MODELLING SOIL AND CLIMATIC CONDITIONS FOR AGRICULTURAL SUITABILITY ASSESSMENT IN THE SIBERIAN ALTAI

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ABSTRACT

This paper discusses methodologies and appropriate adaptations of existing solutions to model land suitability for the valley and basin areas of the South-Siberian Altai Mountains within a GIS environment. Starting-points are two methods, the Soil Suitability Model 'Almagra', MicroLEIS system (De la Rosa, 1992) - developed for Mediterranean regions - and a method specifically compiled by Burlakova (1988) for the Altai and based on weighted means of a factor set. Since agricultural suitability has to thematically integrate various aspects of the physical environment and the human management and utilisation, a GIS will form a basic and handy tool for data integration, evaluation, rating and cartographic presentation. Presently, these mentioned approaches are not integrated into a GIS. Furthermore, the paper presents ideas how Remote Sensing might interact with the Geo-Information System (GIS) where - like in the present case – the required input geo-data are not fully sufficient to (1) feed the models formalising soil and climatic conditions, and (2) to characterise the patterns of land management within the study area.

Three agricultural crops (summer cereals, sunflower, and potato) are relevant for the Altai Region at a regional level and had, therefore, to be considered. A rating is envisaged using five suitability classes according to the FAO classification (1976). For the case study the Uimon Basin has been chosen. Details are given below. Social and economic factors are so far excluded, but can be added within a further phase of development.

Keywords: Agricultural land use suitability, GIS, remote sensing, Altai, Russia.

1. INTRODUCTION

In its vegetative cycle plant physiology implies strict physical minimum requirements to allow crops to grow and prosper. If they are fulfilled at a place during most of the vegetation periods (taking into account the statistical behaviour of the crucial meteorological elements), productivity can be checked. A forecast of productivity of crops at a regional level is definitely a major question of agrarian science. Appropriate land use decisions are vital to achieve optimum productivity and to ensure environmental sustainability. They require an effective management of information on which rational decisions can be based. This is even more relevant as various parameters are dynamic in character: the climatic setting with its trends related to global climatic change, crop species through the creation of new breeds with altered requirements and reactions to the environment, or soil properties, if land management cannot achieve stable conditions (e.g. soil degradation). It is well-known, that especially areas on the brink of physical threshold conditions will react most sensitive to global change and to even small local man-induced alterations.

Land suitability evaluation, commonly referenced as 'land evaluation', may be defined as 'the process of assessment of land performance when the land is used for specified purpose' (FAO, 1985). Suitability is assessed for a sustained production in a rational cropping system (FAO, 1976; McRae and Burnham, 1981).

There are two kinds of land suitability evaluation: qualitative and quantitative. A qualitative approach is used to assess land potential at a broad scale, or employed for preliminary results to subsequently add more detailed investigations (Dent and Young, 1981). The classification results are given as qualitative terms, such as highly suitable, moderately suitable, and not suitable. A second approach uses parametric techniques requiring and involving more detailed land attributes and, thus, allowing various statistical analyses to be performed. This should end in quantitative and crop-specific yield predictions with a statistically defined degree of uncertainty.

This study aims, in the present state, at a qualitative approach using IT systems and tools, namely GIS. Their capabilities for storing, retrieving and manipulating information about objects which can be exactly outlined and defined in terms of location, attributes and relations are undisputed (Burrough, 1991). Efficient data models and functions dealing with temporal variations (e.g. time series) are, however, not fully satisfactory and are, therefore, often still transferred to programs outside of a GIS.

The study allowed to gain GIS experience through integrating land-resource surveys and related geo-data from various sources. GIS could significantly assist in every stage of thematic and cartographic modelling. The present implementation makes use of approaches employed in the Mediterranean soil suitability model "Almagra" (De la Rosa, 1992) and an 'Altai-specific' method by Burlakova (1988).

