MAPPING AND MONITORING OF CROPLAND AREA IN MONGOLIA BY REMOTE SENSING AND GIS

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Thesis by

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Abstract

概要

モンゴル政府は、急激な経済変化の混乱の中で天然資源の管理や農地の土地利用政策に用いる正確で迅速な情報を必要としている。農業はモンゴル経済にとって重要な分野の一つであり、土地・水資源を主に利用する人たちや雇用源としても重要である。

モンゴルは 1950 年末、1976 年、2009 年の各年に新開墾地での耕作を開始し、1990 年代からは計画経済から市場経済への移行を始めた。市場経済への移行は、天然資源とその管理に大きな影響を及ぼし、都市化によって土地の民有化や断片化が進んだ。この 1991 年以降の市場経済への移行は、肯定的なものであったが困難なものでもあった。改革の過程において、この民有化は次の 3 つの理由から必要不可欠なものであった。一つ目は市場を良く機能させるため、二つ目は決定機関の市場への反応を刺激する為、三つ目は改革そのものの進行の為である。

農業における持続可能性は先進国、発展途上国を問わず全ての国で重要であり、農業分野の開発論議は十分な食料安全保障をどうやって維持するかという問題と農業生産者の収入をどうやって維持するかが中心になっている。農業分野の開発は土地利用と強く関わっており、食料安全保障、経済開発、環境にとって土地利用は大きな意味をもっている。戦略的な穀物（小麦、大麦、じゃがいも、野菜など）の生産自給率を上げる事がモンゴルの政策決定者の目的の一つであり、モンゴルは現在これらの穀物の大部分を輸入している。経済及び社会的な理由から、自給率と生産量を上げる事は急務であり、モンゴルにおける農地のモニタリング及びマッピングの開発が必要となっている。

本研究の主の目的は以下の通りである。

1- 1989年から2000年の間の農地変化の見積もり、及び様々な農地の空間的な変化の研究におけるリモートセンシング及びGISの可能性の調査。

2- 正確な農地テクノロジーの導入とモンゴルの農地情報システムの開発。

3- リモートセンシング技術を用いた小麦生産地域の穀物ストレス指数の研究。

1つ目の目的を達する為、1989年と2000年のLandsat TM およびETM画像（パス/ロウ 132/25-27、133/25、131/26-27）に対して教師付き最尤法による分類と変化検出法を用い、モンゴルの主要な農業地域であるTov、Selenge aimagの農地変化マップを作成した。教師付き分類はグランドトルースデータを用いて六つのバンド（バンド1からバンド5、バンド7）で実施した。マッピングは1989年と2000年別々に実施したが、10％の雲被覆などによる画像の不足を補う為前後1～4年の画像も用いた。主な植生の成長期である理想的な“夏の”期間は6月から9月末である。LANDSATの3つのパスに本研究地域が含まれ、15シーンが必要だった。補助データ、この地域の専門知識と視覚判読によって分類結果が精錬され、クロス集計による分類後の変化検出法によって変化画像を作成した。

2つ目の目的を達する為、現地調査とデスクワークによってデータを収集し、関連文献も調査した。8～3000haの大きさのポリゴンをサンプリングして3年にわたる詳細なデータを収集した。多くのケースでは、各ポリゴンのフィールドデータの収集には数日かかった。2007年から2009年の間の小麦の成長期から収穫期までの数ステージの5時期のフィールドデータを収集した。作成したXYシェープファイルはフィールドデータに基づいており、WGS 1984 座標系を用いてArcMapで表示した。 本研究の主な目的はモンゴルの穀物情報システムと地籍図の幾何精度の改良法を開発する事である。経済的、技術的、法的、社会的、財政的な点から、穀物情報システムと穀物地籍図の更新を行った。

3つ目の目的を達する為、モンゴルTsagaannuurの小麦畑での穀物ストレス指数を調査した。乾燥・半乾燥地域では、大きな旱魃や水管理の問題によって天水・灌漑農業が水不足の危機に瀕している。モンゴルの農業経済部門は、主に家畜資源と一部の限定的な灌漑農業の農地の範囲に限定されている。この生物・非生物ストレスは植物生理学的に変化を引き起こし、穀物の成長に影響を与える。この方法によって、より正確な水資源管理が行え、灌漑政策の判断を容易にする。

Abstract

In the turmoil of a rapidly changing economy the Mongolian government needs accurate and timely information for management of their natural resources and formulation of agricultural land-use policies. Agriculture is one of the most important sectors of the Mongolian economy, as it is the major source of employment and the main land and water user.

Mongolia began to cultivate virgin lands at the end of the 1950, 1976 and 2009 years.

From 1990s, Mongolia entered a period of transition from a central-based planned economy to a market economy. The change to a market-oriented economy had also an impact on the natural resources and their management, not only due to privatizations, but also because of the strong land fragmentation as a result of the land distribution and increased urbanization.

Mongolia’s transition experience since 1991 has been positive, but difficult. Privatization is considered essential to the process of reform for three main reasons: in *first*, to establish well-functioning markets, *secondly* to create incentives for decision makers to act in response to market signals, and *third* one is to assure irreversibility of the reforms themselves.

Agricultural sustainability has the highest priority in all countries, whether developed or developing. The discussion about development of the agricultural sector has often centered on the question of how to achieve adequate food security, while simultaneously providing sufficient income for food producers. Agricultural sector development is strongly related to land use. The way land is used has obvious implications for food security, economic development and the environment.

Increasing the level of self-sufficiency in the production of strategic crops (e.g., wheat, barley, potato and vegetables) is one of the objectives of Mongolian policy makers. Currently, Mongolia is importing a significant part of its national requirements for these crops. For economic and social reasons, increasing national production and the level of self-sufficiency is urgently needed. Therefore there is need to develop mapping and monitoring cropland area in Mongolia.

The main objectives of this study are;

4- to provide a recent perspective for cropland cover changes that have taken place between 1989 and 2000 and to examine the capabilities of integrating remote sensing and GIS in studying the spatial distribution of different cropland cover changes

5- to introduce precision farmland technology and to develop cropland information system in Mongolia

6- to investigate a crop stress index in wheat planting area using remote sensing techniques.

To achieve the first objectives, maximum likelihood supervised classification and post-classification change detection techniques were applied to Landsat TM and ETM images(with path/row 132/25-27, 133/25, and 131/26-27) acquired in 1989 and 2000, respectively, to map cropland cover changes in the principal cropland area (Tov and Selenge aimag) of Mongolia. A supervised classification was carried out on the six reflective bands (bands 1-5 and band 7) for the images individually with the aid of ground truth data. The baseline date for the mapping was 1989 and 2000 separately but, to accommodate any image shortage, e.g., due to 10% cloud cover, plus and minus 1 to 4 years allowed. The ideal "summer" period covered the main plant growing season, June to late September. Three LANDSAT paths cover study area and 15 scenes were required for this study. Using ancillary data, visual interpretation and expert knowledge of the area thought GIS further refined the classification results. Post classification change detection techniques were used to produce change image though cross-tabulation.

To achieve the second objective, data was collected through a combination of the fieldwork and some desk study. Related papers was reviewed prior to, during and after fieldwork. We were chosen for detailed sampling each polygon, where data was obtained over the course of three years. The parcels varied in size from about 8 to 3000 hectares. In most cases, due to the size of the parcels, field data collection for a single parcel would take several days. Field data was collected at 5 different times during 2007 and 2009, spanning both the cropping seasons as well as several stages of wheat maturation, from

the early growth to pre-harvest. A Creating XY shape files, based on the field data a gathered is the first stage in creating continuous vector coverage's using with in an ArcGIS with attribute data. Shape files were displayed in ArcMap and projected to the WGS 1984 coordinate system. The main objective of this research is to develop an approach (methodology) to improve the geometric quality of the cropland information system with cropland cadastral map in Mongolian case study in first time. Cropland information system and cropland cadastral map renovation has been conducted in terms of economical, technical, legal, social and financial aspects.

To achieve the third and last objective of this study, an investigate crop stress index in the wheat field in Tsagaannuur of Mongolia. In arid and semi-arid regions, rain fed and irrigated agriculture is threatened by water shortages caused by pronounced droughts or water mismanagements. The agriculture economic sector of Mongolia is limited mainly to range resources-based livestock and pockets of arable farming based on rainfall and limited irrigated agriculture at several places. These abiotic and biotic stressors cause changes in plant physiology and thus affect crop growth. This methodology can be used to generate more accurate water management practices and facilitate decisions about irrigation applications.

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1. Introduction

1.1 General Introduction

Since the launch of Landsat-1 in 1972, remote sensing has become an important tool in many resource management areas such as land-cover classification, mapping, resource inventory, pollution detection, environmental impact assessment, and environmental modeling. Generally, a remote sensing system consists of five components. They are the energy source, the sensor, ground objects, the data-handling system, and the multiple data users. According to the source of energy used, two types of remote sensing systems active and passive are distinguished. "Active" refers to a sensor that supplies its own source of energy or illumination. Imaging radar sensors are active sensors, which emit a burst of microwave radiation and receive the backscattered radiation. Most commercial satellite sensors are passive solar imaging sensors. In this case, the sun is the source of electromagnetic radiation (ERDAS Field Guide 1997).

Compared to more traditional mapping approaches such as basic aerial photo interpretation, land-use mapping using satellite imagery has very good advantages, respectively:

- Any land-use types can be mapped from digital satellite imagery faster and often with lower costs;
- Fast and inexpensive updating of land-use map products is possible. This is because satellite images are captured for the same geographic area at a high revisit rate;
- Satellite imagery data are captured in digital forms. They can therefore easily be integrated with other types of ground object information through such techniques as GIS;
- Satellite images cover large geographic areas. The great economies of scale provided by digital image processing make it relatively inexpensive to map large expanses of land, making it easier and more cost effective to generate large amounts of map products.

The remote sensing and GIS technology and the information technology, make a revolution to traditional agricultural system. Remote Sensing (RS) and geographical information system (GIS) plays a significant role in compilation, analysis, presentation and monitoring of spatial data. Remote sensing and GIS technologies are of particular relevance to developing countries, where areas of interest are often large, communications are difficult and existing databases are incomplete. Moreover, the requirement for management of the land resources in these areas is particularly of immense interest as many of the worlds most fragile and threatened ecosystems are found in these countries (Belward et al., 1991).

As indicated in the Figure 1-1, in the context of land resource management RS data coupled with field observation are used for resource inventory and analysis of the existing situation. Such information, once integrated in a GIS environment can be used to quantify and analyze the verifiers or the decision factors associated with the decision problem; for example, identification and proper allocation of a set of land use systems, crop monitoring for an area can be analyzed by overlaying interacting biophysical (slope, soil type etc.) and socio-economic (% land holding, fuel/fodder deficiency etc.) factors. The functionalities of GIS are frequently supplemented through the application of various external models.

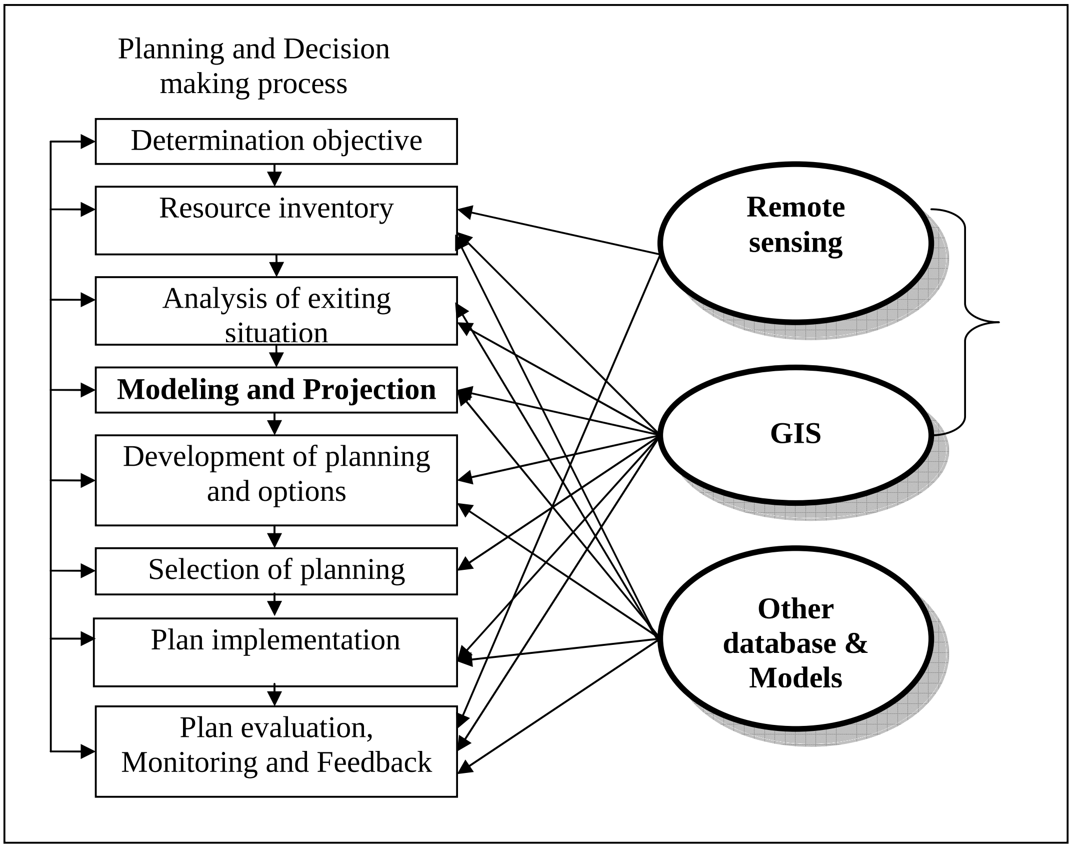

Figure 1-1 Integration of Remote sensing and GIS and other database and models into planning and decision making process (Adopted from Anthony, 2000)

Agricultural remote sensing is commonly done in the visible, near-infrared and thermal infrared portions of the spectrum; however, new applications in the microwave area are under development. The given wavelengths are employed in agricultural survey through Electromagnetic radiation by using remote sensor system.

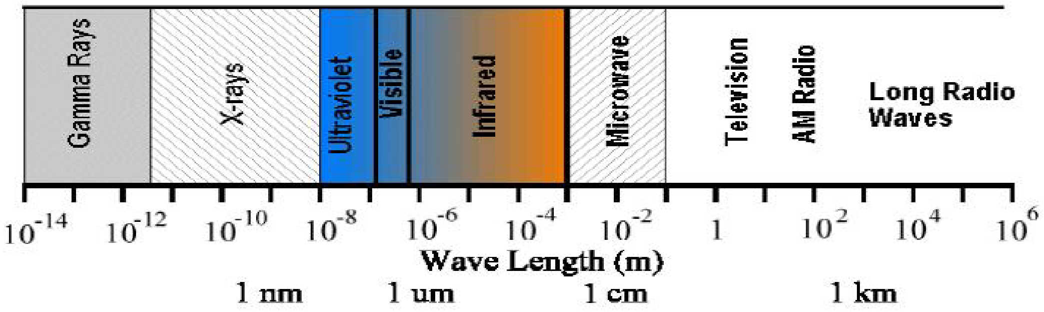

Table1. 1 Use of wavelength region for agricultural survey

Area of agricultural phenomena	Wavelength employed
Plant diseases and insect infestation	0.4-0.9 mm and 6-10 mm
Natural vegetation, types of crop and fresh inventories	0.4-0.9 mm and 6-10 mm
Soil moisture content (radar)	04-0.8 mm and 3-100 mm
Study of arable and non-arable land	0.4-0.9 mm
Assessment of plant growth and rigour for forecasting crop yield	0.4-0.9 mm
Soil type and characteristics	0.4-1.0 mm
Flood control and water management	0.4-1.0 mm and 6-12mm
Surface water inventories and water quality	0.4-1.0 mm and 6-12 mm
Soil and rock type and conditions favorable for hidden mineral deposits.	0.4-1.0 mm and 7-12 mm

Agricultural applications of remote sensing technology could be determined in the following trends:

Estimation of cropland area: An accurate and timely forecasting system of crop production is an essential element in ensuring a country’s food security and proper distribution. In this, remote sensing is of best importance in identifying areas under cultivation.

Pest detection: Brown and Steckler (1995) developed a method to use digitized color infrared photographs to classify weeds in a no-till corn field. The classified data were placed in a GIS and a decision support system was then used to determine the appropriate herbicide and amount to apply. Penuelas *et al.* (1995) used reflectance measurements to assess mite effects on apple trees. Powdery mildew has also shown to be detectable with reflectance measurements in the visible portion of the spectrum (Lorenzen and Jensen, 1989). The ability to detect and map insect damage with remotely sensed imagery implies that methods can be developed to focus pesticide applications in the cropland areas of fields most infected, thus decreasing the damage to beneficial insects.

Crop stress: Crop stress includes anything occurring in the field different than what was planned. Some of the common crop stresses that can be measured are drought, weed patches, soil erosion, nutrient deficiency and similar conditions. When trying to identify these types of stress using remote sensing, one can utilize some of the computer-aided methods or simply use visual methods to discriminate. The ratio of the red to blue to the near-IR scene reflectance can indicate plant stress before it becomes evident on the ground. Emissions in the thermal IR band also can indicate plant health conditions. Many methods have been developed to utilize color-infrared images to classify weeds in no-till cornfields (Brown and Steckler, 1995) and have been established to identify water stress in plants with the difference of remotely sensed surface temperatures and the measurement of ground based air temperatures (Jackson *et al.*, 1981)

Water stress: The difference between remotely sensed surface temperature and ground based measurement of air temperature has been established as a method to detect water stress in plants (Jackson *et al.*, 1981). More recently, methods to integrate spectral vegetation indices with temperature have been used to improve remotely-sensed estimates of evapotranspiration (Carlson *et al.*, 1995; Moran *et al.*, 1994). Moran *et al.* (1994) defined a Water Deficit Index, which uses the response of a vegetation index to account for partial canopy conditions, so that false indications of water stress due to high soil background temperatures were minimized. Spectral indices have also been used to determine "real-time" crop coefficients to improve irrigation scheduling (Bausch, 1995).

Soil properties or soil inventory: Soil investigations, surveys and mapping are three types of applications using remote sensing information. They include three different approaches: the effects of soil properties on reflectance or image response, the influence of soil surface conditions on the response, and the use of imagery in mapping soil patterns. Soil spectral image responses are related to soil organic matter content, i.e., dark soils (higher organic matter) contrast to lighter soil (lower organic matter). The vegetation spectral response can also be used to infer various soil conditions. Yang and Anderson (1996) used these vegetation responses to define management zones within fields. The management zones are an aid to soil sampling as they define logical boundaries for obtaining samples. Remotely sensed images are also being used in "directed soil sampling" where one can map "soil management zones", which would be sampled as separate units. The management zones would become the basis for adjusting nutrient application rates using variable rate technologies

Predicting crop yield: Remote sensing data are used to estimate some of the crop biometrics parameters such as Leaf Area Index (LAI) and crop cover, which in turns are parameters required to predict crop yield. Crop yield is influenced by a large number of biotic factors. The data through remote sensing gives an integrated picture of the effects of all these factors on its growth. Several approaches adopted for predicting crop yield using remote sensing data or derived parameters (Spectral Vegetation Index: SVI) have proved to be of immense use to policy makers.

Nutrient detection: Using remote sensing information to detect field nutrient situations requires a thorough knowledge of what effects nutrient variations can have on the plant and on soils. Soil characteristics, such as color, relate to organic matter content from which one can predict nitrogen (N) release to the plant. Other soil properties such as pH, texture and nutrients such as phosphorus (P) and potassium (K) are difficult to detect. Leaf greenness is related to chlorophyll content, which is directly related to plant N concentration. Most of the nutrient work in remote sensing has focused on N. There have been some encouraging results. For instance, leaf color measurements made at ground level have correlated well with corn plant N status (Blackmer *et al*., 1996).

Vegetation change: Images from the green and near infrared bands highlight the amount of vegetation and give an indication of plant vigor. Some companies have been providing "crop vigor" maps to farmers to assist them in seeing where vegetative growth is occurring and to determine areas within the field were vegetation is not progressing, as it should. Change detection can be accomplished by overlaying images from two flight dates and showing the vegetation change occurring between the two dates.

Detection of crop injury: Hail and wind damage is a common occurrence in many parts of the country. For wheat, the greatest yield effects from hail or wind are usually related to leaf loss, stand loss, or lodging. In each case, the amount or orientation of leaves and stalks is altered and can be measured by remote sensing. Direct damage to the ears, pods or seeds is another component that is difficult to detect and measure directly. Images from non-damaged adjacent areas or before-storm condition would aid in the accuracy assessment. These images normally are color or color infrared. The use of color infrared film assists in the detection of damage areas. Color infrared gives a good indication of the amount or volume of vegetation or biomass present; therefore, lower values of red reflectance reveal vegetation damage or loss.

1.2 The Mongolia and Mongolian agriculture

Mongolia is the 18th-largest country in the world and located in the eastern central part of Asia and covers an area of 1,565,000 sq. km and between the latitudes of 41°35’N and 52°09’N and the longitude of 87°44’E and 119°56’E. (Fig.1) Nearly 90% can be used for agricultural or pastoral pursuits, 9.6% is forest and 0.9% is covered by water. Only, a 1% of Mongolia’s land area is suitable for cultivation. Less than 1% has no effective use.

Mongolia is a landlocked country, between two big neighbors, Russian and China, and no access to the sea. The time zone is 8 hours ahead of Greenwich meantime. Khalkha Mongolian is the official language. The population of Mongolia is 2,754,685 and although in average 1.5 persons occupies 1 sq. km area, half of the population or 1.3 million people live in the Capital city –Ulaanbaatar. Administratively, Mongolia is divided into 21 aimags (prefectures or provinces) and the capital city (Ulaanbaatar). The aimags are subdivided into soums (district). Mongolia has 329 soums. Mongolia has Parliamentary type of governance, with President is second in authority to Parliament.

Figure 1.2 Map of Mongolia (*Source: Google earth*)

The Mongolian agriculture sector has four discrete sub sectors:

- Extensive livestock, which is the traditional semi-nomadic pastoral system, where camels, horses, cattle, sheep and goats are grazed together;
- Mechanized large and small-area crop production of cereals and fodder crops;
- Intensive farming, producing potatoes and other vegetables, with both mechanized and simple production methods;
- Intensive livestock, with housed dairy cattle, pigs and poultry. The livestock sector dominates, contributing 84.9% of total agricultural production.

1.2.1 Peculiarities of Mongolian geography

Although famous for its seemingly endless expanses of steppe, Mongolia is a mountainous country with almost 80% of its territory located at an elevation of 1000 m or more above sea level. The average elevation is 1580 m above sea level with the highest peak being Tavan Bogd (4374m) and the lowest depression being Khuk lake Hollow (560m). Mongolia is surrounded by the Eastern and Western Alpine Ranges; Great Sayan, Buteel and Khentii Mountains in the north; Great Khingan Mountains in the east; Mongolian Altai and Gobi-Altai Ranges in the south-east and south; Khan Khuhii and Khangai Mountains in the west and the Gobi Desert in the south.

1.2.2 Climate

Nomadic Mongols migrate across mountains, steppe and desert of their expansive mainland throughout four seasons of the year.

Mongolia has an extreme continental climate with hot summers, a cold winters, windy and dry springs and pleasantly warm autumns.

January is the coldest month of the year with a mean temperature of 35^{o}C in the northern parts (with the lowest temperature of -50^{o}C at the Depression of Great lakes and mouth of the Tes River) and -10^{o}C in the Southern Gobi. Summers are short. Mean July temperatures range from $18\text{-}26^{o}$C with a maximum of 40^{o}C. Frost is possible at any time of the year, and frequent unseasoned frost in late spring and early autumn can adversely affect both quality and yield of crop output. Mean annual precipitation is 200-300 mm in the northern portion of Mongolia, 400-500 mm in the southern portion of the country. More than 80% of the precipitation falls between the May and September. The dry weather conditions prevalent in the planting season in may make successful crop establishment difficult. Strong spring winds precede the onset of the summer rains, causing high evaporation and soil erosion in cultivated areas. Climatic stress, particularly unseasoned frosts and drought can cause harvest losses of between 10 and 40%.

1.2.3 Open and underground water

Small and big lakes, streams and rivers are abundant in the northern portion of Mongolia. Major rivers originating from the Altai, Khangai, Khentii and Khuvsgul Mountains drain into the Pacific Ocean basin, while small rivers and streams flow into small likes. Of the 3811 streams and rivers in Mongolia, the Selenge river is the largest with a total length of 600 km ranging in depth from 70 to 200 m in width and averaging 6-7 m in depth.

The Selenge River is fed by converging tributary rivers such as the Tamir, Khangai, Tuul, Orkhon, Delger and Egii Rivers with a water collection area of about 400 000 square kilometres. The Kharaa and Eroo Rivers coverage with the Tuul River that originates on the soutern slopes of the Khentii Mountains. The longest river draining into the Pacific Ocean is the Kherlen River. Its length is 1264 km, of wich 1090 km flows through the territory of Mongolia. Its depth average 135 cm in spring and 193 cm in summer and autumn. The deepest river draining into the Pacific Ocean is the Onon River (222 cm depth), wich flows 300 km thought Mongolia. The second deepest river emptying into the Pacific is the Ulz river, wich is 428 km long. There are several large rivers with no access to the sea, such as the Tes, Khovdo, Zavkhan, Baidrag, Tuin, Ongi and Bulgan rivers.

