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Supporting Mongolian pastoralists by using GIS to identify grazing limitations and opportunities from livestock census and remote sensing data

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Abstract

Since 1990, Mongolia has experienced a radical change away from centralized livestock production to more traditional rangeland management practices. As the herders now have increased access to the pastures, they need to be able to evaluate the sustainable level of exploitation of the rangeland. This paper demonstrates how pertinent information on the state of the rangeland resources can be made available to herdsmen by using a Geographical Information System (GIS). The focus is on the importance of having a sound data and information framework when assessing rangeland resources. The three main requirements are: first, knowledge of the production system; second, a natural resource inventory; and third, an assessment of the natural resource exploitation. Workshops held in the field brought together herdsmen, administrators, scientists and project personnel to identify and discuss issues of range management. From topographic maps, a digital elevation model was created using GIS, which together with a recent land-cover map elaborated from a SPOT satellite image made it possible to map the important areas suitable for winter grazing. The exact locations of the family winter settlements were recorded and linked to annual livestock statistics using GIS to identify the areas being grazed and to calculate the stocking rates by household. It was shown for the administrative unit of Arbayasgalan that the ratio of stocking rates to carrying capacity exceeded one, which indicates overstocking. However, the uneven distribution of grazing pressure over the study area enabled the proposal of actions to mitigate serious overgrazing. A discussion of range management practices was facilitated by providing the herdsmen with information on the extent and location of the problem.

Introduction

The Mongolians have exploited the vast grazing resources of their country for the past 4–5000 years through extensive livestock production managed under semi-nomadic conditions. During the 20th century, the agricultural sector has become increasingly important and by 1990 it accounted for 20% of the national income and 30% of employment, with the most important sub-sector bring pastoral livestock production, that contributed with 73% of the gross agricultural output (Danagro, 1992). Under the socialist period, from 1921 to 1990, a collective farm system was introduced to maximize productivity. Supplementary winter and spring forage was used in certain areas as a means to boost the production of livestock and hence respond to the rising urban and industrial demands. This strategy allowed stocking rates to exceed the carrying capacity of the land.

In 1990, the Mongolians began to move away from a command to a market economy. This has radically changed the livestock production system from being centralized, state controlled and highly subsidised, to traditional pasture management practices based on the natural resource base. One of the challenges currently faced by the government, is how to support the herders in the co-ordination of their production and land management activities in order to achieve the sustainable use of the grazing areas (Danagro, 1992).

In 1995, the Mongolian Ministry of Nature and Environment (MNE) and Danida (Danish Development Assistance) established a joint project to strengthen the availability and quality of information and data on pastural resources. The overall objective was to support the pastoralists to enable them to maintain or intensify their production through informed decisions. The strategy was to exploit existing data, remote sensing data and to use Geographical Information Systems (GIS) to compile and analyse the natural resources versus the demand (Danagro 1995). Pilot studies were conducted in two Mongolian *aimags* (counties) namely Arkhangai and Dornongobi, and within these in two soums (municipalities). This paper reports the findings from Arkhangai *aimag*.

The immediate objectives of this paper are: first, to propose a framework for analysing rangeland information and data; second, to demonstrate the usefulness of GIS tools and remote sensing data to locate opportunities and potential problems related to the management of the pastures.

Methods

The method adopted was to compare the availability of resources versus the demand by using the concept of carrying capacity (CC). Since any estimate of the CC is based on conditions found within a production system at a given time and place, the use of CC figures must be accompanied by an assessment of their validity.

An in-depth knowledge of a production system is inevitably necessary prior to any estimation of resources versus their exploitation. Although this may appear obvious, it is far from generally observed when GIS tools and remote sensing data are exploited for natural resource management purposes. Attractive and convincing maps and figures are often produced using GIS despite their having little or no relevance to the problem in question. The reason for this is that the broad community of map users are not yet accustomed to the opportunities of easy map creation offered by GIS.

This potential pitfall can be circumvented by placing emphasis on having an in-depth knowledge of the production system, which can guide the analytical work and hence improve the reliability of the results. The following three key requirements were necessary for the information and data framework:

(1) knowledge of the production system,
(2) natural resource inventory),
(3) inventory of the natural resource exploitation.

When this information is presented spatially, a GIS can be used to identify and locate the limitations and opportunities of livestock production by combining layers of data. These layers are digital maps where data files are attached to points, lines or polygons, each representing different map elements (Chrisman, 1997). The advantage of a GIS compared to traditional statistical methods is the capacity to handle abundant spatial data and its flexibility to change and the ability to update various conditions, parameters etc. The same type of analysis is equally possible using paper maps and data. Due to the tedious nature of the work, however, traditional map analysis is often based on summarized statistics covering a larger area, from which it is impossible to identify exact geographical locations of resource opportunities or problems.