2. STUDY AREA

The study area is an intra-montane basin, called 'Uimon Basin'. It is a plane measuring approx. 1050 km^2 with – apart from a couple of isolated bedrock outcrops - low local relief and the result of tectonic movements along major structure lines of the mountain range. Within the Russian Altai it is located in the central-western part north of the main cumulation of the mountain range. Administratively, it belongs to the Altai Republic, an area with part autonomy within the Russian Federation, bordering Kazakhstan, China and Mongolia (Fig. 1). The basin floor falls within an elevation range between 900 m and 1,000 m with the highest points being located at the upper edges of large alluvial fans which are fed by tributaries draining the Terekta Chain – the northern frame to the basin. The opposite basin side borders the Katoon Range, which has its highest culmination at Mt. Belukha (4506 m). The whole area drains through the River Katoon, which crosses the basin in WE-direction south of its long-axis. The climate can be described as sharp continental and similar in character to other basins in the Western Altai, but less extreme compared to basins along the Chouya River in higher elevation and further to the east. Based on readings of the meteo-station of Ust-Koksa, the July temperature mean is 16.1 °C (1970-2000) with possible daily maxima reaching up to 25-30 °C. January mean temperature is –20 °C, but absolute minimum readings can be as low as –50 °C. The vegetation period with daily temperature means above +5 °C is usually 150-165 days.

Figure 1. Sketch map of the study area.

3. DATABASE

3.1 Soil data

The soils of Uimon Basin were mapped using different primary geo-information: A first insight into the variety of soil types is given by cartographic documents from the 1960ies, which have been prepared to assist land improvement schemes. A necessary genetic link (for evaluation and detailing) can be established by comparing the indicated soil distribution to a morphogenetic and morphochronological stratification. It delivers different types of clastic Quarternary basin fillings dating from the last deglaciation phase to most recent sediments. Satellite image interpretation, geomorphological maps and ground truth form the sources. The mapping units originating from these documents now allow to label the individual fields (mappable by space imagery) according to the dominant substrate/soil unit. By subsequent field checks and soil sampling these units can in a next step be characterised by a set of *physical and chemical soil parameters*. For a statistical validation of the field and laboratory data the number of samples is still inadequate, but could be extended in the future.

Such a soil description contains the following items:

Soil texture (%),
pH, humus content (%),
Nitrogen, N (%),
Phosphorus, P (%),
Potassium, K (%),
Carbonate, Ca (%),
Cation exchange capacity, CEC (meq 100 g-1).

Characteristic for the more humid parts of the intra-montane basins of the Altai is a dominance of the fertile chernozem soils. Due to the low relief impact and low soil mass displacement in the area, the standard chernozem is more abundant than the mountain chernozem of the steeper parts along the basin margins. The typical chernozem's agricultural productivity and potential is usually high and mostly varies with the depth, structure and degree of leaching of the A-horizon. The following Table names the variety of soils from the soil map and briefly explains the sub-types:

Table 1. Soils and soil characteristics of the study area (after Stolbovoi, V., 1998 and Kovalev R., 1973).