There are more than 3000 lakes and ponds in Mongolia. Of them, 80% are saline. The largest is Khuvsgul Lake which is 134 km long and 35 km wide. Additionally, there are more than 190 cold rivers, 250 cold and hot springs. Almost 65% of the territory of Mongolia has no open water sources and 45-50% of its nearly unused because of the lack of water. About 35% of exploitable underground water sources are found in the Dornod plain, 25% in the Khangai-Khentii Mountains, 32% in the Gobi and 8% in The Altai Mountains. In the other words, 70% of underground water resources can be found in the Gobi and steppe zones, which have limited water sources.

Stretches of fertile grassland along rivers and lake are dominated by meadow vegetation, which can be irrigated using simple flooding methods. During the 1980-1990 years more than 90 000 hectares of hay-land were irrigated. There are considerable opportunities to utilize open water sources for irrigated crop production by means of flow challenging and the building of water reservoirs

1.2.4 Soil and vegetation

Mongolian location between the Siberian taiga and Central Asian deserts has resulted in great variations in Mongolia soil and vegetation structure. Mongolian terrain is divided into the Central Asian and Dzungariin Gobi Regions or the Khangai and Gobi Regions, as well as latitudinal, altitudinal, and mixed zones with 58 districts.

1.2.5 Agro ecological regions of Mongolia

The territory of Mongolia is divided into six natural (vegetation) zones (alpine, taiga, wooded steppe, steppe, desert steppe and desert) with markedly different terrain, climate, flora and fauna and divided into five main agro-ecological regions with a certain bio-climatic potential (Enkh-Amgalan 1997), see figure 1-3 and table 1-2.

The agro-ecological region is based on topography, climate, soil and natural vegetation types. The agro-ecological zones differ greatly with respect to soil fertility and plant cover. The productivity and yield of pasture varies over time and depends on (agro) ecological region, e.g. with respect to thawing rate of soil, vegetation composition and growth rate and its sensitivity to amount of rainfall.

The semi-forest steppe and steppe zones is commonly rich with a dark chestnut and brown soil with high fertility. This soil type covers over 60 % of Mongolia territory. The semi-desert and desert zones consist of gray brown soil with poor organic elements and heavy salinity. The mountainous ranges and areas of Western and northwestern Mongolia contain a fertile dark brown soil cover. Vegetation in mountainous and steppe zones consists of a rich variety of species, whereas the Gobi desert has a scarce flora.

Land suitability for crop agriculture is determined by combinations of climate and physical factors including precipitation, elevation, temperature, frost free days, soils and topography. Only valley bottomland and the lower slopes of hills with sufficiently deep soils are cultivated. A smaller cultivated area is widely distributed in the Khangai-Khovsgol Region in the northwest and central and Eastern Steppe region. Cultivated land is primarily devoted to rain fed cereal grains, mostly wheat. Only, about 3% of the cultivated area is irrigated. The irrigation systems comprise numerous small schemes totaling 57, 000 ha located primarily in the north-central and western parts of the country. However, many schemes are no longer operational due to inadequate maintenance, and only about 35, 000 ha are currently being irrigated. Crops grown under irrigation include cereals, potatoes, vegetables and fruit. The principal crop growing areas are in the central part of the country and included Selenge, Tov and Bulgan aimags, which account for about 70% of total cultivated land.

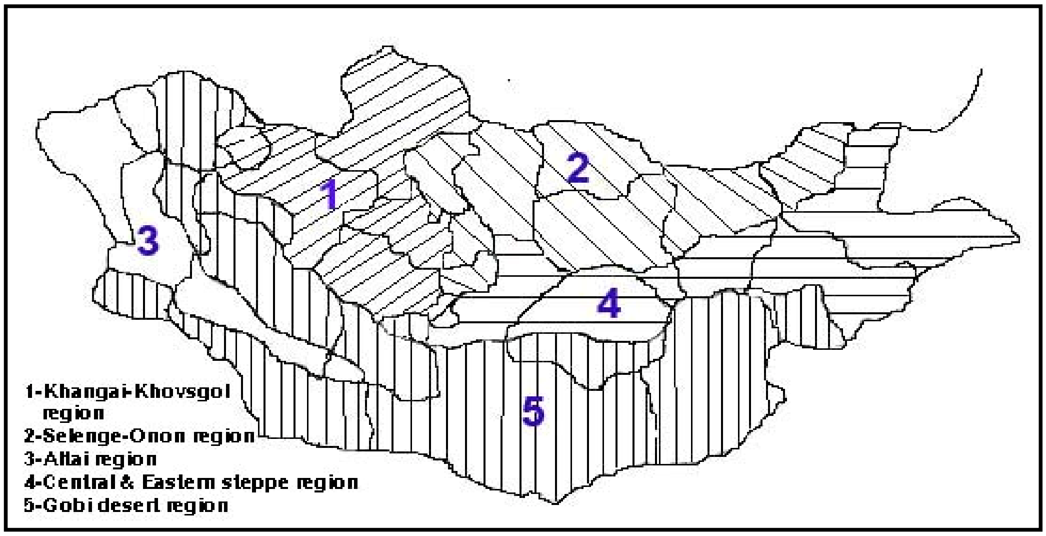

Figure 1-3 the major 5 (I-V) agro-ecological regions in Mongolia

1. Hangai-Hovsgul Region

The Hangai-Hovsgul Region is situated in the northwest portion of Mongolia. This is a mountainous region of high elevation (2,000 to 3,000m) and deep valleys with some forest and arid steppe (Tsegmid.S et al., 1990, Gunin PD et al., 1999); mean annual temperature is -2.5°C to 7.5°C with the lowest temperature in January (-24°C) and warmest temperature in July (19°C); 60 to 100 frost-free days; and an annual precipitation of 200 to > 400mm (Batjargal Z.1996). Wind speed averages between 2-4 m/sec, and snow cover is often > 15 mm in depth (Tsegmid S et al., 1990).

2. Selenge-Onon Region

The Selenge-Onon Region consists of broad valleys and plains with elevations between 1,500 to 2,000m (Tsegmid S et al., 1990), mean annual temperature of 0.0°C to 2.5°C with the coldest temperature in January (-20°C) and warmest temperature in July (19°C); 70 to 120 frost-free days; and an annual precipitation of 250 to 400mm. Snow cover averages 5 to 10mm in depth, and wind speed averages 4-6 m/sec (Tsegmid.S et al., 1990).

3. Mongolian Altai Region

The Altai Region is located in western Mongolia and has two distinct districts. The first district is the Mongolian Altai, which stretches from the northwest to the southeast for more than 1,500 km. The second district is the Turgen Mountains and Lake Ureg-Nur. These districts have elevations ranging from 1,500 to 4,000m (Tsegmid S et al., 1990); mean annual temperatures of -2.5°C to 5.0°C with the coldest temperature (-24°C) in January and warmest temperature (22°C) in July; 60 to 120 frost-free days; and an annual precipitation of 400 to 500mm (Batjargal Z.1996). Snow depth ranges between 5 to > 15mm, and wind speed averages 2-6 m/sec (Tsegmid.S et al., 1990).

4. Central and Eastern Steppe Region

The Central and Eastern Steppe Region is the broad, essentially treeless region in central and eastern Mongolia (Lavrenko E.M.1983), which is characterized by low knolls, hills, and high plains. This region has elevations ranging from 900 to 2,000m (Tsegmid.S et al., 1990); mean annual temperature of 0.0°C to 2.5°C with the coldest temperature in January (-20°C) and warmest temperature (22°C) in July; 110 to 140 frost-free days; and an annual precipitation of 150-250mm (Batjargal Z.1996). Snow depth ranges between 5 to 10 mm, and wind speed averages 4-8 m/sec (Tsegmid.S et al., 1990).

5. Gobi Desert Region

The Gobi Desert Region includes the semiarid and arid southern portion of Mongolia. This region has elevations ranging between 700 and 1,400m (Tsegmid.S et al., 1990); mean annual temperature of 0.0°C to >2.5°C with the coldest temperature in January (-20°C) and warmest temperature (23°C) in July; 90 to >130 frost-free days; and an annual precipitation of 100mm (Batjargal Z.1996). Lack of snow as a water source is a major factor limiting livestock production in the Gobi Desert Region.Wind speed averages 2-8 m/sec (Tsegmid.S et al., 1990).

Table 1-2 Climatic information AEZ

Zone	Av.Elev (000 m)	Mean annual (C^{o})	Temp Jan (C^{o})	Temp Jul (C^{o})	Heat sum >10C^{o}	Grow/ days	Frost free days	Precipi-itation (mm)	Snow cover (mm)	Wind speed (m/s)
1	2.2-3.0	-2.5-7.5	-16-30	6-19	400-2000	70-100	60-110	200-400	>15	2-4
2	1.5-2.2	0-5.0	-16-24	15-19	1000-2000	70-100	80-120	250-400	5-10	4-6
3	1.5-4.0	-2.5-5.0	-16-24	8-22	400-2600	70-120	60-140	400-500	5-15	2-6
4	0.5-2.0	0.0-2.5	-20-24	15-22	1400-2600	90-130	110-140	150-250	5-10	4-8
5	0.7-1.4	0.0-2.5	-16-24	19-23	2000-3000	90-130	120-140			2-8

1.2.6 Mongolian agriculture and land fragmentation

Agriculture is one of the most important sectors of the Mongolian economy, as it is the major source of employment and the main land and water user. Increasing the level of self-sufficiency in the production of strategic crops (e.g., wheat, barley, potato and vegetables) is one of the objectives of Mongolian policy makers. Currently, Mongolia is importing a significant part of its national requirements for these crops. For economic and social reasons, increasing national production and the level of self-sufficiency is urgently needed.

Mongolia began to cultivate virgin lands at the end of the 1950, 1976 and 2009 years. Virgin Lands programs increased the area under crops from 265,000 hectares in 1960 to a peak of 838,000 ha in 1989. The 1980s saw a major growth spurt as Mongolia was more tightly integrated into the Council for Mutual Economic Assistance (CMEA) international planning system. With large inflows of capital, inputs and technology from Eastern Europe and the Soviet Union, net imports amounted to a massive 30% of GDP.

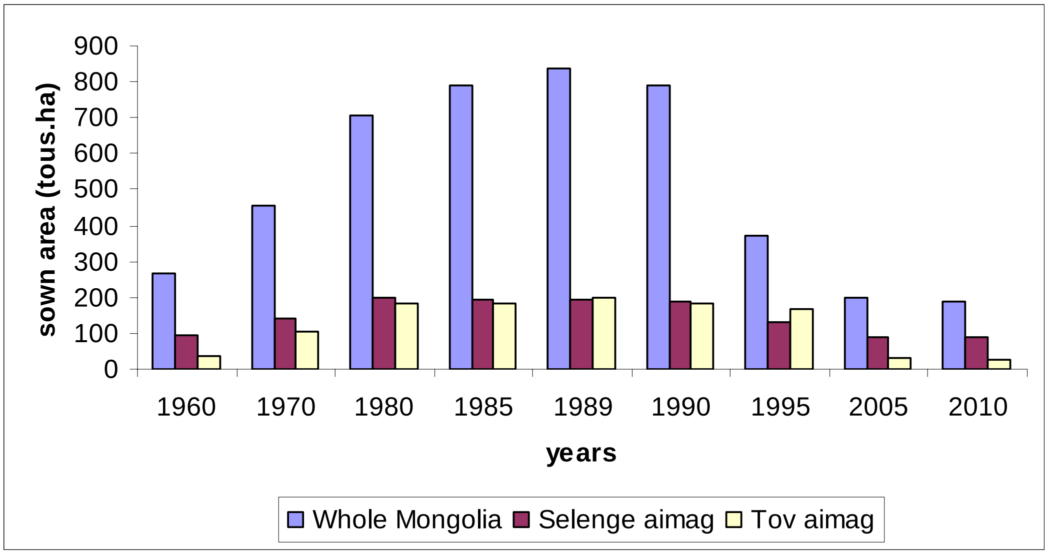

Figure 1-4 Whole Mongolian cultivated areas with Selenge and Tov aimags

Since 1989, all formerly centrally planned economies of Mongolia like that Central and Eastern Europe have been making radical changes in both their political and economic systems. From 1990s, Mongolia entered a period of transition from a central-based planned economy to a market economy and all cooperatives (farming) are in deep crisis and crop production has dropped. The negative output performance of the first half of the 1990s was centered on agriculture, industry and some mining activities. The sown area declined from its 1989 peak of 837,900 to 372, 600 hectares in 1995, as supplies of mechanical and chemical inputs were cut off.

Mongolia's transition experience since 1991 has been positive, but difficult. Each has followed its own way and time path, although there are clearly common characteristics. One of those characteristics is the policy of transferring public and collective property to private ownership. Privatization is considered essential to the process of reform for three main reasons: in first, to establish well-functioning markets, secondly to create incentives for decision makers to act in response to market signals, and third one is to assure irreversibility of the reforms themselves (World Bank, 1995). During the 70 years of communist rule, agriculture was led, as was the whole Mongolian economy, by centralized laws and bureaucratic methods of command and control which gradually brought about economic and social stagnation. This stagnation was attributed to some factors that were considered to be deeply rooted in the Mongolian socialist system such as: the mismanagement, financial imbalances, the collectivization campaign, bad structural policy, and misallocation of investments and resources.

The so called “shock therapy” underlying the political and economic reform applied in Mongolia at the beginning of 1990s, brought about a new structural framework in the agricultural sectors. The state-controlled cooperatives and state farms were broken up and new production structures composed of a great number of small-scale farms emerged. In the command system, agricultural production was centrally planned and directed, as was the research and extension system. Therefore, the existing institutions of agricultural research and extension could not continue functioning in the same way as with the previous production structures. Under these circumstances, there was a pressing need to reconfigure technology institutions including research and extension in support of evolving production structures.

The present private farm units in Mongolian agriculture suffer from a lack of balance between production factors available to each farm and institutional structures needed to support efficient agricultural operations. Many elements of the old agricultural institution system have either stopped functioning due to shortage of public funds, or do not respond to the deep political, social and economic changes that have occurred in Mongolia during the past 15 years. Mongolian farmers are operating production and market activities in the absence of an integrated system of technology institutions such as agricultural research, extension service, and agricultural education. Actually, institutional change in Mongolian agriculture is happening very slowly.

The change to a market-oriented economy had also an impact on the natural resources and their management, not only due to privatization, but also because of the strong land fragmentation as a result of the land distribution and increased urbanization. For the first time in 30 years people were free to move around. The rural population sharply decreased because of urban drift or migration abroad. The increasing pastoral economy and husbandry caused landscape degradation and natural resources depletion in many regions of the country. Uncontrolled timber harvesting, gold-mining area, overgrazing and overexploitation of wood and other forest products have changed environmental assets. The depletion of forest and water resources, particularly in accessible areas, has become alarming. Scarce possibilities of control and a lenient policy caused severe, sometimes even irremediable, damages to the natural resources of Mongolia (B.Erdenee., et all, 2010). In a subsequent phase many cropland areas were abandoned and changed followed by people left the rural areas to become resident in urban centers. These urban centers, however, were not prepared to receive the massive influx of people. In the turmoil of such a changing economy and the spatial and temporal dynamics of land cover/use that are continuously evolving, it is important for the Mongolian government to have accurate and timely information for natural resources management, land-use planning and policy development, as a prerequisite for monitoring and modeling land-use and environmental change and as a basis for land-use statistics.

From the 1990, Mongolian agriculture has been greatly accelerating, the natural and labor resources being replaced with the economic collapse and mining industrial inputs. At the same time, some trends appear to have reduced the environmental impact by reducing the amount of artificial chemicals released into the environment, so as to ensure its sustainability.

Like other European countries, Mongolia is now in the midst of transition toward developing a functioning market economy. It has already privatized agriculture, housing, small and medium industries and is working on privatizing large state enterprises.

Mongolia is an agricultural country and as such the role of agriculture within the Mongolian economy has historically been and will continue to be the predominant factor in its growth and development for many years. Actually, half of country’s GDP comes from the agricultural sector and it employs over 50 per cent of the total work force. Some 50 per cent of the population lives in rural areas. Therefore, it is necessary to have an agricultural LCLU analyze and crop monitoring framework to support it.

1.3 Problem Formulation

The discussion about development of the agricultural sector has often centered on the question of how to achieve adequate food security, while simultaneously providing sufficient income for food producers. Agricultural sector development is strongly related to land use. The way land is used has obvious implications for food security, economic development and the environment. Land in developing countries is increasingly subject to population pressure, soil degradation and pollution (Lal, 2009). The issues and dimensions involved in land use policy analysis are very complex. Moreover, land use problems deal with multi-purpose use of land, trade-offs between different functions of the land, and conflicting interests among different categories of stakeholders and between individual and collective goals and needs. Under these conditions, designing policy interventions supporting successful land resource management for agricultural development, to satisfy changing human needs, while maintaining or improving the quality of the environment and conserving natural resources in developing countries, presents an enormous challenge to all those concerned (Fresco et al., 1992).

Plant biotechnologies have been developed; around the world researchers are examining a wide range of possibilities for improving the productivity of crops, ranging from developing crops with resistance to herbicides and insect pests, to crops with an increased ability to withstand drought or frost. In addition, new techniques remote sensing and precision agriculture are leading to better methods of producing and managing agricultural products, but primarily within the developed world.

Remote sensing has been used to monitor vegetation for a few decades. It provides timely information over large areas of economic importance for example wheat and other crops (Penuelas and Inoue, 1999; Osborne *et al*., 2002a). Crop health and productivity can be estimated by almost instantaneous non-destructive data acquisition over vast areas (Clevers, 1997). Also, the innovative technique of airborne remote sensing can provide valuable information in crop stress management (Steven 1993, Reyniers *et al*., 2004).

Such timely information concerning crop productivity is of vital importance for decision makers, from small-scale farmers to the national government, providing a potential way forward for increasing crop productivity whilst using water resources more efficiently.

Monitoring water status has traditionally been based on destructive sampling. Furthermore, monitoring plant status using sample-point technique is tedious, laborious and a costly process. A promising alternative is the use of remotely sensed measurements as a quick, reliable and non-destructive tool that integrates the plant response to water stresses.

Therefore, the relative change in the reflected light energy from the plant canopy could be used as a key link between various combinations of stress.

1.4 Research objectives are:

- **To monitor and mapping principal crop land area of Mongolia**
- **To characterize the farming sector in Mongolia and to develop parcel based crop land information system in the intensive agricultural land area**

- **To investigate a drought index in wheat planting area using remote sensing data**

Selenge and Tov aimag are producing most of Mongolian agricultural output including the main crops like wheat, fodder crops and vegetables. In the last two decades, different positive and negative land cover changes have been occurred in this area. For this reason, remotely sensed satellite data was used to estimate and analyze these changes, which will help the agricultural strategist to launch better agricultural policies or modify the exiting ones.

Beside the analysis of the development of farming movement in Mongolia, we aim, in particular, to understand the reasons for converting to precision.

Drought are major inhibitors to Mongolian agronomic production and increasing efforts to remotely detect the effects of moisture induced stress for irrigation management are needed since few studies have quantitatively assessed the ability of remote sensing technology to characterize simultaneous water stress on crop yields (Poss *et al.*, 2006).

1.5 Outline of the thesis

This thesis comprises different chapters.

Chapter 1 includes general introduction, statement of the problem, the objectives of the study and the background for understanding the previous work related to the main points and general outline of the thesis.

Chapter 2 it describes the resource bases and Mongolian agriculture and location, climatic conditions the study area

Chapter 3 studied the cropland use/ cover changes of the study area through integration of visual interpretation through GIS.

Chapter 4 introduced about a precision agriculture technology and presents a study about to design cropland information system. Case study: Tsagaannuur district, Selenge, Mongolia and importance of this information system.

Chapter 5 investigate specific methodology for remote sensing based crop stress index in the wheat area of Mongolia

Chapter 6 summarized the results and gave general conclusions and recommendations

Appendix and reference

Figure 1-5 is presented general methodology of this thesis.

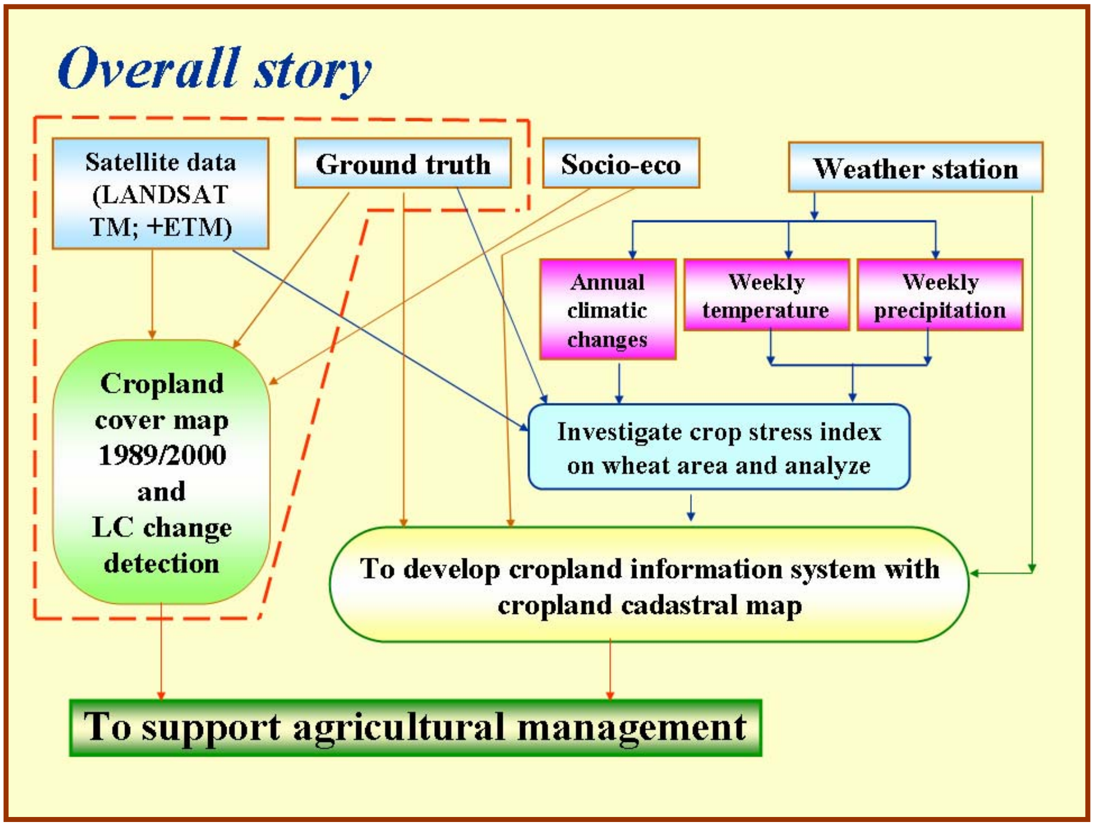

Figure 1-5 General methodology of the thesis

2. Description of the study area

2.1 Location

The selected study area Selenge and Tov aimag is prime cropland regions and located in the Northeastern part of the Mongolia, measuring approximately 41,152.63 sq and 75,000sq, respectively. The geographic boundaries of the area are 47° 30′ 0″-47° 50′ 0″ N, 106° 15′ 0″-106° 25′ 0″ E (Figure2.1).

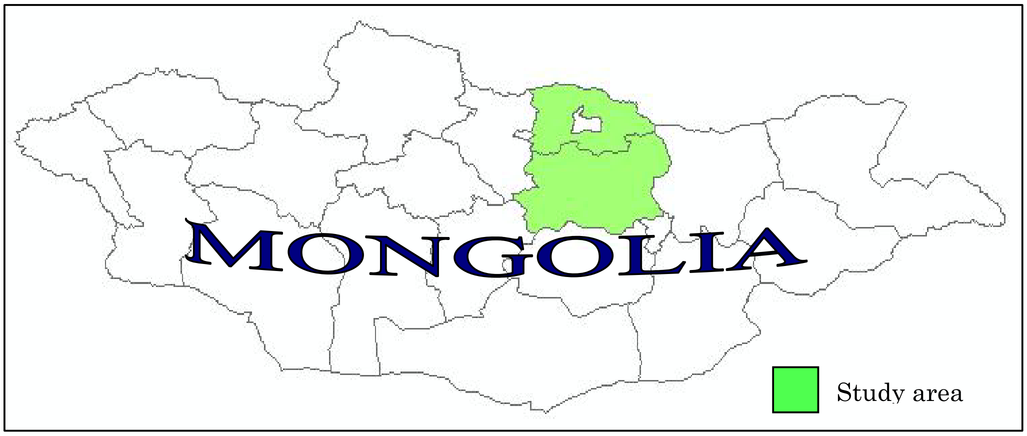

Figure 2.1 Location of the study area

Selenge aimag is produces 60 percent of grain and Tov aimag is produces 22 percent of grain and about 70% of vegetables of the country. The climate of the region is semi-arid and arid; the growing season is 100 to 120 days in duration and annual precipitation ranges from 200-350 mm.

The main crops being grown in this region are wheat, fodder crops, potato, and some vegetables. Except for wheat, fodder crops are rain fed and potato, vegetables semi irrigated. The planting dates of wheat and fodder crops are mostly planted in from the mid of May to October period. For vegetables planting starts in the end of May and continues until the end of August and mid-September. Almost all the crops present an important vegetative development in the June–August period. The wheat is harvested between September and early October. Vegetables are harvested gradually from late July to September.

2.2 Resource base

2.2.1 Climate

The extreme continental climate, with long cold winters and low precipitation, is a serious constraint to agricultural production.

Mongolia also has a relatively dry climate with prolonged sunshine days and plentiful precipitation in summer and little snowfall in winter (Dashdondov and Bakey 2000). About two thirds of all precipitation and almost all growth of vegetation take place during May to September. In September the winds turn to the north-east and convey cold temperatures, dust and little or no moisture from the dry and extremely cold regions of Siberia (Sheehy, 1993). Large fluctuations in temperature occur, with a maximum difference in temperature between day and night of 20°C-30°C and annually up to 90°C.

