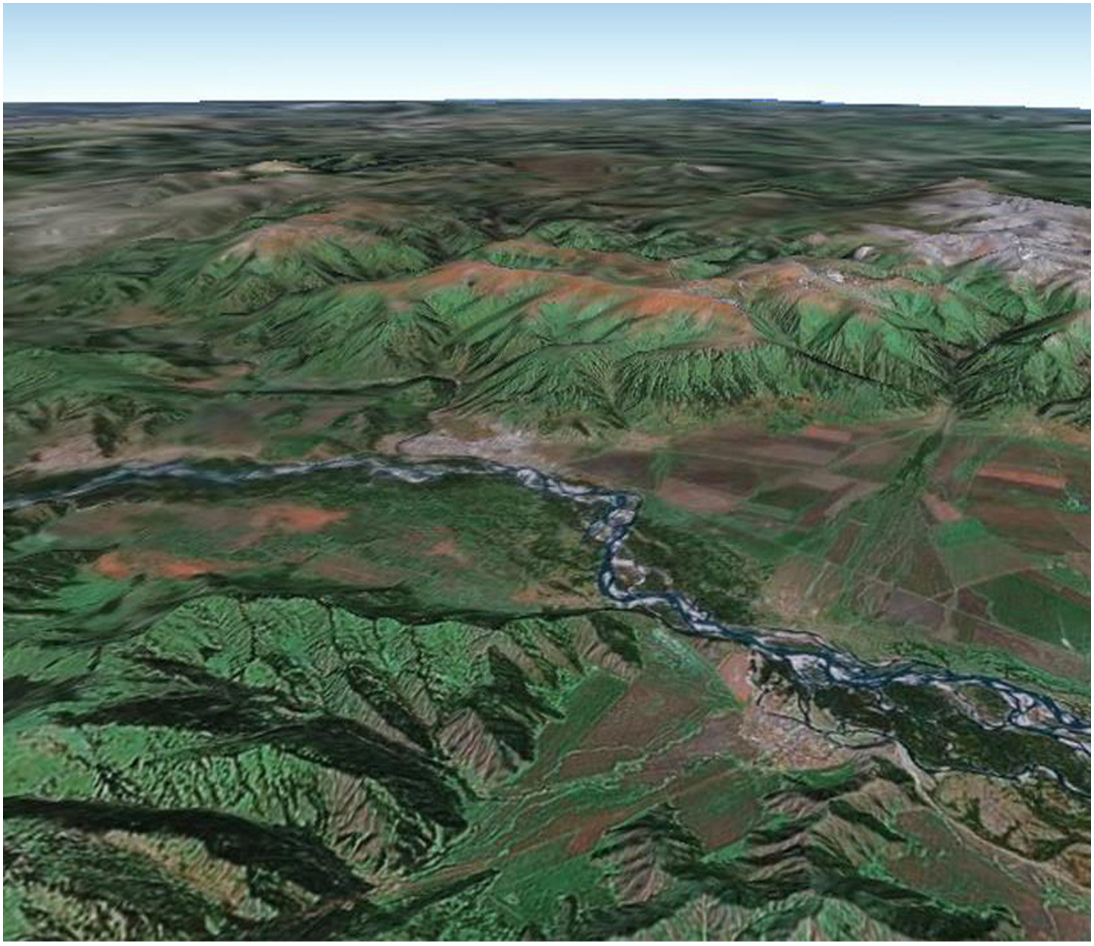
TECHNISCHE UNIVERSITÄT DRESDEN

Institut für Kartographie

Kamilya Kelgenbaeva

Agronomic Suitability Studies in the Russian Altai Using Remote Sensing and GIS



KB 36

Kartographische Bausteine
Band 36
Dresden 2007

Kartographische **B**austeine
Band 36
Dresden 2007

Cover photograph:

Oblique view of the western part of the Uimon Basin from SSE. In the foreground one sees the northern foothills of the Katun Range (culmination point Beloukha, 4506 m), behind the Uimon Basin lies the Terekhta Range, reaching up to 2000 m, i.e. some 1050 m above the average height of the Uimon Basin. Near the N-E trending Katun River, in the centre of the image, the village of Ust-Koksa can be seen. Clearly, the fluvial sediments of the Terekhta River which drains into the basin from North are tracing through the agricultural pattern. Image based on Landsat TM data from 2002 draped over the GTOPO30 DTM.

TECHNISCHE UNIVERSITÄT DRESDEN

Fakultät Forst-, Geo- und Hydrowissenschaften

AGRONOMIC SUITABILITY STUDIES IN THE RUSSIAN ALTAI USING REMOTE SENSING AND GIS

Dissertation zur Erlangung des akademischen Grades
Doctor-Ingenieur (Dr.-Ing.)

an der Fakultät Forst-, Geo- und Hydrowissenschaften
der Technischen Universität Dresden

Gutachter: Herr Prof. Dr. phil. habil. Manfred Buchroithner (Betreuender Hochschullehrer)
Korreferent: Herr Prof. Dr. rer. silv. habil. Franz Makeschin
Korreferent: Herr Prof. Dr.-Ing. Dieter Morgenstern

Dresden, Dezember 2007

Herausgeber:	Technische Universität Dresden, Institut für Kartographie M. F. Buchroithner
Verfasser:	Kamilya Kelgenbaeva
Vervielfältigung:	Institut für Kartographie, Kartographisch-Technische Einrichtung © 2007-12-18 beim Autor
ISBN:	978-3-86780-067-9
Bezug über:	Technische Universität Dresden, Institut für Kartographie, Helmholtzstr. 10, 01062 Dresden
E-mail:	steffi.sharma@tu-dresden.de

Declaration

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgment has been made in the text.

Kamilya Kelgenbaeva
Dresden, December 2007

Acknowledgments

First of all I would like to thank **the Master of All Creatures, GOD, the Almighty** for giving me knowledge, power and all necessary conditions to obtain an education in scientifically highly developed western european countries and to complete this interesting study.

I am deeply indebted to my supervisor **Prof. Dr. Manfred Buchroithner**, Director, Institute for Cartography, Dresden University of Technology, for his excellent scientific supervision, many scientific critical remarks, understanding and his confidence in me during my research. Without his highly scientific and personal support, it would not have been possible to achieve this work.

I am especially thankful to my second (non-official) guide, **Dr. Nikolas Prechtel**, manager of the Altai Project for his fruitful and useful scientific discussions and remarks. The provision of satellite- and other data from the Altai Project and other supports are very much appreciated.

Many thanks to **Prof. Dr. Ingeborg Wilfert** and **Prof. Dr. Wolfgang Koch** for their kind assistance during my research and for the friendly atmosphere and reception at the Institute for Cartography. Special thanks must go to Prof. Dr. Koch for his interesting and detailed lectures on theoretical cartography and map production.

I would also like to thank **Dr. Alexander Wolodtschenko** for his useful discussions on cartosemiotics related to my topic. I am very thankful to **Dr. Olga Wälder** for her helpful discussions on fuzzy logic mathematics and statistics and their application to my thesis. Additionally, I would like to express my sincere gratitude to **Mrs. Steffi Sharma** for her great support and her creation of an open and friendly atmosphere at the Institute for Cartography.

I would like also express my gratitude to the rest of the staff of our Institute: **Mrs. Christine Rülke, André Kunert, Claudia Hänel, Sven Etzold and Klaus Habermann.** Sincere many thanks to **Robert Hecht** for his useful discussions about the GIS AML program.

My sincere thanks to **Prof. Emilia Grigoryeva, Prof. Dr. Lidia Burlakova** (Barnaul State University, Russia) and **Prof. Dr. Diego De la Rosa** (Seville, Spain) for their kind discussions and for providing useful information about their methods and models on soil evaluation.

Many thanks for sharing knowledge and fruitful discussions must go to **Dr. Vladimir Butvilovski** (TU Dresden), **Dr. Irina Rotanova, Prof. Dr. Viktor Rudsky, Dr. Zoya Lysenkova, Dr. Ljudmila Kasantzeva and Lilia Buchtueva** (Barnaul State University, Russia)**.**

I am grateful to **Prof. Dr. Christian Opp,** University of Marburg, for his kind consultation regarding the soils of Altai, and to **Dr. Ralf-Uwe Syrbe,** Saxonian Academy of Science for his kind consultations on fuzzy logic, useful discussions and support for my research.

I would also like to thank all my friends and colleagues from Germany, Australia, Russia, Egypt, India, Sudan, Lebanon, Syria and Kyrgyzstan and elsewhere for their kind support.

I am grateful to the **German Academic Exchange Service (DAAD)** and the **Friedrich Ebert Foundation** (FES) for granting me scholarships. My sincere thanks go to **Mr. Alfred Post**, the late Chancellor of TU Dresden and Head of the Association of Friends and Sponsors of TU Dresden e.V. (GFF), for the financial support. I am grateful to **Dr. Kubanychbek Kulov,** Director of the Kyrgyz Irrigation Research Institute (Ministry of Water Resources and Agriculture) for granting me leave for the study period.

Last but not least, I am deeply thankful to the **members of my family** for their warm encouragement and support.

Kamilya Kelgenbaeva

Satellitenfernerkundung, GIS, Bodenwissenschaft, Agronomie, Modellierung, Altai-Republik, Russland
Kamilya Kelgenbaeva – Dissertation, Institut für Kartographie, Technische Universität Dresden

Untersuchungen der Landwirtschaftseignung im Russischen Altai unter Verwendung von Fernerkundungsdaten und GIS

Kurzfassung. Diese Doktorarbeit beschreibt Methoden und geeignete Anpassungen bereits existierender Lösungen, um auf zwei verschiedenen Wegen die Landeignung für die Tal- und Beckenregionen der Südsibirischen Altaigebirges innerhalb eines Geoinformationssystems zu modellieren (GIS). Die Ausgangsmethoden sind: 1) die Bodeneignungsmodelle „Almagra" and „Cervatana“ (MicroLEIS System), entwickelt für die Mittelmeerregionen (De la Rosa et al. 1992 and 1998) und die „Gewichtsmethode“, welche Burlakova L. M. (1988) speziell für die Altairegion entwickelte. Letztgenannte Methode basiert auf den gewichteten Mitteln für eine gegebene Anzahl von Faktoren. 2) Zum Vergleich, die zweite, dritte und vierte Version des gleichen Modells mit drei unterschiedlichen Typen wurden mit Fuzzy-Logik-Methoden entwickelt. Sie werden benutzt, um darzustellen, wie unscharfe Mengen zum einen die Berechnung von Gauß-Mitgliedschaftsfunktionen bestimmter Klassen veranschaulichen können, welche zu anderen Klassen gehören, und wie die Variablen in einer mathematischen Handhabung angefasst werden können. Außerdem stellt diese Arbeit Ideen vor, wie die Fernerkundung das Geoinformationssystem (GIS) eingesetzt werden kann, wenn - wie im vorliegenden Fall - nur unzureichend Geodaten vorhanden sind, (i) um in die Modellierung der Boden- und Klimabedingungen einzugehen und (ii) um die Charakteristik des Landmanagements im Untersuchungsgebiet zu kennzeichnen. Drei landwirtschaftliche Agrarkulturen (Sommerweizen, Sonnenblumen und Kartoffeln) sind für die Altairegion auf regionaler Ebene von Bedeutung und wurden daher in die vorliegende Untersuchung einbezogen. Die Bewertung erfolgte nach fünf Eignungskategorien, entsprechend der FAO Klassifikation (1976). Das Uimon-Becken wurde als Untersuchungsgebiet ausgewählt. Soziale und ökonomische Faktoren wurden bisher ausgeschlossen, können aber innerhalb einer weiteren Entwicklungsphase hinzugenommen werden.

