Comparative study of agro-climatic zoning

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Abstract. *This paper shows the results of air, soil surface temperature & precipitation analyzes and their change and Agroclimatic zones for Selenge aimag of Mongolia. In the Fig 1 we have given the air temperature change due to climate change in the area. According to our study the air temperature is increased by 0.1-1.8^{0}C. The air temperature seasonal change analyze says that warming is more intensive in the winter season, particular in February the value reaches until 3.7^{0}C. The soil temperature change analyze gives that, it increased from zero to 1.2^{0}C. The most warming 3.7^{0}C of soil temperature observed also in the winter, in February. Precipitation decreased by 1-29% per a year and by 7-12% for the growth period. We have calculated the water & heat coefficient, the water & heat provision for spring wheat in the central and mean agricultural region of Mongolia. Due to this calculation we tried to give the Agroclimatic zoning for Selenge aimag of Mongolia. Following our study selected aimag has divided into 3 zones, such as subhumid-colder, semiarid-warmer, arid-warmer. Also we compared agroclimatic zones before and after 1990. From the comparative study we can see some changes in zones. Before 1990 Selenge aimag had 2 agroclimatic zones, but after 1990 it has 3 zones. Due to climate change some area (Baruunburen) has shifted from semiarid-warmer area to arid-warmer.*

Key words: air temperature, soil surface, period without cold, precipitation, moisture temperature coefficient, heat supply, moisture supply

Introduction

Scientists and researchers working worldwide are warning that minimal loss will be for those who are able to develop and accomplish expeditious, optimal and accurate variants in connecting closely the issues associated with climatic changes, and making arrangements during climatic changes to implement socio-economic measures tended to accomplish objectives of sustainable development of the country.

In order to manage crop productions effective for supplying human populations with food and industries with raw materials, methods and technologies scientifically based on optimal use of favorable natural and climatic conditions, and overcoming unfavorable conditions with minimal loss are necessary.

For our country with severe continental climate, climatic conditions and resources are major factors of socio-economic development. Under the impacts of global warming and climatic changes, frequency of climatic disasters such as drought and zud is increasing in Mongolia, and also there is a tendency to intensify further. Such issues as to study adverse impacts of these changes on our country's socio-economic situations, develop ways of adaptation, ensure sustainable developments of the country's economy in the future, especially detect the possibilities of enhacing agricultutal production, and create technologies based on nature and ecology are being sharply faced and they become actual problems facing not only sciences, but laso whole community. In order to choose and implement variants of measures for adapting and overcoming with minimal loss, the climatic changes, suitable to each economic sectors and areas in this conjunction, more detailed studies and analyses are essentially important and it is necessary to work with integrated policy not only at sector level, but also at state, government, national and regional levels for developing and implementing policies and strategies interconnected with such natural and climatic changes.

Although crop production is being affected by climatic changes of Mongolia, including Selenge aimag due to effect of global warming and grain crop production of majority of crop farms is decreasing due to summer overheating and aridification in the last years, crop production diifers with neighboring farms. Therefore, study of changes of agro-climatic conditions, agro-climate and its resources, and their impacts on cultivated crops at present time of greater necessity of agrotechnical renovations adapted to chnaging climatic conditions will be important for effective and correct organization crop production, and development and maximal use of well suited technology.

1. Air temperature

Indicator of climatic heat and cold regimes is air temperature. Air temperatures differ with the regions and main factors exerting effects on them are seasons, days, sun height, latitude, earth surface types, coastal and main land localizations and above sea altitude.

Loss of thermal balance and water equilibrium results in heating surfaces around urban areas as well as vertical surfaces of houses and building in urban areas absorb heat, and it also causes overheating. Overheating leads to sharp increase of plant transpiration, inability of its replacement from soil loisture, loss of moisture balance of plants, shortage of water reserve, slowing down, retaining, and arrest of growth and development, and degradation of biosphere, as well as hzards to public health such as activation of causative agents of some disease, loss of human body thermal balance, sunstroke, recurrence of chronic diseases and impairment of cardiovascular diseases.

