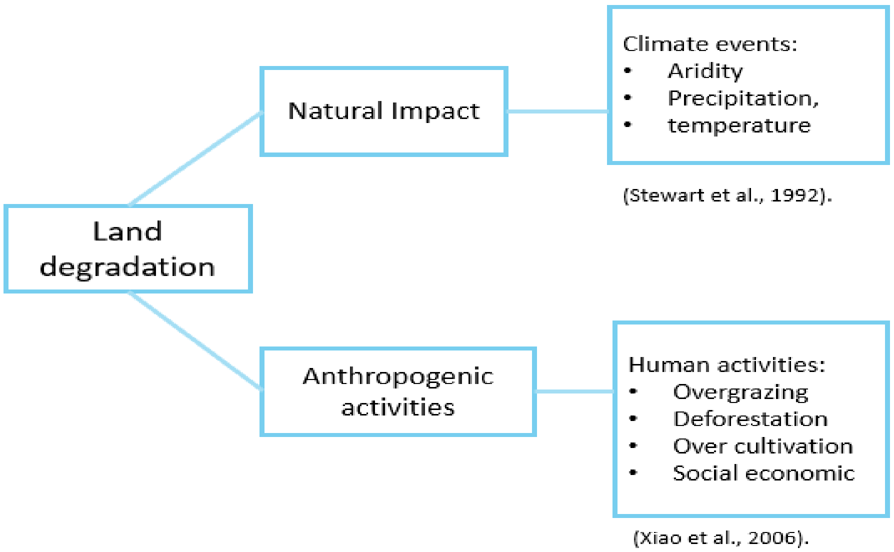


Figure 2. Dynamics of land degradation

Climate factors of desertification

Climatic factors are the key impacts of desertification vulnerability, especially in semi-arid, steppe, and desert regions. The major causes of desertification in Mongolia are noted as the decline of mean annual precipitation and growing season rainfall. (Baysgalan and Dash, 2002). Climatic features, particularly recurrent climate changes, might aggravate desertification through alteration of spatial and temporal patterns in temperature, rainfall, droughts, dust storms and winds (Sivakumar, Mannava 2011). In semi-arid regions, plant productivity is moderately low (Behnke and Scoones 1993), due to low rainfall variations. (Goudie and Middleton 1992). Hence, low precipitation trend is the major cause of increasing desertification (Burton 2001, IPCC 2001). Precipitation in Mongolia is on a downward trend as seen in figure 3. Linacre and Geerts (2002) found a close relationship between rainfall and dust storms. Consequently, dust storms are the results of the long-term decline in rainfall (Tchayi 1994). Drought, i.e., a shortage of precipitation over an extended period of time, is a regular and repetitive feature of the Gobi desert climate in Mongolia (Baysgalan and Dash, 2002; NDMC, 2006).

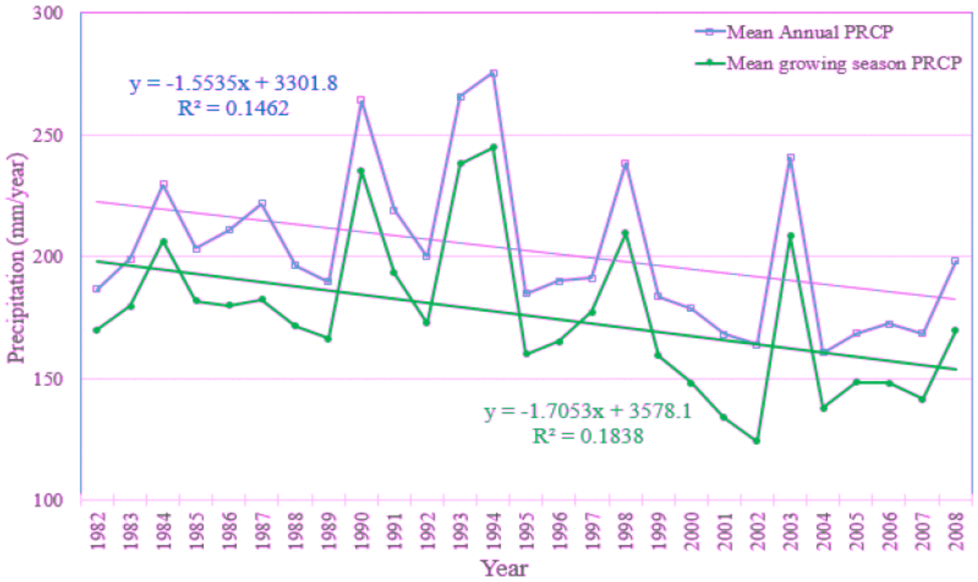


Figure 3. Precipitation trend in Mongolia (1982-2008)

Effect of human activities on Desertification

Anthropogenic factors play an important role in the disruption of grasslands. In particular, economic activities such as timber logging, overgrazing, increasing livestock and inadequate agriculture land use are the key causes of grass land disturbance (Li, Suying; Li, Lv; Verburg, Wu 2012).

Livestock and farmland

Livestock industry of Mongolia has a long and rich tradition of raising animal husbandry. Its pastoral production system dates back to at least 1,000 years. Mongolia is a home to 43 million head of livestock, (National Statistic, 2010) consisting mostly of goats, sheep, horses, cattle, and camels. This number has significantly risen in recent years.

When humans convert natural grassland into farmland, they harshly farm it by repeatedly planting the same crops every year. By doing this year after year, the soil quality becomes deteriorated because the crops suck all the nutrients out of the ground (Jin-Tun, Zhang 2006). When the farmer is no longer using the land for farming, the grassland is left in an extremely poor condition, almost impossible to grow back (Akiyama and Kawamura 2007).

Road network

Land degradation occurs when humans move into new areas and build roads and settlements etc. (Sha, Zongyao; Yichun Xie, 2012). As a result, roads reduce the area where grass can grow prosperously. Also, the settlements constructed by herdsmen are closely accompanied by their animal husbandry which further harms the region, and becomes the most damaging factor of grassland degradation.

Forestland

Deforestation has been creating wastelands via the process of soil erosion and land degradation (Jin-Tun, Zhang 2006). When the trees are demolished and cut down, the soil lacks the former strong root system. Deforestation is the result of agriculture, fuel use, (firewood), timber harvesting, growing population and animal husbandry. It has been the cause of an enormous number of species extinctions, the large tracts of land, climate changes and top soil erosion. Therefore, the soil becomes distressed and more susceptible to landslides, and cannot support the plant life well. (Jin-Tun, Zhang 2006).

Pastureland

Pastoral and wildlife ecosystems pose very challenging management problems associated with ever increasing livestock populations, rangeland degradation and alteration of pastoral migration patterns (Sneath, 1998, Ojima, 2001). The grazing compels the greatest pressure to settlements and water sources (Batjargal, 2001).

Population growth

E. Bosereup (1965) emphasize that population growth in rural areas directly affects the natural resources. In other words, in the state of land shortage, the growth of labor age population in rural areas provokes a land cost increase and grazing area expansion. In the condition of rapid population growth, the increasing pastureland pressure has progressively involved more intensive use of land resources for grazing. (Gretton and Salma, 1997)

Chapter 3 MATERIALS AND METHODS

3.1 Site description

The study site includes four natural zones of twenty-one aimags[1]. Mongolia is located at the latitudes of 41º35’- 52º09’N and longitudes of 87º44’ - 119º56’E with area of 1,564 square kilometers (Narangarav, Lin 2011).

Under the influence of climatic differentiation, ecosystems across the plateau display different zonations (Bao, Gang, Amarjargal Sanjjava, 2000), comprised of Mountain taiga (4.1%), forest steppe (25.1%), steppe (26.1%), semi-desert (27.2%) and desert (14.5%) (Hilbig, 1995). Roughly, 124.3 million ha or 79% of land area are covered by grassland and about 7% are covered by forest or shrub land (Hilker, Natsagdorj 2014).

For statistical analysis, the study was conducted among desert, semi-desert, forest steppe and steppe zones (Figure 4).

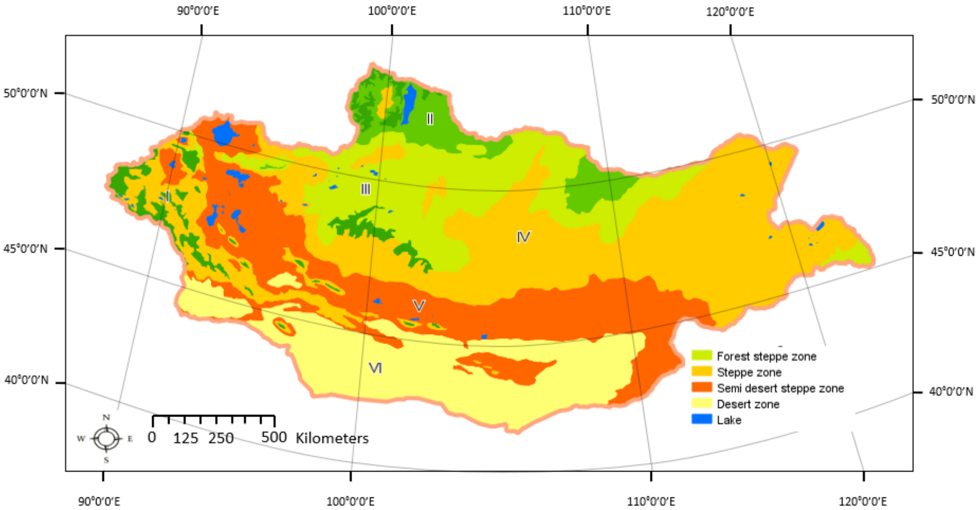


Figure 4 Natural Zones of Mongolia

1. FOREST STEPPE ZONE: About 25% of Mongolia is covered by a mix of forest and grassland. To the south, this zone is a transition zone between taiga forest and

[1] Unit of Provinces, in Mongolia

steppe. The northern slopes are covered with trees, while the southern slopes are clothed with wild flowers of open grassland.