Satellite Remote Sensing, GIS, Soil Science, Agronomy, Modelling, Altai Republic, Russia
Kamilya Kelgenbaeva – Ph.D. Thesis, Institute for Cartography, Dresden University of Technology

Agronomic Suitability Studies in the Russian Altai Using Remote Sensing and GIS

Abstract. The doctoral thesis describes methodologies and appropriate adaptations of existing solutions to model land suitability in two ways for the valley and basin areas of the South-Siberian Altai Mountains within a geo-information system (GIS) environment. Starting-point approaches are: 1) the Agricultural Soil Suitability Model „Almagra” and Land Capability Model “Cervatana”/MicroLEIS System (De la Rosa et. al 1992, 1998) developed for Mediterranean regions and a method specifically compiled by Burlakova L. M. (1988) for the Altai based on the weighted means of a factor set. 2) For comparison purposes, second, third and fourth versions of the same model are developed using three different types of Fuzzy Logic approaches. They are used to present how Gauss membership functions of particular classes can be computed as different classes and how variables taking values in ranges can be handled in a mathematical way. Furthermore, the paper presents ideas on 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 (i) feed the models formalising soil and climatic conditions, and (ii) to characterise the patterns of land management within the study area. Three agricultural crops (summer wheat, sunflowers and potatoes) are relevant to the Altai Region at a regional level and are, therefore considered. A rating is classified using five suitability classes according to the FAO classification (1976). For the case study the Uimon Basin was chosen. Social and economic factors are so far excluded but can be added within a further phase of development.

CONTENTS

Tables

Figures

Abbreviations

ALSM	Altai Land Suitability Model
AML	Arc/Info Macro Language
CRT	Crop Requirement Table
DEM	Digital Elevation Model
DTM	Digital Terrain Model
Gaussmf	Gauss membership function
GIS	Geo-Information System
GLASOD	Global Assessment of Soil Degradation (Method)
GMF	Gaussmembership Function
JMF	Joint Membership Function
Fuzzy Logic GMF Approach	Fuzzy Logic Gaussmembership Function Approach
Fuzzy Logic - SOM Approach	Fuzzy Logic Smallest of Maximum Approach
Fuzzy Set Theory - JMF Approach	Fuzzy Set Theory Joint Membership Function Approach
LSE	Land Suitability Evaluation
MicroLEIS	Microcomputer-Based Mediterranean Land Evaluation Information System
MF	Membership Function
RS	Remote Sensing
SI	Suitability Index
S1	Very High Suitability
S2	Good Suitability
S3	Moderate Suitability
S4	Marginal Suitability
NS	No Suitability
SCS	Soil Conservation Service
SIS	Soil Information System
SOM	Smallest of Maximum
St	Soil Type
UTM	Universal Transfer Mercator
WM	Weighted Means
WOFOST	World Food Studies

1. Introduction

1.1. Introduction

Eine Nation, die ihren Boden zerstört, zerstört sich selbst.
(A nation that destroys its soils destroys itself.)[1]

In its vegetative cycle plant physiology implies strict physical and chemical 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.

The forecast of crop productivity 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: e.g. the climatic setting with its trends related to global climatic changes and the 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.

Historically modern land evaluation has been considered as a practical application of soil science and soil mapping. In fact, there is a substantial overlap between soil survey and land evaluation (Dent and Young 1981). Soil surveys normally include the evaluation of more gene-ralised land use types. Vice versa, the process of land evaluation, which consists of a number of basic surveys, always includes soil survey. Moreover, soil maps are often the main basis for land evaluation because other environmental factors, such as climate, vary at larger scales (Diepen et al. 1991). These reasons resulted in a dominant role of soil surveyors in land evaluation. And even though recently other disciplines have become more important, soil surveying continues to play an important role.

One of the first modern land evaluation tools is the Land Capability Classification (LCC). System for general agricultural use developed in the fifties by the United States Department of Agriculture (USDA) and widely used around the world (Klingebiel and Montgomery 1961). Originally the LCC has been developed for soil conservation planning at farm scale in the USA. Since then many evaluation systems have been developed in different countries. Most of these systems are derived from the LCC system and supplemented with local expert knowledge (Diepen et al. 1991).

[1]) Wissenschaftlicher Beirat Bodenschutz beim Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (Hrsg.): Ohne Boden – bodenlos. Eine Denkschrift zum Boden-Bewusstsein. Berliin, 2002. Originally Ed. by Frédéric Albert Fallou (1862).

In the seventies the Food and Agriculture Organisation (FAO) of the United Nations suggested the "Framework for Land Evaluation" (FAO 1976), which has been internationally accepted. The concepts of this framework are considered standard practice in many researchs (Bastian and Schreibe 1994, Beek 1987, Davidson et al. 1994, De la Rosa et al. 1992, Dent and Young 1981, Dumanski et al. 1987, Kalima et al. 1987, Landon 1984, Pohjakas 1987, Purnell 1987, Steeg 2003, etc.). Inappropriate land use leads to inefficient exploitation and destruction of land resources, to poverty and other social problems, and even to the destruction of civilization [INT-01]. Land is the ultimate source of wealth and the foundation on which civilization is constructed. One of the solutions is land suitability evaluation leading to rational land use planning and an appropriate and sustainable use of natural and human resources [INT-01]. Considering these two aspects land evaluation, may be defined as “process of assessment of land performance when used for specific purposes” (FAO 1976). Or as “all methods that explain or predict the use potential of land” (Diepen et al. 1991). Land evaluation is a key tool for land use planning, either by individual land users, by groups of land users, or by society as a whole. There is a diverse set of analytical techniques that may be used to describe land uses, to predict the response of land to these in physical, social and economic terms, and to optimize land use in the face of multiple objectives and constraints. 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 Geo-Information Systems (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. Efficient field data and functions dealing with temporal variations (e.g. time series) are, however, not fully satisfactory for dynamic regional evaluations and are, therefore, should be integrated into GIS. The study allowed applying GIS 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 shows adaptation of mediterranean models to the study area, use of existing local models (from 1988) and mathematical approaches with additionally application of RS and GIS, which had been resulted modelling of the new Altai land suitability model. Soil, agroclimatic and flood frequency factors (totally 11) are taken as evaluation criteria.

1.2. Motivation and Aim

Agriculture is as ancient as human civilization itself and is the fundamental activity through which humans survive on earth. Especially in developing countries, agriculture is the primary contributor to the nation's economy. Agricultural practices, however, may contribute to global climate change: Arable farming, burning and clearing of forests, wetland rice cultivation, raising of livestock, and use of nitrogenous fertilizer can lead to increased concentrations of carbon dioxide, methane, and nitrous oxide in the atmosphere. Conversely, global climate change could affect agriculture by reducing the amount of land available for cultivation, decreasing crop yields, and threatening food security, especially in the developing countries. Therefore, identifying appropriate technological and policy interventions to mitigate global climate change is crucial at the national, regional, and local levels. Indigenous environmental knowledge, including human adaptive strategies, is necessary to strengthen technological and policy initiatives ([INT-02]. A fundamental requirement of the Agenda 21 of the United Nations Conference on Environment and Development (UNCED) held in Rio de Janerio, Brazil, 3 to 14 June 1992 has declared, that is necessary to support sustainable development while safeguarding the earth's environment. This will require optimal management of natural resources which depends upon the availability of reliable and timely information at national and regional levels. Remotely sensed data play an increasingly important role as a source of reliable and timely information needed for sustainable management of natural resources and for environmental protection.

Some of the most important motivating factors for studying the Uimon Basin are (i) limits of natural conditions (e.g. climate), (ii) the necessity of solving the problem of sustainable development of mountain farming based on approaches on rational land use with the aim of increasing the socio-economic level of local people, (iii) application of remote sensing data and GIS for land suitability evaluation (LSE) and (iv) modelling of new land suitability evaluation methods with further preparation of digital maps for the area.

Concerning previous works on LSE, nothing has been undertaken for the evaluation of soil productivity in the Altai Region except for the work of Burlakova (1974 and 1988). It relates a long-term experienced method (about 40 years) in the Altai Region, a very detailed and easy calculable method, although there is no integration of RS and GIS.

We know a lot about Mediterranean land evaluation models and other international modern methods. The adaptation of the famous Mediterranean “Almagra and Cervatana Models”/ MicroLEIS System to Russian conditions became one of the objectives of the thesis (these models also do not have any links to RS and GIS). For comprison was developed another version of the Model applying the mathematical approach Fuzzy Logic. The followings objectives were determined:

- Study and analysis of the natural conditions (soil, climate, geography, land use, drainage etc) and soil-forming factors of the Uimon Basin for the agricultural suitability of the specific agricultural crops of the Altai Republic.
- Preparation of thematic input maps (soil, slope, quaternary, erosion, DEM, DTM and landuse).
- Cartographic representation of the four versions of Altai Land Suitability maps for the Uimon Basin after the generation of:
  i) MicroLEIS Mediterranean models and local (Burlakova's) approach
  ii) Fuzzy Logic Approach
- Use of RS data and integration of the data into a GIS (Arc/Info) environment
- Comparison of model outputs (four versions) and identification of the most suitable areas for specific crops.
- Statistical analysis of the results.
- Cartographic design of the work.

Hence, the thesis is structured as follows: the description of the study area is introduced in Chapter 2. The 11 evaluation factors for Altai Land Suitability are presented in Chapter 4. In Chapter 6, the modelling of four approaches in GIS environment is introduced. The Chapter 7 and 8 present results and conclusions of the present work.

1.3. General Preconsiderations Regarding Land Suitability Modelling

The physical environment of agricultural crops is variable and includes all necessary factors such as illumination, temperature, soil nutrients and etc. There are 'landuse laws' which reflect the naturally occurring objective processes (Ermokhin and Nekludov 2002). For instance, "the law of autotrophy of green plants" plays a significant role in biology and agronomy. As known, green plants utilize sunlight energy, absorb carbon dioxide from atmosphere and water and mineral compounds from soil to synthesize all necessary organic matters in such quantities that maintain their growth and productivity (Gunar 1967, Ermokhin and Nekludov 2002). Therefore, one of the basic factors for gaining high yields is the formation of an optimum green sheet which can get maximum of sun energy in order to accelerate the process of creation of new cells, tissues and the general growth of plant.
Further of importance are „the law of non-renewability and equivalence of the factors". The statement of the non-renewability of factors says, that it is not possible to apply an excess of one factor in order to compensate the deficiency of another one. For instance, it is not possible to put more phosphorus into the soil to replace the missing nitrogen. Furthermore,

there are important periods, when deficiency of one of the factors can strongly affect the whole subsequent processes of metabolism negatively (Ermokhin and Nekludov 2002).

It is well known also that the concepts of “minimum”, “optimum” and “maximum” are quantitative. “Minimum” refers to a deficiency threshold of a specific factor (for example, soil moisture) for carrying out the required process, “optimum” refers to the best quantity of a factor for a plant and “maximum” describes an excess of a factor.

Moreover, “the law of limiting reasons” plays a significant role in landuse practices. Based on the Nartzissov researches (1982), the development of plant and crop yields is function of factors that are either in deficiency or in excess. Other limiting factors in this regard are cited as disease, pests, weeds, etc.

William (1951) in his “law of integrity of life factors” states, that the effectiveness of yield is higher if there is optimum availability of all required factors. In other words all life factors work sumultaneously, closely connected between themself and can influence on each other.

An important role in landuse plays, “the law of recovery of substances into the soil”, described by the German scientist Justus von Liebig more than 160 years ago. According to this law, the disturbance of the balance of nutrients (as a result of harvest or due to other reasons) must be restored by putting fertilizers into the soil). It is necessary to note that the soil plays the role of a converter and accumulator of nutrients, and the plants are the receptors. Otherwise the balance of substances in the soil is destroyed, rendering the soil fertility to a poor level. For instance, the simultaneous loss of humus results in the destruction of the soil structure, and consolidation of soil leads to the deterioration of the soil physical and chemical properties.

“The law of crop rotation” has a great value of importance in landuse practices too. It emphasises on alternation of agricultural crops with different physiological, biochemical, agronomical and economic properties both in terms of time and space. Crop rotation also include under fallow practices.

All above principles and theories have been used in modelling of present Altai Land Suitability Model. In addition to these theoretical knowledges, remote sensing and GIS techniques were used intensively in developing of the Altai model.

As already stated, GIS-related advantages are integration of the field data and creation of a data base can support the land suitability modelling by a set of numerous standard functions. Before modelling comes into sight the *data preparation*: at present study, both the topographic map and soil map (or more correct to say “schemas”) do not have coordinates and required time-consuming geo-referencing based on homologue terrain features, which are referenced to ortho-images of the AltaiGIS. Furthermore, the limited graphic quality of the original documents mostly requires manual digitising instead of quick automated vectorisation.

The first step is a delineation *of the agricultural land* from satellite image which is mostly congruent with field polygons. This information can give some knowledge (proposal) about relief, soil type and their properties. The availability of soil, drainage, contour (or topographic) maps in scale 1:25,000 give possibility to get more accurate and reliable results.