Detailed study of changes of average annual air temperatures after 1991 in comparison with that in 1990 revealed annual average change around high mountains such as Khentii mountains branches, Buren and Buteel ridges, and territories of Khuder, Bugant and Tsagaannuur soums was 0.1-0,4^{0}C (Figure 1), relatively lower or less by 0,5^{0}C, but warming is more intense around basins of larger rivers or change is greater than 0,5^{0}C or ranges between 0,9 and 1,8^{0}C. It is associated with the loss of natural equilibrium due to increased urbanization and human actions in the areas of larger river basins, as well as geographical conditions.

Figure 1. Distributions of annual average air temperature changes in Selenge aimag.

Study shows observation of the maximal annual average air temperature of 1.8°C (Table 1) in Mandal soum is seen to be impacts of number of factors such as concentrated human populations (24,400), many enterprises and crop production since earlier period.

Table *1*

Changes annual average air temperature, cels

Average	Sukhbaatar	Baruunkharaa	Orkhon	Eroo	Orkhontuul	Tsagaannuur	Zuunkharaa	Baruunburen	Zuunburen	Zelter	Khuder	Bugant	Average
1960-1990	0,0	-0,9	-1,1	-2,3	0,8	0,9	-0,9	1,1	0,2	-1,9	-0,7	0,5	-1,0

1991-2008	1,1	0,3	0,1	-1,1	0,4	1,3	1,0	2,3	1,1	-1,0	-0,5	0,5	0,6
Changes	**1,2**	**1,1**	**1,3**	**1,2**	**-0,4**	**0,4**	**1,8**	**1,3**	**0,9**	**0,9**	**0,2**	**0,1**	**1,6**

Annual distribution of air temperature changes demonstrates 3.7^{0}C, a maximal value of warming was in February (Figure 2), while minimal value of 0.8^{0}C was observed in October, air temperature of the warmest month or July warmed by 1.7^{0}C, and remaining months by $0.8\text{-}1.8^{0}$C. Warming is seen in the areas of study for all year round, and it is in agreement with conclusions of other researchers [4] that air temperature increases by 3,6°C in cold seasons, while it increases by 1.4-1.9°C in spring and autumn seasons [4].

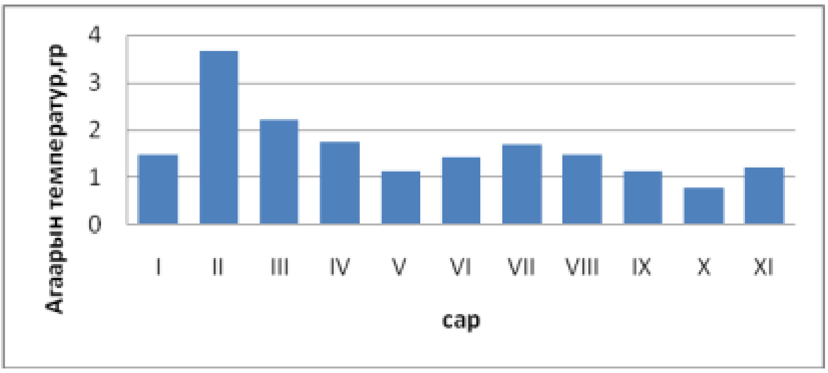

Figure 2. Monthly average change of air temperatures in Selenge aimag

For annual average changes of ground surface temperatures, warming by 1.1^{0}C-1.2^{0}C occurred in the territories of Eroo, Zelter and Tsgaannuur soums or intermediate regions of high mountaisn and river valleys, while warming by $0\text{-}0.4^{0}$C or lowest ones were in Bayangol, Zuunburen and Sukhbaatar soums. As compared to larger river basins, lowlands and other areas, overheating occurs in above areas and therefore annual average temperature remains almost unchanged.