TYPE	Subtype	Horizons	Brief characteristics
Chernozem	Standard Ch. *(Haplic Chernozem Ch-h)*	A_1-A_1B_{ca}-B_{ca}-BC_{Ca}-C_{ca}-C_s	Soils mostly under cereals and grassland, often under cultivated steppes. Decreasing humus and increasing carbonate and salt contents with depth. Effervescense in the whole A-horizon in contact with hydrochloric acid. Humus is calcium-humate. Carbonate concretions in B-horizon. Reaction neutral, cation exchange capacity 35-55 cmol kg^{-1}. Undifferentiated distribution of clay and sesquioxides in the profile.
	Leached Ch. *(Luvic Chernozem – Ch-l)*	A_1-A_1B-B_t-B_{Ca}-BC_{ca}-C_{Ca}	Soils mostly under grassland and within forest-steppe zone, often cultivated. A-horizon composed of two sub-horizons: A1 dark grey to black with granular structure and A_1B brownish with larger peds. Darker colour compared to podsolized chermozems in all A-horizons. Dark brown, compact B_t with clay and sesquioxide accumulation and void of carbonate with blocky subangular structure indicating sesquioxide migration and clay redistribution. No carbonate horizons when formed on non-calcareous parent rock. pH usually around 6,0. Cation exchange capacity 25-45 cmol kg^{-1}.
	Meadow Ch. *(Gleyic Chernozem Ch-g)*	A_1-A_1B-BC_{ca}-$C_{Ca(g)}$	Soils mostly on poorly drained river terraces, in the lower sections of slopes and in flat depressions under meadow-steppe vegetation. Dark-grey A1 with loose, granular or subangular-granular structure. Merges into a dark grey to brownish AB with coarse granular or subangular structure with clearly decreasing humus content. Effervescense in the lower A-horizon in contact with hydrochloric acid. A weakly developed carbonate accumulation horizon B_{ca} is situated on top of calcareous parent rock with – sometimes – gleylike features from the upper part of the C-horizon downwards.
	Leached Meadow Chernozem-like Soil (Haplic Phaenozem Ph-h)	A_1-A_1B-B-BC_{ca}-$C_{Ca(g)}$	Soils mostly on fine-textured deposits under an intensive percolating water regime in the Chermozem zone. In contrast to Meadow-Chernozem with a non-calcareous B-horizon with neutral reaction between the humus horizon and the upper boundary of the calcareous C-horizon. Hydromorphic features in the C-horizon.

Table 1. continued

	Mountain Forest Chernozem-like Soil *(Mollic Leptosol Lp-m)*	$O\text{-}A_1\text{-}A_1B\text{-}B_{(Ca)}\text{-}BC_{ca}$	Soils of the lower mountain zone on moderate slopes on top of solid bedrock under broad-leaved open forest and grassland. Dark-grey, crumbly, granular, humouse horizon up to 30 cm in depth with a humus content of 9-16%. B_{ca}-horizon slightly compact and weakly structured. Carbonates are leached and transported to different depths to form pseudomycelia, loose aggregates and films on the surfaces of rock particles, which become more abundant with increasing depth.
	Mountain-Steppe Chermozem-like Soil *(Mollic Leptosol Lp-m)*	$O\text{-}A\text{-}B_{(Ca)}\text{-}BC_{ca}\text{-}C_{ca}D$	Soils of the mountain zone on the upper slopes on top of solid bedrock under broad-leaved open forest. Clearly shorter A-horizons with lower humus contents compared to the types of the planes. Strong reaction to HCl in the deep parts of the profile due to weathered calcareous bed-rock.
Mountain Forest Soil	Mountain Forest Soil *(Umbric Leptosol Lp-u)*	O-A-AB-B-BC-CD	Soils of the higher mountain zone on top of solid bedrock under closed forest stands. Weakly differentiated profile with rather floating layering of the horizons. The colour is generally a medium brown. Humus content is lower compared to all chermozems.
Meadow Soil	Meadow Soil *(Umbric Gley Gl-u)*	$A_1\text{-}A_1B\text{-}B_{g,Ca}\text{-}C_{ca,g}$	Soils are formed on calcareous parent rock under excessive water seasonal or temporal percolation linked to a high ground water table. Well-developed crumbly-granular humous A-horizon. Hydromorphic traces like rusty spots starting within the intermediate AB-horizon of a coarse crumbly structure downwards. $B_{g,Ca}$ shows a higher calcareous content basically from the parent material.
Alluvial Soil	Alluvial Soil *(Umbric Fluvisol Fl-u)*	$A\text{-}B_g\text{-}C_g$	Soils on young flat alluvial plains but without regular disturbance by flood events. 30-50 cm A-horizon, often greyish or brownish grey with 3-5 cm of sod in the upper part, thin B-horizon leading over to alluvial deposits. Loamy humous parts with rusty spots and veins.