The study area

The *aimag* of Arkhangai is located in the mountainous area of the central part of Mongolia, and is subdivided into 18 *soums*. Each *soum* is further subdivided into *bags*, which correspond to the area exploited and managed by a group of herders. The study area is located within the *soum* of Khangai, and more specifically in the *bag* of Arbayasgalan; this covers an area of 366 km^2 and had a population of 535 with 23,472 sheep units in 1996. The yearly rainfall is 272 mm with 82% falling from May to October. The first snowfall occurs in September, and during winter the snow reaches an average height of 20 to 30 cm. The average temperature in January is −23 deg, with −47 deg being the absolute minimum. In July, the average temperature is 13 deg with an absolute maximum of 36 deg (HEMC, unpublished). Arbayasgalan *bag* is characterised by a valley running north-northwest to south-southeast some 2100 m above sea-level, with mountains reaching up to 2800 m on either side. The late melting of the snow in the spring contributes to the soil moisture, which results in the northern slopes being partially forested (see Figures 1 and 5).

Data and information

The production system

Information on the production system was obtained by consulting the herders, the soum authorities and national resource people dealing with livestock resources. A workshop was held in the field where a number of *gers* (traditional Mongolian woollen tents) were set up to accommodate the above mentioned people along with the project personnel for 5 days. During the workshop, formal presentations were made covering a range of different aspects of livestock production. Excursions around the terrain were also made which contributed greatly to the discussions and provided a good understanding of the functioning of the production system. The herders' movements throughout the year, the characteristics of the seasonal grazing areas, and the constraints and the limiting factors of livestock production will be briefly presented below.

By moving around throughout the year, herders are able to optimize their exploitation of the available grazing resources and gain protection from the severe weather conditions during winter. In the summer, the herders choose to use the pastures located in the valley plain where the wind is mild and access to water is not a problem. They often move from place to place in order to profit from the abundant resources and to avoid the disadvantages of staying in one place for longer time (such as the accumulation of manure which attracts flies). In the autumn, the herders usually move to the mountains for the first time between September 10 and October 15, and may move as many as three times during autumn. The moves enable them to gain shelter from the increasingly strong, cold northwesterly winds while still benefitting from exposure to the sun on the southern slopes. During the winter period. from November 15 to April 15, the herders move further up the southern slopes of the mountains to a narrower zone (aspect of 90–225 degrees), to gain shelter from the increasingly cold north-westerly winds which are especially severe from December 15 to March 15. The herders prefer slopes of 12 to 15 degrees as they provide

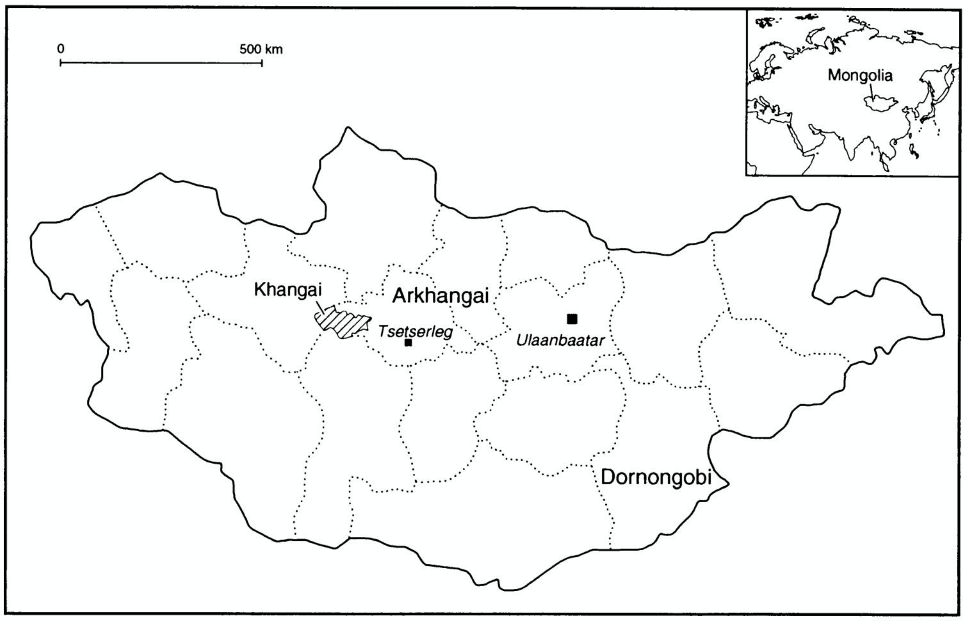


Figure 1. Mongolia showing the location of the study area.

good drainage, and an altitude of typically between 2200 and 2500 m. During one day, the livestock can search for pastures within a distance of 2.5–3 km. In the spring, the herders move down the mountain again staying on south facing slopes where, due to exposure to the sun and the accumulation of humidity, the first vegetation appears. Table 1 summarizes the climatic conditions and the suitability of keeping livestock on the mountains.