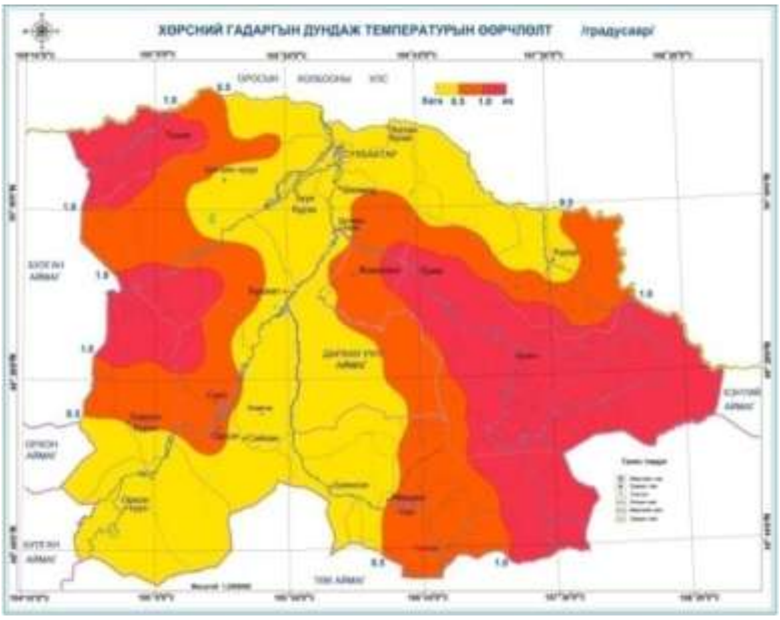

Figure 3. Distribution of changes of ground surface annual average temperature,

With changes of monthly average temperature of ground surface, it colds in January by 0,3^{0}C after 1990, changes are slight from October through December or 0.1-0.2^{0}C, while maximal warming is in February and July or warmed by 2.7 to 1.8^{0}C and 0.6-1.5^{0}C in remaining months. In such case warming is generally the same with monthly average change of air temperature or maximal warming occurs also during February and July.

In association with air temperature increase, in the last years duration without cold prolonged and average air and ground surface temperatures of aimag increased by 11 (table 2) and 5 days respectively. From above it is shown that period without cold for air and ground surface lasts 117 and 104 days respectively.

Duration without cold temperature in air and ground surface, *day*

Table 2.

Meteorological stations	1965-2008 year		1965-1990 year		1991-2008 year		Difference	
	Air	Surface	Air	Surface	Air	Surface	Air	Surface
Сүхбаатар	124	110	119	105	130	114	11	9
Баруунхараа	121	106	118	103	127	110	9	7
Орхон	114	103	113	101	119	105	6	4
Ерөө	102	94	98	93	109	98	11	5
Орхонтуул	108	98	104	96	111	101	7	7
Цагааннуур	114	102	108	101	120	104	12	3
Зүүнхараа	119	102	112	103	128	104	16	1

Зүүнбүрэн	103	102	97	98	110	100	13	2
Хүдэр	95	94	91	89	99	97	8	6
Бугант	111	101	96	91	115	102	19	11
Дундаж	**111**	**102**	**106**	99	**117**	104	**11**	5

2. Precipitation

Precipitation rate is absolutely important for crop production. Number of researchers studied precipitation rate and soil moisture, and their effects on cultivated crop production. For example, 0.1-3.0 mm precipitation during summer in central crop producing region does not increase soil moisture, but exerts effect on crops [5]. B.Avirmed, S.Shiirev-Adya (1985) emphasized that greater crop production during earlier precipitation occurs and abundant moisture, and decreased crop production during arid years is associated with that main factors crucial for crop production is soil moisture, and also noted that if precipitation is less than 30 mm per month in summer in forest steppe region, it affect adversely crop production, while 40-50 mm results in mid level yield, and 60-70 mm is sufficient for high yield. However, precipitation less than 5 mm for each first decade of summer season can be seen as arid.

Investigation of annual distribution of changes of sum precipitation reveals aimag's average increased by 0,4-4.9 mm (13-29%) in March, May, November and December, and decreased by 0.1-8.8 mm (4-11%) in remaining months. Especilaly precipitation is greatest in July or decreases to 8.8 mm (11%) and average air temperature becomes warmer, which provides a condition for causing summer or late drought.

Sum of annual and monthly precipitation and changes, mm

Table 3.