3.2 Agro-Climatic Data

Due to mostly rather favourable soil conditions, the more severe limiting factors for the selection of crops and yields to be expected are associated to meteorological elements. Agro-climatic factors are establishing a quantitative connection between vegetative processes of specific plants and their in-situ atmospheric environment. To some degree it is, however, problematic, to relate the standardised readings in 2 m above ground at a meteo-station to unknown in-field parameter values close to the ground.

Low high-winter temperatures with frequent daily minima below –20 °C in January and February are by far exceeding the frost resistance of winter cereals. A typical temperature threshold that allows growth and bio-mass production to begin is 5 °C for summer cereals and around 4 °C for potatoes. As a result of the dependence of the growth rate on the ambient temperature, an average of 150-165 days with temperatures exceeding these thresholds, illuminates the uncertainty of profitable cash crop farming in the study area. Harvest times are pretty late in the year and can be endangered by cold air mass incursions in September.

The sum of the daily mean temperature above a variable threshold ($\sum T_{>X°C}$) is based on literature (Grigoryeva, 2001; Yashutin, 1996; Chirkov, 1988) and individually calculated for the relevant crops.

In particular, precipitation data were considered to calculate the Hydro-Thermal Coefficient (HTK_i), which approximately shows an excess or a lack of humidity during (1) the root growing period (May-June) - termed HTK_1 -, and (2) HTK_2 for the remaining vegetative period in the area (May-September). Daily temperature and rain records are at our disposal from 1995 to 2001. Calculation of the HTK_i is based on Selyaninov's formula (Chirkov, 1988).

$$(1)\quad HTK_i = \Sigma P / [0.1 * \sum T_{>X°C}]$$

with: HTK_i: *Hydro-Thermal Coefficient*
ΣP: *sum of precipitation [mm]*
$\sum T_{>x}$: *sum of positive daily mean temperature [°C]*
x: *crop-specific threshold temperature [°C]*

3.3 Satellite Imagery and Topographic Data

Most high-resolution multi-spectral satellite images of the study area *(Table 2)* have been acquired and processed within the scope of a long-term joint international co-operation project between the Dresden University of Technology and the Altai University, Barnaul, aiming at the generation of a comprehensive environmental GIS for the area (Prechtel, 2003; Prechtel and Buchroithner, 2003). The benefit of the MK-4 images is a combination of high geometric resolution (around 12 m) and stereo-capability (60% overlap along track; Prechtel, 2000). Multi-spectral imagery from the 1990ies has only recently been augmented by actual ASTER-images from 2000 and 2002 with good image quality and a higher number of spectral bands, while, on the other hand, the swath widths demanded mosaicking and, thus, led to slight phenological inconsistency between its parts.

Within another context, about 50 AVHRR images of 1997 and 1998 covering the whole Russian Altai have been processed to monitor the seasonally varying snow extent (Höppner and Prechtel, 2002). The importance of a snow layer for the energy and water household of the underlying soil is quite clear; the fairly short time range was due to project duration limits. This helpful time-series should definitely be extended to be statistically relevant for an integration into the characterisation of agricultural production conditions.

Table 2. Available high-resolution satellite orthophotos - part of the GIS ALTAI-100.

SENSOR	DATE	IMAGE PARAMETERS	PROCESSING STAGE
MK-4 (3 Scenes)	08/30/1995	Orbit Height: 240 km Coverage: 140 km x 140 km; Original Ground Resolution: 12 m	Multi-spectral orthoimages (processed at Institute for Cartography)
IRS –1C LISS-3	06/16/1997	Orbit Height: 817 km Path/Row : 97/33 Coverage: 142 km x 142 km; Resolution: 23.5 m	Multi-spectral orthoimages (processed at Institute for Cartography)
ASTER	09/06/2000 09/12/2002	Orbit Height: 705 km Coverage: 60 km x 60 km Resolution: 15 m (NIR) / 30 m (SWIR) / 90 m (TIR)	Multi-spectral orthoimages stitched to mosaic (processed at Institute for Cartography)

In the given context, the most important information derivable from the high-resolution imagery are listed in the order of the work flow as follows (proposed method is given in brackets):

- ancillary information for a morphogenetic classification allowing a pre-stratification of soil units (easiest by visual interpretation)
- delineation of actual land with agricultural use (agriculture mask) = outer boundary of the study area (easiest by visual interpretation)
- delineation of field patterns (comparing imagery from different dates of data take to extract stable patterns) – to generate assessment units (generated by visual interpretation or automated segmentation)
- splitting of the cultivated land into arable land and meadows (automated classification)
- assistance with the mapping of flood plains to account for polygons with springtime flood risks (easiest by visual interpretation).