2. STEPPE ZONE: Located in the further south, the Steppe Zone is famous by calling as a sea grass. This zone covers a total of 20% of Mongolian territory, and it is the crucial hometown for the livestock of the semi-nomadic herder families. The steppe Zone is an essential place for the semi-nomadic life with livestock such as horses, goats, cattle, yaks and camels.

3. SEMI-DESERT ZONE: The semi-desert zone is situated in the south of Mongolia, on the north rim of the Gobi Desert. This is a transition zone, covering 20% of Mongolia, and is a dry region of parched grasslands and salt pans, strong winds and dust storm. The semi-desert zone is abundant in grasses and shrubs which are very different from those of the Steppe zone, and many of them are unique to Central Asia.

4. DESERT ZONE: the desert zone is located in the South, and lay in the vast Gobi. The substantial desert mounts the border of Mongolia and the Inner Mongolian region of China. The Gobi is one of the world's great deserts with bare Rocky Mountains, sand dunes, and huge desert flats.

Climate condition

The climatic regime is characterized by typical continental climate, which generally has extremely cold, dry winters and warm summers. Figure 5 shows the long term annual mean temperature. Mean annual temperatures range from -7°C in the mountain-steppe to 8°C in the desert-steppe (Hilker, Natsagdorj 2014).

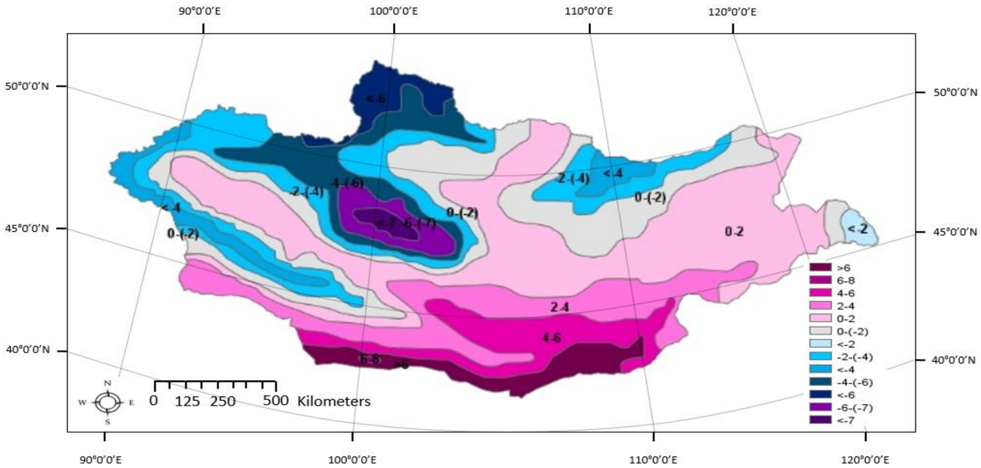


Figure 5 Long term annual average temperature

The most of annual precipitation is concentrated in the warm season months (85 %), from April to September, and 50 - 60 % of this precipitation falls in July and August (Natsagdorj and Sarantuya, 2014).

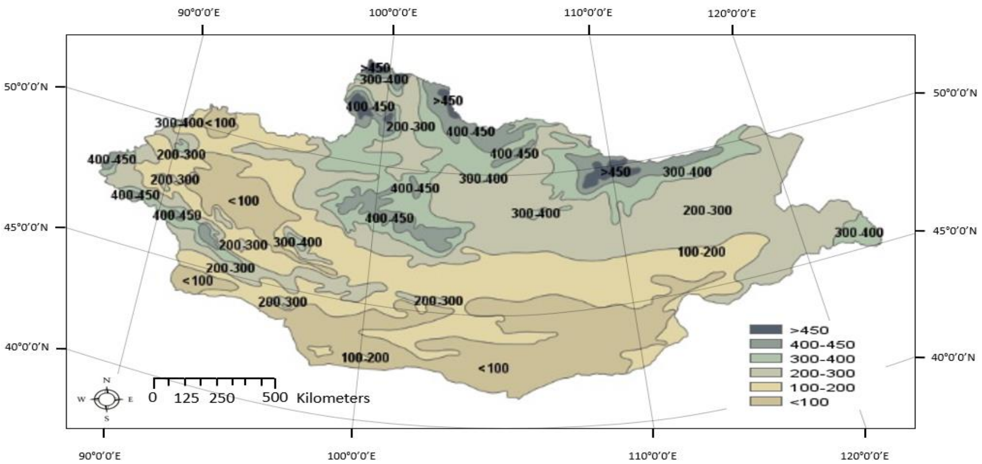


Figure 6 Long term annual average precipitation

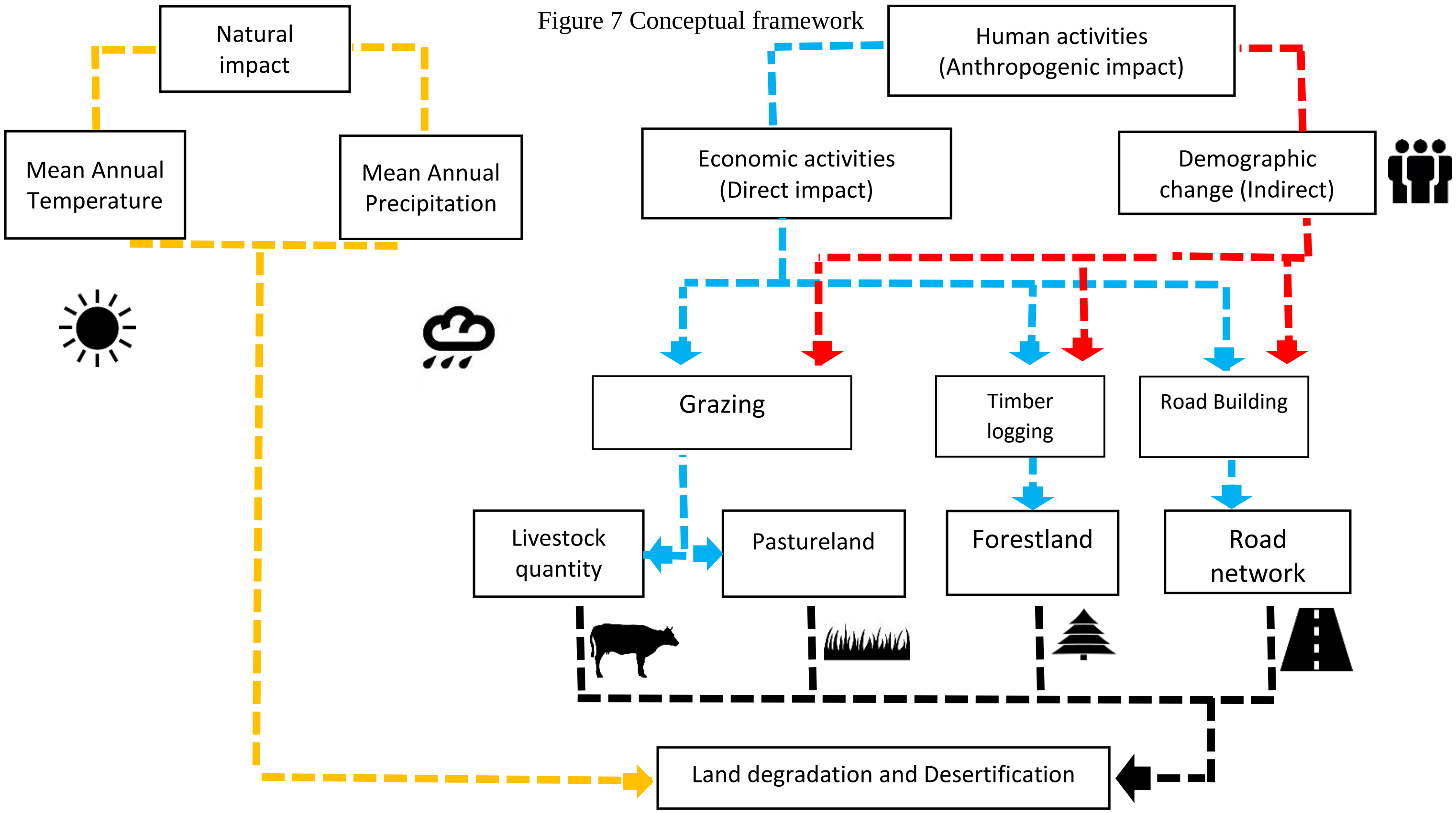
The number of rainy days also varies regionally, affected by different elevation (Sarantuya, 2014). Figure 6 represents the long term average annual precipitation.

3.2 Conceptual Framework

Based on the literature review, the impacting variables, and their relations are demonstrated in Figure 7. The predicted desertification variables are divided into natural and human impacts. Natural impacts include mean annual temperature and precipitation; these variables are counted as the key natural factors of desertification (Baysgalan and Dash, 2002). The human factors are distinguished into direct and indirect variables. Direct human-based variables are noted as economic activities such as livestock quantity, timber logging (forestland), pastureland (overgrazing) and road network construction. Population growth is incorporated as an indirect human factor.

Population growth substantially boosts economic demand, so natural resources and population growth are expected to have a negative correlation. In contrast, population growth is hypothesized to have positive relations with both road network and livestock quantity respectively. Also, livestock quantity and pastureland are predicted to positively relate because when livestock quantity rises, the demand for wider pastureland increases. The final consequences of all these desertification factors contribute to land degradation and desertification.