A (basically sensible) spatial modelling of the meteorological data should account for topoclimatic effects. Presenly, meteodata is available only for the Ust-Koksa. It will be preferable additionally to have data for Chendyk, Gorbunovo, Multa and Verkhni Uimon villages due to a few climatic differencies. Thus, the recorded values of the Ust-Koksa meteostation 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.* The other temporal variant – *the yield value for each crop* recorded over 20 years can be useful to determine the dependence of (1) crop yield on (2a) soil-physical properties and (2b) temperature using statistical analysis. *The long-term yield value records* can serve as additionall information for the final classification of land suitability.

Three relevant crops (*summer wheat, sunflowers and potatoes)* have been picked as a modellingling example. Soil suitability assessment can, in a first instance, follow the idea of the Almagra and Cervatana Models: 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 factors of this universal model are: soil layer depth accessible by the root system of the plant, soil pH, humus, soluable NPK, HTC_1 and HTC_2 as indicators for humidity of area, CEC, flood frequency and erodability. 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 Katun 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 (1988) which exist for several crops. A flow chart of the new model is presented in Fig. 1.1

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). In present thesis, the following classification was used: S1 – High Suitability; S2 – Good Suitability; S3 – Moderate Suitability; S4 – Marginal Suitability and NS – No Suitability (cf. Table 1.3).

Table 1.3: Land suitability classification adapted after FAO (1976) for the Uimon Basin.

Class	Suitability	Land characteristics and land indices
S1	High	Land without significant limitations. Permits to expect over 90% of the potential yield.
S2	Good	Land with little limitations. Permits to expect between 89 and 75% of the potential yield.
S3	Moderate	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 74% to 50% of the potential yield.
S4	Marginal	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 49% to 25% of the potential yield.
NS	No	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 25% of the potential yield.

Table 1.4: Conversion of suitability indices to land potential.

Class	Suitability	Land Potential in %
S1	> 0.90	> 90
S2	0.89 – 0.75	89 – 75
S3	0.74 – 0.50	74 – 50
S4	0.49 – 0.25	49 – 25
NS	< 0.25	< 25

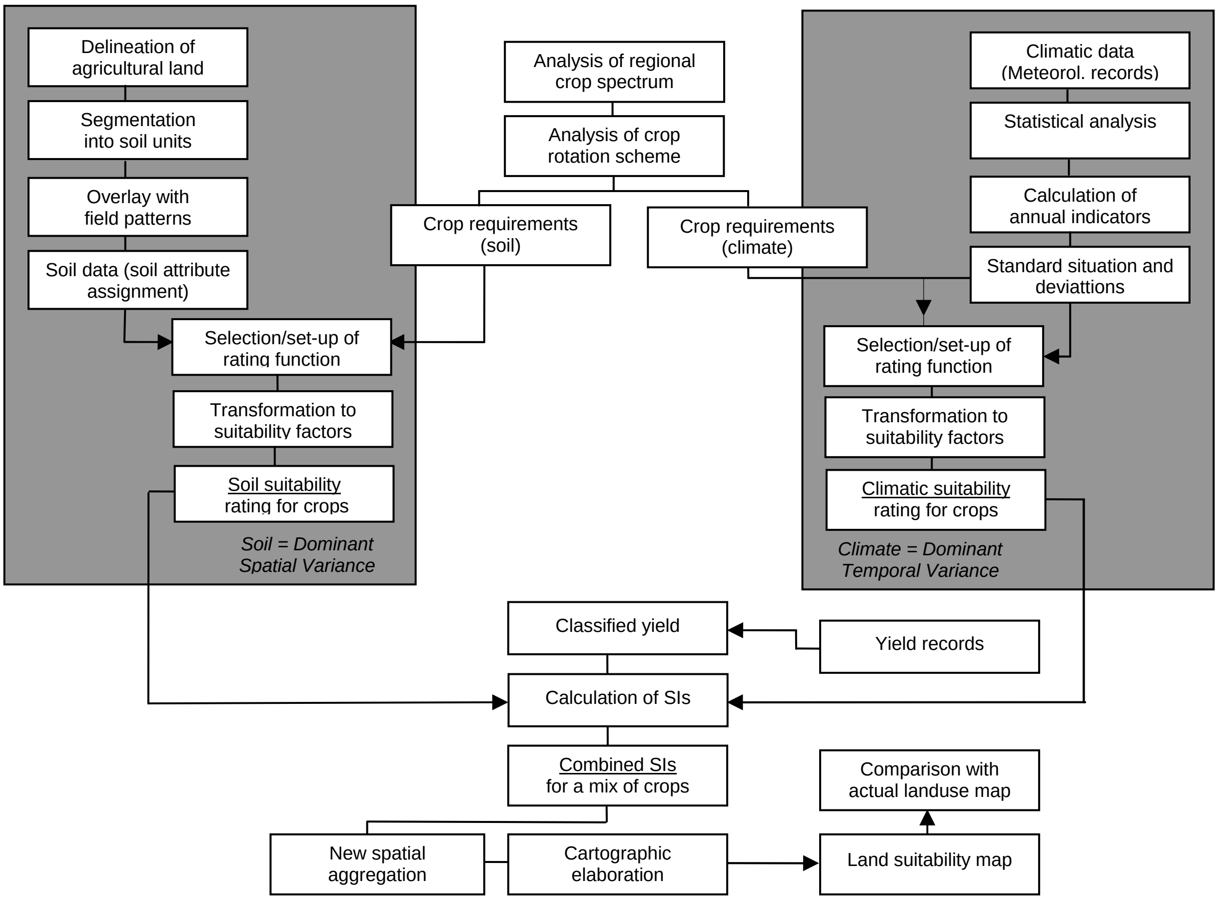


Figure 1.1: Flow chart showing the methodology of the land sutability modelling.

The second version of the Altai Land Suitability Model (ALSM) can be modelled using Fuzzy Logic Approaches. A fuzzy classification mechanism can be applied in order to categorize the soil/land objects into classes by assigning a membership grade to each class. The Gauss membership function (Gaussmf) can be used to generate the number of fuzzy classes. Results can be presented in figures 0 to 1 or 1 to 100%. A flow chart showing modelling of the ALSM using four different approaches is presented in Fig. 1.2.

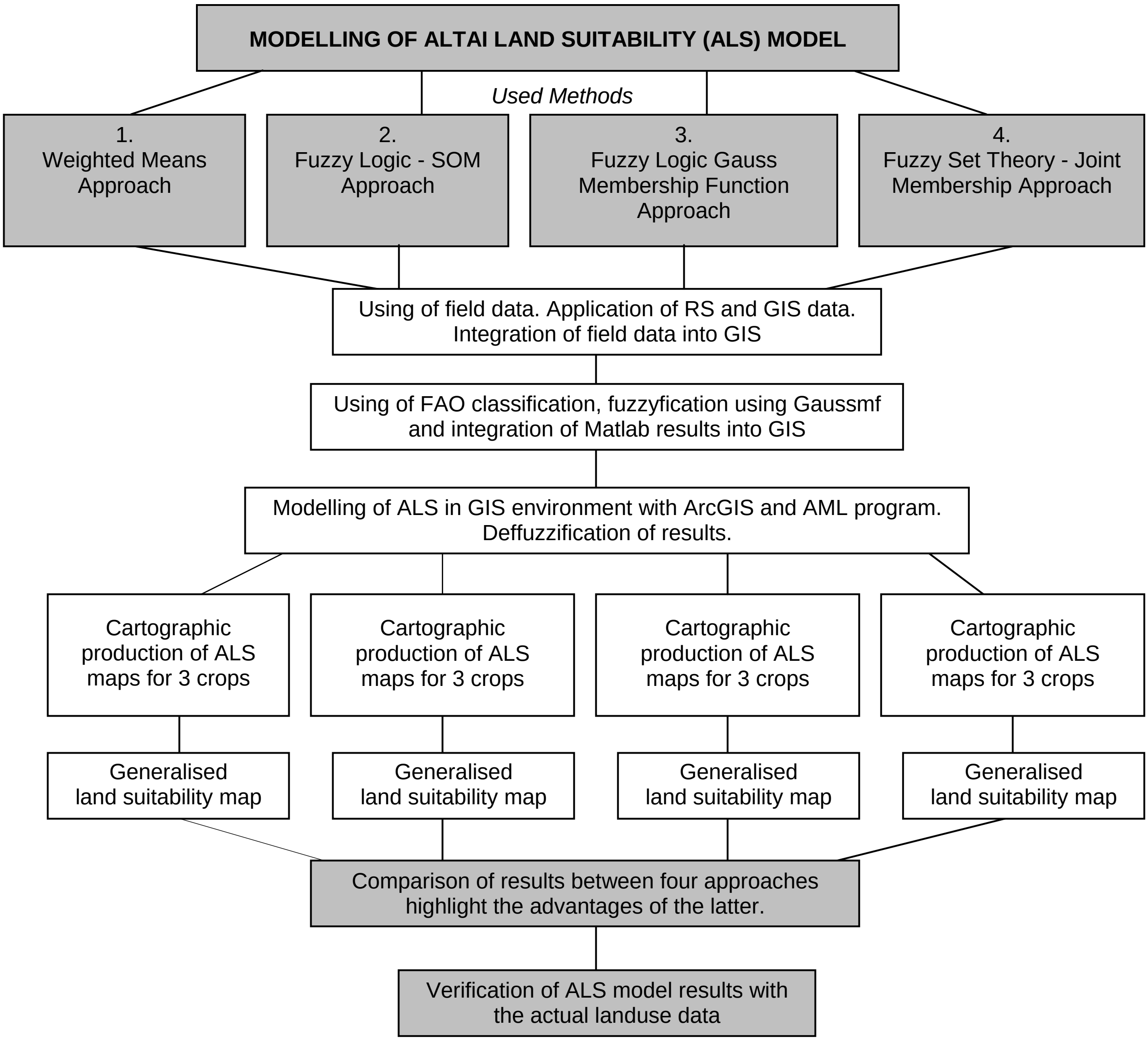


Figure 1.2: Generalised flow chart showing the modelling of Altai Land Suitability using Weighted Means and Fuzzy Approaches.

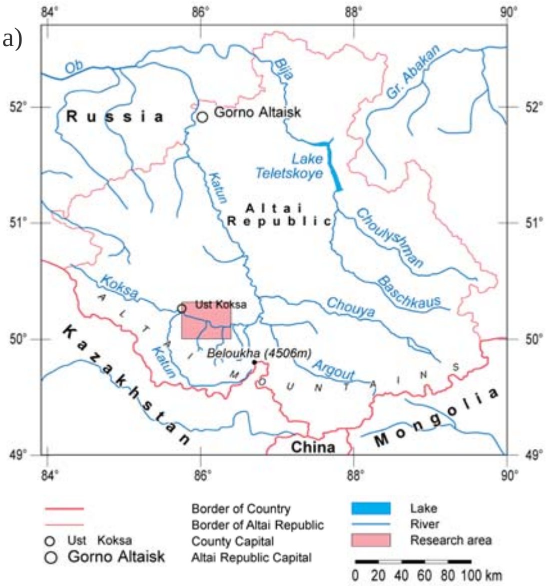
2. General Geographic Setting of Study Area

2.1 Location and Topography

The study area is an intramontane basin in the Altai Mountains, called Uimon Basin. It is a tilted plain measuring 429.89 km^2 (42989 ha) with – apart from a couple of isolated rock outcrops - low local relief. The basin is a result of tectonic movements along major structural lines of the mountain range. Within the Russian Altai it is located in the central-western part, north of the main culmination of the mountain range. Administratively, it belongs to the Altai Republic, an area with partial autonomy within the Russian Federation, bordering Kazakhstan, China and Mongolia (Figure 2.1). Gorno-Altaisk is the capital of the Altai Republic.

The basin floor falls within an elevation range from 900 m to 1100 m the highest points being located at the upper edges of large alluvial fans which are fed by tributaries draining the Terekhta Chain (1900-2000 m) at the northern margin of the basin. The southern basin rim borders the Katun Range (2500-3000 m), which has its highest culmination at Mt. Beloukha (4506 m). The whole area drains into the River Katun, which crosses the basin in W-E direction south of its axis.

a)



b)

Fig 2.1: a) Location map of the study area (from Mannheim 2001),

b) View of the Uimon Basin (from Kuchuganova 2000).