Furthermore, imagery from sensors with a short repetition rate but coarse geometry like AVHRR can deliver other information dealing with the prevailing weather state which is obviously more indirectly connected to the task:

- duration of snow cover (comp. above)
- start of the green-wave using NDVI series.

For a direct crop identification from imagery on a field-by-field base, a multi-temporal image set falling within one vegetation period would be a pre-requisite, which is presently not available and hard to acquire as a result of the cloudiness.

The topographic data can be divided into two groups, a first one being an integrative part for the modelling and a second one being an integrative part of the cartographic output. The first group contains a detailed numeric description of the relief (Digital Terrain Model), the second one basically orientation elements like communication lines, settlements, non-agricultural land cover types and drainage elements; all of them have been ready-to-use at the beginning of this project.

Since the relief forms are among the main steering factors for soil development (directly through displacement of particles, indirectly through an influence on the water and energy household), a DTM with high accuracy definitely increases the overall accuracy and reliability of the soil assessment model. A major shortcoming of the present study is the lack of such a high-resolution model. From the above-mentioned Altai-GIS, a raster-DTM with a cell spacing of 100 m is available. It can, however, not satisfy the user requirements for the given task in terms of resolution and accuracy.

The classification of topographic and other geo-information in the Russian Federation and, especially, the strict limits for a free use of large-scale topographic maps has so far prevented the generation of a high-quality DTM for the basin. The same restrictions prevent the use of aerial photographs.

Summing up, we can state that much of the topographic information (apart from the DTM, which has a hybrid origin in maps and space-image photogrammetry) has been extracted from standard 1:200,000 topographic scale maps (Novosibirsk Cartographic Survey). It has been imbedded into a well-structured medium-scale GIS. Substantial improvements would be possible by an integration of large-scale data.

4. METHODS FOR MODELLING

4.1 General Preconsiderations

The GIS-related advantages to integrate, harmonise and manage a database and to support the thematic and cartographic modelling by a fund of numerous standard functions have already been stated. Before modelling comes into sight, a quite cumbersome job is the *data integration and harmonisation*: much of the historic analogue documents do not show co-ordinates and require time-consuming geo-referencing based on homologue terrain features, which are referenced to ortho-images of the Altai-GIS. Furthermore, the limited graphic quality of the original documents mostly requires manual digitising instead of quick automated vectorisation.

The first direct model-related step is a *segmentation of the agricultural land* into attributed parcels (mostly congruent with field polygons). Depending on soil-types these modelling units inherit the physical and chemical properties of the soil field investigation. Once these data are in the system, an additional consistency check is directed to topological relations (e.g. hydromorphic soils in the vicinity of a drainage channel). An exemplary further plausibility test evaluates gradients of soil properties within the model zone.

A (basically sensible) spatial modelling of the meteorological data should account for topoclimatic effects. Without further measurements this is, however, a difficult, if not tentative task (only the young Katoon flood plain which is cut into the basin with a step of up to 20 m in some sections might show a significantly different behaviour). Thus, the recorded values of the Ust-Koksa meteo-station are considered a uniform data set for all units. *This means, that the internal variation of the suitability for a given vegetation period will only be ruled by the soil parameters. On the other hand, a temporal variation of the suitability patterns will be steered by meteorological data only, since soil parameters can be regarded as relatively static, when a period of 10 or 20 years is assessed.*