Figure 7 Conceptual framework



3.3 Methodology

The purpose of the correlation analysis was to find out closer relationships among the independent variables. The correlation coefficient, r, ranges from -1 to +1. If a correlation coefficient is greater than 0.7, it is considered that the variables are highly correlated (Rajdeep Grewal. 2002).

$$\boldsymbol{r} = \frac{\sum_{i=1}^{n} x_i\, y_i - \frac{1}{n}\sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{\sqrt{\sum_{i=1}^{n} x_1^2 - \frac{1}{n}(\sum_{i=1}^{n} xi)^2}\ \sqrt{\sum_{i=1}^{n} y_i^2 - \frac{1}{n}(\sum_{i}^{n} y_i)^2}} \quad \textit{(eq)}$$

The stepwise regression analysis: is a semi-automated process of building a model by successfully adding or removing variables based solely on the P-Value <0.05 of their estimated coefficients. All candidate variables in the model are checked to see their significance, and if a nonsignificant variable is found, it is removed from the model.

Desertification Ratio was chosen to be the dependent variable y, and annual mean temperature, precipitation, forestland, pastureland, road network, and population density were selected as independent variables x. For the purpose of finding relationships between Desertification Ratio and the seven variables, stepwise multiple regression analysis was conducted. A stepwise selection method was used to reach the final regression model.

Multiple linear regression equation:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots\ldots B_n X_n \quad (eq)$$

In the equation, Y stands for the dependent variable of desertification ratio, and X_1, X_2 etc. stand for the independent variables of temperature, precipitation, population, livestock quantity, pasture land, forestland, and road network respectively. Further β_0 is the intercept, while β_1, β_2 etc. represent the slope coefficients of these independent variables. A 95% confidence interval was used for this work's regression analysis. Analysis of covariance was conducted for every possible pair of indicators.

3.4 Data collection

Measurements for the seven variables of temperature, precipitation, population density, livestock quantity, pastureland, forestland, and road network were selected for data collection. According to the literature review (Xiao et al., 2006) these variables presumably have the highest probability of affecting desertification in Mongolia. The variables include both natural and socio-economic factors. In addition, each aimag's total land area and the territory of degraded area were included in data collection. Table 1 lists the selected data sources (1991-2010). The statistical measurements for the above mentioned variables were collected from various organizations. The data about temperature and precipitation was collected from Information and Research Institute of Meteorology, Hydrology and Environment. The Mongolian Statistic Information Service provided access to the information about population and livestock densities. From the Land Information Database Center (Agency of Ministry of Environment and Green Development), data on pastureland, forestland, and road network was gathered. Finally, the information about the desertification ratio was collected from the Environment Information Database Center (Agency of ministry of Environment and Green Development).

Table 1. Data sources

Desertification factors		**Source**
Climate Factors	Annual Temperature (C^0)	Information and Research Institute of Metrology, Hydrology and Environment Link: http://www.icc.mn/
	Annual Precipitation (mm)	
Socioeconomic factors	Population density (number of people per square kilometer)	Mongolian Statistic Information service

	Number of Livestock (Cattle, Sheep, Goat, Horse, Camel)	Link: http://en.nso.mn/
Land data	Pastureland (km^2)	Land Information Database Center (Agency of Ministry of Environment and Green Development) Link: http://land.eic.mn/
	Forestland (km^2)	
	Road network (km)	
Dependent variable	Desertification Ratio	Environment Information Database Center(Agency of ministry of Environment and green development) Link: http://eic.mn/

Research procedure and data

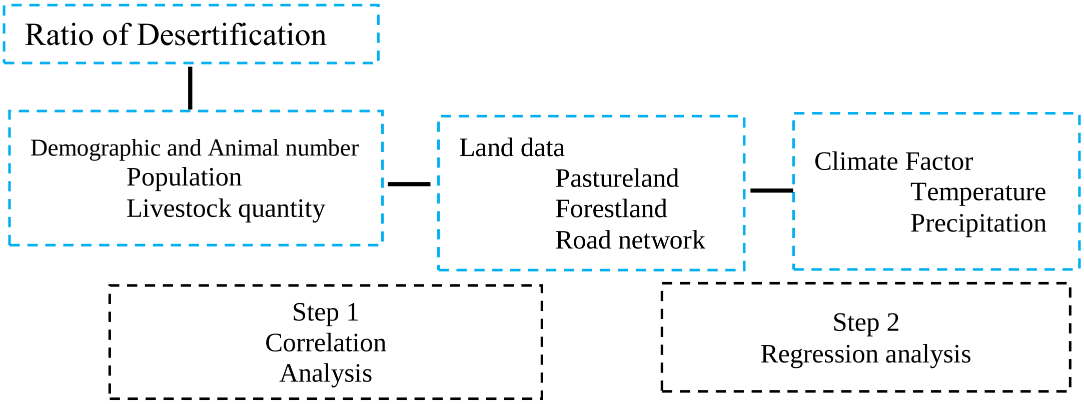


Figure 8 Research procedure

Figure 8 provides an overview of the implemented research procedure. The data is aggregated in a 20 year time period, and covers four natural zones in Mongolia. Correlation and regression analyses were utilized in this research.

Desertification ratio

Desertification ratio represents the degraded area, and is illustrated as a division of degraded area by total land area, using the 20 year data from Environment Information Database Center (Agency of Ministry of Environment and Green Development). In table 2, total land area is demonstrated by each aimag. (For the purpose of calculating desertification ratio, forests, mountain areas, rivers and lakes are not included in total land area).

$$\textit{Desertification ratio} = \frac{degraded\ land\ \ area\ (km^2)}{Total\ \ land\ area(km^2)}\ \ (eq)$$

Table 2. Land area by Aimags

Aimags	Mountain, Forest, Lake area km^2	Land Area km^2	Total land area km^2
Arhangai	17091.72	38221.28	55313
Bayanhongor	695.86	115281.14	115977
Bayanolgii	4616.10	41087.90	45704
Bulgan	10526.33	38206.67	48733
Darhanuul	1424	1850	3275
Dornod	9885	113709	123597
Dornogovi	109.47	109362.53	109472
Dundgovi	1493	73198	74692
Govialtai	848.68	140598.32	141447
Govisumber	44.328	5496.672	5541
Khentii	17350	62974	80325
Khovd	3194	72864	76060
Khuvsgul	31094	69533	100628
Orkhon	328.32	515.68	844
Selenge	26131	15020	41152
Suhbaatar	493.72	81793.28	82287
Tuv	16289	57752	74042
UB	1011	3692	4704
Umnugovi	1653	163726	165380
Uvs	7793.52	61791.48	69585
Uvurhangai	1698.17	61196.84	62895
Zavhan	2803.47	79651.53	82455

3.5 Data Description

Climate factors

Mean annual temperatures range from 0.36 °C in the forest-steppe to 3.34 °C in the desert zone. The coldest month in all regions is January with -38 to -43°C. The annual highest temperature is between 19°C and 23°C. Figure 9 exhibits the temperature trend over 20 years in Mongolia.

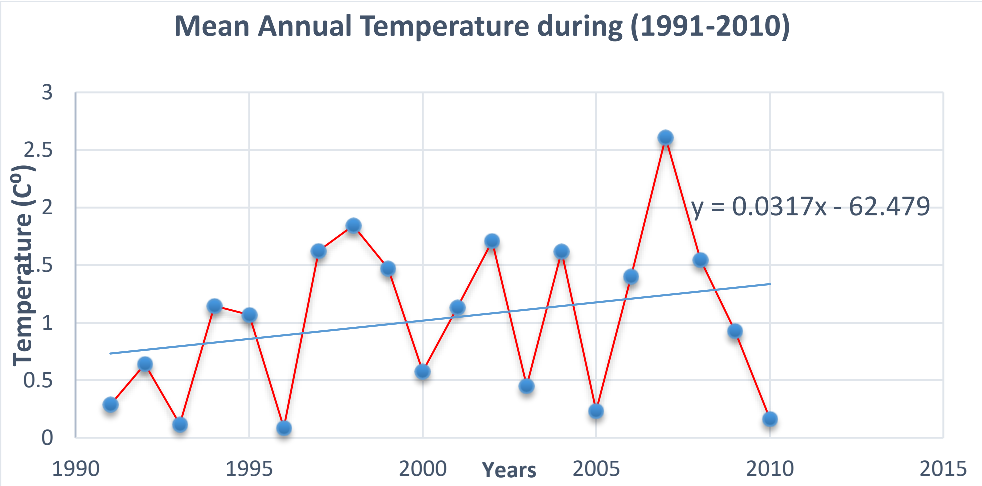


Figure 9 Temperature trend in Mongolia (1991-2010)

In 1991, the annual temperature was on the rise, but in 1996 it showed a sudden drop of 0.1°C. In the following year of 1997, the mean annual temperature started to increase again; however in 2005, it decreased to 0.2°C. The highest annual temperature during the 20 year periods occurred in 2007, when it reached 2.7°C.

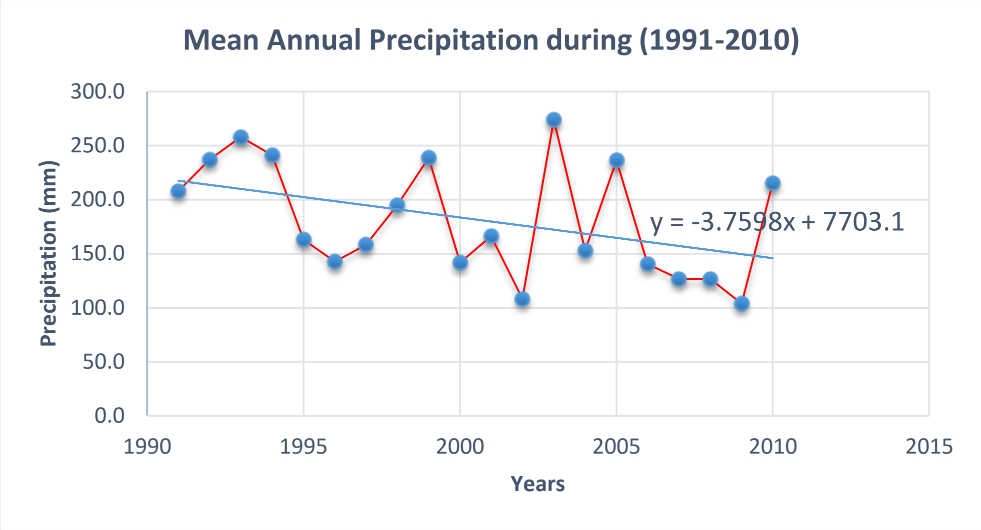


Figure 10 Precipitation trend in Mongolia (1991-2010)

The average annual precipitation ranges between 168mm and 280 mm, most of which falls from June through September. Figure 10 shows the precipitation trend for the last two decades in Mongolia. In 1991, the annual precipitation was 240.4 mm, but despite some, fluctuation, later on it generally showed a slightly decrease over the past twenty years. The peak annual precipitation, which was 273.8 mm, was recorded in 2003. Regardless of the small drop after 1994, the annual temperature had remained quiet stable. However, in 2002, it decreased to 108.3 mm which was the lowest measurement during the period in question. After the drop, the annual precipitation demonstrated an upward trend, and in 2010 it reached 215.3 mm.