Он	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	нийлбэр
1960-2008	3,5	2,2	3,1	8,3	18,9	53,4	76,8	71,8	31,9	9,5	5,1	4,4	289,7
1960-1990	3,7	2,3	3,0	8,7	17,1	55,0	80,0	74,6	32,8	9,6	4,7	3,9	295,4
1991-2008	3,2	2,1	3,4	7,6	21,9	50,7	71,2	67,1	30,4	9,4	5,7	5,1	277,9
өөрчлөлт	**-0,5**	**-0,1**	**0,4**	**-1,0**	**4,9**	**-4,3**	**-8,8**	**-7,5**	**-2,4**	**-0,2**	**1,0**	**1,2**	**-17,5**

Changes of annual sum precipitations differ with the soums, increase due to effects of mountains in the territories of Khuder, Mandal, Tsgaannuur, baruunburen and Zuunburen soums around Khentii, Buren and Buteel mountains, and decrease in the territories of remaining soums to 4 -31 мм or by 1.2-10.6%.

Sum of annual precipitation and changes of the stations, mm

Table 4.

Он	Sukhbaatar	Baruunkharaa	Orkhon	Eroo	Orkhontuul	Tsagaannuur	Zuunkharaa	БBaruunburen	Zuunburen	Zelter	Khuder	**Average**
Average	**280**	**301**	**310**	**278**	**295**	**262**	**290**	**249**	**285**	**233**	**321**	289,7
1960-1990	289	311	315	288	295	256	302	230	283	216	300	296,4
1991-2008	270	281	301	258	291	268	277	258	286	236	336	277,9
deference	**-20**	**-30**	**-14**	**-31**	**-4**	**13**	**-25**	**27**	**3**	**21**	**36**	**-18**

According to our study, precipitations occurred annually for 86 days in average in Selenge aimag and increase of days with precipitation by 6 in the last years are associated with increase of momental rains due to overheating. Surveys demonstrated that relatively more days or 99-107 days have precipitations in the territories of Orkhon, Sukhbaatar, Bayangol and Eroo soums in the basins and valleys of larger rivers, while minimal days or 67-69 days have precipitations in Baruunburen, Sant and Nomgon soums, situated in southern west of the region.

Of total days with precipitations, 42-64 days are rainy and this number increased by 3 days after 1990 and in average 55 days are rainy in the aimag.

Number of days with precipitations occurred in various intervals reveals 1 mm or above precipitations occur annually for 42 days in the aimag and it increased by 2 days in the last years. Number of days with 1 mm or above precipitations is relatively greater or 50 days in Khuder soum.

Precipitation

Table 5.

Сумын нэрс	>0,0	>0,1	>0,5	>1,0	>5,0	>10,0	>20,0	>40,0	>60,0	>80,0	>120,0
Сүхбаатар	104	77	58	43	16	8	3	0,4	0,0	0,0	0,0
Баруунхараа	101	87	57	44	17	9	3	0,2	0,0	0,0	0,0
Орхон	107	83	56	44	17	8	3	0,4	0,1	0,0	0,0

Ерөө	99	75	53	41	17	8	3	0,2	0,0	0,0	0,0
Орхонтуул	90	76	53	40	15	7	3	0,4	0,1	0,0	0,0
Цагааннуур	81	76	48	42	16	7	2	0,1	0,0	0,0	0,0
Зүүнхараа	89	76	56	44	17	7	2	0,3	0,2	0,0	0,0
Баруунбүрэн	67	63	50	40	13	7	2	0,2	0,0	0,0	0,0
Зүүнбүрэн	83	77	58	44	16	7	2	0,5	0,1	0,0	0,0
Зэлтэр	72	64	44	33	10	4	1	0,2	0,1	0,0	0,0
Хүдэр	93	84	65	50	20	9	3	0,3	0,1	0,0	0,0
Алтанбулаг	80	72	55	47	21	11	4	0,1	0,0	0,0	0,0
Баянхараат	87	70	53	42	16	7	3	0,4	0,0	0,0	0,0
Номгон	69	62	53	41	19	9	3	0,5	0,1	0,2	0,1
Цагаантолгой	67	56	39	35	13	8	3	0,4	0,0	0,0	0,0
Шаамар	80	68	52	43	16	7	3	0,6	0,2	0,1	0,0
дундаж	86	73	53	42	16	8	3	0,3	0,1	0,0	0,0

Accoridng to our study 5 mm or above precipitations occur annually for 16 days in Selenge aimag and they are greater by 4-5 days in Khuder and Altanbulag soums as compared to othe rsoums. In the last years above numbers remained unchanged.