The summer grazing areas, located on the plains of the river valley, are fairly easily identified, and are defined as:
(1) areas below 2200 m above sea level (the valleys),
(2) slopes less than 5 deg.

The summer grazing period was observed to be approximately 163 days. It was difficult to distinguish clearly between the autumn, winter and spring grazing areas, hence they were consequently grouped together covering a period of about 202 days. The important winter (including spring and autumn) grazing areas were identified as follows:
(1) sloping land facing south-east (aspect of 90–225 deg) providing shelter from the cold north-westerly winds,
(2) land with slopes of between 5 and 40 degrees,
(3) land below an altitude of 2620 m,
(4) vegetated land excluding forest.

A range of constraints and limiting factors were identified in Arbayasgalan *bag*. Drought occurs during years with rainfall significantly below the average, which primarily causes a reduction in pasture production. The last incident of drought was in 1995 and prior to that in 1980. Access to water for the livestock is not considered to be a problem since alternative sources are always available. Flooding of the summer pastures in years with high rainfall presents another problem because the herders are presented from exploiting them. The last time this occurred was in 1993. Fires are an additional hazard and typically occur on the higher altitudes within the forested areas. Snow storms, called *zud*, are a further major hazard which take place when extremely cold winds freeze slush to ice and prevent the livestock from gaining access to the sparse winter vegetation. If the animals are not mobilized in time, the *zud* can cause a serious lose of animals. *Zud* was recorded during four winters in the 1980s.

The natural resource inventory

The natural resource data needed includes information on land cover and vegetation as well as on the physical environment, including the altitude, slope and aspect. The latter can be derived from 1:100,000 maps. Using a GIS, the contours were digitized and a digital elevation model (DEM) was created with a cell size of 20 × 20 m (the smallest spatial unit). The DEM permitted the creation of two related data layers: a slope map and an aspect map. Both of these were in degrees and had the same spatial resolution as the DEM. From these three layers it was then possible to determine the elevation, slope and aspect of any location within the area. Idrisi raster GIS was used to create the DEM including the slope and aspect maps (Eastman, 1995). The administrative boundary, rivers and lakes were digitized and added as separate data layers in a vector GIS, ARC/INFO (ESRI, 1994).

Creating a land-cover map

Information on the vegetation and land cover was very limited. From the topographic maps, which dated back to the 1950s, only a few major vegetation types could be distinguished. Pasture maps have been produced in the past, but the lack of projection along with their sketch-like appearance discouraged their use. Furthermore, any recent degradation of the vegetation caused by overstocking was not indicated on these maps. Consequently, it was decided to produce a land-cover map from recent satellite images. The land-cover classes of pasture, forest, bare soil, rock and water are all fairly easy to map from high resolution satellite data. The major challenge was to obtain a cloud-free satellite image during the summer or late summer period to avoid snow

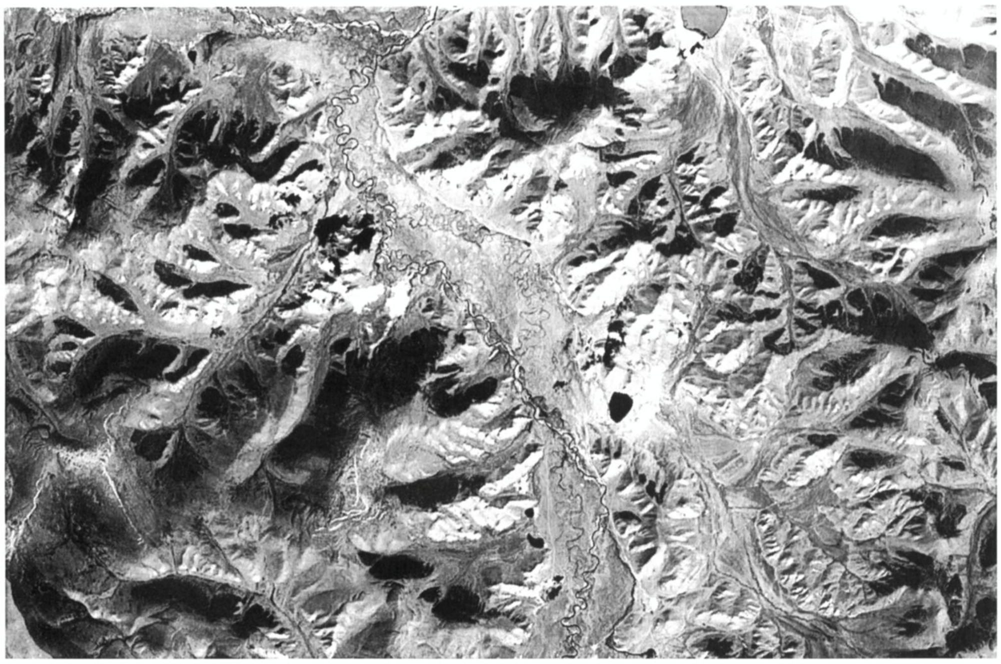
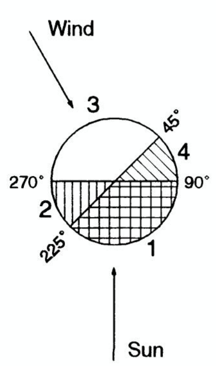