At a glance to the table 3, reveals that the desert zone has had the highest mean annual temperature of approximately 3.46°C. Merely identical measurements of just above 0.3°C were recorded for the mean annual temperature in the forest-steppe and steppe zone. The highest amount of precipitation of about 280mm was found in the forest-steppe zone.

Table 3. Mean and Standard deviation (SD) of Temperature and Precipitation by natural zone

Natural Zone	**Temperature**		**Precipitation**	
	Mean	SD	Mean	SD

Desert	3.346	3.38	189.5	85.8
Semi-desert	1.367	1.107	168.009	35.93
Forest-steppe	0.361	1.152	280.43	68.45
Steppe	0.322	1.26	217.98	53.41

Population

The study shows that population had rapidly risen during the 1991-2010 period by 489 thousand people altogether. But in 2001, the population of Mongolia has relatively declined and this phenomenon occurred due to a low birth rate (Statistical Information 2000-2010) in the Figure 11 it is exhibited that the population growth trend in Mongolia is slow but persistently rising. Settled population in Mongolia reached 2'376'516 as of 2000 and grew to 2'746'395 by the end of 2010. The actual population growth for this period is 366877 people.

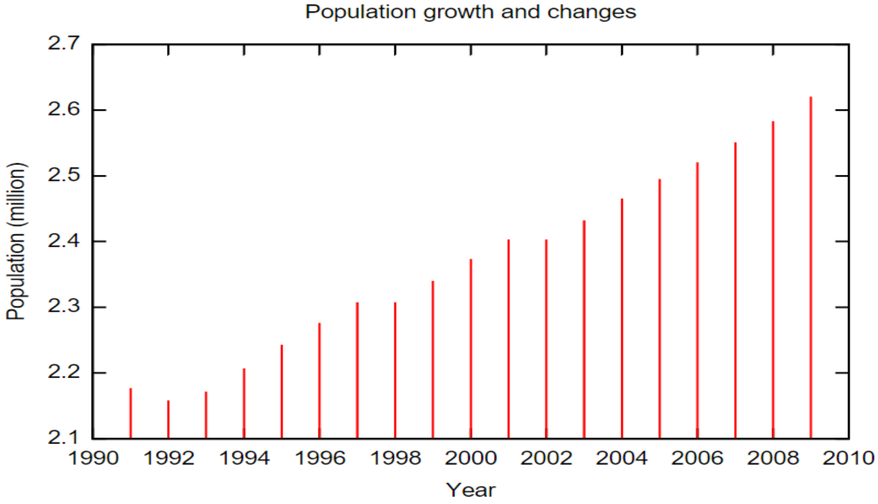


Figure 11 Population change in Mongolia (1991-2010)

In the 2000s, the population in the desert zone slightly declined by 1620 people compared to 1990; only to reach 172,826 people in 2010, which is actual increase by 7%. The population in the semi-dessert zone, on the other hand increased by 6.5% from 1990 to 2000; however during 2000-2010 it significantly dropped by 10% from 401,907 to 360,606 people. As for the demographic dynamic in the forest steppe zone population grew by 7 % during 1991-2000 but the following 10 years (2000-2010) brought about a 2% decline with the figure arriving at 583, 119 people in 2010. In the steppe zone, the first decade (from 1991-2010) was marked by 11% increase and the quantity almost doubled by 22% from 2000 to 2010.

Livestock quantity

Nomadic pastoralism has been the main form of land use in Mongolia for thousands of years, and there have been substantial increases in the livestock numbers since 1992. Privatization of livestock in 1991-2000 due to the collapse of the communist regime led to a livestock increase of some 4.5 million stock units. During the twenty years period in question, livestock numbers have not remained constant but rather exhibited a dramatic fluctuation pattern. For example, the reduction of livestock number in the years 2000-2002 was triggered by the drought and dzud [2], That time combination of drought and dzud continued for two years comprising 60-70% of Mongolian territory, and it caused massive death of 11 million heads of livestock (Open Forum, 2004, Natsagdorj, Sarantuya 2013).

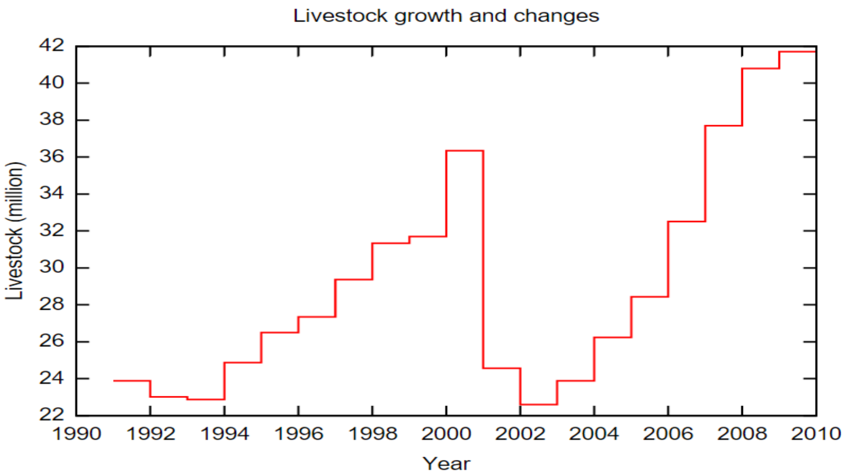


Figure 12 Number of livestock change in Mongolia (1991-2010)

In accordance with the result, 30.5% of the total livestock of Mongolia was counted in the forest-steppe zone. The semi-desert zone had 26.5%, similar, the steppe zone's share of just under 30% of total livestock. Lastly, the desert zone had the least

[2] Harsh winter disaster

amount of livestock's of 15%. Figure 13 shows the number of livestock's by natural zones. The places with the highest livestock density are revealed to be Khovd, Govi-Altai, Bayanhongor, Ovorkhnagai, Dundgovi aimag, Dornogovi, Sukhbaatar, and Dornod aimag.

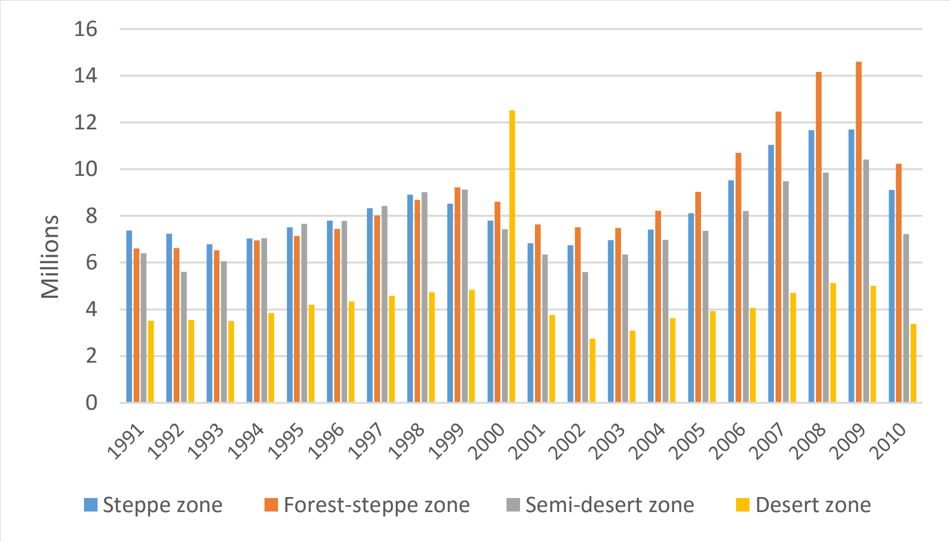


Figure 13 Number of livestock's by natural zones (1991-2010)

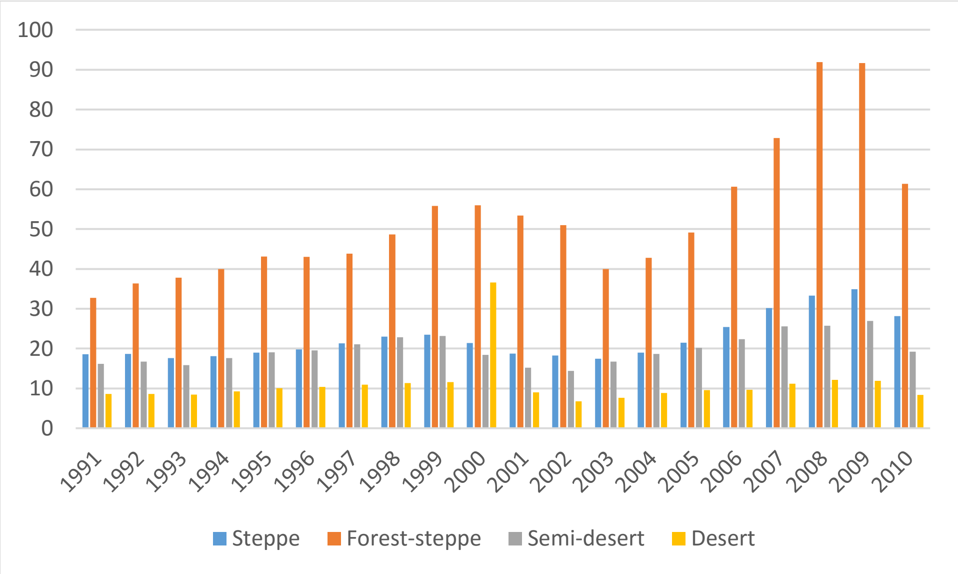


Figure 14 Livestock density by natural zones (1991-2010)

In the dessert zone the livestock quantity expanded by more than 9 million during 1991-2000. Interestingly enough, it fell down again by 9 million in 2010. In the semi-desert zone, livestock quantity increased by 16% in 2000 compared to 1991. But in 2010, it dropped slightly by 2% and reached 7,424,402 heads of livestock. In the forest steppe zone, livestock quantity was boosted by 30% from 1991 to 2000; and during 2000-2010 it illustrated a stable increase of 18%. As for the livestock of the steppe zone, it first, increased by only 5 % during 1991 and 2000 but later on rose by fair 16% between 2000-2010. As seen in Figure 14, the forest-steppe zone demonstrates the highest livestock density.