2.2 Climate

The climate of the Uimon Basin can be described as strongly continental with long and cold winters (November - March) and short warm summers. In its character it is similar to other basins of the western Altai, but less extreme compared to basins along the Chouya River which are at a higher elevation and further to the East. The main factors forming the climate of the region are: (i) continental arctic air; (ii) humid air masses coming from the Atlantic Ocean; (iii) local cyclones formed by relief of the mountain system and (iv) warm western and south-western winds [INT-03].

Mountains, however, complicate the distribution of the sun radiation over the basin due to the frequent cloud cover and the steepness of the surrounding mountains. In summer time the sun rises up to 65°, thus resulting in daytimes up to 16 hours or somewhat less due to the surrounding mountains. In winter the sun rises up to 20° over the horizon and the daytime becomes nearly half as long, i.e. 9 hours. The annual duration of the sun hours amounts to 2296 hours.

The mountainous conditions of the region strongly affect the incoming air flows and form local air masses, which imply that in the Uimon Basin the direction of the air masses, follow the major orographic routes, thus, passing between the Katun and Terekhta Ranges. Due to the partial opening of the basin to the West and Southwest, the western, northern-western and south-western flows become (mainly in summer time) the prevailing ones. Their directions coincide with the direction of the Katun and Koksa Rivers.

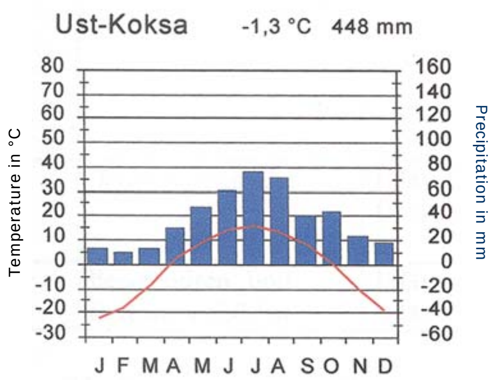
The warm period begins in the Uimon Basin during the first decade of April (Buchtueva 2003). Daily mean temperatures above 5°C are recorded in the third decade of April, which implies the beginning of the vegetation period. Based on readings of the meteostation of Ust Koksa (1995-2002), the vegetation period with daily temperature means above +5 °C is about 150-165 days. The latest spring frost occurs at the end of May/beginning of June. The mean amount of precipitation in April is 16.7 mm. in May 94.23 mm (Table 2.1). Western winds prevail in spring, when quite often frost occurs. The warmest month is July with the mean temperature of 16.6°C with possible daily maxima reaching up to 25-30°C (cf. Kelgen-baeva, Prechtel and Buchroithner 2003). In summer the atmospheric pressure decreases due to the soil warming, which results in a cyclonic weather regime. The western winds also prevail in summer time. The maximum amount of precipitation for the summer period is 275 mm (June - August), the mean annual precipitation is 499 mm (Table 2.1). Often droughts occur. The first fall of temperature occurs at the end of August/beginning of September.

Like in the whole Altai Mountains, in the Uimon Basin, the winter is very long, lasting from November until March. The coldest month is January with the average temperature of -21.0°C (cf. Kelgenbaeva, Prechtel and Buchroithner 2003). The absolute minimum of temperature in Ust Koksa is 56°C. The snow cover lasts from the first decade of November to the first decade of April (in average 30 cm snow depth). With the beginning of winter comes arctic air which brings storms and snowfalls. Clear weather holds most of the winter time with small amounts of snowfall due to the influence of the Asian anticyclones.

The western and, to a smaller extent, the eastern winds prevail in the cold period of the year. The mean value of precipitation for the cold period is 163 mm. Frequently storms and snowfalls occur. The mean annual precipitation amounts to 500 - 600 mm. High summer temperatures warm up the soil, thus favourably influencing the vegetation growth. Table 2.1 gives an overview over the climatic data of Ust Koksa for 1995.

Table 2.1: Climatic data for 1995, Ust Koksa. Altai Republic.

Month	Air temperature in °C			Temp. on soil/snow surface in °C		Mean soil temp. in 20/40 cm depth		Air humidity: relative in %	Air humidity: deficit in mb	Duration of sun shine in hours	General cloudi-ness in number of balls	Max. wind speed in m/sec	Average annual precipi-tation in mm
	mean	max	min	max	min	20	40	mean	mean				
I	- 21.0	1.9	- 33.0	- 1	- 39	- 8.6	- 7.5	83	0.2	151.1	2.6	14	5.6
II	- 14.7	- 0.1	- 30.6	0	- 37	- 7.8	- 8.3	81	0.5	173.5	3.5	9	3.6
III	- 4.6	14.7	- 26.6	21	- 25	- 1.0	- 3.5	72	1.7	211.0	4.9	14	7.5
IV	3.9	20.9	- 8.6	33	- 9	5.6	1.4	63	3.9	249.6	4.8	14	16.7
V	8.6	24.7	- 3.9	44	-7	10.6	5.8	65	4.9	227.9	6.5	11	94.23
VI	13.1	29.9	0.6	50	- 3	15.1	11.0	65	6.7	190.0	5.6	23	89.2
VII	16.6	31.5	1.6	51	- 1	20.1	16.3	77	5.9	278.5	6.7	11	79.6
VIII	14.8	29.2	6.2	50	4	19.2	16.4	80	4.6	231.2	6.7	10	106.7
IX	9.3	23.7	3.4	39	- 10.0	13.5	4.9	70	4.9	250.4	4.2	19	22.3
X	2.3	19.2	- 10.4	30	- 16	7.3	6.2	69	4.3	169.5	5.4	18	37.6
XI	- 8.2	5.13	- 20.0	5	- 23.3	1.1	1.0	80	0.9	133.1	4.2	10	24.1
XII	- 15.0	1.8	- 29.0	- 4	- 36	- 2.4	- 3.2	78	0.6	101.8	5.8	1.1	12.1



Werner (2004) states that from 1951 to 1980 most precipitation fell in the period from April to September, especially from July to August (Figure 2.2). A mean temperature of more than 5°C was recorded during this period with temperatures of above 10°C ring from May until the beginning of September. The figure displays the high humidity of the summer months.

Fig. 2.2: Monthly mean temperature and monthly mean sum of precipitation of the Uimon Basin for 1951 – 1980 (from Werner 2004).

2.3. Geology Including Soils

2.3.1 Rock as Source Material of Soil

As previously mentioned, one of the main objectives of this thesis is the study of the soil fertility of the Uimon Basin to establish the agricultural suitability for particular agricultural crops. In order to obtain detailed information about soil structure, soil type and their zonal distribution it is required to: (i) reveal the characteristics of soil types and their varieties. (ii) establish connections and rules of their interaction with soil-forming factors (relief, geological substratum, climate, biota and paleogeographic conditions). With the help of topographic maps, aerial photographs and satellite images it is possible to produce soil maps based on soil-formation factors and actual soil cover. A soil map is a useful basis for further modelling and evaluation of the soil properties. Therefore, the mapping of soil and soil-formation factors is one of the important input parameter for yield estimation.

What is soil? Soil is weathered rock in which grow living organisms (Kovda and Rosanov 1988, Roy et al. 2006) state, soil is a basis for crop production. One should note that soil is not just “eluvium”, but a very complex and dynamic geobiological system. The concept of “soil” belongs to pedology in the same way as the concept "ground" belongs to soil science. What soil scientists name “soil” is considered by geologists and geomorphologists to be eluvium, diluvium, colluvium, alluvium and etc. Generally speaking, soil is near-surface soft rock which is a medium for the existence of living organisms. Soils include the specific properties of rocks and relief. These properties can be used in soil unit segmentation and soil mapping.

The determination of a soil “unit” is the crucial problem of soil mapping. Let us assume that the soil unit is a mineral homogeneous surface layer of rock which is filled with biota. From this definition, the soil-forming rock and the relief are the initial parameters by which soil units can be identified. One must recognise the fact that these parameters are exceptionally important factors in soil development. Unlike climatic conditions, the soil-forming rock and relief are very stable and at any given moment determine many properties of soils and their development. It is known that the general measurement of “soil fertility” depends more specifically on the soil’s humus content, on soil fauna quantity, mineral contents, structure, physical properties and salt content. However, the general measurement of soil fertility is specified with favourable thermal and hydrological conditions of soil which set up from climate and relief.

The distribution of each soil depends on natural rules, i.e. the conditions of its formation. If soil changes, this means it changes for some reason, for instance either the parent bed changed or there were changes to the relief or of the affect of atmospheric waters or moisture accumulation or plant cover.

The main factors in soil formation are: climate, biota, rocks, relief and time (cf. Kovda and Rosanov 1988), which combined into the following three groups: the first, the factors which are relatively stable and practically do not change for hundreds and thousands of years. These factors include relief and rocks, which can be estimated as bases of soil formation.

Evolutionary changes in the physical-chemical properties of soils mainly occur due to these factors. Second, there are the factors which are unstable and cyclically change within one year or hundreds and thousands of years. These factors include climatic conditions, exogenous geological processes and biota. The cyclic variations in the physical-chemical properties of soils and their development, limited by the conditions of relief and rocks mainly occur due to changes in these factors. The last factor is the time as a factor of stability and steady development of soil.

2.3.2 Relief as an Indicator of Soil Properties

Why is the study of relief so important in the earth sciences? The relief is the main factor in the redistribution of solar radiation and precipitation (Kovda and Rosanov 1988). Minor changes in the relief (for instance: shallow gully. etc.) can reflect upon soil structure, their fertility and landscape too. Butvilovsky (2007a) states about the influence of relief to soil: (i) the relief mainly directly influences soil by the displacement of soil and ground masses with gravitational force using flowing water into the relatively low places of relief; and the indirect role of relief occurs through the distribution of climatic (sun, precipitation. etc.) and water conditions. The quality of soils and crop yield can be influenced by differences in slope, namely exposure, altitude above sea level, inclination, steepness and length (Zvonkova 1959). As a rule, southern and south-western slopes are more favourable for soil quality. A 20 m difference in altitude has an effect on crop yield, moreover, lower sections are more favourable. Relief cavities and steep slope feet are unfavourable for crop growth. Steeper slopes result in less favourable conditions for crop growth; even a difference of 0.5° starts to have a distinct effect on yield productivity. It is known that soil fertility in regions with both similar and varied conditions is specified on the relief predominantly by the slope inclination which determines heat regime, moisture and erosion of the soil.

Lastochkin (1991) also states that the majority of geomorphologic boundaries come out simultaneously as boundaries of soil, vegetation, microclimates and landscapes. This demonstrates the importance of applying geomorphological scientific principles (Kugler 1965, Zvonkova 1962, Barsch and Liedke 1980).

A principle across all earth sciences is that firstly a geomorphological model of the study area is required, and then the data must connect with this model (Lastochkin 1995).

King (1967) asserts on the connection between (i) relief, (ii) soils, landscapes and (iii) their mapping, that “the secret of landscape and soil evolution, evidently consists in the process of slope development”. This assertion appears to be quite correct. Slopes are the dominant area of soil development on the earth's surface. Butvilovsky (2007a) also states about the connection between the evolution of soil formation with the slope processes, emphasising that there is a strong correlation between slope angles and soil properties. The steeper the slope, the lower the soil thickness. Often relief curves are soil boundaries. The denudation balance is very important for soil development. It is very difficult to make a distinction between the genesis of slope and soil, and that the relief allows to get knowledge of a particular soil, and that the understanding of a soil helps in understanding the relief. It is also important to note the location of a soil on a slope. For instance, soils are less consistent on slope-foots. Based on Butvilovsky (1993) the processes of relief formation, particularly in the slope-foot, continue most intensively, and here, again, the most frequent changes are changes in accumulation and denudation states.

“Even insignificant differences in relief can significantly influence soils". It has been observed (Buol et.al. 1977) that the relief influences:

- the depth of the soil root layer
- the humus profile thickness and humus content
- the relative moistening of the profile
- the soil horizon colour
- the degree of profile differentiation
- the soil reaction
- the content of easily-soluble salts
- the character and degree of development of weathering crusts
- the soil temperature
- the character of the source material.

However, soil properties may vary even on slopes with a constant slope angle, and conversely that soils on steep slopes were relatively constant. In this case, the first clarifying questions that need to be asked are: Which properties changed and which did not change? What kind of soil properties were taken into account and which not? How these properties were measured and on what scale were they investigated?