Figure 2. A SPOT scene from September 9, 1996. The scene was geometrically rectified to match the topographic map. The black and white figure is a reproduction of an original colour composite of SPOT band 3, 2 and 1.

Table 1. Climate and grazing conditions for livestock on the mountains during the four seasons. The table is adopted from Dr Dambyn Bazargur, unpublished.



No	Marking	Exposure	Wind and sun	Winter situation	Depth of snow	Evalution of aspects by rating				
						Winter	Spring	Summer	Autumn	Total
1		Front slope	Sheltered southern-exposed to the sun	Warm	Shallow	5	5	2	5	17
2		Western slope	Open-exposed to the sun	Warm with wind	None	4	2	3	4	13
3		Back slope	Open	Cold with wind	Patchy	2	2	5	3	12
4		Eastern slope	Some shelter	Cold	Deep snow	3	4	3	4	14

cover. The archives of recent SPOT and Landsat TM satellite data were consulted without much success; very few scenes were available and they either did not cover the area of interest, or cloud or snow cover impeded their use. This problem was solved by programming the acquisition of a SPOT scene covering the precise area being studied during a period when the vegetation was present. The SPOT scene obtained was from September 9, 1996 (SPOT scene identification KJ, pp. 239–253). The multi-spectral SPOT scene has a spatial resolution of pixels of 20 times 20 m and measures the reflected sun radiation from the surface within three bands of the electromagnetic spectrum, the green and red part of the visual spectrum and the near infrared part[1].

The SPOT scene was geometrically rectified to match the topographic maps of 1:100,000. This was done with an accuracy of ±1 pixel. After the first visual interpretation of the SPOT scene, a field trip was made to more than 30 sites each of which represented a homogeneous area of more than 1 ha. The vegetation cover and height were recorded along with information on soiltype, topography and the type of

[1] When mapping vegetation, it is essential that both the red band is present (where the vegetation absorbs radiation for the photosynthesis) and the near infrared (where the vegetation reflects all the radiation), since the difference between the two provides a measure of the chlorophyll density on the surface, and hence the vegetation cover. The difference between the near infrared and the red band is referred to as a vegetation index.