With forms of rains, days normal rain accounts for 45% of total rainy days, days with drizzling for 28% and days with hevay showers for 27%.

In the territory of this aimag 85% of annaul precipitation occurred during plant growth period or 253 mm precipitation as of multi-year average fall and it decreased to 18 mm or by 7% in the last years. With monthly rates, precipitation increased by 4.8 mm or 28% in may, and decreased by 4.3 mm (7.8%), 8.8 mm (11%), 7.5 mm (10%), and 2.4 mm (7,3%) from June through September. Decrease of precipitation falled during plant growth period was demonstrated from our study.

Sum of annual precipitation and changes during the growing season, mm

Table *.6.*

сар	V	VI	VII	VIII	IX	Total
1960-1990	17,1	55,0	80,0	74,6	32,8	259,5
1991-2008	21,9	50,7	71,2	67,1	30,4	241,3
difference	**4,8**	**-4,3**	**-8,8**	**-7,5**	**-2,4**	**-18,2**

3. Agro-climatic zoning

In order to harvest stable crop yields in crop production, it raises the necessity of zoning crop production and developing policies of agro-technology and crop varieties suited to the zones in regard with anumbe rof factors including regional area humidity, temperature, first and last sudden colds and features of soil.

To make relative evaluations of moisture supply conditions, G.T.Selyaninov's "Humidity and thermal coefficient" was determined. The use of K_S is recommended to use within the period shorter than a month. K_S< 0,5 means there is drought, K_S = 0,5-1,0 semi-arid, K_S = 1,1-1,5 semi-humid, K_S = 1,6-2,0 humid and K_S>2,0 excess humidity. K_S indicates matural zones. K_s = 1,1-1,3 means forest, K_S = 0,8-1,0 forest steppe, K_S = 0,6-0,8 steppe, K_S = 0,3-0,5 semi-desert steppe, and K_S<0,3 desert.

Moisture and thermal coefficient and its changes

Table 7.

soums	1960-1990	evaluations	1991-2008	Evaluations
Sukhbaatar	1.4	Semi-humid	1.2	Semi-humid
Baruunkharaa	1.5	humid	1.1	Semi-humid
Orkhon	1.5	humid	1.2	Semi-humid
Eroo	1.5	humid	1.2	Semi-humid
Orkhontuul	1.5	humid	1.3	Semi-humid
Tsagaannuur	1.2	Semi-humid	1.1	Semi-humid
Zuunkharaa	1.5	humid	1.2	Semi-humid
Baruunburen	1.2	Semi-humid	1.0	Semi-humid
Zuunburen	1.3	Semi-humid	1.1	Semi-humid
Khuder	1.4	Semi-humid	1.4	Semi-humid

According to comparative study of moisture and thermal coefficient aridification occurs in Baruunkharaa, Orkhon, Eroo, Orkhontuul, Zuunkharaa and Baruunburen soums, shifting from humid into semi-humid and from semi-humid into aridic or moisture and thermal coefficient decreased by 0.1-0.4, which evidences humidity and thermal changes occur in the region of our study.

Agro-climatic zoning is made on the basis of thermal supply, moisture and thermal coefficient, and period without cold, and attempts to measure its changes and shifts, followed by comparative study.

With moisture supply, there are 2 zones; semi-humid in case of K=1.5, aridic in case of K = 1.2-1.4, and with thermal supply, it is divided into 2 zones; cooler in case of sum temperature of 1500-2000°C, and warmer in case of above 2000°C. Based on such, territory of Selenge aimag is divided into the following 3 agro-climatic zones:

I. Semi-humid and cooler
II. Semi-arid and warmer
III. Arid and warmer

3.1. Semi-humid and cooler zone

All areas at 700-1200 m above sea level belong to this zone. In other words this is a zone between branches of Khangai and Khentii mountains and basins of Orkhon, Selenge, Kharaa, Eroo and Khuder River.

Average air temperature during January is approximately -22 to -24 degrees. Daily average air temperature becomes warmer above 10 degree during early June, while it decreases below 10 degree during seond half of august and early September, and then drops further. Meanwhile, sum of active temperature above 10 degree ranges between 1500 and 2000 degrees.