2.2.2 Rainfall

Rainfall is concentrated in the summer period with 65-75% of rainfall occurring between June and August. The dry weather conditions prevalent in the planting season in May make successful crop establishment difficult. Strong spring winds precede the onset of the summer rains, causing high evaporation and soil erosion.

2.2.3 Air temperature

The ranges of variation in air temperature between different years are quite small. Highest temperature degrees are recorded during July and August and then decrease gradually to their minimum in December and January; 70 to 120 frost-free days; and an annual precipitation of 250 to 400mm. The lowest temperatures are observed in January and February. Spring begins in the firstly weeks of May and there is a marked increase of the maximum day temperature above 15-20^{o}C but the nights in general remain cool. March, April are characterized by frequent "sand storm" bringing the maximum temperature over 10^{o}C or even 20^{o}C for 2-3 days at a time. The summer lasts over 3 months, from June till the end of August. The temperature is warm and is fluctuating between 18-21^{o}C, the night temperatures are rather high particularly in August and September (more than 15^{o}C).

2.2.4 Air Humidity

Relative air humidity ranges between 60-70 percent. Maximum relative humidity is occurs at July and August.

2.2.5 Wind

Different investigations indicate that the wind speed, at an altitude 1.5-2 meters, range between 2.5-3.0m/s. The prevailing wind is mostly from the north.

2.2.6 Soil

The arable soils of Mongolia comprise dark chestnut and chestnut soils, which are classified as Mollisols (see more, http://en.wikipedia.org/wiki/Mollisols) and are typical of soils that evolved with steppe vegetation. Similar soils are found in the Great Plains of North America, parts of South America and a large part of Central Asia. Covering about 40% of the country, these are inherently fertile but shallow soils, with an average depth of 30 cm. These soils have organic matter content 3-4% and are slightly acid to neutral with a pH of 6.0-7.0. Because of their light texture, moisture retention is low and the soils are susceptible to erosion.

3. Mapping and monitoring principal crop land cover/ use changes in Mongolia

3.1 Introduction

Crop area mapping and estimation is an essential procedure in supporting policy decisions on land use allocation, food security and environmental issues. Nevertheless, producing agricultural statistics in regions with limited financial resources and restricted access is a challenging task. Agriculture is one of the major economic sectors of Mongolia, representing around 40% of their gross domestic product.

Land use affects to land cover and changes in land cover affect to land use. The driving forces to this activity could be economic, technological, demographic, scenic and or other factors. Hence, Land Use and Land Cover dynamics is a result of complex interactions between several biophysical and socio-economic conditions which may occur at various temporal and spatial scales (Reid *et al.*, 2000).

A remote sensing device records response which is based on many characteristics of the land surface, including natural and artificial cover. An interpreter uses the element of tone, texture, pattern, shape, size, shadow, site and association to derive information about land cover.

However, crop areas are currently estimated using a subjective approach, which is mostly based on interviews carried out with local producers. Although such an approach can sometimes retrieve relatively accurate figures, it is highly subject to biases and uncertainties. Moreover, it is costly and slow, given that it requires a large number of agents and vehicles to carry out the interviews.

During the last years, remote sensing techniques and Geographical Information Systems (GIS) have proven to be efficient tools to monitor agricultural activities. However, although remote sensing has proven to be useful in different agricultural applications, many limitations are still faced in the operational usage of this tool to estimate crop areas. Consequently, the integration of remote sensing techniques with ground surveys has been the focus of much research in past years (Pradhan, 2001; Epiphanio et al., 2002; Gallego, 2004).

In Mongolia, inappropriate agricultural practices, deforestation and overgrazing are affecting crop and livestock productivity of the rural poor and hence their livelihoods.

From 1990s, Mongolia entered a period of transition from a central-based planned economy to a market economy. In the turmoil of such a changing economy and the spatial and temporal dynamics of land cover/use that are continuously evolving, it is important for the Mongolian government to have accurate and timely information for natural resources management, land-use planning and policy development, as a prerequisite for monitoring and modeling land-use and environmental change and as a basis for land-use statistics.

The objective of this research was to investigate principal cropland areas changes in Mongolia, by integrating a GIS and remote sensing techniques.

3.2 Study area

The selected study areas Selenge and Tov aimags are prime cropland region and located between 47^{o}30`00``North and 106$^o$30`00``East in the Northeastern part of the Mongolia and it covers about 115195 km^2. In this area covers mostly forest-steppe, steppe and is rich in chernozem soil. The climate of the study area is arid and semi arid type. Detailed description of the study area is shown in Chapter 2.

3.3 Materials

Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) images (with parth/row 132/25-27, 133/25, and 131/26-27) acquired on 1989 and 2000, respectively, field data were used to map agricultural land cover changes in the study area.

The baseline date for the mapping was 1989 and 2000 separately but, to accommodate any image shortage, e.g., due to 10% cloud cover, plus and minus 1 to 4 years allowed. Mostly images were cloud free and of good quality. The ideal “summer” period covered the main plant growing season, June to late September. Three LANDSAT paths cover study area and 15 scenes were required for this study. The satellites orbit at an altitude of 705 km and provide a 16-day. These satellites also were designed and operated to collect data over a 185-km swath.

Table 3.1 Used data

LANDSAT Path-Row	Acquisition date	
	Landsat-5 TM	Landsat-7 ETM
133-25	29 September, 1989	11 September, 2000
132-25	21 August, 1989	24 July, 2002
132-26	21 August, 1989	20 September, 2000
131-26	01 October, 1989	13 September, 2000
131-27	30 August, 1989	31 August, 2001
132-27	12 September, 1994	20 September, 2000
130-27	24 September, 1989	26 July, 2002

3.4 Methodology

3.4.1 Data preprocessing

3.4.1.1 Geometric and radiometric correction and image registration

Since your ETM+ image already has a projection (UTM) and datum (WGS84), so we can directly convert it from one projection to another without any problem. Before calculating NDVI's, atmospheric correction, geometric correction and image registration are conducted. Dark-object method for atmospheric correction proved to be an effective way and is used to correct the images. Although the Digital Number (DN) of red and near infrared bands can be used to derive NDVI directly, it has been proved that reflectance could perform much better than DN value in terms of computation of NDVI's. All the images are processed by radiometric correction individually. Radiometric correction is done for the red and near infrared image obtained from different sensors.

Radiometric and atmospheric normalization:

The radiometric and atmospheric normalization of the Landsat TM image to the Landsat ETM (reference) image involved the following phases:

1. Selection of normalization targets;
2. Registration of the DN values of the selected targets in both images;
3. Regression of the DN values of the image against the DN values of the reference image;
4. Calculation of the Landsat normalized image.

Image registration is the process of overlaying two or more images of the same scene taken at different times, from different viewpoints, and/or by different sensors. It geometrically aligns two images-the reference and sensed images. The present differences between images are introduced due to different imaging conditions. Image registration is a crucial step in all image analysis tasks in which the final information is gained from the combination of various data sources like in image fusion, change detection, and multi-channel image restoration.

Two methods are used for geometric correction and registration: one is map to image method, and the other is image to image method. Global Positioning System (GPS) was used for ground truth survey at the representative land cover areas, and more than 100 Ground Control Points (GCPs) were selected.

Landsat 7 ETM+ imagery has been used to produce the baseline interpretation of 2000 using on-screen digitizing and visual interpretation. For the 1989 visual interpretation use has been made of Landsat 5 TM images (Table 3.1). For interpretation purposes the multiple view approach was selected combining multi-stage sensing (i.e. high-resolution satellite data is analyzed in combination with low altitude data such as topographic maps, and field survey data), multi-spectral sensing (i.e. data are acquired simultaneously in several spectral bands) and multi-temporal sensing (i.e. data about the terrain is collected at different dates). The 2000 images have been geo-referenced using the topographic maps of the Mongolian Military Geographic Institute at scale 1:100,000 (image-to-map approach) and the 1989 images have been geo-referenced according to the geo-referenced 2000 set (image-to image approach) and the RMS error between the two images was less than 8.55 m which is acceptable. Nearest-neighbor re-sampling was performed.

3.4.1.2 Image enhancement and visual interpretation

In the interpretation process various levels of complexity exist, from simple direct recognition of objects in the scene to inference of site conditions. The interpreters use the process of convergence of evidence to successfully increase the accuracy and detail of the interpretations. During the interpretation process special attention was paid to: (1) the spatial coherence of polygons, i.e. are the boundaries in the appropriate place and have the same logical and functional thinking been applied in a consistent manner in the area of interpretation; and (2) the thematic coherence, i.e. is the label given to the polygons correctly describing their contents and are other areas with similar features described in the same manner. A continuous crosschecking of the 1989 and 2000 interpretations was necessary in order to guarantee spatial and thematic coherence within the interpretations and between them. The 1989 interpretation has been validated using 231 field observations and 108 additional observations.

Data processing and analysis operations were carried out using ENVI 4.3 and PCI GEOMATICA Image Analysis software. Color composite of bands 5, 4, 3 was generated for the images and visual interpretation was performed. Figure 3.1 and Figure 3.2 show the (5, 4, 3) color composite of the data.

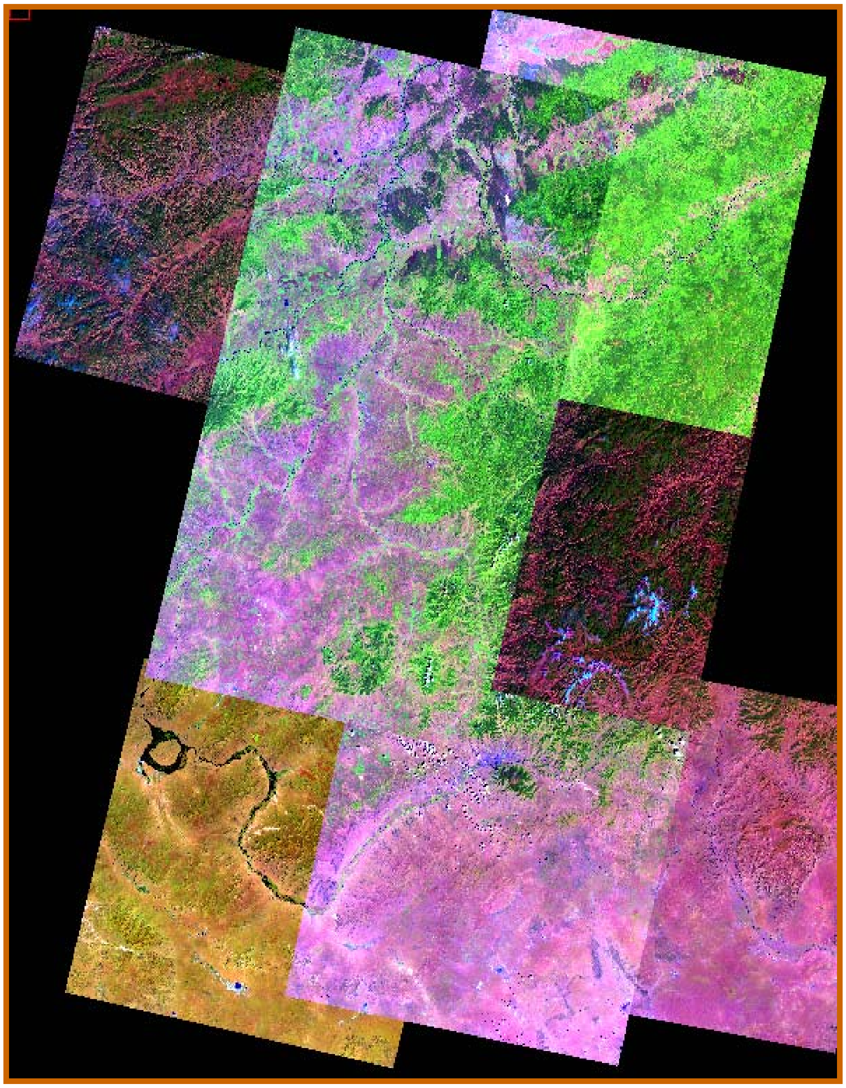

Figure 3.1 (5 4 3) color composite of Landsat TM data acquired in 1989

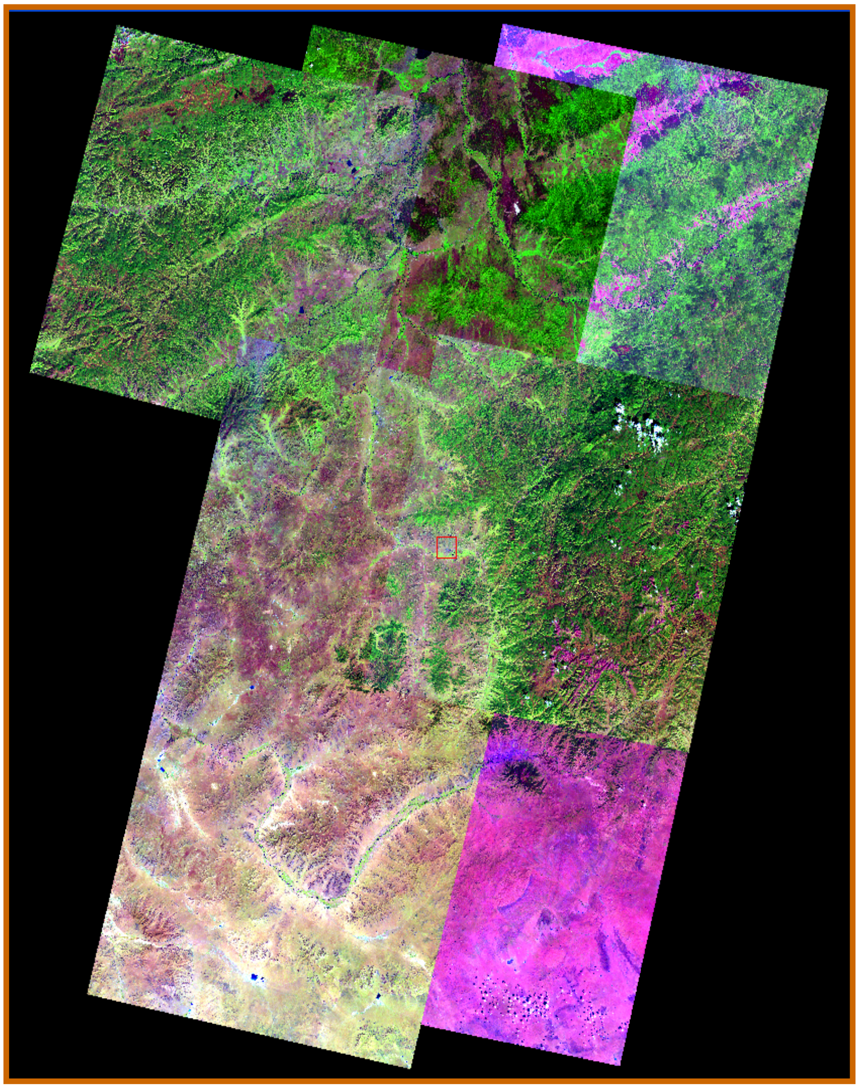

Figure 3.2 (5 4 3) color composite of Landsat ETM data acquired in 2000.

3.4.1.3 Supervised classification

Supervised classification was used to produce agricultural land cover map for the study area. Supervised classification is one procedure most often used for quantitative analysis of multidimensional remote sensing image data. It rests upon using suitable algorithms to label the pixels in an image as representing particular ground cover types, or classes. A variety of algorithms is available for this, including those based upon probability distribution, fuzzy logic and neural network models for the classes of interest. Irrespective of the particular method chosen, the essential practical steps are:

1. Decide the set of ground cover types into which the image is to be segmented. These are the information classes and cloud, for example, be water, cropland, urban regions, mountain ranges, etc.
2. Choose representative or prototype pixels from each of the desired classes. These pixels are said to form training data for the classifier. Training sets for each class can be established using proto interpretation of a color composite image formed from the image data.
3. Use the training data to estimate parameters of the particular classifier algorithm to be used; these parameters will be the properties of the model used, sometimes called the spectral signature of that class.
4. Using the trained classifier, label or classify every pixel in the image into one of the desired ground cover types. Whereas the training in Step 2 may have required the user to identify perhaps 1% of the image pixels manually, the algorithm will label the rest by classification.
5. Produce tabular summaries or thematic (class) maps which quantify the results of the classification.

Maximum likelihood (ML):

ML classification seems to be the most common supervised classification method used with remote sensing image data. The approach followed in this thesis uses Baye’s theorem for the maximum likelihood decision rule, and multivariate normal class models. The algorithm derivation is presented below:

Let the spectral classes for an image scene be represented by

$$\omega_i, i = 1,\dots M \qquad (1)$$

where M is the total number of classes. In trying to determine the class or category to which a pixel at location x belongs to is strictly the conditional probabilities

$$p(\omega_i \mid x), i = 1,\dots M \qquad (2)$$

that are of interest. The position vector x is a column vector of intensity values for the pixel, which describes the coordinates in multi-spectral space of the pixel. The probability $p(\omega i \mid x)$ gives the likelihood that the correct class is ωi for a pixel at position x. Classification is the performed according to [7]

$$x \in \omega_i \text{ if } p(\omega_i|x) > p(\omega_j|x) \text{ for all } j \neq i \quad (3)$$

or, the pixel at x belongs to the class ω_i if $p(\omega_i|x)$ is the largest. Despite the simplicity of this decision rule, these posterior probabilities are unknown. Training can be used to instead estimate the class-conditional probability density $p(x|\omega_i)$, which describes the chance of finding e feature vector from class ωi at the spectral position x. The desired $p(\omega_i|x)$ and the available $p(x|\omega_i)$ are related by the Baye's theorem [7]:

$$p(\omega_i|x) = \frac{p(x|\omega_i)p(\omega_i)}{p(x)} \qquad (4)$$

Where $p(\omega_i)$ is the prior (a *priori*) probability of class ω_i, and p(x) is the probability of finding any class at position x. Introducing (4) into the decision rule of (3) modifies the class decision to [7]:

$$x \in \omega_i \text{ if } p(x|\omega_i)p(x\omega_i) > p(x|\omega_j)p(\omega_j) \text{ for all } j \neq i \qquad (5)$$

where p(x) has been conveniently dropped as a common factor. This new decision rule is more acceptable since the class conditional probabilities are know from training data, and the analyst can conceivably estimate $p(\omega_i)$ visually from the scene (or assume equal class probabilities without much penalty). Defining discriminate functions $g_i(x)$ [7] such that

$$g_i(x) = p(x|\omega_i)p(\omega_i) \qquad (6)$$

permits the final decision rule used in maximum likelihood classification to be defined as:

$$x \in \omega_i \text{ if } g_i(x) > g_j(x) \text{ for all } j \neq i \qquad (7)$$

This classifier requires some model for the class conditional probability distributions to function. This could be estimated from analysis of the data; however, a commonly held assumption is that each class can be modeled by multivariate normal density functions. In (6) it is therefore assumed for N spectral bands that [7]

$$p(x|\omega_i) = \frac{1}{(2\pi)^{N/2}\left|\sum_i\right|^{1/2}} e^{\left[-\frac{1}{2}(x-m_i)^T \sum_i^{-1}(x-m_i)\right]} \qquad (8)$$

Where m_i and $\sum_i$ are the mean vector and the NxN covariance matrix for each class ωi. An unbiased estimate for the covariance matrix is given by [7]

$$\sum_{i} = \frac{1}{q_i - 1}\sum_{j=1}^{q_i} \left\{ \left(x_{j-m_i} \right) \left(x_j - m_i \right)^T \right\} \qquad (9)$$

Where q_i the number of training is samples in class ω_i, and x_j is the jth training sample. A modification to the discriminant function using the monotonicity property of logarithmic functions permits the following simplification [7]

$$g_i(x) = \ln \left\{ p\left(x \middle| \omega_i\right) \right\} + \ln \left\{ p\left(\omega_i\right) \right\} \qquad (10)$$

without violating the decision rule in (7).

Finally, incorporating the model in (8) into the discriminant defined in (10) permits the decision rule to use [7]

$$g_i(x) = \ln \left\{ p\left(x \middle| \omega_i\right) \right\} + \ln \left\{ p\left(\omega_i\right) \right\} \qquad (11)$$

as a discriminant function, where the term $-(N/2)\ln(2\pi)$ is dropped as a term common to all $g_i(x)$.

The effectiveness of maximum likelihood classification depends upon reasonably accurate estimation of the mean vector m, and the covariance $\sum$ for each spectral class. This in turn is dependent upon having a sufficient number of training pixels for each of those classes; if this not possible, it may be necessary to resort to an algorithm which depends upon mean positions and not be covariance of the spectral classes since these are easier to estimate. Determining a necessary number of training samples is more or less dependent upon the type and dimension of the data, but minimum N-1 samples are required to prevent a singular covariance matrix. While it is fairly easy to obtain enough for 7 band multispectral data, this task is challenging for hyper spectral sources, which can have over much more spectral bands.

Maximum likelihood classifier quantitatively evaluates both the variance and covariance of the category spectral response patterns when classifying an unknown pixel so that it is considered to be one of the most accurate classifier since it is based on statistical parameters. Supervised classification (ML) was done using ground checkpoints of the study area.

In first;The area was classified into four main classes: cropland, bare land, water body and forest. After completing the classification procedure, the classified outputs were combined to make a single classified image and then carried out on the final classified output by computing the percentages of classified images within only cropland areas class as using (active) area and unused area in that year.

To assess the accuracy of the classification, field, to each of the classified images, compared the reference data. For each classified data, those fields set aside to be used as independent check fields were compared with the reference data to establish whether or not it had been classified correctly. There were not many vegetables and fodder crop fields. Therefore, for these classes, all reference fields were used to compute the accuracy. For each classified output, the error matrix was generated and the producer's and user's accuracy were calculated.

3.4.1.4 Field work

We completed the vector coverage of the study site, the vector field boundaries were built and digitized from the ground truth data using with ARCMAP software. To do that the each polygon points was then registered to Geographic lat/Long (Zone-48 WGS84 using) projection and the evenly distributed. The registration was based on first-degree polynomial and nearest neighbor re-sampling techniques. The accuracy of the registration was measured using independent check grids, which were not included in the transformation.

Each polygon was assigned a numeric code and the crop types of the ground-visited fields were recorded as attribute information. The polygon topology was then created and the attribute database was linked to the polygons to make polygon selection possible through a database query. This map was used to validation of classification result.

Prior to describing the steps of the supervised classification procedure and evaluation of its results, a reference will be made to how the samples, both for training and reference, were prepared.

3.4.1.5 Accuracy assessment

Accuracy assessment is very important for understanding the developed results employing these results for decision making. The most common accuracy assessment elements include overall accuracy, producer's accuracy, user's accuracy, and Kappa coefficient.

A most common and typical method used by researchers to assess classification accuracy is with the use of an error matrix (sometimes called a confusion matrix or contingency table) (Card, 1982 and Congalton, 1991). An error matrix is a square assortment of numbers defined in rows and columns that represent the number of sample units (i.e., pixels, clusters of pixels, or polygons) assigned to a particular category relative to the actual category as confirmed on the ground. The rows in the matrix represent the remote sensing derived land use map (i.e., Landsat data), while the columns represent the reference data (i.e., ground truth, *in-situ* samples) (Jensen, 1986). These tables produce many statistical measures of thematic accuracy including overall classification accuracy (the sum of the diagonal elements divided by the total number in the sample), percentage of omission and commission error by category, and the KHAT coefficient (an estimate of the Kappa coefficient, an index that relays the classification accuracy after adjustment for chance agreement) (Cohen, 1960; Congalton et al., 1983).

Error of omission is the percentage of pixels that should have been put into a given class but were not. Error of commission indicates pixels that were placed in a given class when they actually belong to another. These values are based on a sample of error checking pixels of known land cover that are compared to classifications on the map. Errors of commission and omission can also be expressed in terms of user's accuracy and producer's accuracy. User's accuracy represents the probability that a given pixel will appear on the ground as it is classed (the percentage correct for a given row divided by the total for that row), while producer's accuracy represents the percentage of a given class that is correctly identified on the map (the percentage correct for a given column divided by the total for that column).

To assess classification accuracy one needs to compare two different maps: **1)** the classified map derived from remotely sensed data and **2)** existing sources of reference information such as *in-situ* data or interpretations from aerial photos which allow a means of time and cost-efficient error checking. In order to assess classification accuracy, there must be perfect or near perfect registration between the reference information and classified maps.

Usually, the "assumed-true" reference data are derived from ground truth data. However, it is typically not practical to ground truth or otherwise test every pixel of a classified image. Therefore, a set of reference pixels is usually used. Reference pixels are points on the classified image for which actual data are (or will be) known. Normally, reference pixels are randomly selected based on available sources of land cover reference information, such as field plots, existing maps or aerial photos. If these sources are accurate and chosen independently of those used to classify the land cover map, an accurate assessment of error can be made.

An important factor in determining the accuracy of a classification is the number of reference pixels used. Congalton (1991) states that it has been shown that more than 250 reference pixels are needed to estimate the mean accuracy of a class to within plus or minus five percent.

The cropland cover information collected during the field visit allowed sample land parcels with known cropland cover to be labeled. The labeled land parcels were divided between "training" and "validation" sets by alternatively assigning them when selected. The training set of 380 cropland parcels was used as the input into the classifier. The validation set of 113 land parcels, was used later to assess the accuracy of the results.