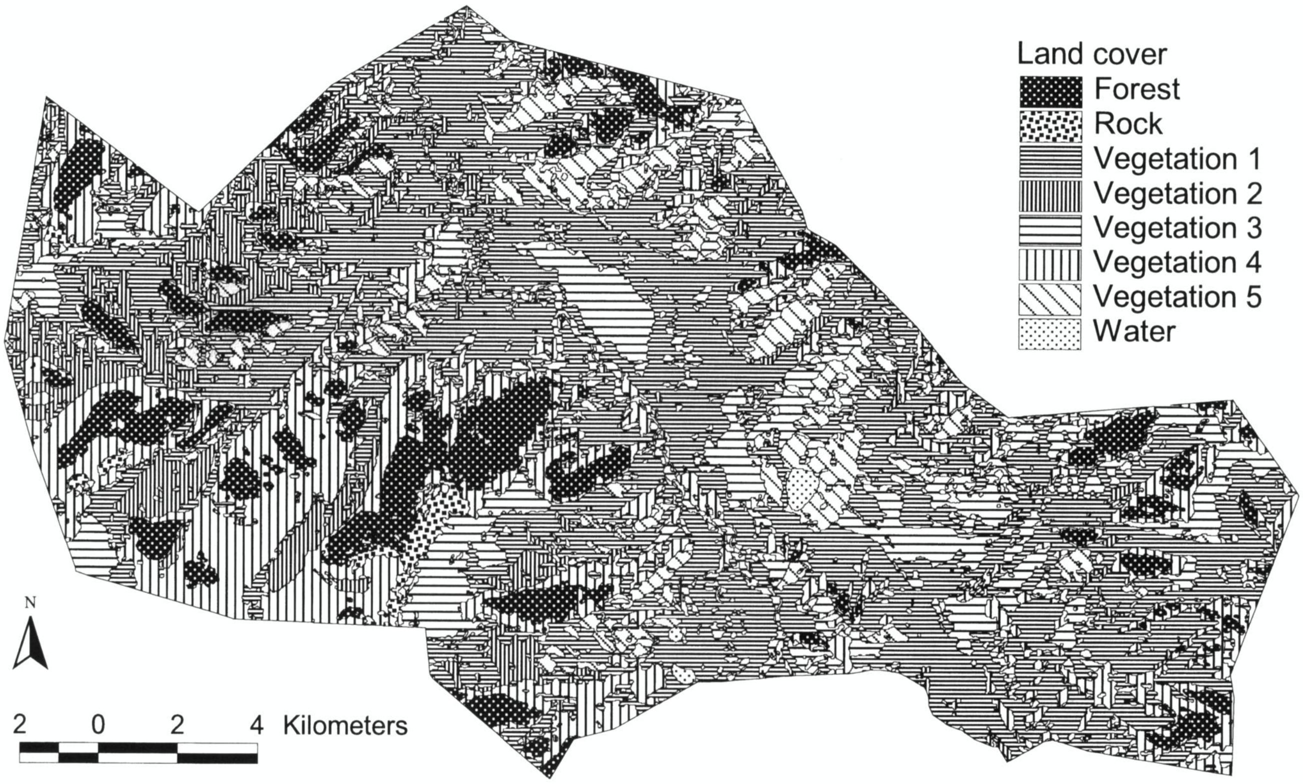


Figure 3. The land-cover map for Arbayasgalan *bag*. Through field verification the accuracy was assessed to 87 percent. Table 2 explains the characteristics of the five vegetation classes.

seasonal pasture. A Global Positioning System (GPS) device was used to determine the geographic coordinates of each site with an accuracy of ±50 m. This information was subsequently used as an input to a supervised maximum likelihood classification of the digital SPOT scene. Eight land-cover classes were retained: water, bare soil and rock outcrop, forest, and five vegetation classes (see Table 2). The differences between the five vegetation classes were proved to be statistically significant at the 0.05 level from an Analysis of Variance (ANOVA). The classified SPOT image was checked in the field by visiting a further 30 sites. From this independent survey, the overall accuracy of the land-cover map was assessed to be 87%[2]. Figure 2 shows the original SPOT scene, Figure 3 shows the land-cover map created and in Figure 4 the digital elevation model (DEM) can be seen. Figure 5 demonstrates the synergy of the DEM and the original SPOT image by creating a three dimensional view (3D) of the valley. These visual forms of presenting the data proved to be an excellent point of departure for discussions with the herders.

Table 2. Description of the five vegetation classes and percent area of the eight land-cover classes within the *bag* of Arbayasgalan.

Land-cover class	Average ground cover (%)	Average height (cm)	Percent area in bag
Vegetation 1	90	9	40
Vegetation 2	89	9	7
Vegetation 3	75	7	15
Vegetation 4	69	8	20
Vegetation 5	64	5	8
Forest	–	–	10
Rock	–	–	<1
Water	–	–	<1

Resource exploitation

Every year, a livestock census is carried out by the administrative staff of each soum. The number of different animals by *khotail* (the traditional settlement of a group of families) is recorded along with a simple household inventory[3]. Livestock census data from 1994, 1995 and 1996 were used in this project. The exact location of some of the khotalls was identified using a hand-held GPS, whereas the remainder were located using maps and interviews with herders. Within the study area, 23 *khotails* were located to an estimated accuracy of ±100 m.

The grazing area of each *khotail* was defined as follows: the maximum distance from the settlement site was

[2] All digital image processing was done using the software WinChips (Hansen 1998). A good introduction to remote sensing and digital image processing is provided by Jensen (1996).

[3] There is a long tradition of collecting livestock data in Mongolia where the consistency of the data is ensured by various means of cross checking. This contributes to the overall high quality of the data, however, no independent check was made.