Sometimes, the difference between residual and displaced soils is a basic source of confusion. Furthermore, one should not confuse soil with soil formation processes; one or the other process can go on infinitely, but still may not form a fertile soil type. For instance, this can be due to a constant removal of substance (by denudation). Therefore, Olliyer (1987) states that it is necessary to distinguish between denuded (residual) and accumulative (displaced accumulated) soils.

Butvilovsky (1993) states a very useful and interesting report about the connection between relief and soil which holds special value in soil mapping: relief mainly checks spatial regularities in the soil cover, which makes the creation of a soil map not only easier, but this also to a significant degree makes soil maps more objective documents. A relief is easily viewable, measurable and can be objectively evaluated, whereas other factors are hidden from direct observation at any point. A relief is a reliable basis for soil mapping. not only because soil scientists and cartographers do not have the possibility to see the soil (soil horizons) in most cases and have to show on the map what they presume but cannot see; and also because soil classification and its system is still not completed, and the determination of soil types are frequently very subjective. These conclusions are completely correct, but their application in soil science is nonetheless limited by the imperfections of theoretical geomorphology.

It is necessary to note that during the study of the pedosfere, primary attention was paid and continues to be paid to the morphology of the internal soil structure and to the recent processes of soil formation. However, the exterior form, the structure of soil cover, genesis, the methods of the formation and development of soil and the history of the development of pedosfere have not been sufficiently investigated for effective analysis. Until now there are still no clear ideas about pedosfere in terms of their system and methods of development (Butvilovsky 1993). This rather debatable conclusion can easily be resolved by examining various soil maps; maps merely summarise the results of geographical studies of soils. What types of information does a soil map display? It displays information on the soil types. soil varieties, the soil mechanics and mother rock composition. Age sequences and soil genetics usually present the structure and dynamics of systems which cannot be found in soil maps as an object-system.

2.3.3 Geological Processes as the Background of Soil Formations

The Altai is a very old crystalline mountain range with granitic and other magmatic intrusions. After earlier tectonic activities, during the Palaeozoic it was significantly shaped by further tectonic processes, i.a. by the so-called Altaic Phase at the beginning of the Palaeozoic. In Silurian and early Devonian times extensive marine deposits were folded. During the Carboniferous (Variscian Phase) they were refolded and are today visible in the northern Altai and in parts of the Central and Southern Altai. In the core zones of some larger up-lifted areas Precambrian magmatites (granites and granodiorites) and metamorphites (gneisses and micaschists) are cropping out. Crystalline rocks of Palaeozoic age are most abundant in the North-East Altai. There the mountains are characterized by green-violet volcanically influenced rock sequences (Buchroithner 1985).
The left bank of the Uimon Basin is filled with the products of the down-wash and weathering of quartz-chlorite-sericite, orthoslate and paraslate of the Terekhta Range metamorphic complex with a mixture of basic and oxidized Devonic volcanites. The right bank of the basin is often partially filled with the products of the down-wash of metamorphic basalts, gabbro-basalt and quartz-feldspar sandstones of the Cambrian Katun Series, Ordovician and Middle Devonian granite and diorite (Butvilovsky 1993). In the Cenozoic, the Katun Valley was tectonically thrusted and lowered as the result of the upthrust/overthrust of the Terekhta Block which is filled (at the mouth of the Akkem River) up to 200 - 300 m with loose Oligo-cene-Miocene and Quaternary lacustrine-fluvial and proluvial-dilluvial sediments.
A typical geological sequence of the loose sediments of the northern portion of the Uimon Basin is represented in profiles drilled in 1957 by a geological Altai expedition near the village Kastachta (Butvilovsky 1993).
a) Quaternary dilluvial-proluvial and fluvial deposits (view from top to bottom):

1) Rubbly deposits with an admixture of sand (5%), clay (10%) and small boulders of shale, sandstone and vulcanite (10%); layer thickness: 6 m.

2) Detritus with boulders of shale, sandstone and vulcanite; observed colour is grayish-yellowish; layer thickness: 28 m.

3) Pebble and gravel deposits with frequent layers of brown sandy clay; layer thickness: 16 m.

b) Neogene-Paleogene Dilluvial-Proluvial Deposits:

4) Clays of red-brown colour (at the bottom: grayish-brown) with a considerable irregular admixture of strong weathered gravel and small pebbles; big boulders of quartz and quartz sandstone (up to 0.5 m) can sometimes be seen; layer thickness: 34 m.

5) Fractured bedrock metaslates from the Proterozoic; layer thickness: 40 m.

The general thickness of the above described loose deposits at this area amounts to 84 m. In relation to petrography, the loose deposits of the Uimon Basin present a mixture of erosion products from the adjacent parts of the Terekhta and Katun Ranges as well as from the upper course of the Katun River.

It is known that the composition of the top layer of soil (where soil formation occurs) play an important role in soil fertility. The creation of this layer is related to the newest stage of the geologic-geomorphological development of the territory, namely "the latest glacial-interglacial cycle (Late Pleistocene-Holocene)". A more detailed description about the paleogeography of the Uimon Basin for the period of the latest glaciation is given by Butvilovsky and Prechtel (2000). The course and peculiarities of this latest glaciation in the Uimon Basin is briefly described below.

According to Butvilovsky (1993) and Butvilovsky and Prechtel (2000), a large glacial lake was formed in the eastern area of the Uimon Basin. One of the factor which confirms the existence of this glacial lake (with altitude of 1300 – 1400 m above sea level) are the lake and lake-glacial deposits which were discovered in the four profiles made in the Uimon Basin (near the villages of Kastachta and Zernovoe), and also in the profile of the Akkem River and Tiungur. At the bottom of the Uimon Basin, on the banks of the Katun River and in quarries, different combinations of lake deposits with other sediments can be observed (Butvilovsky and Prechtel 2000. Figure 2.3 c. d. e). It was discovered by the authors that the lake deposits form several unevenly aged horizons (at least three) which indicate the repeated flooding and draining of the reservoir in the period of the last glaciation. Second, the thickness of the lake deposits reaches its maximum values in the central and western area of the basin, reduces towards its borders, and narrows in its eastern portions. In the eastern part of the basin, the deep uneven erosion of the lake deposits, indicated by skew-laminated and cross-laminar dark-gray gravel deposits and boulder pebbles of the catastrophic breakthroughs of lake waters, can be observed.

Lake deposits are found amongst the deposits of Late Pleistocene and Holocene alluvial-proluvial pebbles and boulders, the skew-laminated pebble-boulder sediments of the gigantic ripples, the pebble-gravel deposits of eskers (western part of the Basin), the moraines in the region of the Akkem River mouth and the dilluvial soil layers (usually at the slope foot). Other younger horizons of lake sediments cover the moraines in the Akkem River mouth.

The ridge-hollow relief of a typical gigantic ripple can be observed near the Multa and Akchan River mouths. Here, the asymmetrical ridge widths reach from 40 to 70 m with a maximum of 100 - 120 m. the extension of ridges being 200 - 800 m. Their height varies from 1.5 to 4 m and may reach 6 to 7 m. The steepness of the western ridge slopes is 20 - 35°, and is 3 - 15° for the eastern slopes. The ripples of the Multa River mouth formed with obliquely laminated pebbles and small boulders containing a rather low admixture (less than 3 - 5%) of finer material (gravel and sand). The “ripple basins” are partially filled with sand and silty lake deposits. They cover the gentle ripple slopes with a layer of up to 0.7 m in thickness which results in special conditions for both soil formation and soil cover diversity in this area.

Typical catafluvial gravel-pebble swells in the hollows between the basic spurs have been discovered. However, these swells fence-off oval-shaped shallow dry basins and form an erosional-accumulative complex in the eastern part of the basin. This proves the presence of catastrophically strong and rapid water flows in the basin, connected with breakthrough and water discharge of a glacial reservoir. Tracks of these flows have also been fixed near the mouth of the Koksa River in the form of powerful block trains and an inclined boulder terrace. These can also be found in the region of the Akkem River mouth as steep inclined socle boulder-block terraces and terrace swells. These formations logically have their own special soil cover.

Eskers in the central part of the basin (between the Kastachta and Big Terekhta Rivers) have also been discovered (Butvilovsky and Prechtel 2000, Figure 2.3 (c)). Eskers occur on lake sandy clay or proluvial pebbles and after their formations again overlap with lake sandy clay which indicate that they were formed during the short periods of the drying-out of the Basin reservoir. These formations now have gently sloping shafts (to 20 m) or steeply inclined rocky hillocks with areas of approximately 5 km^2.

Holocene formations of the study region are mainly indicated by proluvial-alluvial debris cones, floodland and river terraces of both the Katun River and its large tributaries. The typical profile of the accumulative proluvial-alluvial debris cone for the contemporary continental-semiarid climate zone (mountain steppe on the southern side of the basin) is composed in the following sequence (from bottom to top):

1. Yellow-brown clay with detritus and small vulcanite blocks, schists; sandstone (up to 40%). It is soliflucted with a total thickness of 0.4 m.

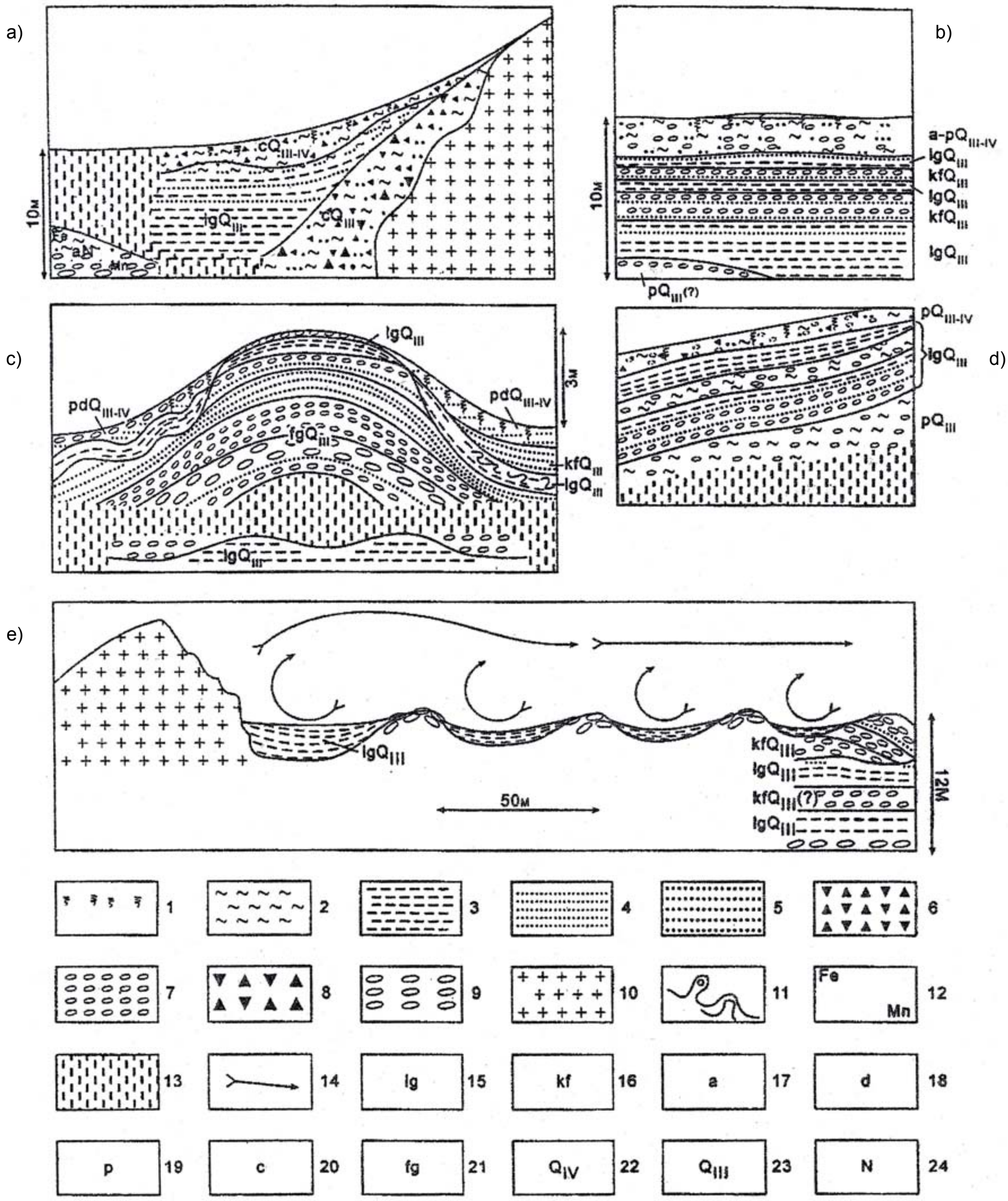


Figure 2.3: Five geological profiles in the Uimon Basin: a) Koksa River, 5 km downstream from the mouth of the Krasnoyarka River, b) delta deposits near Kurumda, c) the western section of the Multa River mouth, d) 10 km east of Ust Koksa (central part of the Uimon Basin), e) eskers between the Kastachta and Big Terekhta rivers (central part of Uimon Basin) (from Butvilovsky 1993; Butvilovsky and Prechtel 2000, Butvilovsky 2007a).