3.4.2 Cropland cover/use change detection

Change detection methods have been broadly divided into either spectral change identification methods or post classification methods (Singh, 1989). Macleod and Congation (1998) list four aspects of change detection which are important when monitoring natural resources:

1. Detecting the changes that have occurred
2. Identifying the nature of the change
3. Measuring the area extent of the change
4. Assessing the spatial pattern of the change

The success of change detection from imagery will depend on both the nature of the change involved and the success of the image pre processing and classification procedures. Post classification is the most obvious method of change detection, which requires the comparison proved to be the most effective techniques, because data from two dates are separately classified, thereby minimizing the problem of normalizing for atmospheric and sensor differences between two dates. In this study post classification change detection technique was used. Outline of the general mapping/monitoring methodology and the image classification methodology were presented figure 3.3 and 3.4.

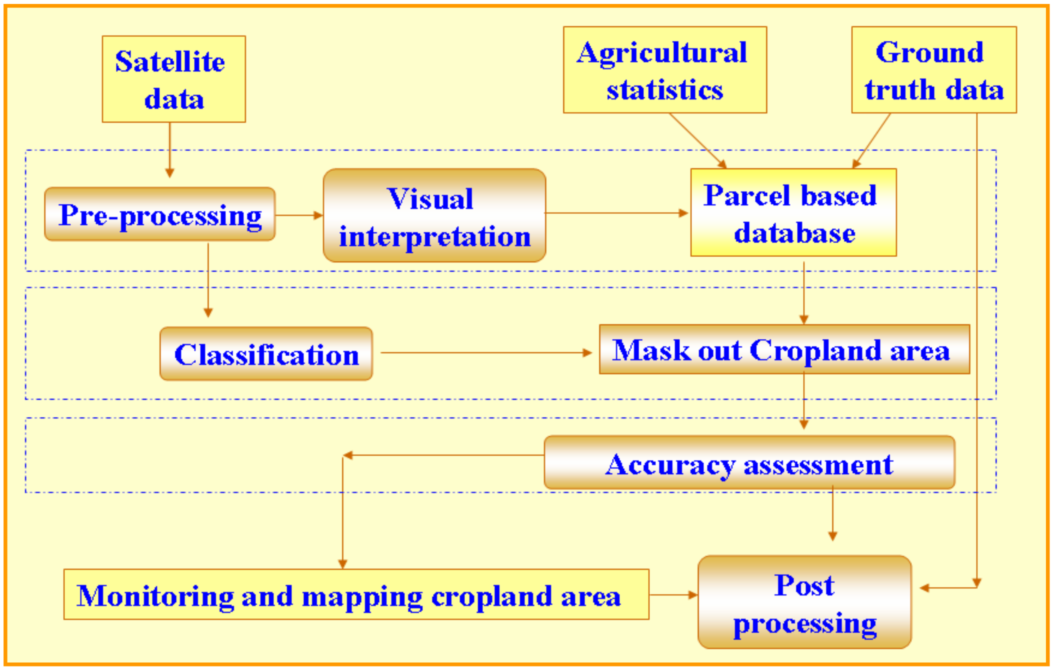

Figure 3.3 General methodologies (mapping and monitoring) of flow chart

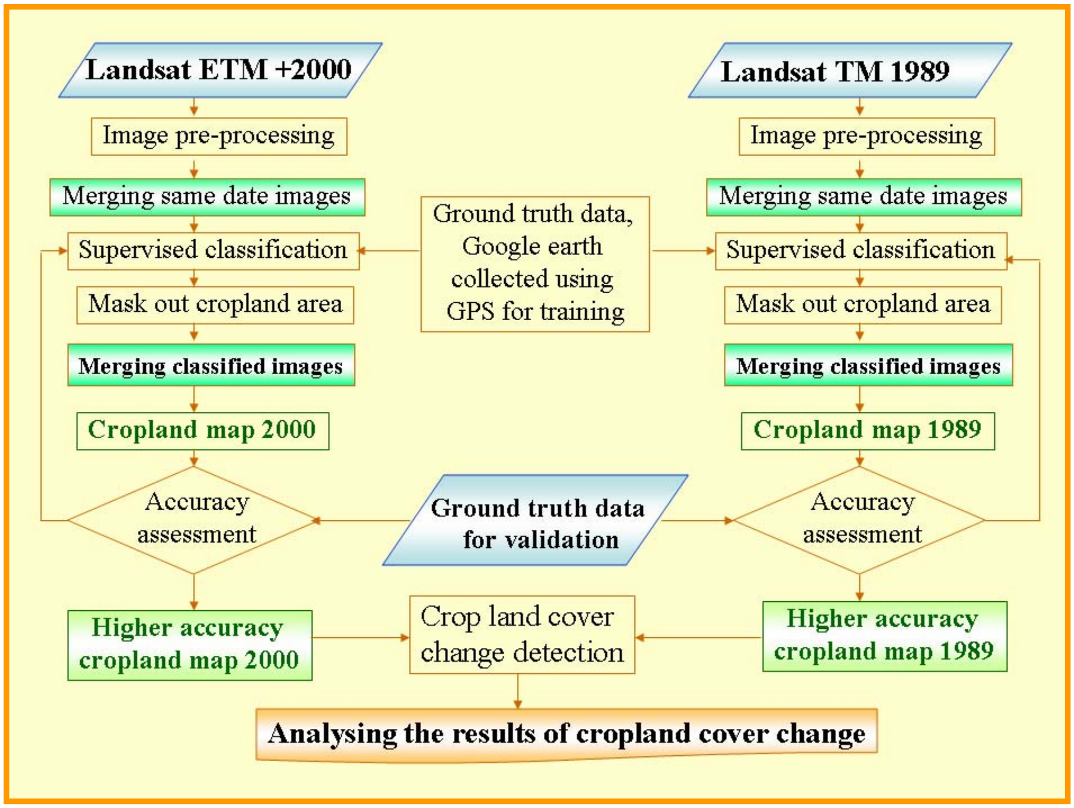

Figure 3-4 Image classification methodology flowcharts

3.4.3. Results and conclusion

The color composite was generated using bands 5,4 and band 3 of the image acquired in cropping season 1989 and 2000 showed (Figure 3.3 and 3.4) a comparative view for visual interpretation through on screen digitizing.

This can be easily noticed inside cropland area were many small polygon abandoned and some area not in the one of 2000. Supervised classification using all reflective bands of the two images acquired on 1989 and 2000 respectively was carried out using maximum likelihood classifier in order to produce cropland cover/use maps of the study area. The results of the supervised classification of the two images are presented; Figures 3.5 and 3.6 active croplands represented 507111.1 ha to 259262.9 ha of the total area in 1989 and 2000 respectively.

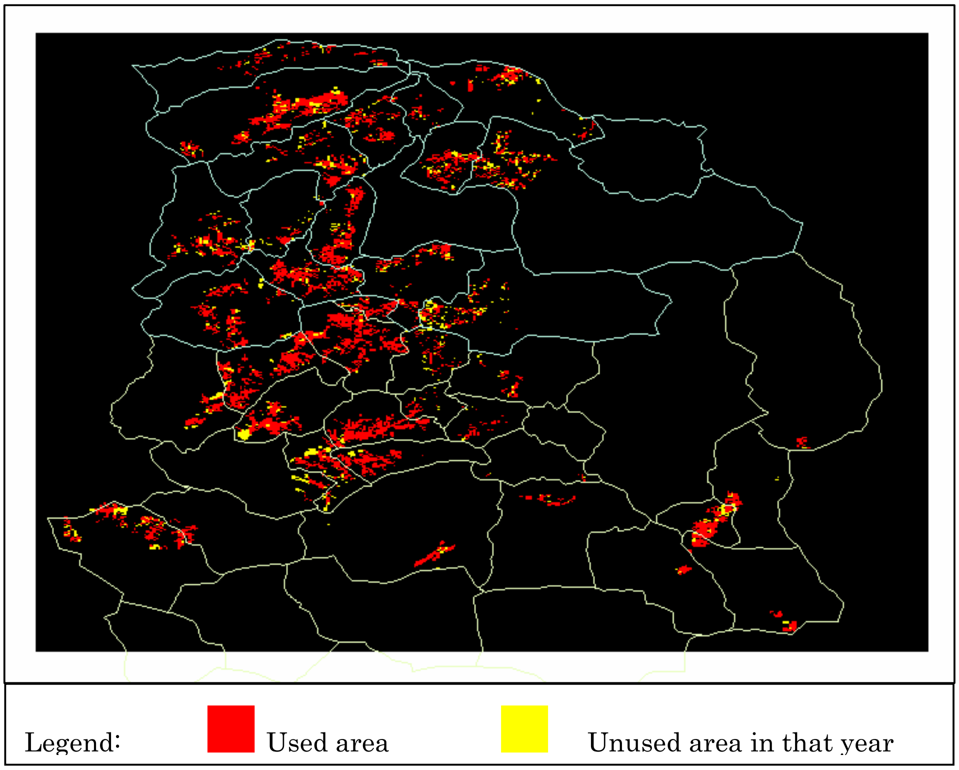

Figure 3.5 Maximum likelihood classification 1989 data (Landsat TM)

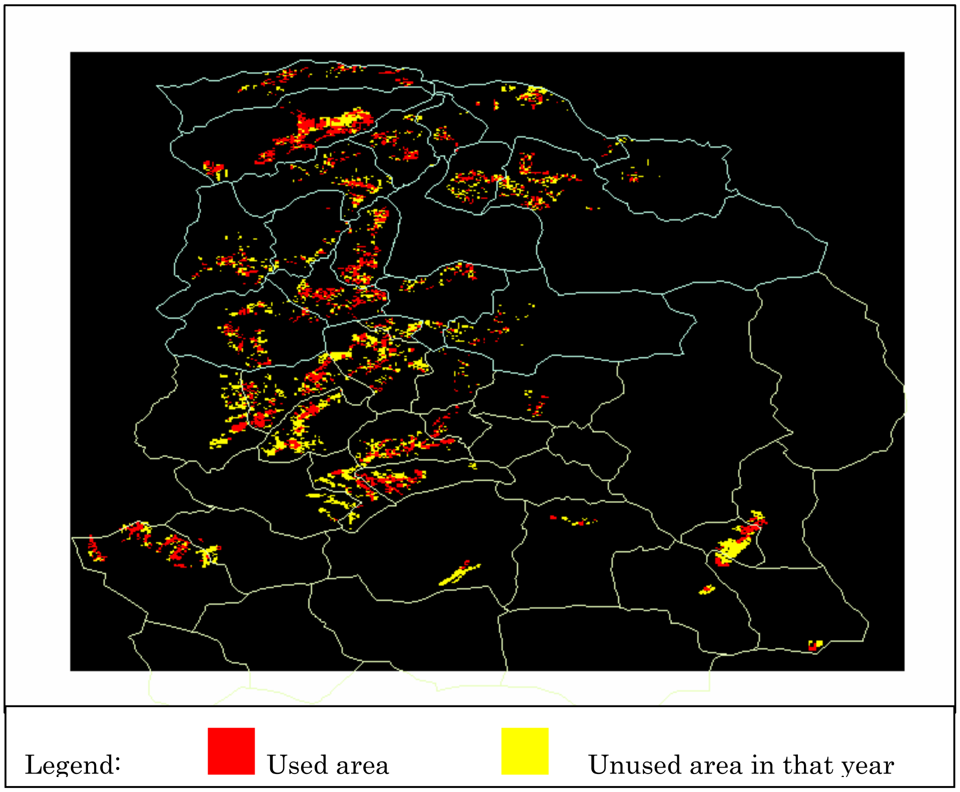

Figure 3.6 Maximum likelihood classification 2000 data (Landsat +ETM)

In this study the overall classification accuracy was found to be 89.5%for 1989 and 90.0% for 2000. Details of single class accuracy for both images of 1989 and 2000 can also be found in table 3.2 and 3.3.

Table 3.2 Accuracy statistics for the classification result of 1989 Landsat TM image

Class name	Producer's accuracy	User's accuracy
Active Cropland area	93.9%	91.5%
Unused cropland area in that year	91.8%	87.6%

Table3.3 Accuracy statistics for the classification result of 2000 Landsat +ETM image

Class name	Producer’s accuracy	User’s accuracy
Active Cropland area	88.5%	92.0%
Unused cropland area in that year	93.1%	88.0%

Also, detailed information amount of the changes between the two dates was extracted from the statistical data through post-classification change detection technique as represented in table 3-4.

Table3.4 Area change and percentage of change of the classified two images dated in 1989 and 2000.

	Active Cropland area (by hectare)	Unused cropland area in that year (by hectare)
1989	507111.1	107983.1
2000	259262.9	281445.5
change	247848.2	-173462.4
% of change	48.9	160.6

Cropland use change detection has shown that the active used cropland area decreased between 1989 and 2000 years by 48.9 percent from 507111.1 hectares to 259262.9 hectares.

Land Use and Land Cover dynamics is a result of complex interactions between several biophysical and socio-economic conditions. The effects of human activities are immediate and often radical, while the natural effects take a relatively longer period of time.

The spatial-temporal aspects of principal cropland-cover/use dynamics in the period 1989–2000 have been analyzed for the first time for the whole of Mongolia through an analysis of spatially explicit data collected through remotely sensed data interpretation and field validation.

Privatization of agricultural land has changed agricultural production considerably. In the present study only two years are available: 1989 describing the land-cover/use situation under the centralized government and 2000 in a market-oriented economy.

The mid 1990s are not represented but stand for the moment in which the land was distributed to rural households and registration as private property took place. Considering the above-described limitations of remote sensing for analysis of land-cover/use dynamics, one could state that the present results are more likely an underestimation of change than an overestimation. If more land-use aspects and information would be integrated into the study, the area subject to change would be likely to be more extensive.

The results show that it is not only important to monitor the extent of natural resources areas but also the quality of these resources. The monitoring system should have a national and a district component as the first is the level at which policies are formulated and the latter is the level at which management takes place and laws should be enforced. The monitoring and information flow, however, should be focused on the production of elements for decision making in natural resources management. People's participation in this democratic dialogue should be promoted by increasing the influence of civil society in the decision-making processes.

4. Precision agriculture and cropland information system

Introduction

4.1 Motivation

A principal concern of any country in the world today is to define and better understand the interrelationships between population, environment, natural resources and economic development for the purpose of realizing what is collectively known as "sustainable development" (WCED, 1987).

Mongolia is at the beginning of 1990s brought about a new structural framework in the agricultural sectors. The state-controlled cooperatives and state farms were broken up and new production structures composed of a great number of small-scale farms emerged. In the command system, agricultural production was centrally planned and directed, as was the research and extension system. Therefore, the existing institutions of agricultural research and extension could not continue functioning in the same way as with the previous production structures.

The present private farm units in Mongolian agriculture suffer from a lack of balance between production factors available to each farm and institutional structures needed to support efficient agricultural operations. Many elements of the old agricultural institution system have either stopped functioning due to shortage of public funds, or do not respond to the deep political, social and economic changes that have occurred in Mongolia during the past 15 years. Mongolian farmers are operating production and market activities in the absence of an integrated system of technology institutions such as agricultural remote sensing research, extension service, and agricultural newly education. Actually, institutional change in Mongolian agriculture is happening very slowly.

Over the last decade, technical methods have been developed to utilize modern electronics to respond to field variability. Such methods are known as spatially variable crop production, geographic positioning system (GPS)-based agriculture, site specific and precision farming (PF). Digital agriculture, also called Precision agriculture, the same name as information of agriculture, framing by inch, or Cyber-farm, is an advanced technological system related to middle or small scale farmland, combined directly with activity of agriculture production and administration. The adoption of precision agriculture practice is just starting in Mongolia. Digital agriculture started from 1955 in America. It is different from "agricultural gardening" in 1950-1960`s in Japan, "ecology agriculture" and "green agriculture" coined by developed country in 60-70`s, and "agriculture factory" in Israel. It is an agriculture technology system with the characteristics of integration and information. It means that whole procedure of the farmland management cultivation, semination, irrigation, fertilizer, and protection of forestry, estimate of product, store and administration will be characterized by digital, network, and intelligence, using technology of remote sensing, telemetry, telecontrol and computer aided system. It will constitutes an information based agriculture technology system included monitor and estimation of crop conditions, land soil and current or dynamic analyzes of crop growth and factors of environment, diagnose forecast, cultivation step, management planning and decision support.

Now, in advanced country, digital agriculture includes the automatic agriculture operation and the technology of agricultural production and management using remote sensing, GPS, GIS, DSS, network and biology engineering.

In this study to developing a parcel based cropland information system in Mongolia in first time.

A parcel based agricultural information system can offer farmers the convenience of rapid access to their test results as soon as the tests have been completed.

In the first instance, it indicates the growing need for secured land ownership, with its associated spatial information, and then the need for a system to support agricultural land administration and management from the environmental and economic perspectives. One such system is the parcel-based land information system, which maximizes security of land tenure, reduces agricultural investment risks, and facilitates, and lowers the cost of, land transactions.

The agricultural or cadastral parcel is a well-defined land unit based on a homogeneous interest with a unique identifier. All information is collected, stored, referenced and retrieved at the land parcel level. It is also linked to crop management, land use; land allocation, valuation and taxation systems.

Although the use of GIS is still very low in public sector in Mongolia, but most private organizations are now computerized. Few public GI organizations are embracing computerization to support their functions. The few public GI organizations are now adopting GIS tools for data handling and process management. The growth of many of these GI organizations depend on this new development, so critical analysis on effects of IS on their organization, most especially their structure is necessary.

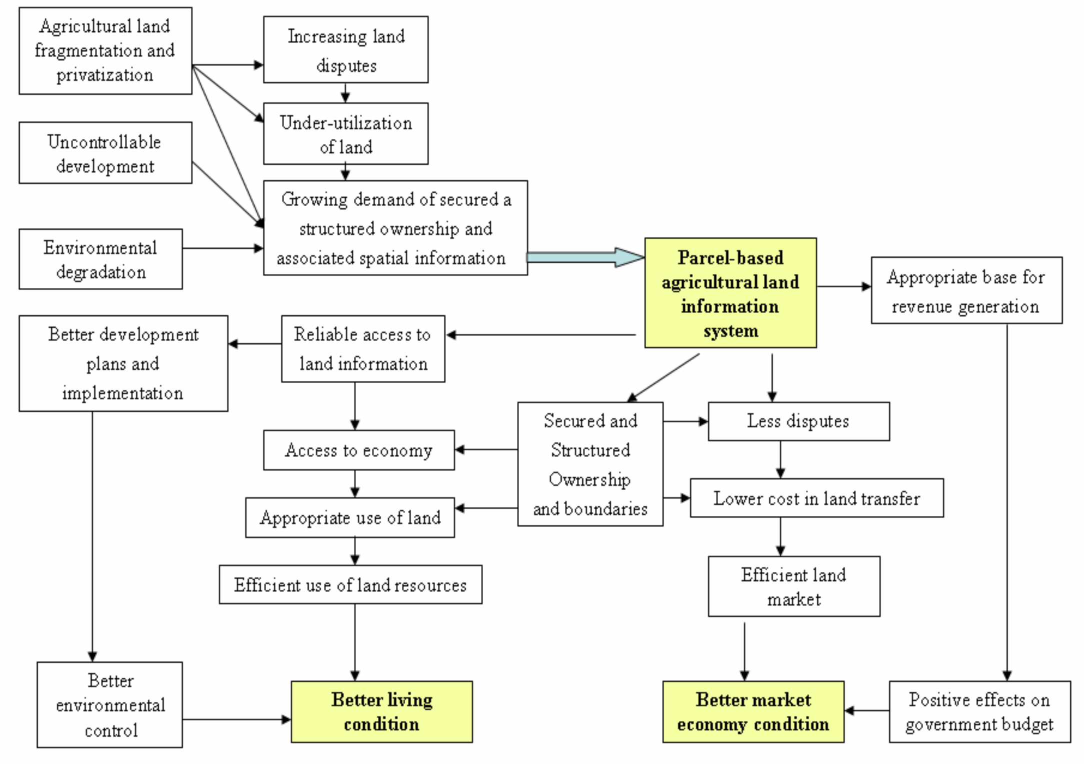

Figure 4.1 Motivation for parcel based cropland information system

4.2 Research Problem

Sustainable agricultural development is not possible without the development of Information Technology, which has high influence on human development.

The current policy of the Mongolian Government, outlined in the Human Development Report (Government of Mongolia, UNDP, 2000) emphasized the fact that the Mongolian rural population (nomads) is very vulnerable to mismanagement and to the high risk of natural disasters. Poor land related information, resulting in inadequate analysis, leads to misguided policies on natural resources management and environmental policies on national and regional levels.

The Mongolian Government has set basic objectives and activities directed to improve regional development policy. As a result, policy makers will have new possibilities to influence correct allocation of fiscal and another resources for the state as a whole and for separate regions, to implement long and short time regional development plans, and, most importantly, to make good use of new knowledge, information and new advanced ideas (Tsedendamba, 2000). The other prominent existing problems in Mongolia, which have negative influence into regional and state environmental planning in terms of information management related to agricultural land and land use/cover, are:

- Poor Geoinformation quality and luck of information exchange within organizations;
- Inappropriate institutional arrangement and any type (cropland, urban, forest.,etc) of land management at national and regional level;
- Weak linkage between governmental policies, community initiatives, activities and their implementation.

Therefore, demonstration of application of land Information Technology as a supportive tool for agricultural land use management and planning will be a necessary step contributing to Mongolian sustainable agricultural development.

4.3 Objective

The general objective of this chapter is

- **To the design of a parcel based cropland information system.**

Because Mongolia has a weak linkage within governmental policies and community initiatives and their implementations on agricultural land use planning, this information system can be useful for agricultural land assessment, and may provide a clear overview about environmental situation related to crop production, crop management, land taxation, leasing and decision support system (DSS) for land use planning for small land owner's (small farmer's) in rural areas.

4.4 Study area

The present research focused on Tsagaannuur district of Selenge province, in northeastern Mongolia.

The current region was selected for the following reasons:

- It is one of the biggest wheat regions of Mongolia;
- It is an ideal area for any research related to the environmental problems;
- We pointed out some already existing environmental problems within the region, such as agricultural land privatization, land fragmentation, agricultural mismanagement, which need to be studied and solved.

The reason of choosing this particular topic was due to currently existing problems of agricultural land information system, which has had serious influences on the Mongolian agricultural management.

One of the main causes of this problem can be found in the effects from agricultural land privatization in Mongolian agricultural zones and which a major cause of agricultural management is change. Climate constraints, with unpredictable year-to-year irregularity in rainfall result in reduction of crop productivity. This makes agricultural crop planning difficult, especially in rural areas.

Therefore, information system on agricultural land problems needs to be analyzed.

The selected study area Tsagaannuur is located in the Northeastern part of the Selenge province in Mongolia, covers mostly forest-steppe, steppe and is rich in chernozem soil. The geographic boundaries of the area are 49° 45′ 0″-49° 75′ 0″ N, 106° 30′ 0″-106° 50′ 0″ E. The climate of the region is semi-arid and arid; and the mean annual precipitation is 250-301 mm. Except for wheat and all other crops are rain fed.

Figure 3-2 shown us selected study area.

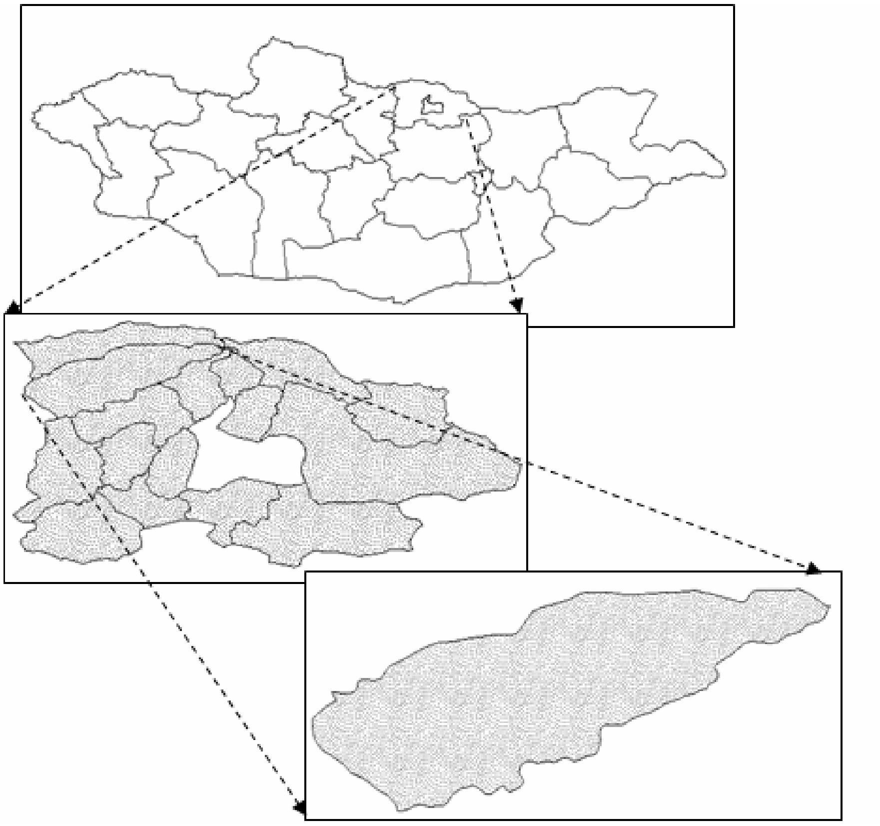

Figure 4.2 Study area Tsagaannuur district, Selenge province, Mongolia

4.5 Data collection and methodology

4.5.1 Data collection

Data was collected through a combination of the fieldwork and some desk study. Related papers was reviewed prior to, during and after fieldwork. Data collected from fieldwork was considered as the primary source of information, while the review of organizational records, related published material in both hardcopy and electronic format from official organizational and other professional bodies' websites was considered as a secondary source of information. Both Primary and secondary data were collected during the Fieldwork. Primary data was collected in three different ways namely; direct (person to person) semi structured interviews (involving individuals and in one case a group), telephone interviews and by email administered semi structured questionnaires. On the other hand, secondary data was obtained through organizations' official websites, professional bodies' conference or workshop publications, organizational reports and minutes of meetings. Figure 4.3 demonstrated data collection methodology.