Pastureland

In the Mongolia the pasture land mainly divided into mountain pasture and steppe pasture (Figure 15).Pastureland in the dessert zone expanded by 73% during 1990 and 2000 but later on started declining and registered a 14% drop by 2010. Meanwhile, in the semi desert zone the pastureland area moderately expanded between 1991 and 2000, by more than 8 million square km. Pastureland, maintained its upward trend in to next decade, expanding by 13% from 2000 to 2010.

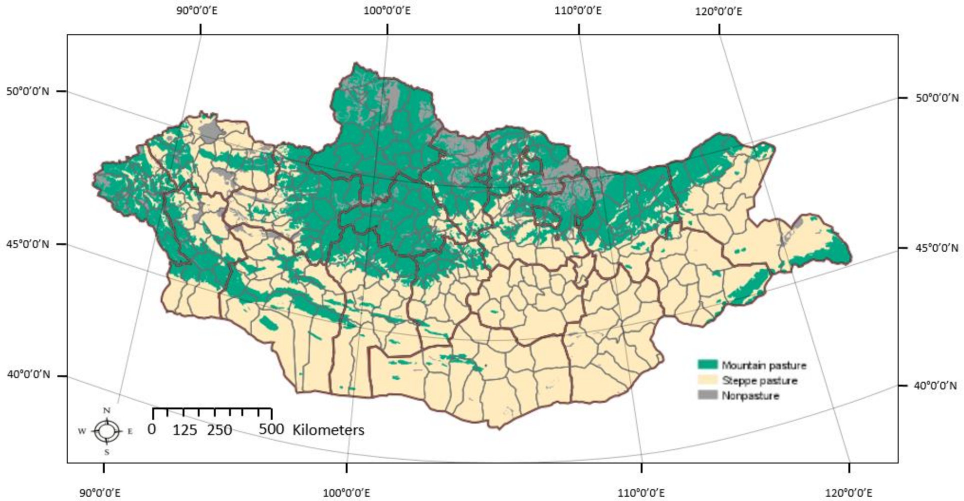


Figure 15 Mountain pasture and steppe pasture

Figure 16 exhibited pastureland change by natural zones. In the forest steppe zone, pastureland area greatly expanded by 78% during 1991 and 2000; however the following decade brought a decline of 11 %. The pasturelands of the steppe zone were broadened by 67% in the 1991-2000 period but saw a 2% contraction between 2000 and 2010.

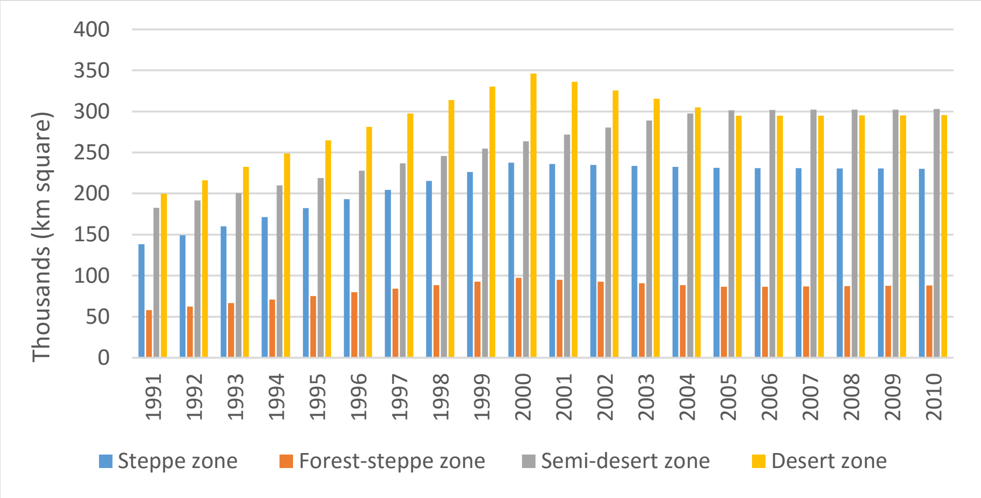


Figure 16 Pastureland by natural zones (1991-2010)

Forestland

In 2010, the total forestland has decreased by 68.4 thousand hectares, compared 2009, and reached 16,565.5 thousand hectares. In the desert zone, forested area was reduced by 8% during 1990 and 2000. What is even worse, in 2010 it contracted further by 1,348,424 square km compare to the 2000 baseline. In the semi-dessert zone, the forestland area shrank by 5 % during 1991 to 2000, and in the next decade (2000 to 2010), the forested area was dramatically reduced by additional 14%. In the forest-steppe zone, during 1991 and 2000, the forested area contracted by 6028 square km indicating a 7.1% decline. After a decade, in 2010, the forestland area was reduced to 75,448 square km.

Lastly, in the steppe zone the forested area was 42144 square km in 1991, and this figure fell down to 40262 square km in 2000. Further, in 2010, the forested area declined by 41% (compared to 2000) and reached 23768 square km. As shown in

Figure 17, the forest steppe zone claimed the largest share of forest land area.

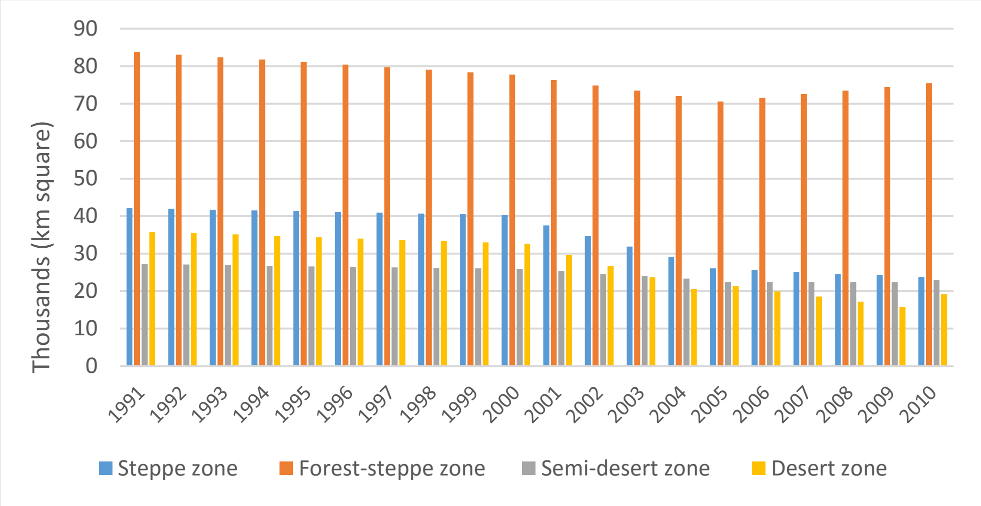


Figure 17 Forestland change by natural zones (1991-2010)

Road network

The road construction nationwide expanded by 3 % from 1991 to 2000; and peaked by further 30% from 2000. Road construction in the dessert zone saw a slight boost of 1.5% from 1990 to 2000. During 2000 and 2010, the road network coverage doubled from 40520 square km to 82776 square km.

In the forest steppe zone, the area occupied by physical infrastructure expanded moderately by 7% within the decade of 1991 to 2000, and from 2000 to 2010, it stretched further by more than 9 thousand square km. In the steppe zone, the road continuously expanded first, by 10% between 1991 and 2010. And later on by 71% between 2000 and 2010, respectively. Figure 18 shows an example of an unpaved earth road in the steppe zone. In the semi-desert zone, the road network had dramatically stretched from 31086 square km in 1991 to 41798 square km in 2010. The road network exhibited a 34% expansion during the period.

Figure 18 Unpaved earth road in Dornod aimag of Steppe zone

Table 4, illustrates the average values for the 20 years period in the four natural zones. The most severe land degradation occurred in the desert and semi-desert zones. The desertification ratio in these zones scored above 0.65. As the steppe zone is the most highly populated, population density in this zone reached 31 per square kilometer. The forest-steppe and steppe zones are home to the largest number of livestock, more than 8 million individually. Moreover, the forest-steppe zone is the least abundant in pastureland but; in contrast, it has the greatest amount of forested area and vastest road network.

Table 4. Population, Land use and Desertification ratio by natural zone

	Population Density (per square km)	Number of animal	Pastureland km^2	Forest land km^2	Road length km	Desertification Ratio
Dessert zone	1.2	4451478	289212	27705	28241	0.65
Semi-dessert	1.2	7617492	259223	24868	34740	0.68
Forest-steppe	17.3	8895014	83253	77118	258147	0.34
Steppe zone	31.7	8321320	210002	34728	42664	0.56

Chapter 4 RESULT AND DISCUSSION

4.1 Relations among natural and social factors

1. Desert zone

If a correlation coefficient is greater than 0.7, the variables are considered to be highly related to each other (Rajdeep Grewal. 2002). In the desert zone, the variables of population (0.8), forestland (-0.9), and road network (0.8) were reveal to have the highest correlation with desertification ratio. According to the results, population has a positive correlation with desertification ratio, while the factor of forestland has a negative correlation with desertification, which means the decrease of forestland area will cause an increase in desertification. Lastly, the factor of road network construction has a positive relation with the desertification ratio. In the correlation matrix, it is demonstrated that the expansion of road networks will contribute to the rise of land degradation. Also, there as an indication of a strong negative correlation between the variables of forestland area and road network.