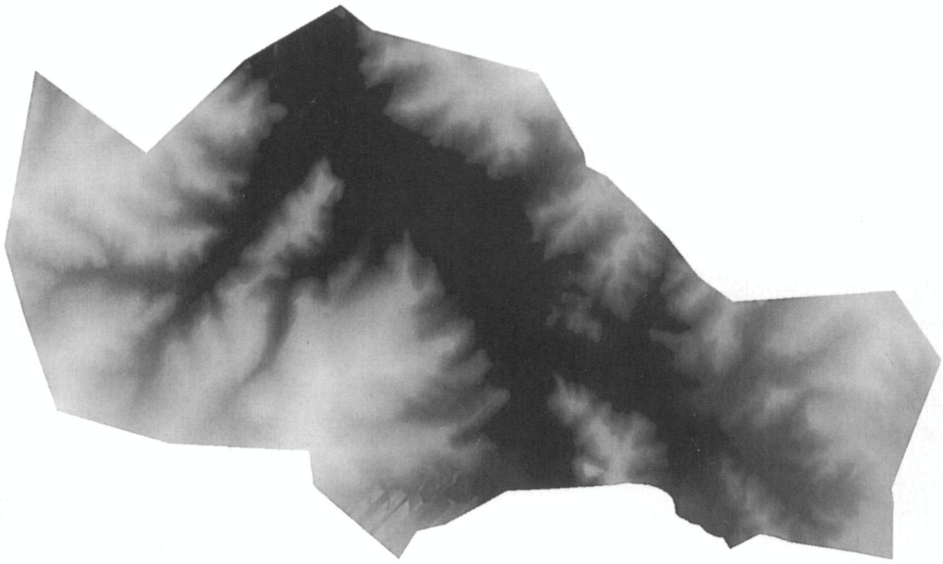


Figure 4. The digital elevation model (DEM) covering the Arbayasgalan bag of Khangai *soum*, Arkhangai *aimag*.

3 km, and where two *khotails* were less than 6 km apart the area-was subdivided by the centre line. Minor modifications were made to match watersheds and other natural features that were known to delimit the grazing areas. Furthermore, land not suited to winter grazing was excluded. Using these criteria, the winter grazing sites were identified and the exploitable area was calculated using GIS. Each polygon, which shows the grazing area for the individual *khotail*, was linked to the census file with the corresponding livestock and household data. The stocking rate for each winter grazing area was calculated as the number of livestock expressed as sheep units per km^2 of suitable land. The subdivision of the Arbayasgalan *bag* into winter grazing areas by *khotail* can be seen in Figure 6.

A standard average winter carrying capacity (CC) of 106 sheep units per km^2 for 202 days was used (Dr D. Bazargur, pers. commun.). Not all herders, however, stayed in their winter sites for so long and the CC was adjusted accordingly using a linear relationship. For example, if a herder stayed 101 days rather than 202 days the CC was doubled for the area. The summer CC used was 203 sheep units per km^2 for 163 days (Dr D. Bazargur pers. commun.). If CC figures were not available, it would be possible to assess potentially available forage from remote sensing data (see Rasmussen, 1998).

Traditional analysis of livestock production and resources

A traditional assessment of suitable winter and summer grazing areas was done for Arbayasgalan *bag*. The grazing area was assessed by stratifying topographic maps according to the information in Table 1 without discriminating between vegetated or non-vegetated areas. The stocking rates were calculated as the total number of sheep units divided by the total area of winter and summer grazing respectively for the entire *bag*.

Results

The identification of suitable grazing areas from the land-cover, elevation, slope and aspect maps was compared with the extent of the winter grazing areas. It was shown that the present winter grazing area could be expanded by 5%. These areas, however, were small, highly dispersed and mainly located in remote areas. Consequently, they did not represent substantial resources.

The ratio of stocking rate to the pasture CC was calculated for the winter period. If the ratio is one, the pasture can support the number of animals present. The range of the ratio for the different winter grazing areas in Arbayasgalan *bag* was between 0.18 and 3.71 with an average of 1.42. This indicates that on average the bag contained 42% more animals than the pasture can support during the winter period. The heavily grazed winter sites with ratios above 1 were mainly found to be located close to the valley: 4 out of the 6 most highly grazed sites, which had ratios above 2, were situated close to both the valley and the main track through the area (see Figure 6).

The calculation of the ratio of stocking rates to pasture CC for the summer was done differently. Using the average summer CC of 2.03 sheep units/km^2 and the exact length of occupation of the summer grazing sites by Khotall, the area of pasture required was calculated to be 6245 ha. This was compared to the actual area of available summer grazing areas, which was 4815 ha. The ratio of these two figures was 1.3 and shows that the flood plains are primarily occupied by 30% more animals than it can support. When comparing the percentage of the five vegetation classes by winter grazing area, a high percentage of the poorest vegetation class P5 was found in the heavily grazed winter sites located in the east (see Figure 6).