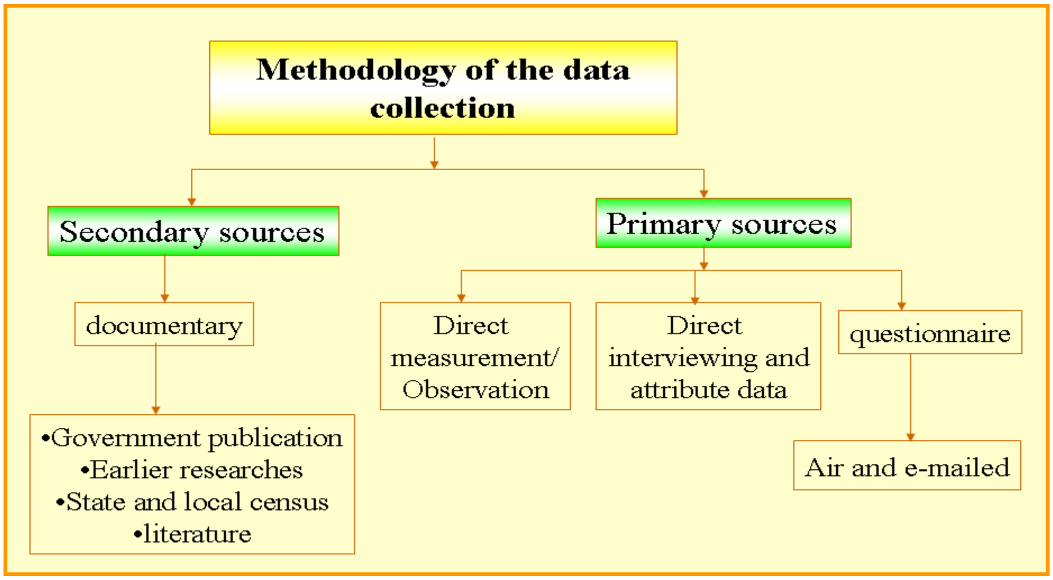

Figure 4.3 Methodology ground truth data collection

4.5.2 Methodology

4.5.2.1 Mapping tools in constructing GIS systems

There are two key components to a GIS system. One is the database that contains the geographically referenced information. The other is the set of maps on which the geographical referenced data are presented. An important part of the implementation of a

GIS system is constructing the base maps. The base maps in the GIS systems can be constructed using desktop mapping programs or web mapping applications.

Maps are an important component in GIS systems. Many GIS systems use maps as their user interfaces. Through maps GIS system users obtain a way to work with the geographic data in the GIS system. Maps in GIS systems link the GIS data to geographic locations. Also the product of a GIS system most often takes the form of a map (a graphical presentation of the geographically referenced data).

Implementation of a GIS system often involves mapping programs for constructing the set of maps in the system. Available web mapping services offer a straightforward way to build maps for web based GIS systems. External data sources can be integrated into the web mapping services to build complete GIS systems.

With the launching of Google Maps, GIS developers are provided with a powerful web mapping service for constructing GIS base maps. Google Maps offers three types of maps (the standard street map, the satellite map, and the hybrid map) of the world at various resolutions. Also, the Google Maps provides a very interactive user interface-navigation on the map can simply be done by performing “drag and drop” on the map using the mouse.

4.5.2.2 Parcel based land Information Systems

Figure 3-4 shows the structure of information system growth leading to the origin and development of parcel based land information systems.

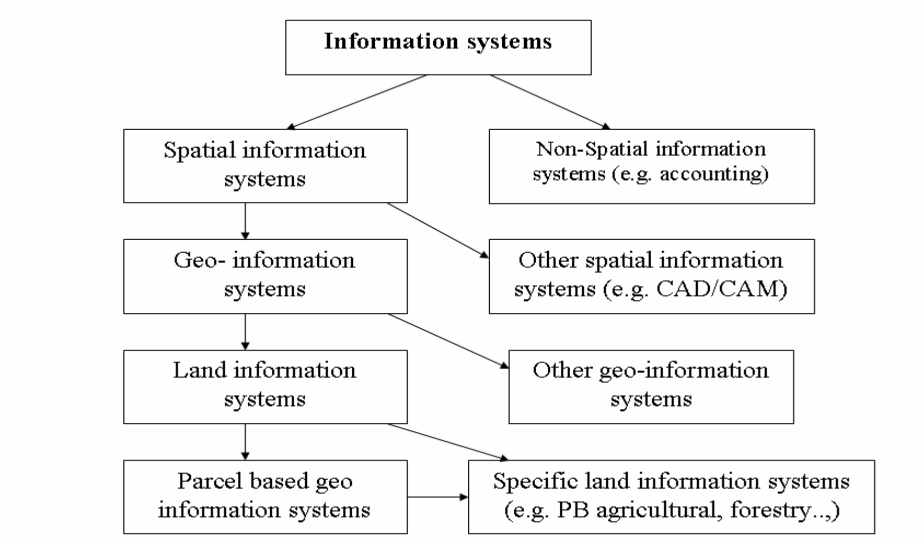

Figure 4.4 Structure of information system (adopted from Dale and McLaughlin, 1988)

It is also considered as an abstract thing that is manifest as a set of rights with responsibilities and restrictions to its use, with a value that can be traded (Dale and McLaughlin, 1988).

A land parcel can be defined as being for all of type of land use, cropland management, DSS, ecological or cadastral purposes, and as a continuous area of land within which unique and homogenous interests are recognized (Henssen, 1995). Thus a parcel based GIS can be defined as a kind of land information system whose basic spatial unit is the land parcel and in which land-related information is collected, stored, referenced, processed and retrieved basically at the parcel level.

4.5.2.3 Parcel based cropland information system (LIS) Components

A LIS consists of the following components that enable it to function well within land administration:

- data sets (related to both spatial and non-spatial data)
- process or functions related to data acquisition, data processing and storage, data maintenance, data analysis and data dissemination
- hardware and software including communication networks
- well trained people

Two categories of data set are generally stored in a LIS. The first category is ***basic parcel*** (see more, from Appendix 3) based polygons (cadastral) data, which is directly connected with land ownership. The second category is ***supporting (additional***) (see more, from Appendix 3) data, such as geodetic reference points, administrative boundaries and topography, which assure basic cadastral data (legal cadastral objects) of accurate referencing in relation to physical objects (especially topographical objects) and to the earth, as well as allowing integration with other types of spatial data.

4.5.2.4 Field sampling methodology

We were chosen for detailed sampling each polygon, where data was obtained over the course of three years. The parcels varied in size from about 8 to 3000 hectares. In most cases, due to the size of the parcels, field data collection for a single parcel would take several days. Field data was collected at 5 different times during 2007 and 2009, spanning both the cropping seasons as well as several stages of wheat maturation, from the early growth to pre-harvest.

4.5.2.5 Digital map creation

Creating the link between the shape file containing the parcel boundaries and the production information was undertaken in two ways: First, using Arc Catalogue a spatial database connection was created with the geographic data stored in the relational database system of the Microsoft Excel. The link created a real-time spatially referenced information system where the digital maps created in ArcINFO had access to the some historical production records. This was created for the purposes of future onsite GIS analysis. Second, the parcel based database information was also extracted as .dbf files and was than linked directly to the vector map of each polygon. Each polygon points were then registered to Geographic lat/Long (Zone-48 WGS84 using) projection and the evenly distributed. The registration was based on first-degree polynomial and nearest neighbor re-sampling techniques. The accuracy of the registration was measured using independent check grids, which were not included in the transformation. Each crop polygon was assigned a numeric code, owner's name, location and the crop types, soil moisture, air temperature, soil temperature of the ground-visited fields were recorded as attribute information.

Also it is possible to do the normal operations related zoom-in and zoom out and other such operations related to layer/image in normal image handling programs. The mathematical operations on attributes aids in building the query and output the display to the monitor either statistically or graphically.

4.5.2.6 Creating XY shape files

A Creating XY shape files, based on the field data a gathered is the first stage in creating continuous vector coverage's using with in an ArcGIS. Once the raw field data was transcribed into spreadsheets and saved as database files (.dbf) (which is the format accessible to ArcCatalogue) the data was thoroughly reviewed visually and via sort functions for obvious value outliers and outliers due to transcription errors. This was an extremely labor intensive process considering the size and number of datasets to be reviewed. Once the datasets were reviewed, they were mapped in ArcCatalogue and XY shape files were created using the 'Create Feature Class from XY Table' command in ArcCatalogue.

Shape files were displayed in ArcMap and projected to the WGS 1984 coordinate system. These shape files were then re-examined for both spatial and value outliers, as once this step was completed it became possible to view the spatial distribution of the data. In order to process spatial outliers, coordinates were examined for expected position in the sequence of points and when the transcription error was not obvious, simple interpolation was used to place point samples in the expected position.

4.6 Result and conclusion

Figure 3-5 demonstrated a parcel based land information system in Tsagaannuur province of Mongolia,

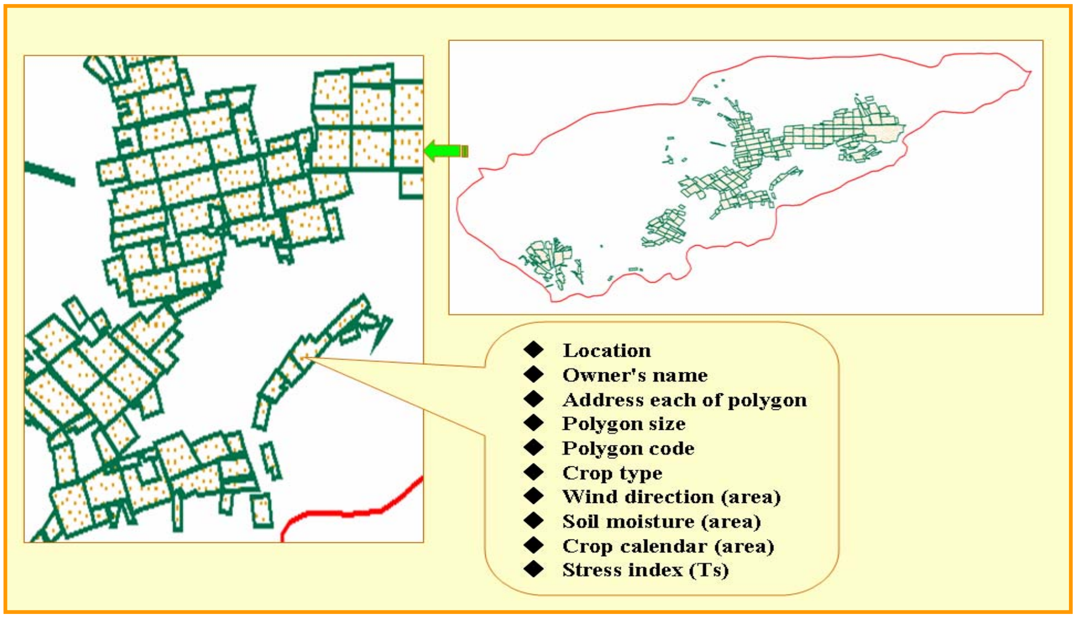

Figure 4.5 Parcel based-cropland information system of Tsagaannuur sum,
Selenge aimag,

Also it is possible to do the normal operations related zoom-in and zoom out and other such operations related to layer/image in normal image handling programs.

Nowadays, the world rapidly grows to be an informative community with the support of the internet. It is recently expected that there are more than thousands of gigabytes of information and more than hundreds of thousands online communities spreading all over the internet. Since the language is the foremost obstacle for people to access the content of such information, it is consider as the barrier for information access. Knowledge and information are important factors for accelerating agricultural development by increasing agricultural production and improving marketing and distribution. Information technology can enhance the integration and efficiency of agricultural systems by opening new communication pathways and reducing transaction costs, given greater accessibility of information on prices, transportation and production technologies.

The main objective of this research is to develop an approach (methodology) to improve the geometric quality of the cropland information system with cropland cadastral map in Mongolian case study in first time.

The cropland information system and cropland cadastral map renovation has been conducted in terms of economical, technical, legal and social aspects, and financial aspects.

- Economic impact: the cropland cadastral map is among the important maps that comprises the base maps. The result of the map renovation is a more reliable standard map to satisfy the users. This does not only include improvement on the cadastral map but the national spatial reference systems, the national topographic templates and many others. Furthermore, cropland cadastral map with information renovation will lead to good land administration and good governance. And this affect the GIS markets as well, various products and services can be created as a result.
- Financial impact; it is obvious that the cadastral map renovation will cost less money than a cadastral resurvey. Cropland cadastral map renovation is expected to decrease the transaction costs and reduce lots of activities by supporting various products and services. This will make a great contribution towards the GI market and e-Government of Mongolia.
- Technical impact; the current cropland information system with cropland cadastral map needs a topological structure and a seamless map. From all those things together with standards, incredible technical improvement would be reaped by the Mongolian society such as least square adjustment, spatial mapping techniques, and datum transformation and so on. Furthermore, this may be used for overseas markets.
- Legal and social impact; the map renovation can support in the reduction of the number of land disputes in Mongolia. One conclusion that may be gleaned from the legal aspect is that Mongolia needs a special law which approves the conduct of the map renovation project. The base maps draw together a partnership within the GI governmental and non governmental organizations. This map renovation

could serve to manage all these aspects. This is Tateishi laboratory product for Mongolian agricultural markets.

5. Monitoring water stress index in wheat field of Mongolia

5.1 Introduction

5.1.1 Global developments in agriculture

Of the world's poor, 70% live in rural areas and are often at the mercy of rainfall-based resources of income. Frequent occurrence of crop growth extremely droughts of 1 to 3-weeks consecutive duration during the main cropping season happens to be the dominant reason for crop (and investment) failures and low yields.

Globally, 69% of all cereal area is non-irrigated, including 40% of rice, 66% of wheat, 82% of maize and 86% of other coarse grains (Rosegrant et al. 2002). Worldwide, non-irrigated cereal yield is about 2.2 metric tons per hectare, which is about 65 % of the irrigated yield (3.5 metric tons per hectare) (Rosegrant et al. 2002). Non-irrigated areas currently account for 58 % of world cereal production (Rosegrant et al. 2002). The importance of non-irrigated cereal production is partly due to the dominance of dry land agriculture in developed countries. More than 80 % of cereal area in developed countries is non-irrigated, much of which is highly productive maize and wheat land such as that in the Midwestern United States of America and parts of Europe (Rosegrant et al. 2002).

The area of irrigated lands used for cereal production has more than doubled between 1950 and 1980. Most of this increase can be attributed to a legacy of the large scale diversion of river water to supply (low efficiency), canal irrigation projects developed during the 1950–1970 period (Lambert et al. 2002). Irrigation enables production of two or more crops per year on the same piece of land, thus increasing the intensity of land use (Cassman, 1999). However, the rate of increase of irrigated land has slowed considerably since 1980 because of rising costs and the threat of long-term salinization (McCalla, 1994). This form of irrigation-induced salinization, also known as secondary salinization, has been extensively described and researched (Ghasemi et al. 1995). This salinization is, however, generally restricted to irrigation in the (semi) arid zone. Out of the 270 million ha of irrigated land in the world, about 110 million ha (roughly 40%) is located in this zone. The yield per unit land has increased markedly in the last 40 years as a result of intensified crop management involving improved germplasm (biotechnology), greater inputs of fertilizer (Cassman, 1999) and the recent advent of precision agriculture management practices (Stafford, 2000).

Molecular genetic biotechnology holds the promise of significant genetic improvements, but that promise is becoming reality much more slowly than earlier forecasts suggested (McCalla, 1994). Sinclair et al. (2004) noted that in spite of the optimistic predictions often made for transformations leading to plant genetic trait improvement resulting in increased yield potential, a historical perspective indicates that a much more moderate expectation is warranted. Forty years of research on the biochemistry and physiology of plant traits considered crucial for yield increases have resulted in few examples where such research led directly to a yield increase. Although past research has greatly increased the understanding of the factors associated with crop yields and contributed significantly to the development of molecular genetics, overall there are virtually no examples of such research leading directly to crop yield increase (Sinclair et al. 2004).

Precision agriculture, as a crop management concept, can help address much of the increasing environmental, economic, market and public pressures on arable agriculture (Stafford, 2000). Precision agriculture has generated a high profile in the agricultural industry over the last decade of the second millennium, although the fact of "within-field spatial variability" has been known for centuries. Nonetheless, further technology development is required, particularly in the area of sensing and mapping systems to provide spatially related data on crop, soil and environmental factors (Stafford, 2000).

Precision agriculture is information-intense and could not be realized without the enormous advances in networking and computer processing power, and access there of to farmers and farm mangers. Stafford (2000) estimated that by the end of the decade, most arable enterprises in the developed nations will have taken on the concept on a whole-farm basis.

This chapter investigates the use of remote sensing data for essential factors for crop growth in cropland area of Mongolia. Mongolian grain productivity needs to occur in an environmentally sustainable manner. The concept of a crop monitoring system developed in this study will contribute towards these goals.

5.1.2 Agricultural production systems and agronomic practices in Mongolia

The development of large scale wheat growing in Mongolia was modeled on the Soviet virgin and idle lands program in western Siberia. These production systems were highly mechanized to cope with time-critical operations, especially planting and harvesting in a harsh and risky physical environment with a short season of typically around 100 days. Virtually all farm machinery, fuel, fertilizers and agrochemicals were imported from the

Soviet Union and provided to farms at highly subsidized prices. In an effort to become self-sufficient, the area under wheat increased from 200,000 ha in 1960 to 533,000ha in 1990 and the process, significant areas of marginal land were brought under cultivation. A wheat/fallow rotation was practiced with either wheat for two years followed by bare fallow in the third year, or wheat and fallow in alternative years: the choice depending primarily on annual precipitation and secondary on the moisture retention capacity of the soil. In general, this meant a three-year rotation in much of the wheat-growing areas in the north-central region, and two-year rotation in drier eastern areas of the country. However, following the withdrawal of Soviet support and the subsequent scarcity and higher cost of inputs, the two-year rotation, with 50% of cultivable land in fallow every year, is becoming standard practice in all wheat-growing areas.

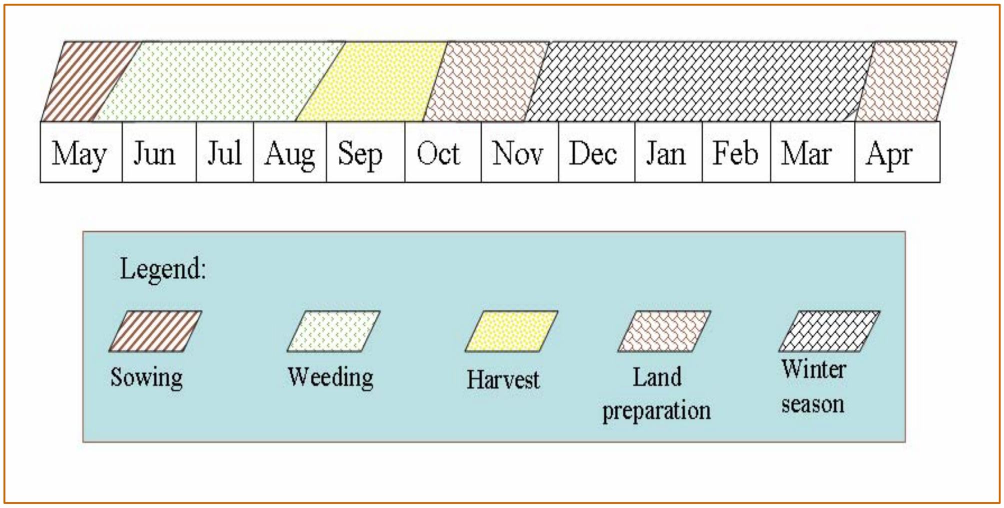

Figure 5.1 Farm activities in the study area

Due to severe winters and minimal snow cover, it is impossible to grow winter wheat varieties, leaving early-maturing spring wheat varieties as the only option. Sowing occurs in May and the crop is harvested in September. The sowing date is major factor influencing grain yield and quality, with May 1 to 10 as the optimal period. Both yield and quality are likely to be seriously affected in crops sown later than May 20. National yield levels, which averaged 1.2 t/ha in the 1980s, have fallen to less than 1t/ha, largely because of the greatly reduced availability (fuel) and use (fertilizer and agrochemicals) of inputs and the resultant negative effect on timely field operations.

5.1.3 Tillage and seeding

Prior to planting land is plowed and or cultivated one or more times to a depth of 15-20 cm, followed by further one or more cultivations to firm the seedbed before sowing at a depth of 7-10 cm. seeding rates are between 180 and 200kg/ha on contrast with rates of 50-70 kg/ha used in a similar agro climatic regions in North America. Relatively deep cultivation of the seed bed has been advocated to allow rainfall and plant roots to easily penetrate the soil. Unfortunately, such deep cultivation depletes soil moisture reserves and leads to soil erosion by strong spring winds. The loss of soil moisture requires deeper planting to ensure seeds are placed in contact with moist soil; but deep planting results in poor emergence and less vigorous seedlings.

Minimum tillage systems involving fewer and shallower cultivations to conserve soil moisture and reduce the risk of wind erosion offer the greatest potential for raising yields and improving cost-effectiveness.

5.1.4 Fertilizer and agrochemicals

The rate of application was quite high and fertilizer use more than doubled between on 1978-1988. Recommended application rates for wheat are 60 kg/ha nitrogen (N), 60kg/ha phosphorus (P) and 40 kg/ha potassium (K), (in practice, rates applied were often lower depending on availability). These recommendations are based on field trials conducted in the 1970s and are designed to give maximum rather than optimal output. Since 1990 fertilizer prices have been more closely related to world prices. With limited access to credit and foreign exchange, fertilizer imports and use have been reduced to a few tons obtained through concessionary lending or by barter for use on vegetables or potatoes; virtually no fertilizer has been applied to the wheat crop since 1991.

Determination of optimal application rates is made difficult by the variability of summer rainfall since yield response to fertilizer is largely dependent on the availability soil moisture.

5.1.5 Harvest

Harvesting needs to be completed as quickly as possible (ideally with in 2 weeks) to minimize the risk of damage by frost or wet weather which adversely affects grain quality. Serous delays can lead to abandonment of the crop. Harvesting is carried out using combines that usually make two passes. The first cut and swathed and left to wilt in the field for about 5 days, after which it is threshed and transported by truck or tractor and trailer to grain-dressing centers at the farm main complex. After the initial wilting, the grain has a moisture content of 20-25 percent. Further drying of the grain takes place while the grain is heaped on the floor of the dressing center. The grain is then processed up to three times using mobile grain cleaners that both clean and aerate the grain, further reducing the moisture content to about 16-20 percent, prior to sale. (The flour mills reduce the moisture content to 14% for long-term storage).

5.2 Wheat

Wheat is one of the leading cereal grain crops produced, consumed and traded in the world today. Wheat is used mainly as a human food. The cultivated wheat belongs to two main classes, common or **bread wheat** (*Triticum aestivum* L.), which accounts for about 95% and **durum wheat** (*Triticum durum*), which accounts for 5 % of world wheat production. Common wheat is used to make bread and biscuits, whereas durum wheat is used to make pasta. Unlike any other plant-derived food, common wheat contains gluten protein, which enables leavened dough to rise by forming minute gas cells that hold carbon dioxide during fermentation and enables production of light textured bread.

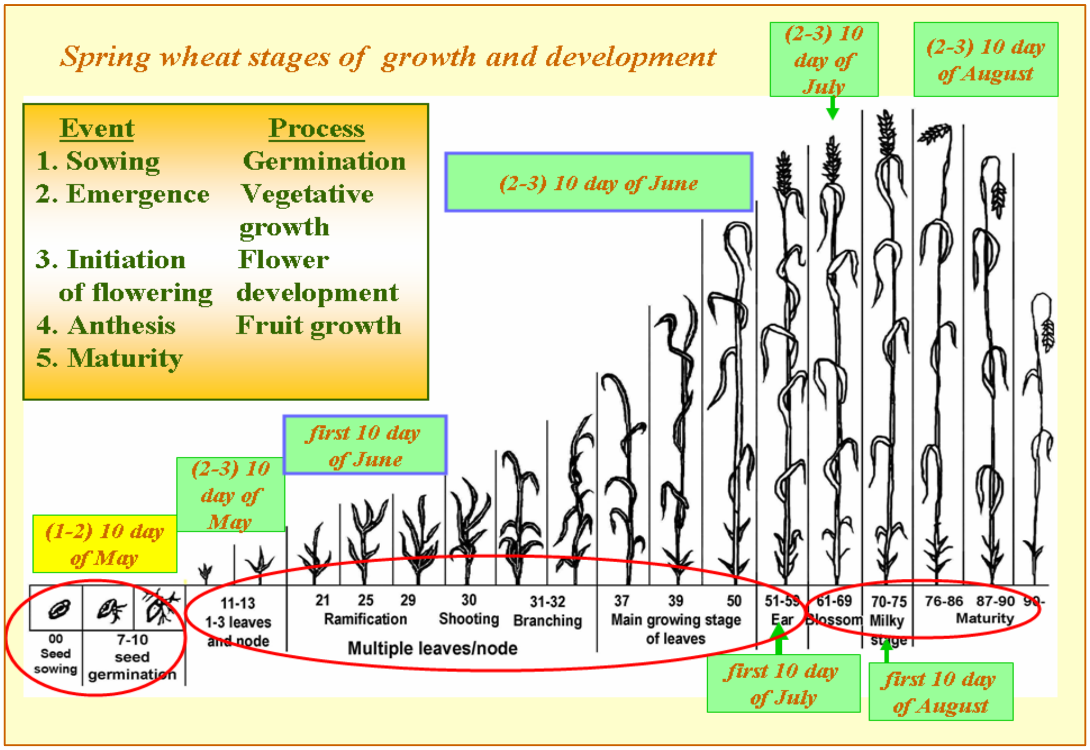

Figure 5.2 spring wheat growth stage (Adopted from Zadoks.J.C., 1974)

Common wheat is classified into **hard** or **soft** wheat based on its suitability for making bread. Hard wheat has a physically hard kernel that yields flour with high gluten and hence high protein content. This type of flour is more suitable for producing bread.