Legend: 1: Soil, 2: Clay, 3: Silt, 4: Sand, 5: Gravel, 6: Detritus, 7: Pebbles, 8: Clod, 9: Big boulder, 10: Bedrock, 11: Slump texture, 12: Ironing (Fe), Magnesing (Mn) of deposits, 13: Turf parts of profiles, 14: Directions of water flow.

Genetic indices: 15: Lake-glacial, 16: Catastrophic fluvial, 17: Alluvial, 18: Dilluvial, 19: Proluvial, 20: Colluvial, 21: Fluvio-glacial.

Age indices: 22: Holocene, 23: Late Pleistocene, 24. Neogene.

2. Mineral chernozem soil on light dilluvial clay with weathered fine detritus (up to 7%); has a coarse-grained texture and does not react with HCl, total thickness: 0.9 m.
3. Humic pebble with gruss and clay sand; contains single shell debris, total thickness: 0.18 m.
4. Fine pebble with gruss and sandy clay. The pebble is medium rounded, lightly weathered in sand-clay gravel cement. The debris composes of slate, limestone, sandstone and microgranite. The layer is proluvial and inclined, with a total thickness of 0.07m.
5. Gray-brown clay with weathered fine detritus (up to 10%), it is carbonated and dilluvial, with a total thickness of 0.20 m.
6. Fine to coarse gray pebble with detritus in sand-clay and gravel cement. The pebble is medium-rounded, and lightly weathered in sand-clay and gravel cement. The debris comprises of slate. Limestone, sandstone, aleurolite and microgranite. The layer is proluvial and inclined with an azimuth fall of $100^o/5^o$. It has a total thickness of 0.10 m.
7. Gray-brown loam with weathered fine detritus (up to 10%); it is carbonated and dilluvial and has a total thickness of 0.15 m.
8. Fine pebble with fine detritus and rock debris. The pebble is medium-rounded and lightly weathered in sand-clay and gravel cement. The debris comprises of vulcanite, sandstone and microgranite. The layer is proluvial and inclined, the azimuth fall is $100^o/5^o$; total thickness: 0.10 m.
9. Gray-brown clay with weathered detritus (up to 10%), the layer is carbonated and dilluvial with a strong reaction with HCl; total thickness: 0.15 m.
10. Gray forest-brown soil, no reaction with HCL, has dilluvial sandy clay with detritus; detritus portions are weathered; total thickness: 0.55 m.

In the nothern side of the basin, the typical profiles of proluvial-alluvial debris cones can be observed within humid to temperate climatic zones. It is presented with similar deposits, however they do not contain carbonate containing horizons or they are located deeper than 1.8-2.0 m. which can usually be recognized by leached chernozem or gray forest soil (Butvilovsky 1993).

The proluvial and dilluvial-proluvial Holocene deposits of these regions can be seen from a paleoclimatical viewpoint. The alternation of coarse debris, clay accumulations and mineral soil is more characteristic for the Katun River. The end of late glaciation and period of early Holocene is dated at 10.200±90 years B.P. (years before present) and is characterized by thick mineral chernozem-like soil and by a sharp reduction of accumulation and denudation processes. These processes had increased threefold times during the Late Holocene era.

Lake alluvial deposits of the Holocene river terraces in the forest-steppe zone have been characterized using the following sequence (Butvilovsky 1993) (from bottom to top):

1. Pebble; brown and grayish-brown gravel with small rounded boulders. River-bed alluvium; total thickness more than 0.4 m.
2. Bluish-gray and grayish deposits, carbonated with thick clay; total thickness: 0.4 m.
3. Interstratifications of carbonated, greenish-bluish clay and pale-beige marls, which also contain oxbow-lake sediments; total thickness: 1.1 m.
4. Black-brown peat bog consisting of soil on top and silt on the bottom; sometimes also with wood and detrite debris; dated 6.880±35 years B.P.; total thickness: 0.6 m.
5. Green-brownish, ferridized, non-carbonated clay in floodland; total thickness: 0.7 m.
6. Mineral soil; meadow and peaty chernozem; dated 3.485±35 years B.P.; total thickness: 0.2m.
7. Brown, spottily ferridized and non-carbonated clay; total thickness: 0.4 m.
8. Mineral soil; black and meadow soil; total thickness: 0.2 m.
9. Modern soil as brown-gray meadow soil on the clay with a mixture of pebbles; total thickness: 0.2 m.

For the southern part of the basin, the following river terrace profiles are typical (from bottom to top):

1. Pebble; small boulders interstratifying in sand-gravel and gravel-clay cement with a visible thickness of more than 2.0 m.
2. Boulder blocks up to 1 m which can be observed across the river flow. The blocks are rounded with pebble and boulders; total thickness of 1 - 1.5 m.
3. Brown-yellow loam; the loam is carbonated at the base and is also alluvial-dilluvial containing a mixture of detritus. It has a total thickness between 0.8 and 1.5 m).
4. Leached and podsolized chernozem soil on clay with a total thickness of 1.0 m.

The recent accumulations in the river flood plain are formed with (from bottom to top):

1. Coarse yellow pebble; gray-yellow pebble with small boulders in sand-detritus-clay cement. The pebbles are fine and strong clayed at the base, with a total thickness of between 0.3 and 1.6 m.
2. Clay silts; spotty-brown, gray and grayish-green silts with detritus. but seldom with pebbles; total thickness: 0.4 m.
3. Coarse gray pebble with small boulders in sand-gravel-detritus cement; total thickness: 0.45 m.
4. Gray, non-carbonated silts containing layers of sand, plant detrite and wood, dated 1.765±45 years B.P. in the oxbow-lake phase; total thickness: 0.35 m.
5. Coarse gray pebble with small boulders in sand-gravel-detritus cement; total thickness: 0.35 m.
6. Interstratifications of sand, silt and sandy clay with plant detrite and detritus debris; dated 900± 25 years B. P.; total thickness: 0.6 m.

7. Brownish-gray, non-carbonated and sandy clay with a mixture of gravel and floodland clay; total thickness: 0.55 m.
8. Dark gray clay soil with a mixture of sand and hydromorphic and floodland-meadow soil; total thickness: 0.3 m.

Two Holocene cycles can be observed here: the early Holocene cycle and the cycle of the historical stage (which began two thousand years later after years B.P.). These are clearly fixed by the phase-lithological changes of the sediments and are in principle both similar to each other, starting as river-bed pebbles and finishing as clay and floodland silts. The dating of the latter indicates their accumulation during the interstage warming up of the Holocene stage. The basic soil formation was completed in the aktra stage. Abundant floral complexes indicate that the essential change of biota took place during the Late Holocene interstage. At the end of the stage when the temperature fell, the tracks of sedge-motley grass swamp, birch forests and the dwarfish birch in silts of oxbow-lake phase were fixed; the number of mesophytes and conifers were increased but the oryctocoenosis of mesophilic meadow associations in soil was concealed. The mineral composition of clay fractions changes only slightly upward through the profile (quartz, plagioclase, hydromica, vermiculite-chlorite and both mixed stratified hydromica-vermiculite). However, the presence of montmorillonite, which is an indicator of alkaline, has been detected in the lower alluvial complex. This is also typical for a more arid zone. According to the lithological data analysis, the same layers differ by the level of carbonate availability; the Late Holocene deposits contain volcanic glass debris which were completely absent in the Early Holocene alluvium. The manganese and gross iron content is less noticeable in the deposits of the Early Holocene and the sands of the Late Holocene eras, but the sodium. Magnesium, aluminum and silica content have here increased.

The terraces and floodlands of the Katun River are of a structure which is typical for terraces of large mountain rivers. This can be observed from the availability of fluvial-glacial boulders, pebbles and the overlapping sand and silts. The presence of a thin fraction of polymict glacial feculence ("flour") is rather more characteristic for water-glacial deposits.

It is necessary to mention the high content of authigenous carbonates and sulfates in the upper parts of the deposits of the high terraces of the Katun River. The strengthening of seasonal floods on the Katun River, change of soil formation types towards more humid types, decreases in the sediment’s carbonate content and also the increase of the admixture of glacial "flour" (index of glacier melting in the upper reaches of the Basin) in the Late Holocene are real (Butvilovsky 1993).

The map of the quaternary sediments of Butvilovsky (2007b) was used to understand the geology of the area and its quaternary deposits (Figure 2.4 and Map A3).

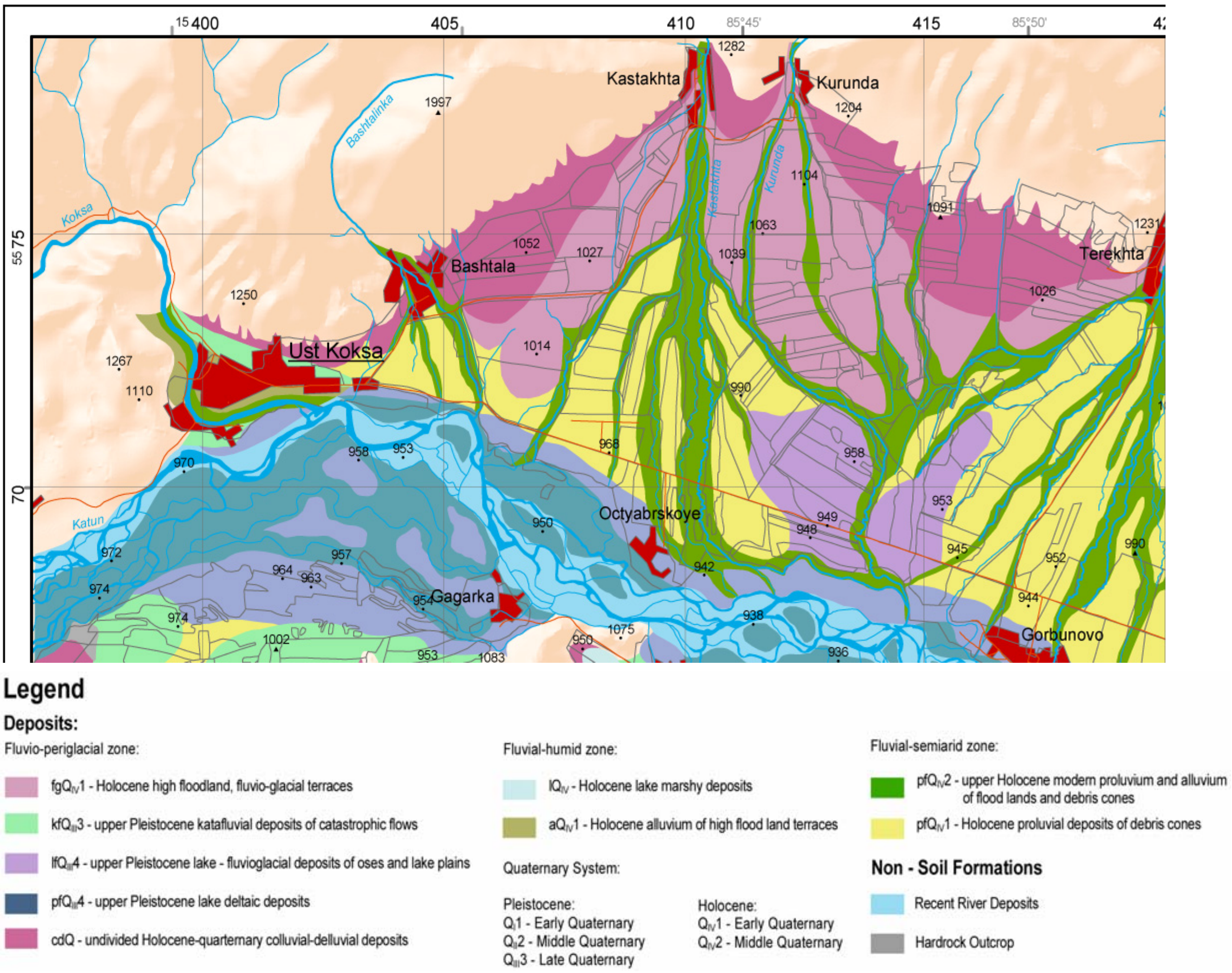


Figure 2.4: Portion of the Quaternary Sediments Map of the Uimon Basin (for more details see Map A3).