Figure 6 summarizes the data and information framework. It shows how the three main requirements of the natural resource inventory, the exploitation of natural resources, and knowledge of the production system, are inter-related

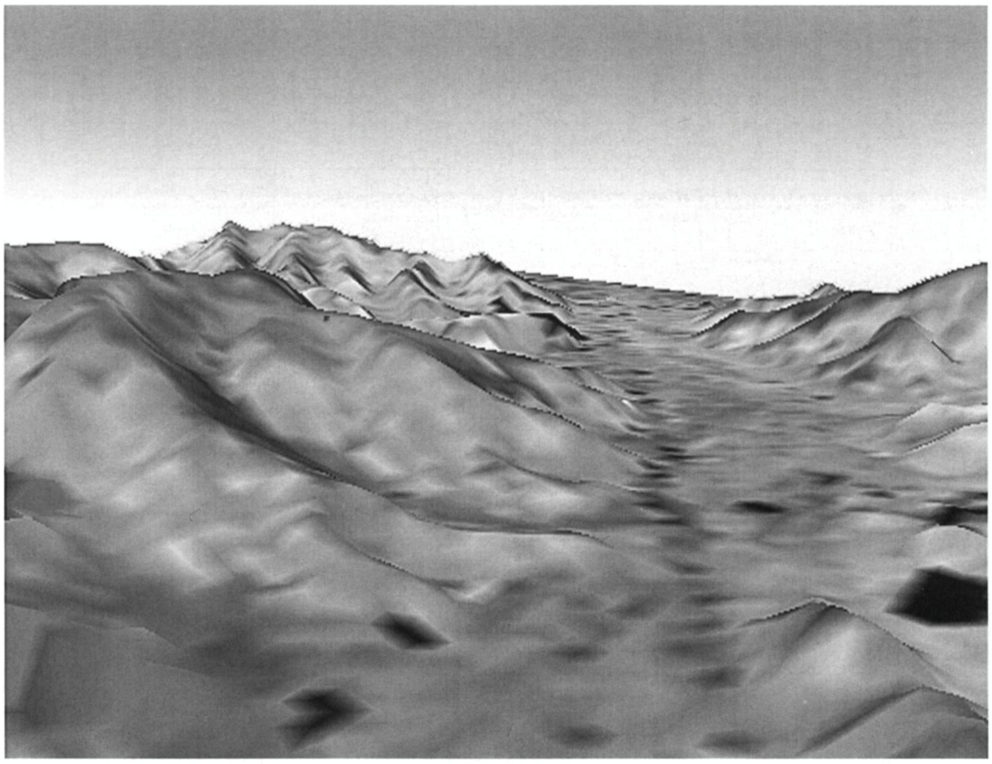


Figure 5. A three dimensional view of the valley in Arbayasgalan *bag*. The observer is placed at the southern edge of the valley (see Figure 3 and 4) looking north up through the valley.

and contribute significantly to an understanding of resource availability and over-exploitation.

Conclusions and discussion

In order to assess the pastural resources in Arbayasgalan *bag*, it is necessary to deal with three main subjects. First, knowledge about the pastural production system is needed to permit the identification of seasonal grazing areas. Second, a natural resource inventory has to be made by mapping the seasonal pastures using a digital elevation model and a recent land-cover map created from a SPOT satellite image. Third, the exploitation of the natural resources has to be ascertained by calculating stocking rates for each individual winter settlement using livestock statistics and the size of the settlement's grazing area. The Arbayasgalan *bag* was found to be overstocked with an average ratio of stocking rate to carrying capacity of 1.42 in winter. Furthermore, the most heavily grazed areas were located next to the poorest vegetation class. A comparison of the present winter grazing areas with the suitable winter grazing areas, mapped from the DEM and the land-cover map, revealed that only marginal supplementary grazing resources are available.

The above assessment was presented to the herdsmen through a workshop and a written document referred to as a *soum* guide. The *soum* guide presented all the findings and addressed two major questions. Is it possible for the herders to adjust their winter grazing areas and thereby reduce the uneven distribution of grazing pressure? Should heavily grazed areas be protected? In contrast to using traditional statistics, the GIS work was able to locate the over- and understocked areas, as well as areas with poor vegetation conditions. This allowed the herdsmen to discuss specific issues related to the identified areas, rather than just having a general discussion of degradation and overgrazing. By being able to document the quality of their land, the herders would be well prepared should the Mongolian Government implement the proposed land act. This act may introduce differential grazing fees as a means of regulating pressure on the pastures.

The work in Arbayasgalan *bag* has shown that it is important that the institutional aspects of rural natural resource management are being dealt with. A first attempt was done by involving the Mongolian authorities at all levels from the ministry to the bag level and the national resource base from research institutions. However, the scarcity of institutions or insufficient empowerment are other major constraints to rural resource management that has not been dealt with here (see Mearns, 1992).