Initially, one relevant crop (*summer wheat)* has been picked as a modelling example. Soil suitability assessment can, in a first instance, follow the idea of the Almagra Model: this means, that within a limited set of most influential classified and ranked soil attributes the *worst entry determines the suitability limitation* and thus the final rating. Consequently, it is recommended but not necessary that all classification factors are present in each class - it is the most unfavourable one that is determinant. The used soil factors of this pretty universal model are: soil layer depth accessible by the root system of the plant, soil texture, drainage of a soil as an indicator for water and oxygen saturation, salinity class, sodium saturation and development stage from an initial soil to a fully developed mature soil. Soil suitability might form an intermediate result but will – in the specific case of the Uimon Basin – not exclude many spots apart from the young Katoon floodplain and the river banks of the tributaries with a marginal low soil development and quality.

In a next step, a set of agro-climatic parameters can be used to determine the influence of the atmospheric environment. A complete assessment in this sense might be based on the ranking tables of Burlakova (1987), which exist for several crops. An example for summer wheat is presented in Table 3.

The final class definitions of the FAO for land evaluation were adopted in terms of two suitability orders (S for Suitable and N for Unsuitable) and five classes:

- Class 1- *Very Suitable (S1).* Land without significant limitations. Permits to expect over 80 % of the potential yield.
- Class 2 – *Suitable (S2).* Land with little limitations. Permits to expect between 60 and 80 % of potential yield.
- Class 3 - *Moderately suitable (S3).* Land that is clearly suitable but has limitations that either reduce productivity or increase the inputs needed to sustain productivity compared with those needed on S1 land. Land productivity is 40% to 60 % of the potential yield.
- Class 4 - *Marginally suitable* (mS). Land with such severe limitations that benefits are reduced and/or the inputs needed to sustain production are increased in a way that costs are only marginally justified. Land productivity is 20% to 40 % of the potential yield.
- Class 5 - *Not Suitable* (N). Land that cannot support a land use on a sustained basis, or land on which benefits do not justify necessary inputs. Land productivity is less than 20 % of the potential yield.

Table 3. Categorical ranking of land attributes measured in an ordinal scale.

No. of factor	Criteria	Parameter (for soil upper layer 0-20 cm, only)	Rating table for land characteristics				
	Suitability Class		***S1***	***S2***	***S3***	***mS***	***N***
1	Depth of humus horizon [cm]	$H_{(A\text{-}AB)}$	ho1	ho2	ho3	ho4	ho5
2	Nutrients	Nitrogen	n1	n2	n3	n4	n5
3		Phosphorus	p1	p2	p3	p4	p5
4		Potassium	k1	k2	k3	k4	k5
5		Humus	hu1	hu2	hu3	hu4	hu5
6	Acidity	pH	ph1	ph2	ph2	ph4	ph5
7	Nutrient availability	CEC [meq 100 g^{-1}]	c1	c2	c3	c4	c5
8	Precipitation	Total Precipitation [mm]	pr1	pr1	pr3	pr4	pr5
9	Thermal conditions	Sum of effective temperature $Sd_{T>5°C}$	t1	t2	t3	t4	t5
10	Flood damage	Flood frequency and duration	d1	d2	d3	d4	d5
11	Seasonal water supply	HTK_1	ht11	ht12	ht13	ht14	ht15
12		HTK_2	ht21	ht22	ht23	ht24	ht25

4.2 Suitability Indices Using Weighted Means

Another type of suitability assessment functions can have the following general form (Burlakova, 1988):

$$(2)\ SI = round\ [\ \sum_{1}^{n} (X_i \cdot w_i)\ ]$$

with: SI: Suitability class for a crop
X_i: ranked factor value
w_i: weight of a factor with sum of all weights adding up to 1
n: number of factors.