Soft wheat on the other hand have lower protein contents and are more suitable for producing biscuits and cakes, which do not require strong flour (i.e. flour with high gluten content). Wheat is also classified as either **red** or **white** wheat depending on the color of the aleuronic layer. Another classification is that based on the growth habit, which group's wheat into spring and winter types. Wheat is a widely adapted crop.

Although it is most successful between the latitudes of 30°-60° N (Mongolia 41°-52°N latitude) and 27° -40° S, respectively, wheat can be grown beyond these limits from within the Arctic Circle to higher elevations near the Equator (Nuttonson, 1955, as quoted by Curtis, 2002). In altitude the crop is grown from sea level to more than 3000 m. It can be grown in areas ranging in annual precipitation from 250-1750 mm, although most of the world crop is produced in areas with 375-875 mm annually (Leonard and Martin, 1963).

5.3 Wheat in Mongolia

Although wheat production is concentrated mainly in the temperate regions of the world, it has also become an important crop in highland areas of some countries such as Mongolia. Wheat was introduced in Mongolia towards of 1950 of the between the 20th century and has since been grown on an increasing scale in the northwest areas. The wheat growing areas between the 800 and 1200 m., and receive more than 350 mm of rainfall per annum. The wheat is grown under rain fed conditions, in small and large farms where nearly all production activities are mechanized. All the wheat is spring wheat and several varieties of both hard and soft wheat are grown.

Wheat is currently the most important cereal crop. The varieties released are suited to the various agro-ecological zones in the wheat-growing region of Selenge, Tov, Bulgan, Zavhan and Dornod aimags. Due to increasing population and changing lifestyles the demand for wheat has steadily been increasing. Wheat is produced in the high potential areas of Mongolia, which cover only 0.07 % of the total land area

5.4 Climate change and crop production

Agricultural production and climate are closely linked, which means any change in climate will affect agricultural production. Climate change will affect the production directly and indirectly, for example, increasing temperature in a specific region will increase evapotranspiration, and therefore, the water requirements of crops especially summer crops. The length of the growing seasons and tolerance to pests and diseases will also be affected. Mongolia is located in an arid region and climate change reduces crop production due to increased demand for water. Although agricultural production per unit area has increased substantially over the last few years, further increases are limited by the availability of water and energy resources, land degradation and desertification, which affect the fertile lands for agricultural production.

5.5 Limiting factors for crop production

Stress factors on crops are multifarious. These ***abiotic*** (drought, salinity, flooding, UV high light, frost, heat, pollutant and mineral deficiency toxic) and ***biotic*** (disease and insects) stressors cause changes in plant physiology and thus affect crop growth. Globally, water is regarded as the major limiting factor that reduces crop productivity especially in arid and semi-arid regions (Jones, 1999). Barnabas et al. (2008) reported that drought is one of the major limitations to food production worldwide. High temperature causes high evapotranspiration making it difficult to meet water requirements of crops (Penuelas et al., 1992). Drought at any growth stage reduces crop yield but maximum reductions occurs at the flowering stage but early growth stage and mid to late grain filling stage are also sensitive (Claasen and Shaw, 1970). Edmeades et al. (1992) estimated that in the developing world, annual yield losses due to drought may approach 24 million tonnes, equivalent to 17% of a normal year's production.

5.5.1 Influence of Droughts on Crop Production

Water stress during crop growth, even during short periods of a couple of weeks, is a major cause of yield reduction. The complexity in defining the magnitude of such water stress is due to diversity of crops grown in a given location, variability in soil type and conditions, spatial variability of rainfall, delay in timely of agriculture, and diversity in crop management practices. The drought may range from a few days to two weeks or even more.

Drought stress is one of the most widespread environmental stresses when the available water in the soil is reduced and atmospheric conditions cause continuous loss of water by transpiration and evaporation (Kramer, 1980). Many regions of the Earth are often or permanently exposed to drought (Bray, 1997). Up to 26 % from the usable areas of the Earth is subjected to drought (Blum, 1986). Drought is the most severe stress and the main cause of significant losses in growth, productivity of crop plants, and finally their yields (Ludlow and Muchow, 1990).

5.5.2 Drought Definition and drought index

Although deviation from the normal amount of precipitation over an extended period of time is broadly accepted as the cause for drought, there is no one, universally accepted definition for drought. This is because different disciplines use water in various ways and thus use different indicators for defining and measuring drought.

Wilhite and Glantz (1985) analyzed more than 150 such definitions of drought and then broadly grouped those definitions under five categories: meteorological, agricultural, hydrological, ecological and socio-economic drought.

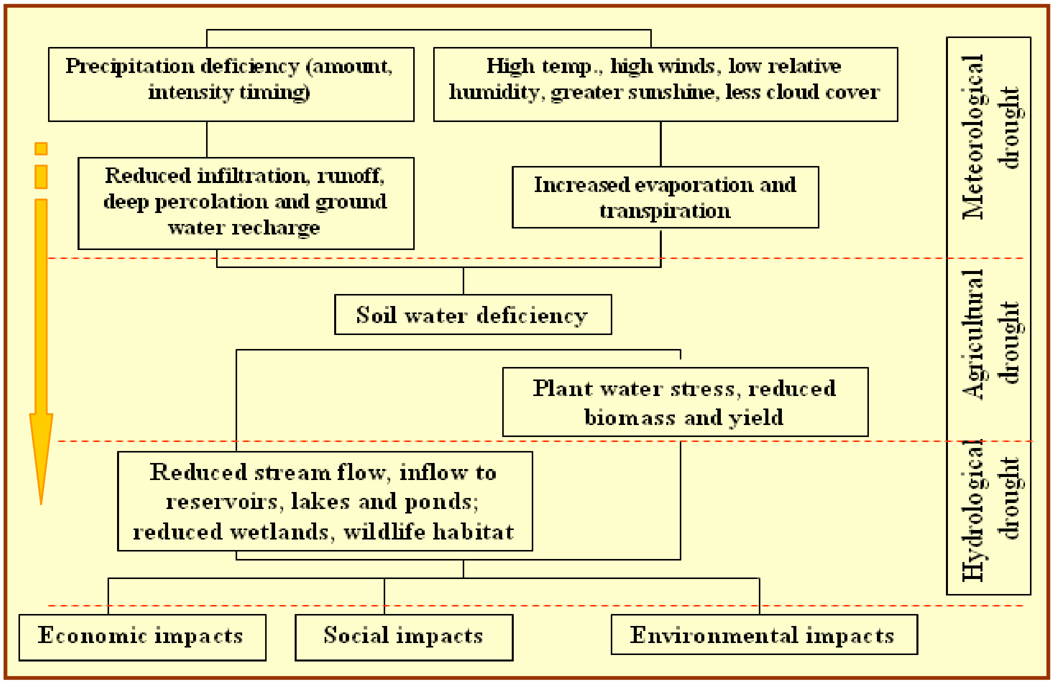

Figure 5.3 Type of droughts (Modified from Wilhite and Glantz, 1985)

Many indicators and indices of drought exist and these may disagree as to the severity of drought conditions. Each of these indices has recognized strengths and weaknesses.

Commonly used drought indices in the include the Palmer Drought Severity Index (PDSI), Crop Moisture Index (CMI), and Standardized Precipitation Index (SPI). Each of these indices has recognized strengths and weaknesses. Indices are often used to trigger both response and mitigation programs by local, state, and federal government. The PDSI, a meteorological drought index, was the first comprehensive drought index developed in the United States (Palmer, 1965). The PDSI provides a measure of the departure from normal of the moisture supply. The CMI is an indicator of soil moisture in the topsoil. The SPI is a simple calculation solely based on rainfall with a temporal flexibility that is theoretically much better suited to the quicker responses in vegetation detected by satellite imagery. It is a statistical measure on the surplus or lack of precipitation during a given period as a function of the long-term average precipitation (McKee, 1994).

Here agricultural drought is given a prime focus in this study of other types of drought. Agricultural drought refers to a situation in which the moisture in the soil is no longer sufficient to meet the needs of the crops growing in the area. Focus is placed on precipitation shortages, reduced ground water/reservoir levels, differences between actual and potential evapotranspiration, and so on.

Drought is a protracted period of deficient precipitation resulting in extensive damage to crops and loss of yield. A good definition of agricultural drought should be able to account for the variable susceptibility of crops during different stages of crop development, from emergence to maturity.

Deficient topsoil moisture at planting may hinder germination, leading to low plant populations per hectare and a reduction of final yield. The water demand of a crop depends on weather conditions (such as temperature, relative humidity), its biological make-up, what stage of growth the crop is in, and the physical/chemical make-up of the soil. However, if topsoil moisture is sufficient for early growth requirements, deficiencies in subsoil moisture at this early stage may not affect final yield if subsoil moisture is replenished as the growing season progresses or if rainfall meets plant water needs.

5.5.3 Remote sensing and drought stress

Remote sensing technology is an economical and promising tool for obtaining land surface parameters. A drought index based on land surface temperature should be more efficient than those based on NDVI.

The drought index that based on normalized difference vegetation index (NDVI) falls short in monitoring drought because NDVI is a rather conservative indicator of water stress, which means that vegetation remains green after initial water stress (Sandholt, 2002). In contrast, land surface temperature (Ts) is more sensitive to water stress (Goetz, 1997).In fact canopy and surface radiation temperature have been suggested as water stress indicators since the early 1960s (Tanner, 1963) and have been popularized since the early 1980s (Jackson, 1981). Temperature as a water stress indicator is based on a relationship between leaf temperature and transpiration. Generally, as transpiration rate is reduced owing to plant water deficit, leaf temperature rises relative to air temperature (Wang, 2004). The combination of NDVI and Ts provides information on the vegetation and moisture status. The scatter plot of remotely sensed temperature and spectral vegetation index often exhibits a triangular (Carlson, 1994) or trapezoidal (Moran, 1994) shape and is called the NDVI-Ts space if a full range of fractional vegetation cover and soil moisture content is represented. The NDVI-Ts slope was related to land surface evapotranspiration rate (Boegh, 1998) and can be used to estimate air temperature (Prihodko and Goward, 1997) in (Wang, 2004). (Boegh, 1998) decomposed the remotely sensed temperature into canopy temperature and soil surface temperature based on the NDVI-Ts relation for certain vegetation types when the canopy is sparse.

A drought can have substantial economic, environmental, and social impacts and it produces a large number of impacts that affects the social, environmental, and economical standard of living. The success of sustained agriculture in arid and semi-arid regions of the world depends entirely on water availability. Wheat is an important cereal crop and is adapted to a wide range of climatic conditions (Ehrler et al., 1978). However, in arid and semi-arid areas, its yield is severely limited by water-deficit stress.

5.6 Motivation

The problem associated with drought is a recurrent feature in Mongolia. In fact drought is a significant environmental problem too as it is caused by less than average rainfall over a long period of time. In Mongolia about 95 percent of total wheat sown area of the country is rain fed. Thus it has serious impacts on macro and micro regional food production, destruction of ecological resources, huge economic losses and food shortages. Therefore it is serious issue to any state authority to know the complexity nature of drought.

Systematic meteorological observations began in the early 1940s, in Mongolia. There is not much recorded or published information on historical climate of Mongolia. Only a few spot points on short period extremes have been recorded in history books (Dorjsuren, 1961, Tsevel, 1966, Tsedevsuren, 1983). Clearly, the number and duration of hot days is increasing.

Evidence for climate change taking place in Mongolia has been an increase in frequency in dust and snow storms with 2 to 3 times since 1960. High levels of climate variability in precipitation occur and it is likely that climate variability in terms of drought frequency and intensity will be increased as a result of climate change. The Mongolian average precipitation decreased by 6% in 1940-2000 years and annual air temperature increased by 1.660°C on average, with clear warming from the beginning of the 1970s. (Figure 5-4 and Figure 5-5)

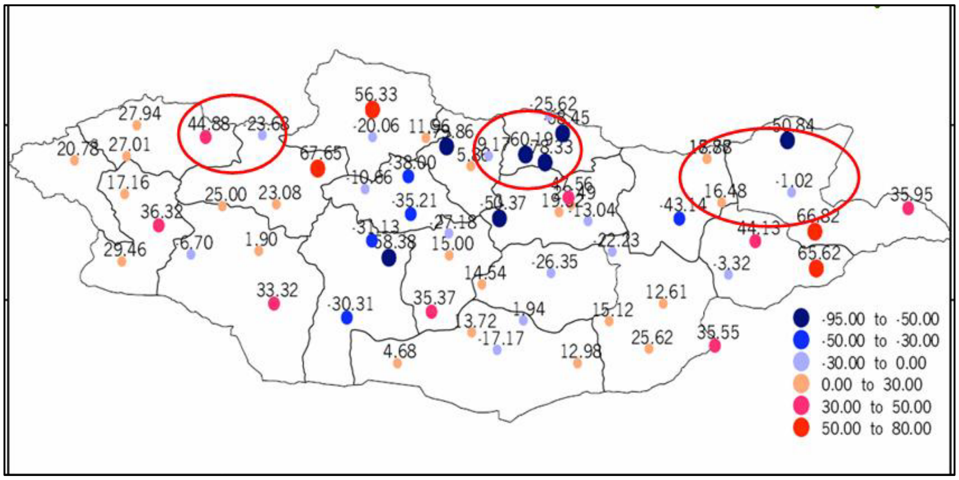

Figure 5.4 Precipitation change 1940-2000, Mongolia

(Source: Institute of Meteorology and Hydrology of Mongolia)

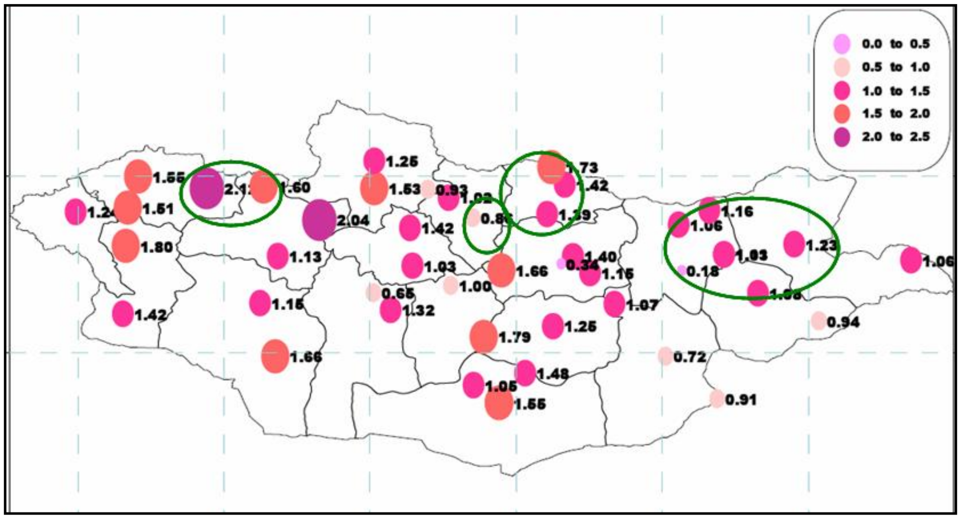

Figure 5.5 Air temperature change 1940-2000, Mongolia

(Source: Institute of Meteorology and Hydrology of Mongolia)

Apart from economic loss due to low agricultural production, loss of animal wealth, inadequate nutrition and primary health care, the impact of the drought is likely to retard the development process. The most severely affected Mongolian principal cropland area. The objective of this study is to demonstrate the use of Water Deficit Index (WDI) derived from LANDSAT satellite data for analyzing wheat area.

5.7 Study area

The selected study area Tsagaannuur district is located in the Selenge aimag. (See more from page 42, chapter-4) The climate of the region is semi-arid and the mean annual precipitation is 250-301 mm. The main crops being grown in this region are wheat, fodder crops, potato, and some vegetables. Except for wheat, all other crops are rain fed. The planting dates of wheat and fodder crops are mostly planted in from the mid of May to end of September. Almost all the crops present an important vegetative development in the June–August period. The wheat is harvested between September and early October. Some times rains very late and light in this region, while farmers using artificial cloud insemination methodology.

5.8 Used data

Landsat Enhanced Thematic Mapper (ETM+) image (with path/row 131/26) used and acquired 2000 years and image is cloud free and of good quality.

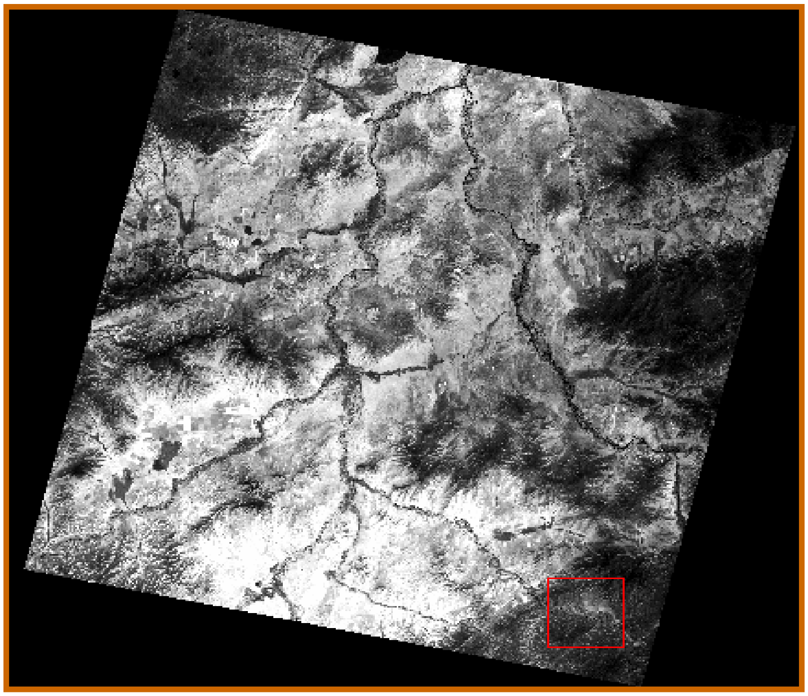

Figure 5.6 TIR Band Landsat +ETM 2002.07.24

The study period for this analysis spans the July 2000, being part of the wheat production cycle. One image generated by the enhanced thematic mapper (ETM) sensor on board of the LANDSAT 7 satellite were used, covering spectral band 3 (red, with 28.5m pixel resolution), band 4 (near infrared, with 28.5mpixel resolution) and band 6 (thermal infrared, with 60m pixel resolution). In the case of the thermal band (band 6), it was necessary to resample the image to the same resolution of bands 3 and 4. The images were acquired on July 24, 2002 Image processing was carried out with ENVI 4.3 and ERDAS imagine programming tool. The image was used to estimate the parameters required to compute water stress on wheat. The normalized difference vegetation index (NDVI) was computed with the red and near infrared bands. This module uses the following algorithm to determine NDVI:

$$NDVI = \frac{NIR - R}{NIR + R} \qquad (1)$$

Where:

NIR and R are the reflectance's in the near infrared and red bands, respectively. Surface temperature (Ts) was computed with the thermal infrared band. ERDAS relies on a conversion algorithm based on tables published by Bartoliucci and Chang (1988).

Because the trapezoid model is specific for a certain crop, we separated the area in the Tsagaannuur district planted with wheat. Also, one weather station located in the Tsagaannuur and data was used for this study.

5.9 Methodology

Vegetation lamina tissues strongly absorb incident radiances in blue, purple and red wavelengths and intensively reflect the near infrared (NIR) spectrum. The thicker the vegetation density, the smaller the reflectance in Red and the higher the reflectance in NIR bands become. Because the absorption of the Red range is saturated quickly, only the increase of reflectance in the NIR region could reflect the increase of vegetation. Then, from Red to NIR spectral region, the reflectance of bare soil is high but increases slowly. However, due to the strongest absorption by water, bare soil reflectance decreases distinctly with the increasing of soil moisture especially in the near infrared domain. Therefore, any mathematical operation which could strengthen the difference between NIR and Red could be used to describe the vegetation, surface drought status and discriminate the soil information from the vegetated pixel. All of vegetation indices (see more from ap.7) were based on this theory. Figure 5-8 is showing methodology.

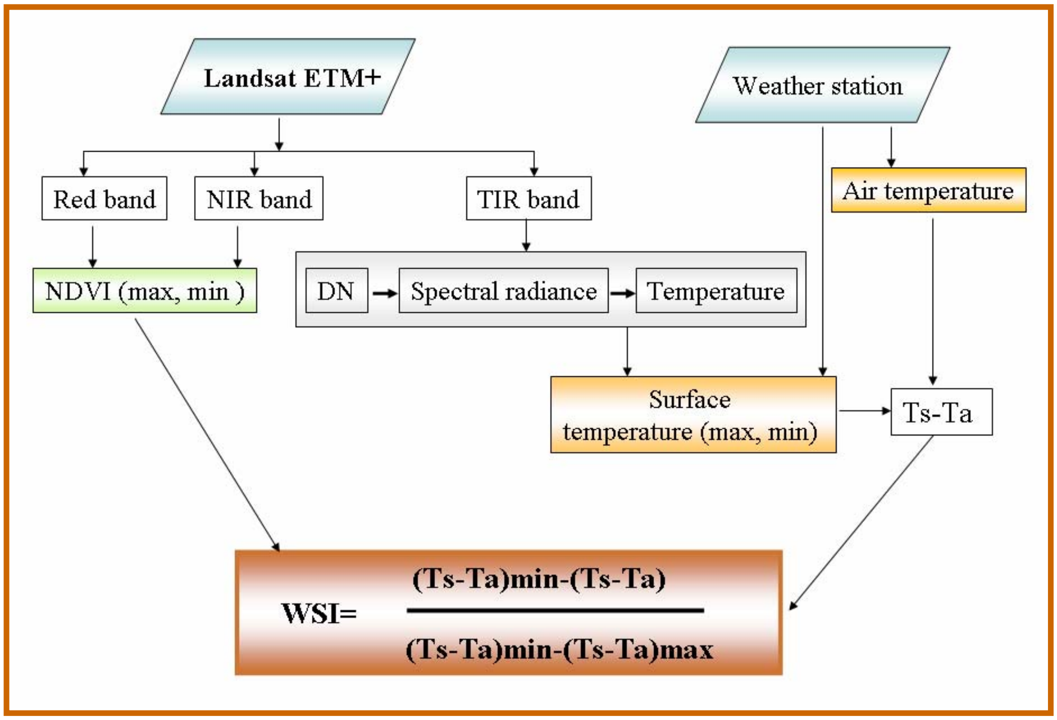

Figure 5.8 Flow chart of methodology

We determined 2 main values from remote sensing data.

1. Soil line and intercept
2. Surface temperature

Soil line:

Considering the spectral characteristics of surface targets and ETM+ spectral features, ETM+ band 3 (Red, 630–690 nm) and band 4 (NIR, 780–900 nm) were selected to construct the NIR–Red spectral space. The scatter plot of the atmospheric corrected NIR, Red reflectance spectrum demonstrated a typical triangle shape (Figure 5.7a). Different land cover types manifested certain regular distribution in the NIR–Red spectral space. Soil line is a linear relationship between the NIR and RED reflectance of bare soil originally discovered Richardson and Wiegand (1977).

$$NIR_{soil} = aR_{soil} + b \quad (2)$$

Where a-soil line slope, b-intercept

The soil line is made up of plots characterizing the spectral behavior of non-vegetated pixels and whose moisture varies obviously. It is not difficult to see from the Fig. 5.7a.

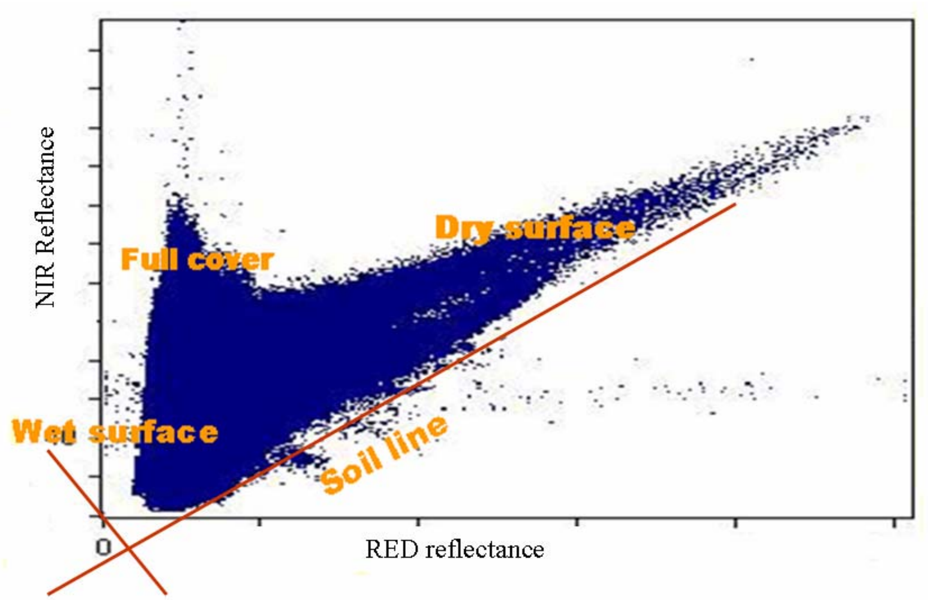

Figure 5.7 a. Construction of NIR-Red spectral space using ETM data

The remote sensing method utilized here to determine water crop stress is based on Moran et al, (1994). As explained before, the relationship between (Ts-Ta) and vegetation cover is defined in a trapezoidal (from R and NIR scatter plotter) shape. The vertices of the trapezoid indicate extreme canopy cover and (Ts-Ta) conditions for a specific crop. Vertex 1 represents full vegetation cover and well watered conditions. When crops are not experiencing water stress, the canopy resistance is at minimum.