Using GIS and remote sensing for rangeland management may initially appear to be an overwhelming task, especially since the initial implementation requires substantial human and financial resources. However, this study has demonstrated how a framework can be established for a pilot area. The project did not encounter serious problems training technicians from the ministry in GIS and remote sensing, nor were the financial requirements for computers and software high as it was possible to carry out all the operations on low cost PC's. The only significant expense was the purchase of satellite images. However, with the launch of Landsat 7 in the summer of 1999, the cost of data per square km will be

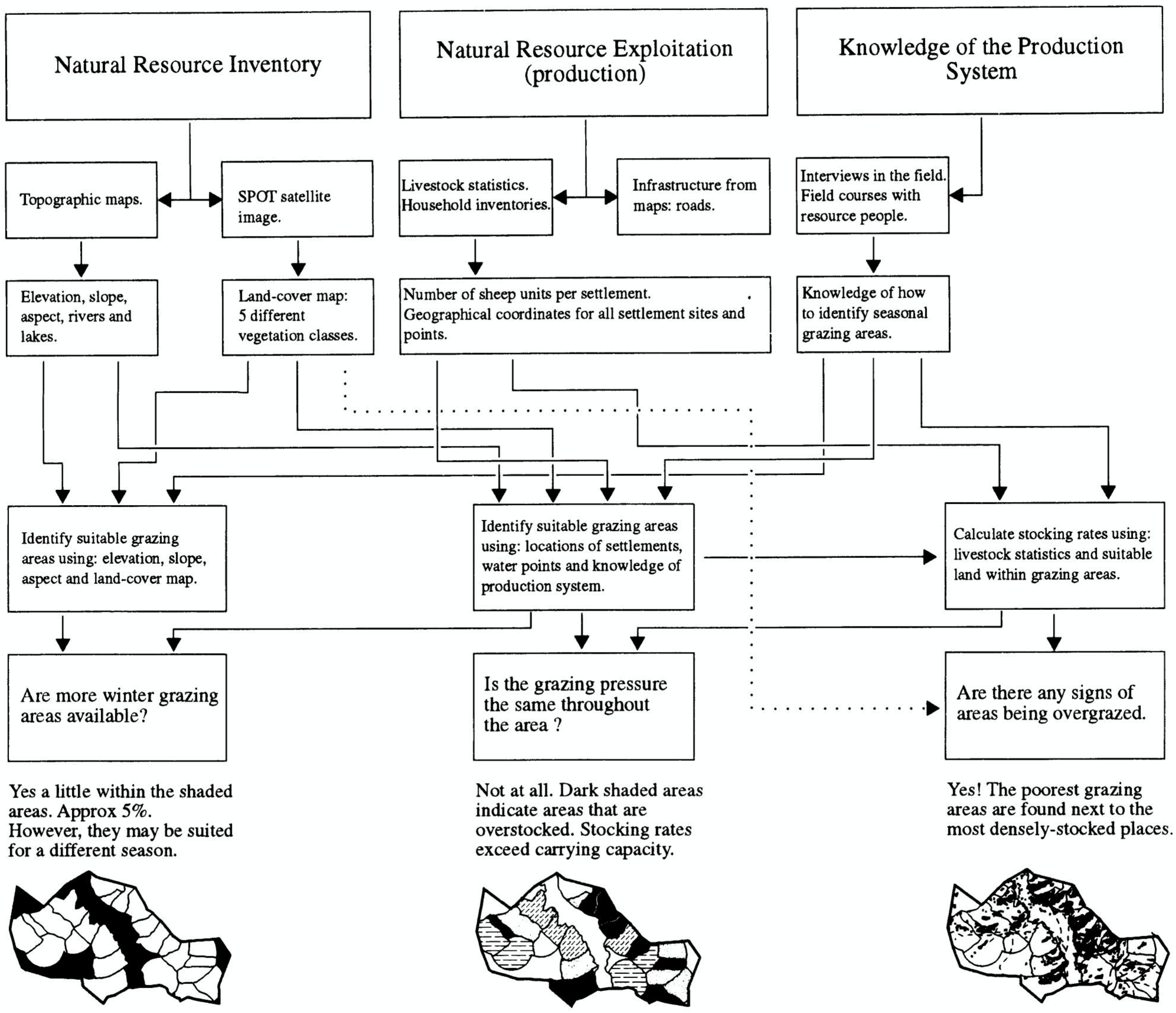


Figure 6. Data and information framework diagram.

reduced by a factor of approximately five. Furthermore, as this study has shown, access to well documented carrying capacity figures reduces the need for satellite data.

The results has not only shown that GIS can be used as an efficient tool to evaluate and propose alternative strategies for the exploitation of the rangeland resources; the study has at the same time demonstrated, that the implementation of GIS can be done by building the human and technical capacity without imposing major expenses on the administration.

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