Table 5. Result of correlation analysis for Desert zone

	Temperature	Precipitation	Pop Den	LS	Pasture land	Forest land	Road Network	Desertification Ratio
Temperature	1							
Precipitation	0.103	1						
Pop Den	0.162	-0.373	1					
LS	0.188	-0.152	0.016	1				
Pasture land	-0.521	-0.414	0.323	0.385	1			
Forest land	0.294	0.554	-0.794	0.097	-0.367	1		
Road Network	0.271	-0.517	0.775	0.152	0.260	-0.985	1	
Desertification Ratio	0.248	-0.490	0.809	0.133	0.223	-0.976	0.891	1

2. Semi-desert zone

In this zone, the variables of temperature, population and livestock were shown to have a less than 0.5 correlation with desertification ratio. The highest correlation coefficients were indicated in the factors of pastureland (-0.7), forest land (-0.9), and road network (0.98). Also, the correlation analysis result indicated variables of forestland and road network have resulted to have a negative correlation between the variable of forest land and road network.

Table 6. Result of correlation analysis for Semi-desert zone

	Temperature	Precipitation	Pop Den	LS	Pasture land	Forest land	Road Network	Desertification Ratio
Temperature	1							
Precipitation	-0.293	1						
Pop Den	0.114	0.125	1					
LS	0.509	-0.315	0.030	1				
Pasture land	0.370	-0.617	-0.018	0.417	1			
Forest land	-0.289	0.578	0.253	-0.428	-0.936	1		
Road Network	0.200	-0.535	-0.320	0.458	0.859	-0.956	1	
Desertification Ratio	0.178	-0.492	0.413	0.416	-0.795	-0.946	0.983	1

3. Forest-steppe zone

In the forest-steppe zone, the factors of population, livestock, and forestland came out as strongly correlated with the desertification ratio. According to the correlation analysis, the variables of precipitation and forestland area have a negative relation with desertification.

Table 7. Result of correlation analysis for Forest-steppe zone

	Temperature	Precipitation	Pop Den	LS	Pasture land	Forest land	Road Network	Desertification Ratio
Temperature	1							
Precipitation	-0.444	1						
Pop Den	0.192	-0.636	1					
LS	0.295	-0.413	0.763	1				
Pasture land	0.392	-0.715	0.719	0.429	1			
Forest land	-0.304	0.697	-0.901	-0.606	-0.713	1		
Road Network	0.233	-0.521	0.629	0.350	0.369	-0.879	1	
Desertification Ratio	0.083	-0.405	0.864	0.789	-0.302	-0.791	0.687	1

4. Steppe zone

In this zone, the highest correlation coefficients were demonstrated in the factors of population, livestock, forestland, and road network. According to the results of the correlation analysis, these factors (population, livestock, and road network) all have a direct and positive correlation with the desertification ratio. In contrast, the variables of precipitation, forestland, and pastureland have a negative correlation with opposite directions towards the desertification. Also, the correlations between the variables of livestock and population, population and pastureland, forestland and road network appeared to be high and strong.

Table 8. Result of correlation analysis for Steppe zone

	Temperature	Precipitation	Pop Den	LS	Pasture land	Forest land	Road Network	Desertification Ratio
Temperature	1							
Precipitation	-0.180	1						
Pop Den	0.145	-0.454	1					
LS	0.382	-0.278	0.703	1				
Pasture land	0.251	-0.538	0.741	0.396	1			
Forest land	-0.156	0.428	-0.972	-0.670	-0.649	1		
Road Network	0.060	-0.410	0.941	0.520	0.660	-0.963	1	
Desertification Ratio	0.117	-0.329	0.942	0.727	0.488	-0.970	0.921	1

4.2 Factors affecting desertification

Desert zone: Stepwise regression analysis is used to select the variables that are proved to be a good fit for the model. It helps exploring the predicting variables and improves the regression model's performance and relevance.

This model explains 98% (adjusted $R^{2} = 0.98$) of the Y variable. The coefficient of livestock quantity is 0.76, and the p-value is 1%. The pastureland coefficient is -2.85 which indicates a negative relationship between desertification ratio and pastureland. The road network coefficient is 2.06.

Table 9. Regression result for Desert zone

Dependent variable: Desertification ratio	*Coefficients*	*Standard Error*	*t Stat*	*P-value <0.05 (5%)*
independent variables:				
Intercept	-0.747628395	0.297124539	-2.51621	2%
Livestock	0.765675939	0.268201396	2.854854	1%
Pastureland	-2.85854E-07	1.4928E-07	-1.91489	5%
Road network	2.06224E-05	9.33312E-07	22.09588	0%

Table 10. ANOVA result for Desert zone

ANOVA	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	3	0.843952	0.281317	484.2891259	6.58467E-16
Residual	16	0.009294	0.000581		
Total	19	0.853246			

Final multi regression model in the desert zone equation:

$$D_r = 0.765(livestock) - 2.85 \times (Pastureland) + 2.06 \times (Road\ network) - 0.747$$

Semi-Desert: In this zone, the regression model excluded precipitation and population because their p-values came out as nonsignificant in the model. This model explains 91% (adjusted $R^2 = 0.91$) of the Y variable. In the semi-desert zone, the most significant variables were found to be temperature, road network livestock, and pastureland. In this zone, the forestland (-6.25) factor has significantly influence on desertification ratio. Also, an increasing pattern of desertification ratio due to the expanding quantity of livestock (3.62) has been revealed. In addition, due to the arid and harsh climate conditions, temperature (0.0063) and pastureland (-1.98) have also influenced the desertification. Moreover, compared to the other natural zones, the semi-desert zone has greater prospects for future road network expansion and city settlements construction, as the current road network is measured at 34740 square km. So, the road network factor (3.09) constitutes another major impact to the desertification in the semi-desert zone.

The regression result indicated that the desertification factors observed in the desert and semi-desert zones are similar due to the similarity of the ecosystem.

Table 11. Regression result for Semi-desert zone

Dependent variable: Desertification ratio	*Coefficients*	*Standard Error*	*t Stat*	*P-value <0.05 (5%)*
Independent variables				
Intercept	1.686214998	0.190472954	8.852779	0%
Temperature	0.006351833	0.002959602	2.146179	5%
LS	3.62E-09	1.54583E-09	-2.33886	3%

Pastureland	-1.98378E-06	1.21452E-07	-16.3339	0%
Forestland	-6.25231E-05	4.73047E-06	-13.2171	0%
Road network	3.09553E-05	1.75552E-06	17.63311	0%

Table 12. ANOVA result for Semi-desert zone

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	0.843952	0.281317	484.2891259	6.58467E-16
Residual	16	0.009294	0.000581		
Total	19	0.853246			

Final multi regression model in the semi-desert zone equation:

$$D_r = 0.006(Temperature) +3.62(livestock)-1.98(pastureland) – 6.25 (Forestland) +3.09(road\ network) + 1.68$$

Forest steppe:

Based on the stepwise regression analysis result, the most significant variables for this zone were livestock, pastureland, forestland, and road network. This model explains 79% (adjusted $R^{2\ =}$ 0.79) of the Y variable. One of the highest regression coefficients belongs to the factor of livestock quantity (2.01). As the total livestock quantity of the forest steppe zone is approximately 8.8 million is on an upward trend the land degradation is also eminently expanding. In this zone, there is a direct relation between desertification ratio and forestland area (-5.1), in other words, when the forestland area decreases, the desertification ratio trend will respectively increase.

Table 13. Regression result for forest-steppe zone

Dependent variable: Desertification ratio	*Coefficients*	*Standard Error*	*t Stat*	*P-value <0.05 (5%)*
Independent variables:				
Intercept	5.132829208	0.16228246	31.62898	0%
LS	2.01911E-09	7.72647E-10	2.613236	2%
Pastureland	-8.60148E-06	2.63397E-07	-32.656	0%
Forestland	-5.18489E-05	1.71082E-06	-30.3065	0%

Road network	3.74E-07	1.7129E-08	-21.8348	0%

Table 14. ANOVA result for forest-steppe zone

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	0.10218158	0.025545	1455.179	3.18721E-19
Residual	15	0.000263322	1.76E-05		
Total	19	0.102444902			

Final multi regression model in forest steppe zone equation:

D_r = *2.01(livestock)-8.6(pastureland)-5.18(forestland) +3.7(road network) +5.13*

Steppe zone:

In the steppe zone, livestock quantity (4.28) is demonstrated as one of the highly influencing factors. In steppe zone alone, the livestock quantity is more than 8 million head, and the pastureland is measured as 210 thousand square km. Therefore, due to the high quantity of the livestock, pastureland is rapidly turning into degraded area. Additionally, the factor of road network has shown up as having a major impact on desertification, as road construction is notably developing in this zone.

Table 15. Regression result for steppe zone

Dependent variable: Desertification ratio	*Coefficients*	*Standard Error*	*t Stat*	*P-value <0.05 (5%)*
independent variables:				
Intercept	0.774846363	0.064889871	11.94094	0%
Pop Den	0.011897824	0.001302378	9.135464	0%
LS	4.28097E-09	1.51476E-09	2.826173	1%
Pastureland	-1.48935E-06	8.72923E-08	-17.0616	0%
Forestland	-9.17435E-06	1.05288E-06	-8.71358	0%

Table 16. ANOVA result for steppe zone

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	0.322148745	0.080537	1662.553	1.17662E-19
Residual	15	0.000726628	4.84E-05		

Total	19	0.322875373

Final multi regression model in steppe zone equation:

$$D_r = 0.011\ (population) + 4.28\ (livestock) - 1.48\ (pastureland) - 9.17\ (forestland) - 0.77$$

Elasticity of desertification with respect to each seven underlying causes.