Hence, when plants are fully transpiring, there is no opposition to water flow and the value is zero. Aerodynamic resistance is also an opposition to flow, and is defined as the resistance from the vegetation toward the atmosphere and involves friction from air flowing over vegetative surfaces (Allen et al., 1998). All these processes produce a larger negative difference between Ts-Ta. Vertex 2 is captures full vegetation cover under drought. Vertex 3 is saturated bare soil and vertex 4 is dry bare soil. Vertices 2 and 4 implies that crop experiences nearly completely stomatal closure, and, since canopy resistance is directly proportional to stomatal resistance, therefore, r_C=1 and would produce a more positive Ts-Ta value. For this theoretical shape, the term vegetation index/temperature trapezoid is utilized. The lines that connect the four vertices have a particular meaning. The line connecting vertices 1 and 2 is the range of all possible values from well watered, transpiring full cover canopy (vertex 1), to a highly stressed, non-transpiring full cover canopy (vertex 2). The line connecting vertices 1 and 4 describes potential evapotranspiration. Finally, the line connecting vertices 2 and 3 defines the zero ET condition because the surface is completely dry.

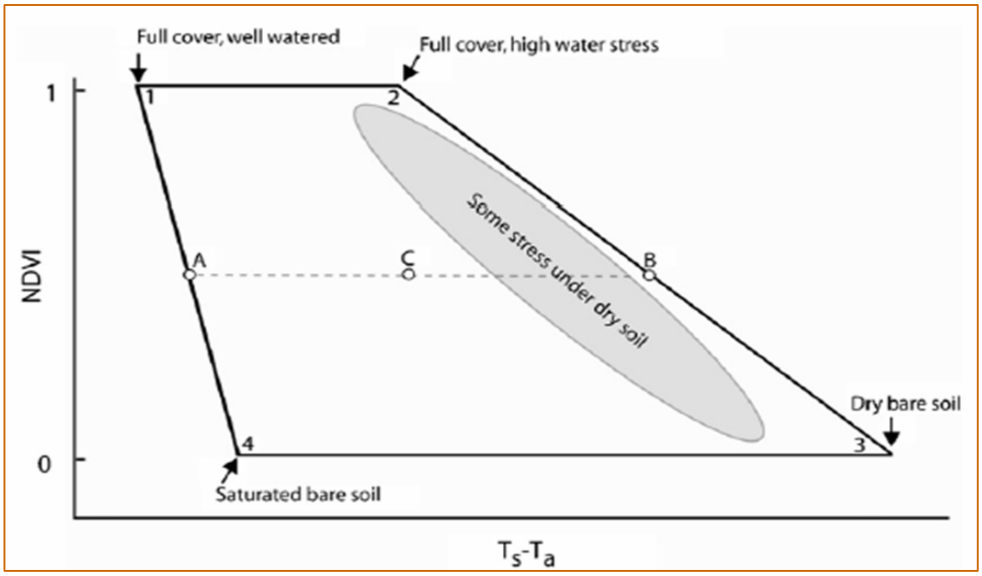

Figure 5.7.b Moran`s trapezoid derived from Figure 5-7.b. (Moran et al., 1994)

However, there is one important assumption to consider for the construction of the trapezoid. This assumption relies in considering that (Ts-Ta) is a linear function of vegetation cover, whereby, the lines connecting the vertices 1-4 and 2-3 are straight (Moran et al., 1994). This statement is supported by Kustas and Daughtry (1990) who found that Ts could be calculated from air, soil and canopy temperature and vegetation cover measurements taken in Arizona. The calculated value was -+1.5 8^{o}C of the value measured by a sensor. For a particular set of (Ts-Ta) and vegetation index (for example, point ''C'' in Fig 5-7), the ratio of the AC/AB distances is defined as the water deficit index. As a result, WDI = 0 refers to conditions under irrigation and WDI = 1 to conditions of maximal stress. In addition, the ratio of the distances CB/AB is defined as the relationship between the actual and potential evapotranspiration (Moran et al., 1994).

To determine the corners of the empirical trapezoid, measured extreme values of wheat NDVI (full cover under wet and dry soil) and the difference between surface and air temperature (full, partial foliage and bare soil) were used.

In the case of drought conditions, the average value of (Ts-Ta) was 0 (with the maximum 1^{o}C), with an NDVI value of 0.9 for full cover. Once the vertices were defined and the empirical trapezoid was built, the equations of the straight lines formed by the vertices 2-3 and 1-4 were obtained (see Fig. 5-7a.b). The equation of the straight line formed by vertices 1-4 provides the point of the minimal value of (Ts-Ta) for a given value of NDVI (point ''A'' in Fig. 5-7a, b) as

$$(T_s - T_a)_{\min} = a_1 - b_1 NDVI \quad (3)$$

Where: a_1 and b_1 are the intercept and slope of the straight line with vertices 1-4. On the other hand, the equation of the straight line formed by vertices 2-3 supplies point ''B'' or the maximum value that (Ts-Ta) can have for a given NDVI value as

$$(T_s - T_a)_{\max} = a_2 - b_2 NDVI \quad (4)$$

From formula (2) and (3) given us for ours general methodology how to define water stress index (see Figure 5-8 shown general methodology).

Final formula is:

$$WSI = \frac{(a_1 - b_1 NDVI) - (T_{s-} T_a)}{(a_1 - b_1 NDVI) - (a_{2-} b_2 NDVI)} \qquad (4)$$

The images are used to estimate the parameters required to compute water stress on wheat. Surface temperature (Ts) was computed with the thermal infrared band. The soil line and intercept are made up of plots characterizing the spectral behavior of non-vegetated pixels and whose moisture varies obviously.

Land surface temperature (LST) defines:

Land surface temperature (LST), controlled by the surface energy balance, atmospheric state, thermal properties of the surface and subsurface, is an important parameter in many environmental models (Becker and Li, 1990), such as, energy and material exchange between atmosphere and land, weather forecasting and climate change. Thermal infrared (TIR) remote sensing is the only possible approach to retrieve LST (Coll et al., 2005) over large portions of the Earth surface at different spatial resolutions and periodicities. In estimation of LST from TIR data, the digital number of the image pixel needs to be converted into spectral radiance using the sensor calibration data (Markham and Barker, 1986) and emissivity correction. However, radiance converted from digital number does not represent true surface temperature but a mixed signal or a sum of different fractions of energy. These fractions include the energy emitted from the ground, upwelling radiance from the atmosphere, as well as the down welling radiance from the sky, integrated over the hemisphere above the surface and type of land use/land cover surface present. These factors are dependent on atmospheric conditions and emissivity of the land surface.

The methodology of LST define algorithm is very easy. All algorithms are available in the Landsat data guide.

Converting ETM+ thermal bands to temperature:

The Landsat Enhanced Thematic Mapper Plus (ETM+) sensors acquire temperature data and store this information as a digital number (DN) with a range between 0 and 255. It is possible to convert these DNs to degrees Kelvin using a two step process. The first step is to convert the DNs to radiance values. There is no need to rectify the spectral radiance value in ETM+ because the two subands in ETM+ band 6, named Low gain 6 (1) and High gain 6 (2) are separated always.

The second step converts the radiance data to degrees Kelvin. In this case we calculated LST from Landsat ETM data used by with ENVI 4.8 programming tool.

To create radiance data layer, from the ENVI main menu bar, select

Basic Tools>Preprocessing>Calibration Utilities>Landsat Calibration. Select the thermal file and the ENVI Landsat Calibration dialog should open with all of the calibration parameters filled in. Click on the Radiance radio button and direct the output result to Memory. After creating this file you can proceed to the optional Section 2 Apply Atmospheric Correction or directly to Section 3 Convert Radiance to Kelvin to generate a new data layer of brightness-temperature in degrees Kelvin.

Land surface radiances derived from Landsat ETM+ TIR data were subsequently converted to radiance values, it is simply a matter of applying the inverse of the Planck function to derive temperature values.

For atmospherically corrected data the formula to convert radiance to temperature is:

$$T = \frac{K_2}{\ln\left(\frac{K_1}{CV_{R2}} + 1 \right)}$$

Where: T is degrees Kelvin

CV_{R2} is the atmospherically corrected cell value as radiance (from step 2)

K_1=666.09

K_2=1282.71

LCT Validation

One of the major problems in the validation of remote sensing data with ground truth observation is the dissimilarity between the spatial scales of field thermometers or local observation office data and that of satellite sensors. The comparison of local observation centers data with that of satellite (area averaged) data is meaningful only when the test site is homogeneous in temperature and emissivity at various spatial scales involved.

5.10 Result and conclusion

In this case were used on cloud-free Landsat-7 ETM+ image of Tsagaannuur district of Selenge province, Mongolia for LST retrieval.

Figure 5.9 shows final calibrated image of the study area and Figure 5.10 shows the empirical trapezoid compared with field and remote sensing data.

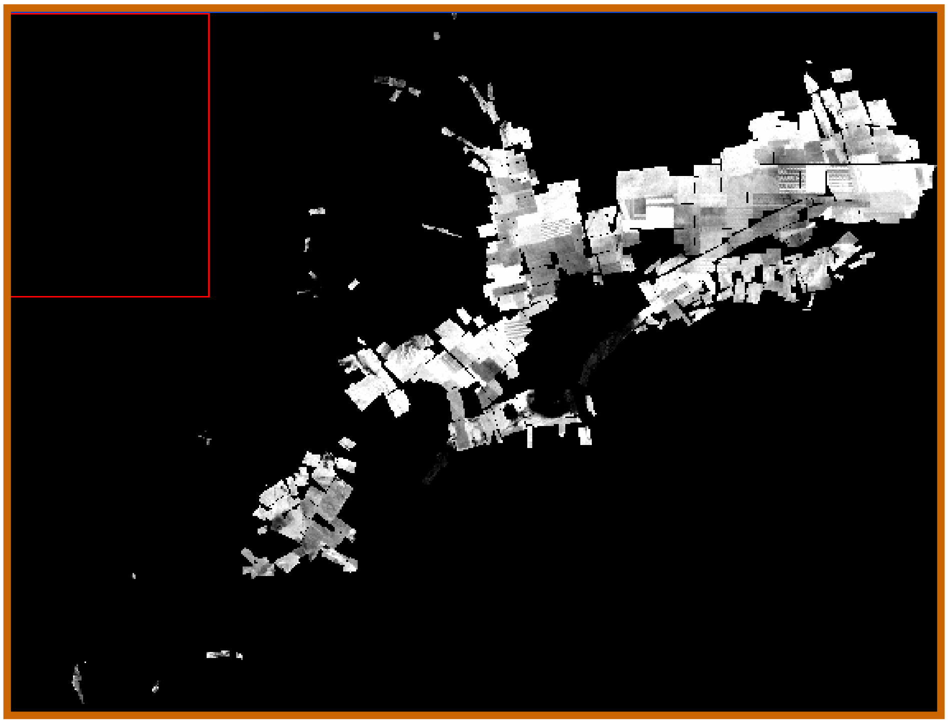

Figure 5.9 Calibrated image 20020724 ETM+,
Study area Tsagaannuur, Selenge

The blue points represent randomly chosen remotely sensed measurements from the area planted with wheat. Both sampling methods were done to verify that all the samples fall within the limits of the empirical trapezoid.

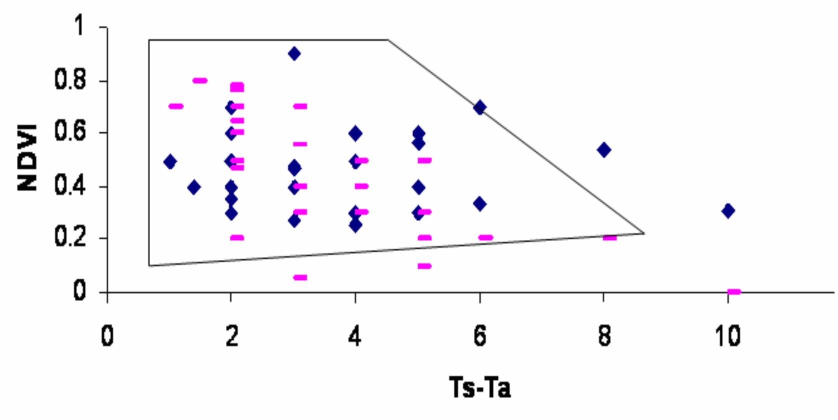

Figure 5.10 WSI in wheat field

This study shows a good agreement of LST derived from Landsat-7 ETM+ TIR data with ground temperatures over thermally homogeneous wheat area and present study has found a significant result for crop drought monitoring by integration of satellite data and meteorological data.

The trapezoidal shape obtained in this work was very similar to that from Moran et al. (1994) and Yang et al. (1996); however, it differs in the range of NDVI and (Ts-Ta) values. The trapezoid method should be applied for each specific crop in order to optimize water stress determination and irrigation management.

LANDSAT data allows estimation of the amount of water stress on small lots and parcels and in large crop fields, in part due to its broad swath width and high spatial resolution. As a result, remote sensing allows estimation of crop water dynamics at both regional and local scales. Furthermore, rapid developments in remote sensing, with the incorporation of improved satellites or sensors, may lead improved accuracy and new applications in the near future.

LST retrieval is quite useful for frequent monitoring of any study area with greater reliability with selective ground temperature measurements. The accuracy of LST retrieved for satellite data can be further improved with accurate measurements of surface emissivity and estimates of atmospheric parameters at each pixel.

In conclusion, remotely-sensed water stress index provided a useful tool for the evaluation of crop water status especially that of wheat in Tsgaannuur, Mongolia and could be useful for rain fed cropland area and irrigation scheduling.

6. Conclusion and recommendations

6.1.1 Conclusion

The remote sensing technology is increasingly being used to study land use and land cover changes and identify changes that has occur through different land use activities which may have negative impact on the sustainability of the environment and biodiversity protection and conservation.

The first objective of this study was to map and monitoring cropland cover changes that have taken place between the 1989 and 2000, to integrate visual interpretation with supervised classification using GIS and to examine the capabilities of integrating remote sensing and GIS in studying the spatial distribution of different cropland cover changes.

Supervised classification using six reflective bands of the two images acquired on 1989 and 2000 respectively was carried out using maximum likelihood classifier in order to produce cropland cover/use maps of the study area. Cropland use change detection has shown that the active used cropland area decreased between 1989 and 2000 years by 48.9 percent from 507111.1 hectares to 259262.9 hectares.

The spatial-temporal aspects of principal cropland-cover/use dynamics in the period 1989–2000 have been analyzed for the first time for the whole of Mongolia through an analysis of spatially explicit data collected through remotely sensed data interpretation and field validation.

In the present study only two years are available: 1989 describing the land-cover/use situation under the centralized government and 2000 in a market-oriented economy. The mid 1990s are not represented but stand for the moment in which the land was distributed to rural households and registration as private property took place.

The main causes of cropland decreasing in the study area are related with land privatization, agronomic mismanagement (seed quality, fertilize, pesticide, tillage, etc), technical or some area moved to mining area and irrigation problem.

This problem needs to be seriously studied, through multi-dimensional fields including socio-economic and legal aspects in order to preserve the newly reclaimed land and increase food production.

The second objective of this research was to develop an approach (methodology) to improve the geometric quality of the cropland information system with cropland cadastral map in Mongolian case study in first time. In this study distributed one part of the parcel based cropland information system on Tsagaannuur of Mongolia.

The cropland information system and cropland cadastral map renovation has been conducted in terms of economical, technical, legal and social aspects, and financial aspects.

The agricultural information sector in Mongolia has a relatively weak technological base and insufficient scientific, technical and educational capacity and thus needs substantial capacity building. There is also a dire need for radical change in the Mongolian agricultural information system, if widespread management and dissemination of information and knowledge in digital format is to take root.

Modern information systems are expected to play an increasingly important role in future in assisting agricultural producers to become more competitive on local and international markets. Producers may expect high returns to information that is pertinent to their businesses.

The third objective of this study was to investigate crop stress index in wheat field. In fact drought is a significant environmental problem too as it is caused by less than average rainfall over a long period of time.

In arid and semi-arid regions, rain fed and irrigated agriculture is threatened by water shortages caused by pronounced droughts or water mismanagements. In this study, was monitored water stress in wheat field using NIR and SWIR wavelengths and surface temperature are determined through analysis of satellite-based remote sensing images in the Tsagaannuur, of Mongolia.

This methodology can be used to generate more accurate water management practices and facilitate decisions about irrigation applications.

In Mongolia about 95 percent of total wheat sown area of the country is rain fed. Thus it has serious impacts on macro and micro regional food production, destruction of ecological resources, huge economic losses and food shortages. This study has found a significant result for crop drought monitoring by integration of satellite data and meteorological data. The trapezoidal shape obtained in this work was very similar to that from Moran et al. (1994) and Yang et al. (1996); however, it differs in the range of NDVI and (Ts-Ta) values.

6.1.2 Recommendations for further research

Some recommendations are outlined below for further research on the use of remote sensing technology in agricultural land use and cover changes monitoring in Mongolia

1. There is a need for further research work on the use of the remote sensing and GIS technology with the research study work covering the whole land cover for Mongolia. This will provide the opportunity in carrying out a comprehensive appraisal of the agricultural land use changes scenario in the whole country. With the northern region of the country undergoing a rapid change in vegetation cover and land use with desert encroachment a major problem, land use planners and environmental managers in the country will be able to make an assessment of the change scenario with a decision on which region of the country will be recommended for specific land use type based on consideration for the environment and its long term sustainability.

2. Agricultural producers in Mongolia are increasingly being exposed to the potential of modern information technologies as a management tool. However, despite the real and potential benefits of using information technologies (including improved flows of relevant and up-to-date information for decision making); their capabilities have not been fully exploited. Reasons include the relatively poor infrastructure in rural areas (e.g. unreliable telephone services), the time taken to obtain information from the Internet, the perceived high cost of some modern information technologies (such as GPS and GIS) in relation to their benefits, and the lack of education in the effective use of information technologies. There is thus a need to improve the quality of electricity and telecommunication services in the rural areas, for software developers to create more efficient algorithms, and for effective educational programmes (involving courses, workshops and phone-in support) to be developed for producers who wish to adopt modern information systems. Farm advisors, including extension officers and private consultants, could make valuable contributions to educating farmers in the effective use of information technologies. With the maturation and development of Internet/Intranet technology, Web mode has becoming the kernel network calculation mode. Web information system is also endowed more plenty content, and integrate the most advanced information technique, it plays an important and actively role in the agricultural field, and has becoming the window for agriculture communicating with the outside. Therefore we have in future needed to develop web based cropland information system.

3. There is also a need for further research work on resource use assessment to identify changes to the environmental resources in the country, more especially the water resources which is a major production resource for agriculture and other types or production activities in the country. With the country an arid region with water a limiting factor and drought a major occurrence in the country, there is need to identify regions already undergoing resource use stress for long term sustainability planning.

6.2 Limitations and significance of this research

6.2.1 Limitations of this study are:

The study had some limitations:

- It was not possible to find aerial photographs and much more high resolution images of earlier dates and recently dates covering the whole study area.

- The other limitation was that the socio-economic and agronomic survey could not include as many farmers as should have been mainly due to shortage of time. On the other hand, the socio-economic data analyzed is mainly based on primary data collected on a single visit through interviews of these sample farmers and hence it may somehow suffer from inaccuracies in some aspects of the measurements used.

- Because of the time and financial limitation, the physical design level was not able to be focused on. The organizational design and the hardware and network design were not able to be performed either. A real-life cadastral information system design must consider these issues. Therefore, a further study can focus on the internal and external organizational designs. An external organizational design should also include principles of the data sharing between several institutions.

6.2.2 Significance of this research is:

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- The spatial-temporal and semantic aspects of cropland-cover/use dynamics in the period 1989–2000 have been analyzed for the first time for the principal cropland area of Mongolia through an analysis of spatially explicit data collected through remotely sensed data interpretation and field validation. This is important for agricultural land use planning and sustainability monitoring to reduce the negative impact of agricultural land use for crop production and increase long term resource use and environmental sustainability

- Modern cadastres tend towards a Land Information System (LIS) approach. However, the cadastral system in Mongolia is not in a LIS approach. In this study, the system requirements were analyzed in accordance to the data collected for the existing cadastral system. The restrictions on land rights, such as mortgage, leasing, usage rights, etc., were not considered during the system requirements analysis phase. The cadastral data should form a base for other applications, such as municipality works, engineering projects, etc.

- The proposed dissertation research will provide a new foundation for GIS-based approaches for assessing, monitoring and managing drought through the development of a spatially distributed drought. The increased spatial and temporal resolution will give the farming community, water managers and policy makers a better tool for assessing, forecasting and managing agricultural drought on a much more precise scale.

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Appendix 1

Mongolian facts

1.1 Geography of Mongolia

Location:	Northern Asia, between China and Russia
Coordinates:	46 00 N, 105 00 E
Area:	total: 1.565 million sq km water: 9,600 sq km land: 1,555,400 sq km
Area comparative:	slightly smaller than Alaska
Land boundaries:	total: 8,162 km border countries: China 4,677 km, Russia 3,485 km
Coastline:	0 km (landlocked)
Maritime claims:	none (landlocked)
Climate:	desert; continental (large daily and seasonal temperature ranges)
Terrain:	vast semidesert and desert plains, grassy steppe, mountains in west and southwest; Gobi Desert in south-central
Elevation extremes:	lowest point: Hoh Nuur 518 m highest point: Nayramadlin Orgil (Huyten Orgil) 4,374 m
Natural resources:	oil, coal, copper, molybdenum, tungsten, phosphates, tin, nickel, zinc, wolfram, fluorspar, gold, silver, iron, phosphate
Natural hazards:	dust storms, grassland and forest fires, drought, and "zud", which is harsh winter conditions
Environment current issues:	limited natural fresh water resources in some areas; the policies of former Communist regimes promoted rapid urbanization and industrial growth that had negative effects on the environment; the burning of soft coal in power plants and the lack of enforcement of environmental laws severely polluted the air in Ulaanbaatar; deforestation, overgrazing, and the converting of virgin land to agricultural production increased soil erosion from wind and rain; desertification and mining activities had a deleterious effect on the environment
Geography - note:	landlocked; strategic location between China and Russia

1.2 Government

Country name:	Conventional short form: Mongolia Local short form: Mongol Uls Former: Outer Mongolia
Government type:	Parliamentary
Capital:	Ulaanbaatar
Administrative divisions:	21 provinces (aimag) and 1 municipality* (singular - hot); Arhangay, Bayanhongor, Bayan-Olgiy, Bulgan, Darhan Uul, Dornod, Dornogovi, Dundgovi, Dzavhan, Govi-Altay, Govi-Sumber, Hentiy, Hovd, Hovsgol, Omnogovi, Orhon, Ovorhangay, Selenge, Suhbaatar, Tov, Ulaanbaatar*, Uvs
Independence:	11 July 1921 (from China)
National holiday:	Independence Day/Revolution Day, 11 July (1921)
Constitution:	12 February 1992
Legal system:	blend of Soviet, German, and US systems of law that combines aspects of a parliamentary system with some aspects of a presidential system; constitution ambiguous on judicial review of legislative acts; has not accepted compulsory ICJ jurisdiction
Suffrage:	18 years of age; universal
Legislative branch:	unicameral State Great Hural (Parliament of Mongolia) 76 seats; members elected by popular vote to serve four-year terms
Judicial branch:	Supreme Court (serves as appeals court for people's and provincial courts but rarely overturns verdicts of lower courts; judges are nominated by the General Council of Courts and approved by the president)

Appendix 2

Sustainable development

1990s, an awareness regarding the dimensions of sustainable development has been paramount in the minds and actions of many.

A principal concern of any country in the world today is to define and better understand the interrelationships between environment, economic development, natural resources and population for the purpose of realizing what is collectively known as "sustainable development" (WCED, 1987).