The problem of such an approach is that it assumes that factors can mutually compensate and, thus, mislead to a moderate or even good total suitability rating despite of one or two factors in the lowest individual suitability classes (as marginally suitable or even unsuitable). Using all the factors of *Table 3*, this is clearly falsifying the results: a regular total loss of the harvest by frequent flooding on a site cannot be balanced by an excellent set of marks for the other factors. This implies, that one unsuitable rating in the whole matrix must automatically lead to a general assessment 'unsuitable'. It is, nevertheless, sensible to not totally disapprove the idea of weighted means. It should make sense (1) in a more generalised view for factor groups instead of individual factors and (2) in case of an absence of very poor ratings in the whole matrix. Therefore, a combination of the maximum limitation approach and the weighted mean approach seems to be a viable solution.

Furthermore, an appropriate choice of weights for each factors is crucial and must again be tuned for each individual species. In the present case, guidance came from literature and communication to experienced local agronomists. A quality test and, eventually, a refinement is expected to be obtained when comparing the agro-climatic properties of a complete time-series with yield statistics of the area. With a sufficient number of years with listed harvest data, sensitivity and behaviour of individual factors and factor combinations can be tested and introduced into the model similar to the Almagra procedure (De la Rosa, 1992).

4.3 Introduction of crop rotation Systems

A necessary step further ahead is the transfer of a single-crop assessment to an assessment that accounts for a whole system of crop rotation. After completing a rating of all members of such a cycle, the whole system can easily be assessed (Wambeke, 1987). Only with this addition (example cf. Table 4) a powerful tool for decision making is formed.

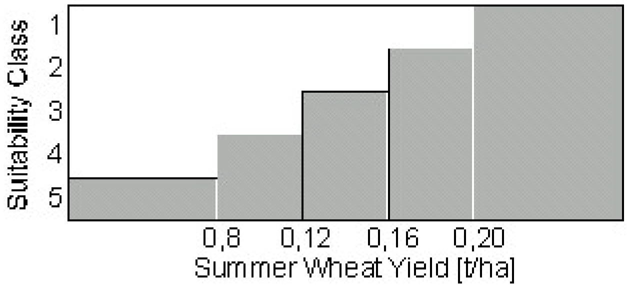
Table 4. Example for a Suitability Rating for a Set of Crops.

Coded Land Type	Suitability		
	Spring Wheat	*Sunflower*	*Potato*
1243	S1	S2	S3
2145	S3	S2	S1
3156	N	S3	S4
4657	S2	S4	N

An example for yield data and its classification into suitability groups is giving by *Table 4*. Summer wheat data were taken from the Ust-Koksa Kolchoz for the period 1991 to 2001.

Table 5. Rating of summer wheat yields to get suitability classes for the Uimon Basin.