Spring last sudden cold occurs around late May or first decade of June, and autumn first cold is at the end of August and early September, and duration of period without cold is 80-100 days.

In average more than 300 mm precipitation falls annually.

In this zone, more suitable areas with micro surface can be selected and summer crops resistant to cold can be planted.

3.2 Semi-arid and warmer zone

All areas at 600-1000 m altitude above sea level belong to this zone. Territories in basins of Selenge, Orkhon, Kharaa, Eroo, Khuder and Zelter rivers are involved.

This zone has less humidity as compared to the first zone, average annual precipitation is 200-313 mm and 158-275 mm precipitation falls during plant growth period.

Average air temperature of January ranges from -21.2^{0}C to -27.3^{0}C, while average temperature eof July ranges from 17.9^{0}C to 21.1^{0}C.

Daily average air temperature is 0^{0}C in the first decade of April, warming exceeds 15 degree during late May or first decade of June, and then become cooler below 15^{0}C at the second half of August, below 10^{0}C in the first half of September, below 5^{0}C at the end of September or in the first decade of October, and below 0^{0}C from mid October.

Duration of period without cold is 100-120 days.

Despite, planting summer wheat and vegetables is suitable, implementation of measures for moisture accumulation and irrigation may be necessary due to climatic changes.

3.3 Arid and warmer zone

Only baruunburen soum belongs to this zone.

Average air temperature of January and July is -20.6^{0}C and 15.2^{0}C respectively.

Air temperture above 5^{0}C occurs in the middle decade of April and above 10^{0}C in the first decade of May, and temperatures of middle decade of September and first decade of October become cooler below 10^{0}C and below 5^{0}C respectively.

Duration of period without cold is approximately 120 days.

In average less than 250 mm precipitation falls annually.

This zone is suitable for palnting summer wheat, but implementation of measures for moisture accumulation and irrigation may be necessary due to climatic changes.

3.4 Comparative study of agro-climatic zones

Determination of moisture and thermal coefficient and sum of active temperatures above 10^{0}C during plant growth period, before and after 1990 shows that there is a tendency of changes in agro-climatic zoning. Our comparative study reveals area of semi-humid and cooler zone drops by almost 2 times, while area of semi-arid and warmer zones increases and a new zone called arid and warmer has been arisen by shifting territory of Baruunburen soum from semi-arid and cooler zone into arid and warmer zone. It is an evident that aridification becomes more intensive. Southern parts of the territory and some areas in branches of Buteel, Buren and Khentii mountains become significantly warmer and it shifts from semi-humid and cooler zone into semi-arid and warmer one.

4 дүгээр зураг. Agro climate Agro climate
subdivisions of the Selenge aimag,
1960-1990 subdivisions of the Selenge aimag,
1960-1990

Lower crop production in the first zone during years with sufficient humidity is associated with lack of heat supply and shorter period without cold. However, majority of crop fields of aimag are in the second zone and because Sant, Orkhon, Bayankharaat, Khushaat, Baruunburen and Mandal soums have lower crop production rates, mostly low risk fodder and technical crops such as barley, raps and oat can be panted there.

Conclusions

1. Climatic changes are intensively emerging in the territory of Selenge aimag. For example, number of days with overheating due to increase of annual average air temperature by 1.6^{0}C, warm and cold season average temperatures by 0,7^{0}C and 1,0^{0}C respectively, and annual average temperatures of ground surface and depth temperature by 0,6-1.0^{0}C, increased by 10 for air and 9 for ground surface. Although annual sum of precipitation decreases by 17.5 mm or 5.9%, it increased by 13-28% in spring and winter months, while it reduces by 1-10.1%.
2. Comparative study of agro-climatic zone in association with intensive climatic changes shows southern area of the territory and parts of Buteel, Buren and Khentii mountains are getting warmer, the areas of semi-humid and cooler zone decrease almost 2 fold, semi-arid and cooler zone is shifted into semi-arid and warmer zone, and arid and warmer zone was newly arisen. Therefore, it is seen to be necessary to make this zone more detailed.
3. It is important to develop technology adapted to changes of agro-climate and its resources and organize effectively and properly crop production.

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