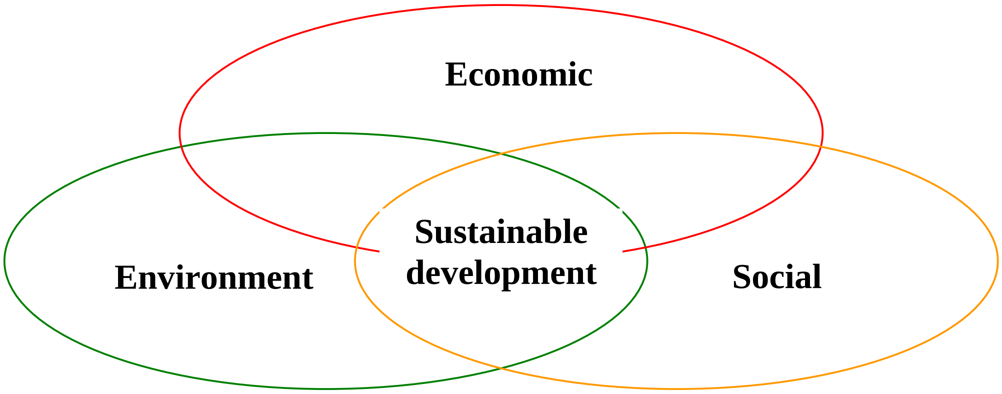

Figure 1.Sustainable development

Appendix 3

History and Scope of the precision agriculture (PA)

The concept of precision agriculture (PA), although present in some form for centuries, was formulated formally in 1986 in a seminal paper written by Fairchild (Fairchild 1994). Since its theoretical inception PA has been explored widely, although it has been applied mainly in Europe and the United States, where farm sizes are large and landowners are willing to make larger capital investments in PA technology (Pederson et al., 2001). Accordingly, many significant PA developments took place in the US, Canada, Australia and Western Europe in the mid-to-late 1980s (Zhang et al., 2002) with principle areas of PA development taking place in regards to high yield crops such as wheat, barley, corn and soybean (Autrey, 1998). Regardless, PA management has experienced considerable attention from researchers worldwide and has become a prominent issue in modern agriculture, with PA related experiments reported in recent literature from China, Korea, Japan, Indonesia, Bangladesh, Sri Lanka, Turkey, Saudi Arabia, Australia, Brazil, Argentina, Chile, Uruguay, Russia, Italy, The Netherlands, Germany, France, UK, United States and Canada (Zhang et al., 2002). All of these experiments with various aspects of PA practice have occurred in parallel with the development of spatial database management and environmental monitoring tools, and the literature explores a range of issues from general PA implementation guidelines to specific indices for the analysis of crop spectral information (Barnes et al., 1996; Atherton et al., 1999). Excellent reviews are available of its development and myriad aspects from leaders in the PA field (Moran, Inoue et al. 1997; Plant 2001).

In spite of these myriad developments and widespread interest, some studies suggest that adoption of PA related technologies, such as yield monitoring, is not as widespread as initially forecasted (Zhang et al., 1997; Lowenberg-DeBoer 2003).

Although there are many complex sociological and economic reasons for this, most studies reveal that the greatest barrier to PA adoption is the substantial initial capital investment required, and the fact that the most significant benefits of PA usually come after the accumulation of many years of detailed soil and plant variability data. (Blackmore et al., 1994; Pederson et al., 2001; Sevier and Lee 2003; McBratney et al., 2004; Adrian et al., 2005). Unfortunately, this barrier may seem even greater in a developing country context, where profitability in agriculture is often even lower (Cook et al. 2003). Despite this uncertainty, PA has been shown to be profitable in both a developed and developing country context (Stombaugh et al. 2001; Godwin et al., 2002; Bongiovanni and Lowenberg-Deboer 2004) and a survey of economic studies related to PA concludes that the majority of PA management schemes show positive net returns (Lambert and Lowenberg-DeBoer 2000). In general, there is also strong correlation between PA profitability and farm size and even farms of just over 200 ha, can expect profits and an amelioration of product quality by implementing PA (Stombaugh, et al., 2001; Godwin et al., 2002). Although smaller farm sizes and land tenure may be an issue in the global south, the existence of landowners with large landholdings such as Azucarera Nacional in Panama provides strong cause for PA implementation in the developing country context, where optimization of production is most pressing.

It is important to note that as sustainable development becomes economically valued, the benefits of PA implementation will accordingly become increasingly apparent. That is, when reduced environmental burdens are recognized and evaluated and become part of the ultimate reward, PA will gain increased importance in the agricultural sphere (Auernhammer 2001).

These results imply that appropriate environmental policy reforms by local governments worldwide will be pivotal in encouraging the use of precision farming and that such management schemes encourage *economic* and *environmental* optimization.

Appendix 4

(a) *Basic Cadastral Data*

There are three main cadastral data types (Dale and McLaughlin, 1988):

- cadastral land parcel
- cadastral records identifying land rights and persons who hold rights
- parcel identifier

Cadastral land parcel: A cadastral land parcel serves as a basic unit for a parcel based land information systems. It is sometimes termed a lot or a plot. It is an area or, more strictly speaking, a volume of space recognized for land administration purposes.

Cadastral records: These generally describe three kinds of information concerning basic objects (land parcels, land rights and persons). However, to cope with the particular country requirements, formal or informal tenure and extended land objects of different types of land rights (e.g. group rights, individual ownership) must also be registered, including the rightful claimants, in the PBLIS. Copies of survey records, land ownership certificates and deeds should also be stored for future reference. The latest technique for archiving these documents is to scan them and store them in a database.

Parcel identifier: The objects with unique identifiers serve to link the cadastral records with many other records or information systems. In other words, they facilitate data sharing among different users of the information system. Even with a traditional system, it is necessary to have a parcel indicator or a unique parcel reference that identifies the parcel and allows cross-referencing within the register and other filing systems. Three important forms of identifier can be distinguished: name-related identifiers, abstract or alphanumeric identifiers, and location identifiers.

Building: In the traditional cadastral systems, the building objects are incorporated as physical objects, not as legal objects. In reality, however, building objects such as apartments are legal entities associated with rights, land parcels and owners. Data about building is also increasingly used for a variety of purposes. Therefore, the building objects are as important as land parcels in PBLIS.

(b) *Additional Data*

In the context of the broader objective of the PBLIS, it is important to relate the following data in the system in addition to the basic cadastral data, as the users (municipalities, utilities, etc.) always expect topographical objects together with cadastral parcels for their multipurpose uses. These additional data as references provide quick and easy access to the area.

National geodetic control points: These control points are essentially used for geo-referencing all kinds of spatial data in a uniform reference system. The global positioning system (GPS) is now seen as the most cost-effective means of establishing a national geodetic reference system, compared with the traditional approaches of triangulation and traversing methods.

Topographical information: Administrative boundaries, transportation networks including roads and railways, cultural features, hydrographical features, utility lines, and digital elevation models are topographical objects.

These physical objects provide extremely valuable supports for many applications in natural resource management and earth science applications, and form the basis for all kinds of boundaries, including land parcels and administrative boundaries.

Ortho-photos or images: Rectified and relief-displacement-corrected aerial photographs or high-resolution images (such as IKONOS or Quickbird) can be extremely effective as backdrops for the cadastral data, enhancing reliability for the users.

Socio-economic information: This includes population censuses, agricultural censuses and other environmental information.

Thematic (natural resource) information: This includes land use, vegetation, weather data and soil, geological and geophysical information.

Many of above datasets are usually produced by the various departments or agencies depending upon their tasks and responsibilities. With advancement of Geo-ICT technology, the data can be made accessible via Geo-spatial data infrastructure. Then a Mongolian parcel based agricultural land information system as a multipurpose system provides various services and products to clients using these datasets.

Geographic Information Systems (GIS) are a cutting-edge technology that allows the unprecedented manipulation and analysis of geographic information. In practical terms, a GIS simply consists of computer software, hardware and data, and personnel to help manipulate, analyze and present information that is tied to spatial location. A GIS can provide farm managers an effective method to visualize, manipulate, analyze and display spatial data, providing the backbone of a PA system.

There are two principal ways to input and visualize data in a GIS:

1) **Raster data:** consists of information in a grid, composed of pixels, where each pixel represents a location and has a certain value. Data obtained from remote sensing, such as satellite imagery and aerial photography are in this format. Discrete point data obtained from field sampling can also be interpolated to create continuous raster coverages of the sampled properties (Crosier et al., 1999).

2) **Vector data:** consists of linear, rather than grid, information and is composed of points, lines and polygons. Geographic features such as buildings, bodies of water and boundaries of fields and agricultural management units etc. are in vector format. One can attach attributes such a size, type and length, among other properties to vector data (Crosier et al., 1999).

The information that can be integrated into a GIS is many and varied, contributing to the flexibility and adaptability of GIS to many applications. In general these in information sources consist of digitized and scanned maps; tables of attribute data, spatial data gathered using a GPS device, as well as data gathered using remote sensing devices such as satellites. What makes GIS a crucial part of PA systems is that they ultimately involve a high level of data integration between positioning and sensing technologies and control systems (Earl et al., 2000). GIS is therefore able to provide the necessary platform for complex information flows, which include spatial and temporal components, and to facilitate the use of expert knowledge already held by farmers, to synthesize information into a scheme for optimal crop management (ESRI, 2007). Once digital maps are created of agricultural holdings and linked to relevant attribute information, query and analysis are the key functions of a GIS system used for decision support. Strengthening the system with continued input of field data, a GIS can be used for site-specific management involving the mapping of yield variability and the identification of limiting factors by combined analysis of soil, nutrients, slope and weather information along with field data and remotely sensed data. Visual displays of how properties are changing over a field are extremely useful for farm managers to manage inputs using management zones (Plant, 2001).

Creating a GIS is the first step in PA implementation (Jhoty and Autrey, 1998) and it is a becoming a commonplace information technology tool for agricultural production applications (ESRI, 2007).

GIS is not only an important tool to input and analyze crop management information, it can also be used in conjunction with GPS and variable rate technology to directly control agricultural inputs once information is gathered. Small-scale variations in site-quality can be detected using GIS and related PA technology and this information can then be translated into valid crop management guidelines (Jarfe and Werner. 2000). German researchers initiated a field-based project where management guidelines were designed and then transformed into software modules to allow farmers to adjust cropping measures to respective management zones in a field (Jarfe and Werner, 2000). They were able to successfully apply a decision support system based on ArcView using if-then rules, for calculating site specific and agronomic optimal sowing rates. Many similar projects have been realized using GIS in conjunction with variable rate controllers for site specific application of fertilizer (Seidl et al., 2001; Miller et al., 2005), herbicides (Al-Gaadi and Ayers 1999) and irrigation water (Perry et al., 2002)

Appendix 5

5.1 Seed quality

Until 1990, the seed sector was centrally organized and subsidized, and was directly under the responsibility of the Ministry of Agriculture of Mongolia.

Seed supply to farmers is mainly from the informal seed sector, from on-farm seed production and exchange. FAO assisted the country through implementation of an emergency wheat seed production and new variety testing project.

Exiting problems of poor seed quality are mostly due to frost damage and the high moisture content of stored seed, resulting in poor germination, lack of vigor and susceptibility to root rot infections. Quality is further lowered by contamination with weed seed. Modest investments in repair and or replacement of screens for grain cleaners and closer attention to correct setting and operation of the equipment would improve seed cleaning operations and eliminate most weed seed. Avoidance of frost-damaged grain earmarked for seed and aeration and drying of stored seed to reduce moisture content to 14% would significantly improve germination and vigor and allow a significant reduction in seed rates.

5.2 Wheat alternatives

Alternatives to large-scale wheat cultivation are severely limited by the harsh climate and lack of markets. Fodder crops which were previously gown in rotation with wheat are in very limited demand following the abolition of subsidized livestock feed. Vegetables, which are consumed mostly by the urban population, are grown almost exclusively under irrigation and relatively small areas are needed to satisfy the demand.

The growing season is too short and rainfall inadequate, and there is a high risk of frost damage, which can seriously reduce root yield and sugar content. Climatic variability between seasons is such that there is considerable risk of crop failure.

Barley, the second most important cereal in Mongolia, is quite well adapted to cool weather and a short growing season, has similar agronomic and equipment needs to those of wheat and is potentially more productive. However, the shortage of inputs and the collapse of the feed grain market have had a dramatic effect on cropped area and yield. The planted area has declined from about 120,000ha in 1990 to 19,000 ha in 1994 and average grain yield, which reached about 1.2-1.3t/ha in the mid of 1980s, has fallen to about 0.6t/ha. Improvements in crop husbandry and post-harvest grain handling and storage, similar to those described for wheat in pare. 3.4-3.14 is required in order to raise productivity and grain quality. In addition, new varieties are needed to replace the current variety “winner” which was originally released in the Soviet Union in the 1920s.

Rapeseed (Canola) may have potential as an alternative to wheat although little agronomic work has been done on this crop in Mongolia to date. Early maturing (85 days) varieties are available and could be imported and multiplied quite rapidly with sowing rates of only 2-15kg/ha. Most of the improved technology recommendations for wheat are equally applicable to rapeseed. However, successful seedbed preparation and crop establishment is more demanding than for wheat. Because of its small seed size, rapeseed requires a shallow planting depth (not more than 5 cm) and given the dry weather prevalent in spring minimum tillage is highly desirable to conserve moisture in the seedbed. Equipment requirements are similar to wheat with some (inexpensive) adaptation necessary for combine harvesters and seed processing equipment. Under good management average yields of 1t/ha should be achievable.

5.3 Crop Genetic Resources

Since the 1940s, Mongolian researchers are estimated to have utilized more than 150 crops in Mongolia, and, from these, 18 crops are used for various purposes, including a few minor crops. Just 5 crops are grown widely in Mongolia. During the last 40 years, the development of communication systems has greatly boosted the phenomenon of cultural integration, including the imposition of the eating habits of the dominant culture. Most important crops were very rapidly replaced by the new varieties from the Soviet Union. Many local varieties of cereals, vegetables were ignored for many years, because of their low yields, but it has only recently been discovered that local varieties carried genes for resistance to drought and diseases, with high protein contents and early maturity. Now, more efforts are being given to the collection and preservation of plant genetic resources, including local varieties.

Appendix 6

6.1 Water stress

When plants are subjected to water stress, it affects the availability of water to plants, and therefore, water content of plant cells is lower than the optimum level and causes some degree of metabolic disturbance, hence, a plant is said to be suffering water stress (Fitter and Hay, 1981). Leaf curling, wilt or drastic decrease of leaf area expansion is generally symptoms of water stress (Alscher et al., 1990). Plants subjected to water stress reduce stomatal conductance, causing a decrease in transpiration rate, this affects the leaf energy balance and ends with increasing leaf temperature (Jones, 1999). Water stress affects leaf area and leaf angle distribution (LAD) in many plant species. Ehleringer and Forseth (1989) reported that several plant species have shown the ability to adjust leaf angle in response to limited soil moisture. The extent of moisture stress impact on plant leaves depends on the occurrence of the water stress relative to the phenological stage of the plant and severity of water deficit (Chaney, 2000).

The availability of soil water is a major factor limiting wheat production in most regions of the world especially under semi arid and arid environments (Ozturk and Aydin, 2004). They also reported substantial losses in grain yield are caused by water deficiency depending on the developmental stage at which water stress occurs.

6.2 Salinity stress

Plant growth is hindered by salinity especially in sensitive plant species; salinity affects plant growth in three major ways (Greenway and Munns, 1980): (a) water deficit arising from the more negative water potential (elevated osmotic pressure) of the soil solution, (b) specific ion toxicity usually associated with either excessive chloride or sodium uptake and (c) nutrient ion imbalance when the excess of Na+ or Cl-leads to a diminished uptake of K+ , Ca+ , NO3 - or PO4 -, or to impaired internal distribution of one or another of these ions.

Excess salinity within the plant root zone has a general deleterious effect on plant growth since water with high salinity is toxic to plants and poses a salinity hazard (University of Texas, 2007). High concentrations of salt in the soil can result in a physiological drought condition-that is, even though the field appears to have plenty of moisture, the plants wilt because the roots are unable to absorb water. They also reported that this effect is primarily related to total electrolyte concentration and is largely independent of specific solute composition. The hypothesis that best seems to fit observations is that excessive salinity reduces plant growth primarily because it increases the energy that must be expended to acquire water from the soil of the root zone and to make the biochemical adjustments necessary to survive under stress. This energy is diverted from the process which leads to growth and yield. Larcher (1995) reported that plants are under salinity stress when salt content in the root zone exceeds the capacity of plants to cope. Plants try to adapt with high salinity in the root zone by reducing leaf size, scorching of leaf tips or margins, and premature discoloration and abscission of the leaves.

6.3 Heat and chilling stress

Heat and cold stress depending on their intensity and duration can impair the metabolic activity, growth and variability of plants and thus limit the distribution of a species. When the critical temperature threshold of a species is exceeded, cell structures and cellular functions may be damaged (Larcher, 1995). Plants under heat stress are darker when compared with non-stressed plants and plants that suffer from this type of stress have dry or yellow – dry spots on their leaves (Staub, 1990).

Physical and/or physiological changes that are induced by exposure to very low temperature include loss of chlorophyll, apparent as leaf yellowing, and purpling as a result of photo-oxidation (Saltveit and Morris, 1990).

It is predicted that increases in greenhouse gas concentration will result in increasing mean temperatures of about 2°C by the middle of the 21st century (Kattenberg et al., 1996). The growth stage of wheat most likely to be affected is the grain filling stage as the duration of grain filling in cereals is determined principally by temperature (Wheeler et al., 1996). They also reported that high temperature episodes occurring near to anthesis can reduce the number of grains per ear and the subsequent rate of increase in harvest index, resulting in smaller grain yields.

6.4 Nutrients stress

Nitrogen deficiency is the most common and widespread nutrient deficiency (Larcher, 1995). When plants are subjected to nitrogen stress the first symptom tends to be yellowing of leaves. Also, due to increasing chemical fertilization prices, farmers can not afford enough fertilizer to compensate for the loss of nitrogen in intensive cropping systems. In addition to grain yield reduction due to the lack of nitrogen, nitrogen deficiency may result in reducing ear biomass at flowering and under drought conditions. (Edmeades et al., 1992).

6.5 Plant morphological responses to stress

Every part of a plant may be affected by any type of stress although in most cases one or some parts of a plant are affected first. Leaf responses to different stresses are very important when taking into account remote sensing techniques in detecting plant stress particularly the decrease in the rate of leaf expansion and consequent decrease in the total leaf area. The decrease in leaf expansion is generally thought to be due to a drop in cell turgor pressure. However, Ball (1988) suggested that it was more likely a result of a change in hormonal signaling from roots to leaves.

Appendix 7

Previously published vegetation indices (VI) collected from literature.

Ratio Vegetation Index (RVI) (Jordan, 1969; Pearson and Miller, 1972). A common practice in remote sensing is the use of band ratios to eliminate various albedo effects. In this case the vegetation isolines converge at origin. Soil line has slope of 1 and passes through origin, it range from 0 to infinity. And it is calculated as follow:

$$RVI = \frac{NIR}{RED} \quad (1)$$

Normalized Difference Vegetation Index (NDVI) (Kriegler, 1969; Rouse et al., 1973) and it is the common vegetation index referring to. This index can vary between -1 and 1. In this case vegetation isolines are considered to be convergent at origin and soil line slope is 1 and passed through origin. It is calculated as:

$$NDVI = \frac{NIR - RED}{NIR + RED} (2)$$

VI`s assumes that external noise (soil background, atmosphere, sun and view angle effect) is normalized, but this assumptions is not always true. The relative percentage of sunlit, shaded soil and plants components is highly dependent upon the view angle. Qi et al. (1995) studied the effect of multidirectional spectral measurements on the biophysical parameter estimation using a modeling approach. When the bidirectional effect is transformed from reflectance domain into vegetation index domain, it could be reduced (Jackson et al., 1990; Huete et al., 1992) or increased (Kimes et al., 1985; Qi et al., 1994b), depending on the vegetation types and solar zenith angles. Qi (1995) suggested that when bidirectional effect is a major concern (NDVI/NDVIo > 1) it is better to use NIR rather than NDVI, and that bidirectional effect on vegetation indices must be quantified before a quantitative VI-LAI relationship can be used.

The Green Normalized Vegetative Index (GNDVI) is a modification of the NDVI where the Red portion is substituted by the reflectance in the Green band (Gitelson et al., 1996).

DVI is the Difference Vegetation Index, (Richardson and Everitt (1992), but appears as VI in Lillesand and Kiefer (1994). Vegetation isolines are parallel to soil line. Soil line has arbitrary slope, passes through origin, and index range is infinite.

$$\mathrm{DVI} = \mathrm{NIR}\text{-}\mathrm{RED} \quad (3)$$

Perpendicular Vegetation Index (PVI) (Crippen, 1990), and it is sensitive to atmospheric variation. In this case vegetation isolines are parallel to soil line. Soil line has arbitrary slope, passes through origin and the index range from -1 to 1.

$$PVI = \frac{1}{\sqrt{a^2 + 1(NIR - aRED - b)}} \quad (4)$$

Where a and b is the coefficient derived from the soil line (In this thesis defined from NIR and RED scatter plot from Landsat+ETM):

$$NIR_{soil} = aRED_{soil} + b \quad (5)$$

Weighted Different Vegetation Index (WDVI) (Clevers, 1988) and like PVI is sensitive to atmospheric variation (Qi et al., 1994). Vegetation isolines are parallel to soil line. Soil line has an arbitrary slope and passes through origin, vegetation index range is inifinite.

$$WDVI = NIR - aRED \quad (6)$$

Where a is the slope of the soil line.

Huete (1988) proposed a **Soil Adjusted Vegetation Index (SAVI)** to account for the optical soil properties on the plant canopy reflectance. SAVI involves a constant L to the NDVI equation. The index range is from -1 to +1.

$$SAVI = \frac{NIR - RED}{(NIR + RED + L)(1 + L)} \quad (7)$$

The constant L is introduced in order to minimize soil-brightness influences and to produce vegetation isolines independent of the soil background (Baret and Guyot, 1991). This factor can vary from 0 to infinity and the range depends on the canopy density. For

L=0 SAVI is equal to NDVI, for L tends to infinity, SAVI is equal to PVI. However for intermediate density L was found equal to 0.5. Huete (1988) suggested that there maybe two or three optimal adjustment factor (L) depending on the vegetation density (L=1 for low vegetation; L=0.5 for intermediate vegetation densities; L=0.25 for higher density).

Transformed Adjusted Vegetation Index (TSAVI) (Baret et al., 1989), and it is a measure of the angle between the soil line and the vegetation isoline. The soil line has arbitrary slope and intercept. The interception between soil line and vegetation isoline occur somewhere in the third quadrant. Baret and Guyot (1991) have proposed an improving of the initial equation as follow:

$$TSAVI = \frac{a(NIR - aRED - b)}{aNIR + RED - ab + x(1 + a^2)} \quad (8)$$

Where a and b are soil line parameters (slope and intercept of the soil line) and χ has been adjusted so as minimize background effect, and its value is 0.08. TSAVI values ranging from 0 for bare soil and is close to 0.70 for very dense canopies as reported from Baret and Guyot (1991).

At 40% green cover, the noise level of the NDVI is 4 times the WDVI and almost 10 times the SAVI, corresponding to a vegetation estimation error of +/- 23% for the NDVI, +/- 7% cover for the WDVI, and +/-2.5% for the SAVI. Therefore the SAVI is a more representative vegetation indicator than the other Vis, but an optimization of the L factor will further increase his value (Qi et al., 1994).

Qi et al. (1994) developed a **Modified Soil Vegetation Index (MSAVI).** This index provide a variable correction factor L. Geometrically vegetation isolines don’t converge to a fixed point as SAVI, and soil line has not fixed slope and passes through origin. Correction factor is based on calculation of NDVI and WDVI as shown by equations (9) and (10):

$$MSAVI = \frac{NIR - RED}{(NIR + RED + L)(1 + L)} \quad (9)$$

Where L is calculated as follow:

$$L = 1 - 2a * NDVI * WDVI \quad (10)$$

This term is computed to explain the variation of L among different types of soils, moreover L varies with canopy cover, and its range varies from 0 for very sparse canopy to 1 for very dense canopy. To further minimize the soil effect Qi et al. (1994), use an L function with boundary condition of 0 and 1 ($L_n = 1 - MSAVI_{n-1}$) and an MSAVI equal to:

$$MSAVI_n = \left[\frac{NIR - RED}{NIR + RED + 1 - MSAVI_{n-1}} \right] * (2 - MSAVI_{n-1}) \quad (11)$$

The final solution for MSAVI is:

$$MSAVI = \frac{2NIR + 1 - \left[(2NIR + 1)^2 - 8(NIR - RED) \right]^{0.5}}{2} \quad (12)$$

OSAVI is the Optimized Soil Adjusted Vegetation Index. This index has the same formulation of the SAVI family indices, but the value L or X as refered by Rondeaux et al. (1996) is the optimum value that minimizing the standard deviations over the full range of cover.

$$OSAVI = \frac{NIR - RED}{(NIR + RED + 0.16)(1 + 0,16)} \quad (13)$$

Generalized Soil Adjusted Vegetation Index (GESAVI). This index is based on an angular distance between the soil line and the vegetation isolines. GESAVI is not normalized and vary from 0 to 1 (from bare soil to dense canopies).Vegetation isolines are neither parallel nor convergent at the origin. Vegetation isolines intercept the soil line at any point depending on the vegetation amount.

$$GESAVI = \frac{(NIR - RED)(b - a)}{RED + Z} \quad (14)$$

Z is the soil adjustment coefficient, and its based on the assumption that vegetation isolines intercept soil line at any point in the third quadrant. Z decrease when vegetation cover increase. However, practically, Z consider vegetation isolines convergent in a point. At least this hypotesis may be limited for dense canopies (Gilabert et al., 2002). To normalize soil effects Z value is found at 0.35.

Indices that include the Mid-InfraRed Band (MIR) is:

Stress related Vegetation Index (STVI) (Gardener, 1983):

$$STVI = \frac{MIR * RED}{NIR} \quad (15)$$

Cubed ratio index (CRVI) (Thenkabail et al.,1994):

$$CRVI = \left(\frac{NIR}{MIR}\right)^3 \quad (16)$$

The VIs that account for soil effect, do not consider atmospheric conditions, sensor viewing angle, solar illumination conditions. Kaufman and Tanre (1992) developed the Atmospherically Resistant Vegetation Index (ARVI) and the Soil and Atmospherically Resistant Vegetation Index (SARVI and SARVI2) where the reflectances are corrected for molecular scattering and ozone absorption. Liu and Huete (1995) incorporated a soil adjustment and atmospheric resistance concepts into a Modified Normalized Vegetation Index (MNDVI).

SARVI2 as well as ARVI, SARVI are able to remove smoke effect and cirrus clouds from images (Huete et al., 1996).