Elasticity is a numerical measure of the relative response of one variable to the changes in another variable. In this study, the impacts of variables on desertification ratio is expressed by elasticity. Table 17 shows the elasticity of desertification with respect to each seven variables. An elasticity coefficient is a number that indicates percentage change in desertification that will occur when one percentage of change in the variable concerned occurs.

$$E = \frac{(\%\ \Delta\ in\ desertification\ ratio)}{(\%\ \Delta\ in\ variables)}$$

Where E is the elasticity of desertification ratio for the year 2009,

$$(\%\ \Delta \text{ in Desertification ratio}) = \frac{(\text{D ratio 2010} - \text{D ratio 2009})}{\text{D ratio 2009}}$$

$$(\%\ \Delta \text{ in variables}) = \frac{(\text{V 2010} - \text{V 2009})}{\text{V 2009}}$$

Elasticity coefficient

|E| > 1 (elastic) in this case, the elasticity coefficient is greater than 1, desertification ratio is very sensitive to change in the variable.

|E| = 1 % meaning that 1 % change in the variable will cause the desertification ratio to change by 1% in the same direction.

|E| < 1 (inelastic) in this scenario, the elasticity coefficient in the absolute term is smaller than 1, desertification ratio is insensitive to the change in the variable.

Table 17. The elasticity of desertification with respect to each seven variables.

	Temperature	Pop Den	LS	Pasture land	Forest land	Road network
Desert zone	0.017	1.382	0.059	33.808	0.088	1.854
Semi-desert	-0.027	1.168	6.307	5.464	0.635	0.759
Forest-steppe	-0.002	0.296	0.025	1.804	0.563	-0.011

Steppe zone	-0.004	0.770	0.135	-77.021	-1.594	0.108

In the desert zone, the elasticity of desertification ratio with respect to temperature, livestock, and forestland was lower than 1. In contrast, the elasticity of desertification ratio with respect to population, pastureland, and road network was greater than 1, meaning that, desertification ratio is driven by these variables.

In the semi-desert zone, the elasticity of desertification ratio with respect to livestock, pastureland, and population was greater than 1, in other words, desertification ratio is induced by these variables. Furthermore, the variables of temperature, forest land, and road network were the inelastic factors.

In the forest-steppe zone, the elasticity of desertification ratio with respect to pasture land was elastic (greater than 1), and it means desertification is induced by the pastureland factor. Also, in the steppe zone, the pastureland and forestland factors were revealed as the strongest driving factors. Table 17 indicates the elasticity coefficients of the factors in all natural zones. It is noteworthy that the magnitude of one variable is different in every natural zone.

Discussion

Pastureland and Livestock

The final regression results provides evidence that livestock quantity and pasture land are major drivers of desertification. Moreover, the research showcased a very strong and positive correlation between livestock and population. Due to the intensive livestock grazing, Mongolian pastures are rapidly degrading. According to some estimations (National Action plan for Combating Desertification), Mongolian pasturelands can sustain a maximum of 40 million head of livestock, however current livestock quantity is far beyond this point. Mongolian pastures are used and re-used for too long, and too many herders are using the same watering points, which result in overgrazing. One of the major underlying facts is that policy makers have failed to effectively organize the steep rise in livestock with regard to the limited rangeland.

Forestland

The variable of forestland is significantly presented as highly impacting factor in the steppe, forest-steppe and semi-desert zones. Forestland area construction is an essential part of the reasons behind the land degradation. Nevertheless, in the case of Mongolia, the forest is cleared to make room for farmland and grazing land, or it is removed for the developments of commercial timber logging, new houses, neighborhoods or expanding cities. So, the conversion of forestland in to areas of economic activities must be effectively controlled after serious deforestation.

Table 18 illustrates the significant factors of desertification by natural zone.

Table 18. Regression coefficient of independent variables for desertification

	Temperature	Population Density	Livestock	Pastureland	Forestland	Road Network
Desert			0.7656	-2.8585		2.06224
Semi-Desert	0.0063		3.62	-1.9837	-6.2523	3.0955
Forest-steppe			2.0191	-8.6014	-5.1848	3.74
Steppe		0.0011	4.2809	-1.4893	-9.1743	

Temperature

Based on the regression analysis result, temperature has had slight impact on desertification in the semi-desert zone. This means that climate change due to increasing greenhouse gas emissions can be a cause of desertification at least in the semi-desert zone.

Road network

Another major factor for desertification in Mongolia is the unplanned road paving. In accordance with the analysis, the road network factor influenced the desertification in the desert, semi-desert, and forest-steppe zones. Particularly, in forest-steppe zone, the road network expansion majorly contributed to the desertification. The increased use of cars, the development of road and transportation networks, the physical expansion of human settlement, human migration and rapid market growth all have simultaneously contributed to the land degradation. Also, especially in provincial areas, mining instruction has dramatically boosted, and road network will likely develop continuously. As a consequence, the construction of the railways, paved roads, (earth road) immediately influences desertification and will bring natural hazardous conditions such as dust storm. The chaotic network connecting human settlements is not only damaging pastures and soils, it is also polluting the air with dust and damaging the environment.

Population

The demographic, the factor has significantly influenced the land degradation in the steppe zone. Initially, Mongolia has started to be concerned about centralization of the population since the 1970s under the government plans. Today, Mongolia is facing intensive internal migration of the population from rural areas to cities. This excessive concentration of people is also further damaging urban ecology, intensifying pollution, and reducing resources. All these damages of demographic factors further influence to the land degradation process.

Chapter 5 CONCLUSION

Since the last few decades, desertification has grown as a serious global concern impacting on economic and social developments. Mongolia is not insulted from such concern as negative desertification impacts have steadily alerted the whole nation. Thereupon, this study has introduced three main findings and attempted to demonstrate its related results. First, the study identified the factors causing desertification in the studied sites. Next, the study has found the common factor of desertification in the observed area. Third, the study has estimated the magnitude of the impact of each underlying cause on desertification for four different natural zones.

The research revealed that the most accelerating and significant factor of desertification is the forestland area. In this sense, when the forested area increases, the desertification ratio shows a decreasing trend; this trend was revealed to be the strongest in the steppe zone. Moreover, the study has determined the most common variables of desertification which are the number of livestock and size of pastureland as shown in Table 18. When the livestock quantity increases, the desertification ratio will increment, in contrast, the desertification ratio increases, if pastureland decrease. In other words, the pastureland can be easily turned into desert.

For the purposes of determining the magnitude of impacts on desertification, the study conducted an elasticity analysis of each seven underlying causes of desertification. In the desert zone, the desertification ratio was elastic to the pastureland, (Table 17). Additionally, the desertification ratio was inelastic to the factor of temperature. By analyzing the elasticity results, it is evident that the elasticity of pastureland was greater than 1 in all four natural zones, which means that desertification ratio is driven by pastureland.

In the case of Mongolia, human activities are considered to be relevant factors of desertification, thus, first of all, it is necessary to arrange anthropogenic activities through policy regulation and decision making. The policy should consider the rational use of natural resources and ensure that stakeholders to implement activities in a sustainable manner. Also, increasing participation of the rural community in the debate raises public awareness, stimulate the sense of personal involvement and contributes to the exchange of experience Moreover, the development of bioengineering science toward to improving high qualitative livestock might decrease pastureland pressure.

Before 1990, Mongolian government owned all livestock and pastureland, herders belonged to collectives and the state determined their rangeland (livestock movement) and provide their supplies. After 1990, the communist regime came to an end, and was replaced with democratization. As herds were privatized, the number of livestock rapidly increased during that time. However, the problem was that pastureland regulation was no longer in place. As a consequence, herders tend to live close to their winter shelters or stay in the same place for a long time. In this sense, the herders use and re-use the same pastureland which lead to overgrazing. The traditional pasture rotation system has been lost during the social transformation. Therefore, restoring the traditional way of nomad livestock management is highly advisable. Finally, any conservation and rehabilitation activities should consider the sustainable use of forestland and water supplies

Limitations

The data used for this study is collected from official documents produced by government officials. So all data are not collected through the field surveys. Additionally, the research has only included and observed seven factors of desertification. Besides, the study has not included other probable desertification factors such as mining activities. The data was observed only for twenty years of time, and the variations in the factors are also somewhat limited. Therefore, the quality of data may limited for the validity of the analysis.