Suitability Class	Yield [0,1*t/ha]
1	>18
2	16-18
3	12-15,9
4	8-11,9
5	<8



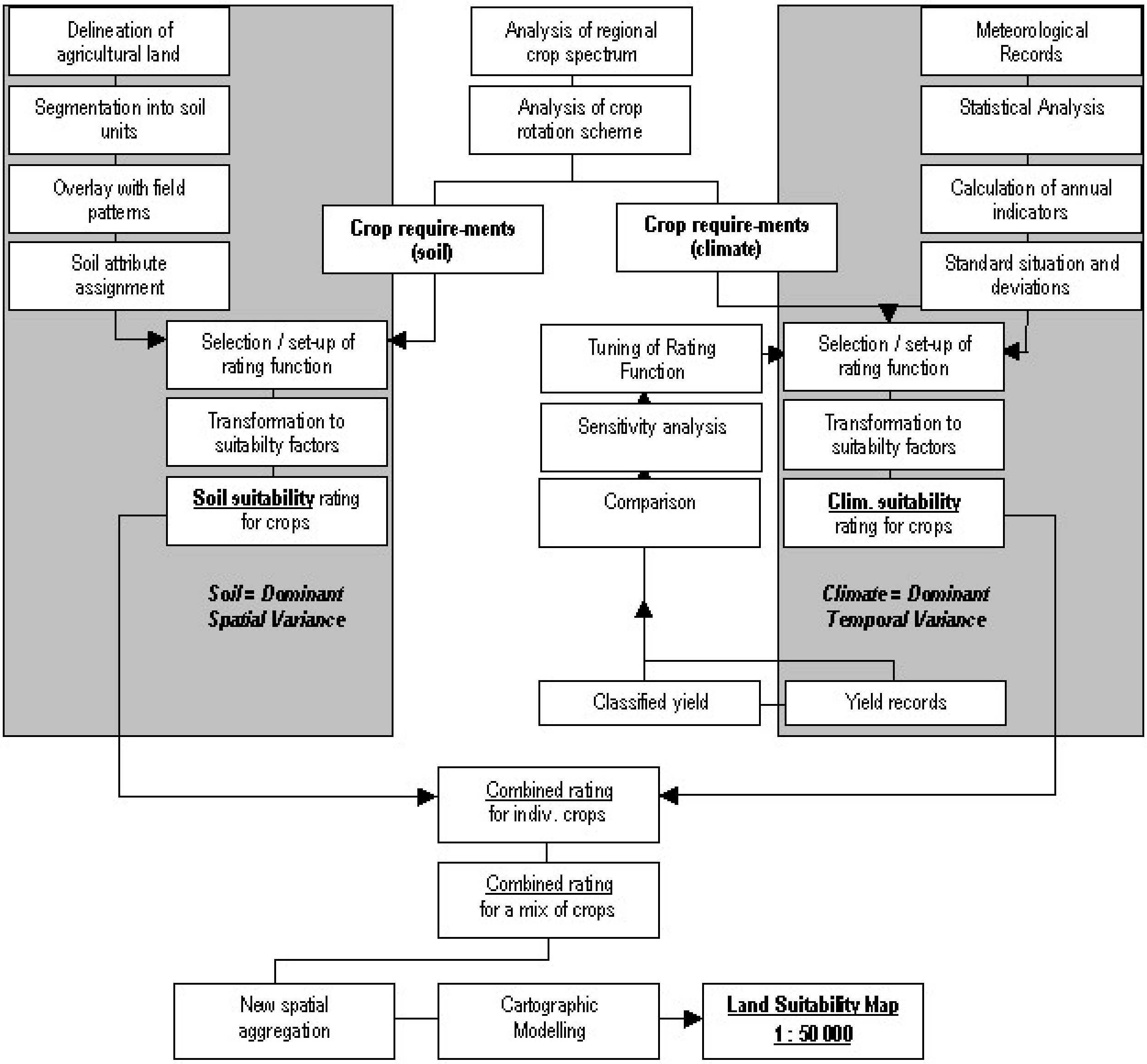


Figure 2. Summarising flow-chart showing the methodology.

5. SUMMARY AND CONCLUSION

The proposed model shows that – especially for regions with limited information about topography and agricultural production – an integration of data of different origin can help to solve modelling and - in a follow-on step - mapping problems. Most steps needed can be achieved within a GIS. For the suitability modelling, sets of criteria for the evaluation of individual productivity factors are at hand. The combination of the individual factors to arrive at crop-specific total ratings can probably not be achieved by a simple rule base only, since it does not account for undisputed interrelations between the individual factors. At present, this critical evaluation step is still in development. It would clearly profit from yield data on a field-by-field base, but – if a study is not carried out not under laboratory conditions – such data can only be gathered for a larger spatial complex, which hampers the isolation of the crucial factor combinations. A further step will be a secondary transition to a smaller scale or – in terms of spatial units - an aggregation of fields with assumed homogeneous parameter sets to larger complexes like farm units or physically defined landscape units. This implies the introduction of value ranges instead of single values to account for spatial variability of geo-factors. Various authors describe the use of fuzzy systems theory for comparable applications (Baja et al., 2001; Davidson, 1994; Burrough, 1991; Syrbe, 1998; Terano et al., 1992) and will be evaluated for the purpose.

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MODELLING SOIL AND CLIMATIC CONDITIONS FOR AGRICULTURAL SUITABILITY ASSESSMENT IN THE SIBERIAN ALTAI

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