2.4 Relief and Soil-Formation Processes

Soil formation is not only the process of the weathering of rocks, but also includes the denudative and accumulative processes (Butvilovsky 1993). Among the 12 types of soil formation processes, nine belong to denudation or accumulation of substances and only three of them belong to weathering processes such as pedoturbation, decomposition, melanization and ferrogenization-gleying (Boul et al. 1977). Based on Butvilovsky (1993), it is expedient both from a geomorphologic as well as a pedologic point of view to consider the development of denudation processes using a slope ranking into 7 gradient classes (see Figure 2.5 and Appendix Map A2) as follows:

1) On slopes with gradients of less than 1.4° external moving media (flowing water, wind, etc.) cause both erosion and deflation of soils and also **suffosion** of the silty to clayey part of the soil substratum. Gravitational denudation is here practically impossible. In any case, it does not influence the relief.

2) On slopes between 1.4 and 2.8°, in addition to the processes mentioned above (i.e. the action of the external moving media and suffusion), the action of down-wash and aggregation

(i.e. the process of denudation due to complete dilution (thinning) of the soil by both water and impacts of rain drops) is an additional factor.

3) Slopes between 2.8 and 5.6° display, in addition to the above processes, further **action of flowing** of the over-moistened silty to clayed soil as a process of denudation due to this over-moistening of soil in its upper layers;

4) On slopes between 5.6 and 11.2°, in addition to all the actions listed above, **solifluction** occurs. This is due to the viscous and slow flow of moist loamy to pebble soil, which presents itself in an arched-stepped surface irregularity (solifluction terraces) whose convexity is directed down-slope.

5) Slopes between 11.2 and 22.5°, show **defluction** processes which can have a clearer impact on the relief. This denudation process occurs due to slip-sliding of clayey

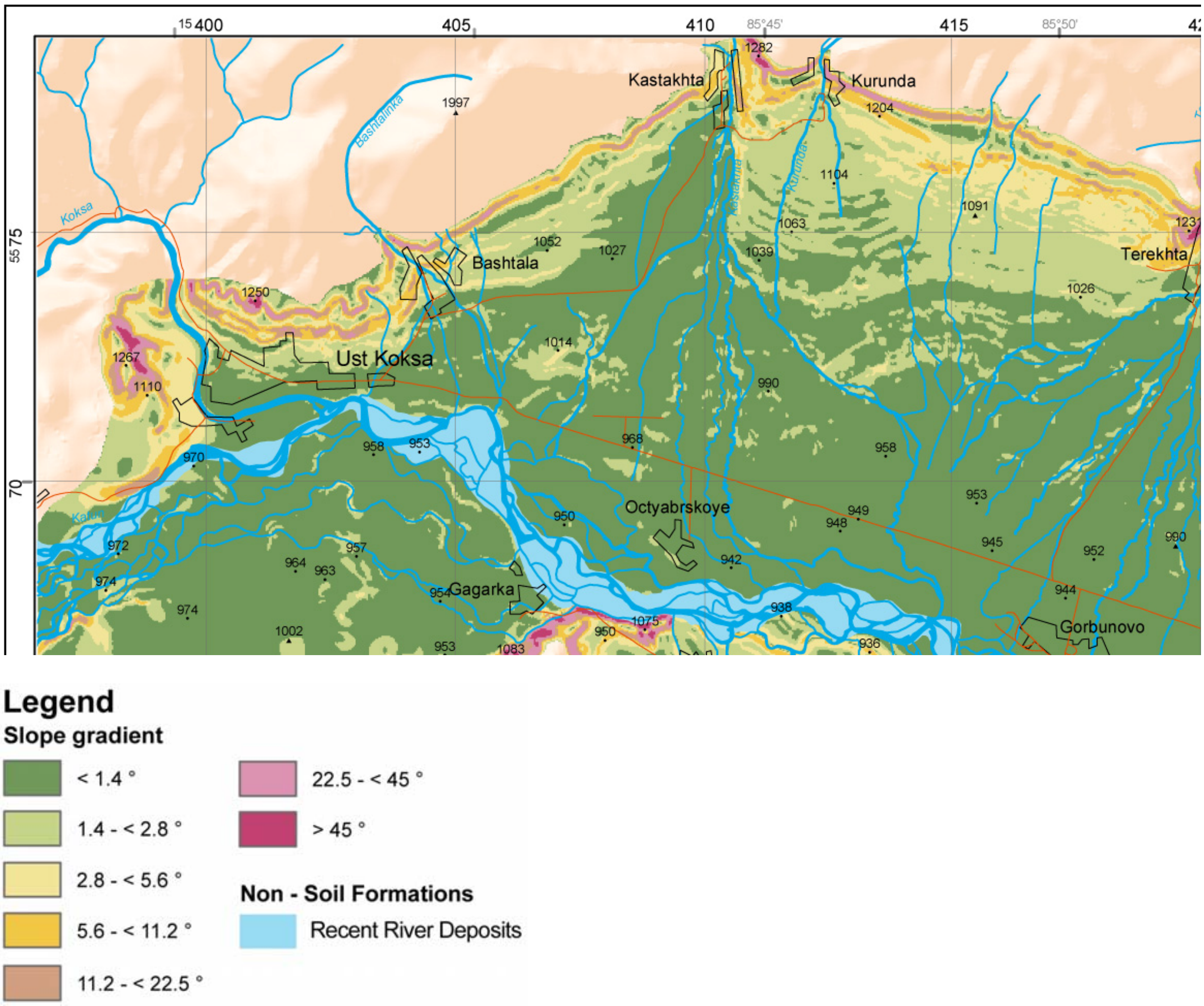


Figure 2.5: Portion of slope map of the Uimon Basin (for more details see Map A2).

to pebbly soil under its periodic moistening, freezing and warming. It is displayed in the relief by unevenly steep gradients. Moreover, the convexity of the arched gradients is usually directed up-slope.

6) On slopes between 22.5° - 45°, the deserption process can be observed, which is also clearly expressed on the relief. This process happens due to the sideways fluctuations and downward motions of stone ground with its periodic freezing and heating. It is presented in the relief as a stony block surface.

7) All the above mentioned processes occur on slopes steeper than 45° and are even more clearly displayed since the additional process of occasional **falling** of fragments (debris) due to the gravitational force under the conditions of the physical weathering of the rocks. Only poor soils can be formed on these slopes.

Slopes steeper than 11° cannot be used for soil fertility studies for agricultural use (cf. Butvilovsky 1993, 1995 and 2007a Stolz 1998). It is obvious that slopes steeper the more of soil fertility loss by down-wash processes. Therefore, most attention should be paid to processes on slopes less than 11° which are typical for the study area.

A slope map has been prepared using a digital elevation model (DEM) and the above statement of Butvilovsky, categorising the slope gradient into 7 classes (Figure 2.5 and Map A2). Based on the obtained results (Table 2.2), the Uimon Basin can be generalised as a plain area whereas the basin slopes exhibit from gentle < 2.8° (56.7%) to medium steep gradients 5.6° – <11.2° (10.5%). The altitude of the Uimon Basin lies between 900 and 1100 m above sea level.

Table 2.2: Evaluation of slope steepness in the Uimon Basin.

No.	Steepness	Slope gradient in °	Area in km^2	% of the total area
1	no	<1.4	195.34	43.7
2	very weak	1.4 - <2.8°	58.24	13.0
3	weak	2.8 – <5.6	18.12	4.05
4	medium	5.6 – <11.2°	47.04	10.5
5	strong	11.2 – <22.5°	90.33	20.2
6	very strong	22.5 - <45° and > 45°	38.27	8.6
Total			447.35	100

2.5 Erodability

Scientists, farmers and others have come to accept the fact that during the process of erosion by water, the fertile topsoil is lost. Many changes in soil physical properties occur as a result of erosion (Lowery et al. 1999). As the topsoil is eroded, the total soil organic matter is significantly reduced because it is primarily located in the upper layers of the soil. In addition to the loss of fertility, the process of erosion alters important physical and chemical soil properties; this alteration is often an unfavourable one. The sorting action of water erosion removes a large proportion of the clay and humus (organic matter) from the soil, leaving behind less productive coarse sand, gravel, and in some cases even stones (Troeh et al. 1980). As aggregate stability decreases or becomes destroyed, the pore size distribution of a soil is reduced and the availability of water to plants and micro-organisms is also reduced. Thus it can be stated that good overall physical soil quality is reduced with erosion, and this has a negative impact on biological productivity, resulting in a reduction in crop production. Water erosion as deflation is also an irreversible process. They are both characterised by the one-sided displacement of the products of washing. In this case the destroyed soils cannot be restored to the initial state, since water erosion leads to such losses which cannot be recovered by soil-generating processes.

An erodability map of the Uimon Basin (cf. Figure 2.6 and Map A5) based on slope only (cf. Table 2.3 and 2.4). Due to the fact that the slope gradient in the agriculturally used parts of the Uimon Basin is very low and that apart from very local erosive events along the rivers and creeks draining the Terekhta Range and the Katun Range there are nearly no erosion occurring. The potential erodability (based on unpublished mappings of Butvilovsky (2007b)), however, is shown in Figure 2.6 and Map A5. Based on the above, the Global Assessment of Soil Degradation (GLASOD) Approach (cf. Middleton and Thomas 1997, Feddema and Freire 2001) was not applied. Reviews are also given by e.g. Buck (1996), Stolz (1998) and Raichert (2004). Their monographs have been also consulted.

Table 2.3: Connection between slope and landuse sustainability (changed after Butvilovsky 2007b, Stolz 1998).

Slope in °	< 1.4 no	1.4 - < 2.8 very gentle	2.8 – < 5.6 gentle	5.6 - < 11.2 medium	11.2 – < 22.5 steep	22.5 – < 45 and > 45 very steep
Land management	without limitation		without significant limitation	landuse is difficult	usual landuse is not possible	absolute grass-land or forest
Machine harvest works	Without difficulties		Increasing of difficulties with root crops	combine harvester		no possible
				still possible	very difficult	
Erodability	no	very low	low	moderate	high	very high

Based on the results (cf. Table 2.4), most of the area comes under the range of soil loss of less 1 t/ha/year (43.7%). This area can subsequently be given a lower priority for soil erosion control and these results also indicate favourable conditions for agricultural landuse and more soil aggregate stability in these areas. The area which has soil losses of 16 – 30 t/ha/year (28.8%) and more can be given a higher priority of erosion susceptibility.

The highest priority should be given to the area experiencing a soil loss of more than 30 t/ha/year.

Table 2.4: Calculation of estimated soil loss of the Uimon Basin, based on Stolz 1998.