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APPENDIX

Data by aimags. (1991-2010)

	Temperature °C	Precipitation(mm)	Population Density	Livestock	Pasture (km2	Forest (km2)	Road (km)
Govi-Altai	-0.54	181.7	0.44	13.37114284	95129.7765	15848.08	1653.6
Zavhan	-1.15	215.6	1.03	27.05692196	616.792275	116.13	1653.4
Uvs	-1.91	149.0	1.24	26.93015664	437.33456	16.99	14210.0
Khovd	1.53	127.5	1.09	0.024905974	1894.34835	603.95	8999.1
Arkhangai	1.36	316.8	1.68	38.64755749	336.536425	116.11	1598.8
Bayn-Olgii	1.42	120.6	8.86	29.01731905	23231.551	3624.93	6760.6
Bulgan	-0.30	323.9	1.20	30.78898077	24071.8705	19829.67	19878.0
Orkhon	1.13	340.2	87.21	176.823282	327.8115	155.04	4389.3
Ovorkhangai	2.06	221.9	1.71	39.1325797	53007.871	2480.34	6139.3
Baynkhongor	0.82	189.0	0.70	16.93001026	64511.8095	3855.65	1520.8
Khovsgol	0.30	232.0	1.16	23.72330564	42550.762	36602.99	7335.8
Govisumber	-0.54	149.0	2.19	22.57926367	4603.24	1079.00	1617.4
Dornogovi	4.93	138.0	0.47	12.69941309	88211.0495	1606.03	15821.1
Dundgovi	2.62	138.0	0.65	23.26181751	65202.038	537.75	10773.4
Omnogovi	5.65	125.9	0.30	7.074198815	105870.815	10250.60	10766.4
Selenge	1.10	279.1	2.33	16.18343944	13875.0595	19650.24	208049.5
Tov	-0.41	269.5	1.28	27.5546217	47353.05975	12299.50	8277.9
Sukhbaatar	1.73	182.7	0.67	1377762.1	70004.1665	16311.78	5689.9
Khentii	0.14	219.6	0.88	19.21985559	49300.514	13769.30	10275.5
Dornod	1.85	218.5	0.61	7.306386077	87108.0255	1543.27	12666.4
Ulaanbaatar	0.08	264.0	177.38	58.89723639	2392.3295	1154.97	3030.8
Darkhan	0.85	322.1	26.33	55.11992366	1653.657	746.68	2685.9

Data by natural zones: Desert zone (1991-2010)

	Temperature °C	Precipitation(	Populatio	Livestock	Pasture (km2	Forest (km2)	Road (km)	Desertification Ratio
1991	2.81	172.0	1.218	3515395	199912	35767	19958	0.49
1992	2.62	157.8	1.161	3546065	216189	35419	19991	0.50
1993	-1.42	192.0	1.157	3494032	232466	35070	20025	0.50
1994	1.90	172.2	1.160	3842151	248743	34722	20058	0.50
1995	-0.78	148.0	1.165	4192200	265020	34374	20092	0.50
1996	-1.72	146.0	1.174	4330616	281297	34026	20126	0.50
1997	0.45	133.8	1.184	4584111	297574	33678	20159	0.50
1998	0.44	154.9	1.190	4734802	313851	33329	20193	0.50
1999	-0.01	174.0	1.194	4835293	330128	32981	20226	0.49
2000	-1.13	131.1	1.198	12520303	346405	32633	20260	0.49
2001	-0.48	116.2	1.208	3760558	336058	29628	24176	0.57
2002	0.29	97.9	1.212	2745428	325710	26624	28091	0.64
2003	-1.19	197.8	1.205	3095006	315363	23619	32007	0.72
2004	0.08	112.6	1.202	3628132	305015	20614	35922	0.79
2005	-1.64	106.1	1.205	3926816	294668	21244	39838	0.87
2006	-0.35	104.5	1.213	4067288	294834	19868	40148	0.94
2007	1.03	118.6	1.228	4701344	295001	18492	40427	0.96
2008	0.11	117.0	1.244	5123496	295167	17116	40722	0.98
2009	-0.65	97.4	1.263	5003930	295334	15740	41016	1.00
2010	-1.37	168.0	1.281	3382597	295500	19149	41388	1.02

Data by natural zones: Semi-desert (1991-2010)

	Temperature °C	Precipitation(	Population D	Livestock	Pasture (km2	Forest (km2)	Road (km)	Desertification Ratio
1991	0.812	193.2	0.97	6399676	182477	27174	31086	0.57
1992	0.778	186.1	1.18	5610421	191545	27030	31219	0.56
1993	0.215	235.2	1.19	6057280	200695	26887	31352	0.56
1994	1.289	269.8	1.20	7049894	209793	26743	31486	0.55
1995	1.356	153.3	1.22	7657225	218975	26600	31619	0.55
1996	0.373	163.6	1.22	7781588	227875	26456	31752	0.54
1997	2.034	192.2	1.22	8424688	236863	26313	31885	0.54
1998	2.249	220.9	1.22	9011333	245748	26169	32019	0.53
1999	1.887	167.8	1.21	9125932	254836	26026	32152	0.53
2000	1.017	119.9	1.20	7424402	263820	25882	32285	0.52
2001	1.631	134.4	1.20	6343766	271966	25240	33347	0.58
2002	1.874	133.2	1.19	5599895	280248	24597	34409	0.64
2003	0.645	227.3	1.17	6347473	288935	23955	35472	0.70
2004	2.056	147.0	1.16	6971229	297652	23312	36534	0.76
2005	0.520	148.4	1.15	7364596	301422	22484	37596	0.82
2006	2.052	119.6	1.14	8213424	301865	22451	38436	0.87
2007	2.810	139.3	1.13	9484966	302249	22418	39277	0.89
2008	1.747	134.8	1.13	9849694	302284	22384	40117	0.90
2009	1.409	118.0	1.14	10412663	302179	22351	40957	0.92
2010	0.596	156.3	1.14	7219689	303040	22899	41798	0.93

Data by natural zones: Forest steppe (1991-2010)

	Temperature °C	Precipitation(	Populatio	Livestock	Pasture (km2	Forest (km2)	Road (km)	Desertification Ratio
1991	-0.527	337.3	14.9	6609006	57814.8	83767	38582	0.29
1992	0.007	282.6	14.7	6625515	62192.9	83097	38907	0.29
1993	-0.563	360.8	14.8	6532175	66570.9	82428	39232	0.29
1994	0.288	351.7	15.2	6947836	70949.0	81758	39557	0.28
1995	0.531	226.5	15.5	7145586	75327.0	81088	39882	0.28
1996	-0.409	209.0	15.9	7436274	79705.1	80418	40208	0.28
1997	0.815	210.8	16.2	8022326	84083.1	79748	40533	0.28
1998	1.245	304.7	16.4	8683891	88461.2	79079	40858	0.27
1999	0.897	221.9	16.7	9218698	92839.2	78409	41183	0.27
2000	-0.116	213.8	17.3	8605337	97217.3	77739	41509	0.27
2001	0.505	208.6	17.9	7637053	95025.8	76313	209948	0.30
2002	1.323	184.9	18.1	7516871	92834.2	74887	378388	0.33
2003	-0.002	250.0	18.1	7487248	90642.7	73462	546828	0.35
2004	0.972	186.4	18.3	8222633	88451.2	72036	715268	0.38
2005	-0.463	203.8	18.7	9027423	86259.7	70600	883708	0.41
2006	0.452	210.9	18.9	10706506	86618.9	71568	724362	0.44
2007	2.105	170.9	19.1	12470174	86978.1	72535	565017	0.44
2008	0.949	214.5	19.4	14164631	87337.3	73503	405671	0.45
2009	0.028	235.3	19.8	14602443	87696.5	74471	246325	0.45
2010	-0.807	244.6	20.3	10238661	88055.8	75448	86980	0.45

Data by natural zones: Steppe zone (1991-2010)

	Temperature '	Precipitation(	Population D	Livestock	Pasture (km2	Forest (km2)	Road (km)	Desertification Ratio
1991	-0.552	221.7	23.1	7368860	138189	42145	33081	0.48
1992	0.254	216.8	23.1	7236407	149214	41936	33459	0.47
1993	-0.474	319.7	23.3	6791989	160240	41727	33837	0.47
1994	0.933	337.5	23.9	7035476	171266	41517	34216	0.46
1995	0.355	215.6	24.6	7509046	182292	41308	34594	0.46
1996	-0.709	204.1	25.4	7798708	193318	41099	34972	0.45
1997	1.038	204.2	26.1	8336630	204344	40890	35350	0.45
1998	1.023	276.0	27.1	8913446	215370	40681	35729	0.44
1999	0.540	204.5	28.3	8525932	226395	40472	36107	0.44
2000	-0.197	197.5	29.7	7802022	237421	40263	36485	0.43
2001	0.177	193.4	30.9	6824780	236196	37466	40383	0.48
2002	0.864	170.4	32.2	6742674	234971	34669	43194	0.52
2003	-0.237	229.8	33.9	6958579	233746	31872	47092	0.57
2004	0.781	173.8	35.6	7419371	232521	29075	49903	0.61
2005	-0.484	199.2	37.2	8118238	231295	26049	55977	0.66
2006	0.579	197.7	38.6	9524222	231073	25649	54227	0.70
2007	1.977	160.5	40.1	11045573	230850	25136	52477	0.73
2008	1.029	199.3	41.7	11666482	230627	24623	50728	0.75
2009	0.090	213.7	43.4	11695860	230404	24223	48978	0.77
2010	-0.529	224.3	45.1	9112110	230314	23768	62501	0.80

국 문 초 록

몽골 사막화의 근본 원인

몽골의 사막화 현상은 급부상하는 환경 문제이다. 몽골 영토의 78%가 사막화의 위험에 처해 있으며, 이 지역 중 60%는 사막화에 매우 취약한 지역으로 지정되었다.

본 연구의 목적은 사막화에 영향을 미치는 요인을 식별하고 각 변수가 사막화에 미치는 영향을 측정하는 것이다. 독립변수는 총 일곱 개이며, 종속변수는 사막화의 비율이다. 독립변수간의 관계를 밝히기 위해 상관분석 방법이 사용되었다.

단계적 회귀 분석의 결과, 사막화에 가장 큰 영향을 미치는 변수들은 몽골의 가축 사육과 방목 압력이다. 산림 지역의 변화는 반사막 지역과 산림 스텝 및 스텝 지역의 사막화에 영향을 미치는 것으로 조사되었다. 온도로 표현되는 기후 요인은 반사막 지역의 사막화에 큰 영향을 미쳤다. 스텝 지대에서는 인구의 증가가 사막화에 보통 정도의 영향을 미쳤다. 산림 스텝 지역에서는 도로망 요인에 의해 사막화가 발생하였다. 일곱 가지 변수 각각의 사막화 비율 탄력성을 살펴보았을 때, 목초지는 모든 지역에서 탄력성이 있으므로 이는 몽골의 사막화는 주로 목초지에 의해 발생함을 의미한다. 결론적으로, 본 연구는 인간의 행위가 사막화의 주 요인으로 고려될 수 있음을 밝혔다.

주제어: 사막화, 근본 원인, 몽골

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