Erodability	Average soil loss in t/ha/year	Area in km^2	% of the total area
no	< 1	195.34	43.7
very low	1 – 5	58.24	13.0
low	6 – 10	18.12	4.05
moderate	11 - < 15	47.04	10.5
high	16 - < 30	90.33	20.2
very high	> 30	38.27	8.6
Total		447.35	100

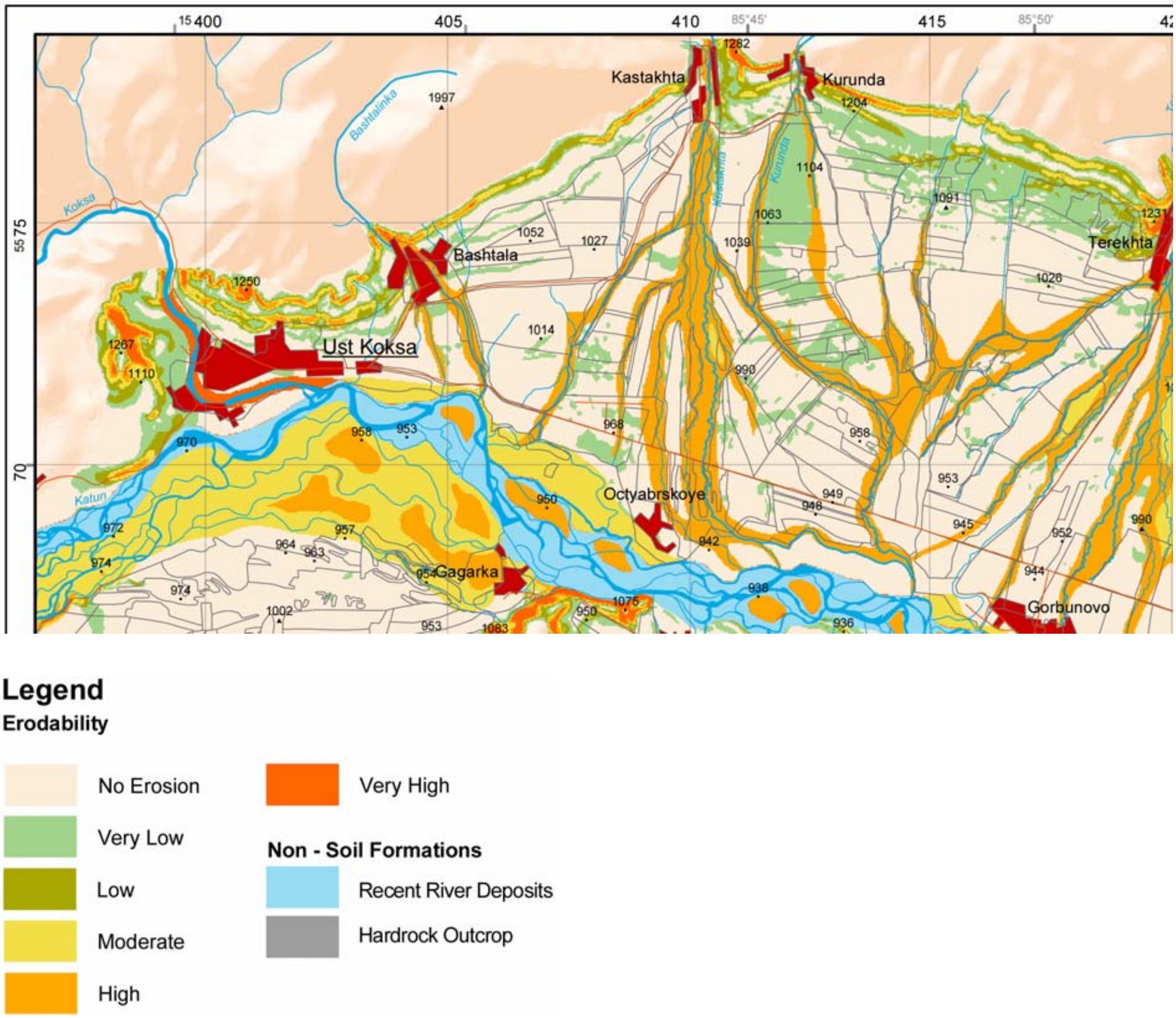


Figure 2.6: Portion of erodability map of the Uimon Basin (for more details see Map A5).

2.6 Soil

2.6.1 Soil Fertility

Historically, the study of soil fertility has focused on managing soil nutrients status to create optimal conditions for plant growth. Soil fertility evaluation will play an increasingly important role in the future of global agriculture in identifying new lands that can be brought into production and to maximize production of existing soils (Sims 2000). The land is viewed here an attribute of place and can range in size from a small parcel to a region. Soil attributes obtained from soil databases are typically used alone or in conjuction with other land characteristics to derive the distribution of land suitability, limitations or potential ratings for various land use types. The analyses provide key information necessarily for land users or managers in making meaningful decisions about management, conservation, and/or land use planning. A general evaluation of the natural fertility levels of major soil groups is given in Table 2.5, but wide variations exist within these major soil groups.

Table 2.5: Inherent soil fertility levels of major soil groups (from [INT-19 to 21]).

Fertility level		
Low	Moderate	High
Soil type		
Arenosols Planosols Podzols	Regosols Andosols Greyzems Podzoluivisols Histosols	Fluvisols Gleysols Vertisols Chernozems Kastanozems Phaeozems Cambisols

Table 2.6: Rating of soil fertility for the different types of soil (from Ermochin and Nekludov 2002).

Soil types	**Soil fertility rating in %**
Leached and podsolized Chernozem	100
Standard Chernozem	98
Southern Chernozem	88
Meadow Chernozem and Chernozem meadow soils	80
Standard Chernozem solonized	78
Dark grey podsolized forest soil	85
Grey podsolized forest soil	75
Light grey podsolized forest soil	57
Turf podsol cultivated soil	66
Podsol gley soil	31
Podsol	10
Solonetz	39
Meadow solonetzed/solonetzic soil	38

2.6.2 Soil Data

Soil is a major component of land system which provides a medium for plant growth. The potentials and limitations of a soil for sustained use under agriculture are controlled by its inherent qualities and characteristics. The quality of soil is a function of its biologic, morphologic, morphometric, physical and chemical characteristics. These characteristics are expressed in the soil map with a reference to location. Soil mapping of the region is intended to serve as a crucial input for modelling of the land suitability evaluation and preparing an integrated plan for the sustainable development of the area.

How is important soil study in land evaluation? Let's propose the term "soil evaluation" for the assessment of soil properties as a phase prior to (or as a base for) land evaluation. Than this involves understanding the soil properties in their broadest sense, including both the intrinsic ones (those of the soil itself – depth, texture, etc.) as well as extrinsic ones (of the soil surface – topography, climate, hydrology, vegetation, etc.). At first, the term "soil evaluation" and "land evaluation" were used interchangeably, but soon the term land evaluation became predominant [INT-04]. "Soil evaluation" fell into disuse. We propose the use of the term soil evaluation in its broadest sense, extending its meaning to all the characteristics that affect the soil, whether these are soil properties themselves or any property related to the soil surface. Soil evaluation would be similar to what today is called land evaluation, but excluding all social, economic and political characteristics.

In the present study, a soil map is used as the basis for the evaluation of the soil properties and for crop yield modelling. Soil is one of the important input parameters in the present modelling. The soils of the 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 1960 (cf. Kuminova 1960), then from the 1970s (cf. Matinyan and Kerzum 1972) which have been prepared to assist land improvement schemes. Recent studies in soil evaluation by Raichert (2004) comprehend comparisons and analyses of the soil samples carried out by Lvov State University in 1971 and by himself in 2002.

Since a soil map is a basic map for land evaluation, it was necessary to generate it as accurate as possible before modelling. The new soil map was prepared by optimizing all previous soil maps, data collected in the field, satellite imagery, geomorphological, and Quaternary map. The units in these documents allow determining the field boundaries. Based on subsequent field checks and soil samplings these units were characterised by a set of *physical and chemical soil parameters*:

soil texture, pH, humus content, nitrogen (N and NO_{3-}), phosphorus (P and P_2O_5), potassium (K and K_20), carbonate ($CaCO_3$) and cation exchange capacity (CEC).

Characteristic for the more humid parts of the intramontane basins of the Altai is a dominance of the fertile chernozem soils. Due to the low relief impact and only little soil displacement in the area, the standard and leached chernozems are more abundant than the mountain chernozems of the steeper parts along the basin margins. The agricultural productivity potential of chernozems is usually high and mostly varies with depth, structure and degree of leaching of the A-horizon. Soil profiles and different subtypes are presented in Table 2.7.

Table 2.7. Soils occurring in the Uimon Basin and brief explanations of their subtypes (changed after Stolbovoi 2000: [INT-19]).

Type	Subtype	Horizons	Brief characteristics
Alluvial Soil	Alluvial-humid leached meadow soil *(Umbric Fluvisol Fl-u)*	A-B_g-C_g	Soils on young flat alluvial plains with regular disturbance by flood events. 10 - 30 cm A-horizon, often greyish or brownish grey till 3 cm of sod in the upper part, thin B-horizon leading over to alluvial deposits.
	Alluvial-meadow soil *(Umbric Fluvisol Fl-u)*	A-B_g-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 humus parts with rusty spots and veins.
Chernozem	Standard Chernozem *(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 calcium-humate. Carbonate concretions in B-horizon, pH reaction is neutral and cation exchange capacity makes 35 - 55 cmol kg^{-1}. Undifferentiated distribution of clay and sesquioxides in the profile.
	Leached Chernozem *(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 chernozems 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 is 6.0. Cation exchange capacity 25 - 45 cmol kg^{-1}.

Meadow soil	Leached Meadow-Chernozem-like Soil (Haplic Phaenozem Ph-h)	A_1-A_1B-B-BC_{ca}-$C_{Ca(g)}$	Soils on fine-textured deposits under an intensive percolating water regime in the Chernozem 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.
	Meadow 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. Colour generally medium brown. Humus content lower compared to all chermozems.
Chestnut Soil	Chestnut Soil *(Haplic Kastano-sems KSh)*	A_1-B-Bca-Bcs-Ccs	The A_1 horizon (10 - 13 thick) has a brownish-grey color, slightly stratified texture. The transitional layer B (28-37cm thick) is a brownish colour. The illuvial-carbonate horizon Bca horizon has yellowish-brown colour. White soft carbonate spots appear at the depth of 40 - 60 cm. The humus content in the upper horizon is 2.0 – 2.5%. The pH changes from slightly alkaline or neutral (7.2 - 7.4) in the upper horizons to alkaline (8.2 - 8.5) in the lower ones.
Mountain Soil	Mountain-Forest Chernozem-like Soil *(Mollic Leptosol Lp-m)*	O-A_1-A_1B-$B_{(Ca)}$-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, humus horizon up to 30 cm in depth with a humus content of 6 - 8%. B_{ca}-horizon slightly compact and weakly structured. Carbonates leached and transportted to different depths to form pseudomycelia, loose aggregates and films on the surfaces of rock particles, which become more abundant with increasing depth.
Marshy Soil	Marshy Soil *(Gleysols GL)*	(O)-A_v –A_1g-B_g-G	Soils formed in lake-marschy deposits. The upper parts of the profile contain peat layer (10 cm). The lower part of this horizon has distinct gley featutes.

40 soil samples were collected from 24 points of plain arable land in the Uimon Basin. They were analysed at the laboratory of the Faculty of Agrochemistry and Soil Science of Barnaul Agricultural State Institute in 2002. It was found that the humus concentration of the soils of the Uimon Basin decreases with the soil depth and ranges from 4 to 5.84% within the upper 20 cm. Based on the chemical analyses, a significant reduction of humus content occurs in the B_{ca} horizon and also increasing of carbonate is observed here. The presence of pseudomycelia in the soil profiles is a characteristic feature for these carbonated soils. The pH values of the soils of the Uimon Basin are slight acid (6.4 – 7.8%) in the upper horizons and slight alkaline (7.9 – 8.3%) for the lower horizons based on soil chemical analyses. This soil also has a highly exchangeable capacity, reaching 40 meq/100 g for a calcium content of

94 – 95%. The texture of Uimon Basin soils is not distributed homogeneously in its soil profiles which are related to the variety of soil-formation rocks. A hard and light loamy soil texture prevails. The grain size of the humus horizon is characterised by a high content of dusty and sandy portions. The grain size portions decrease and the sandy portions increase with increasing depth. As the analyses show, the macrostructure of the arable horizon and below is sufficient. This may be a result not only of the mechanical impact of plant roots but also a consequence of the active working of the mesofauna, in particular earth worms. The grain size fractions are typical: i) from 1.0 to 0.25 mm: 3.51 – 22.9%; ii) 0.25 to 0.05 mm: 5.92 – 43.6%; iii) 0.05 to 0.01 mm: a minimum percentage. The soils show a reasonable amount of moisture, dense grass vegetation, a large amount of organic matter and sufficient mesofauna activity. The Table 2.8 shows the percentage of soil distribution in the Uimon Basin (cf. Figure 2.7). The results show that most of the area in the Uimon Basin consists of standard and leached chernozem (52.9%). Alluvial soils are prevalent mainly on low flood lands and fluvioglacial terraces (28%).

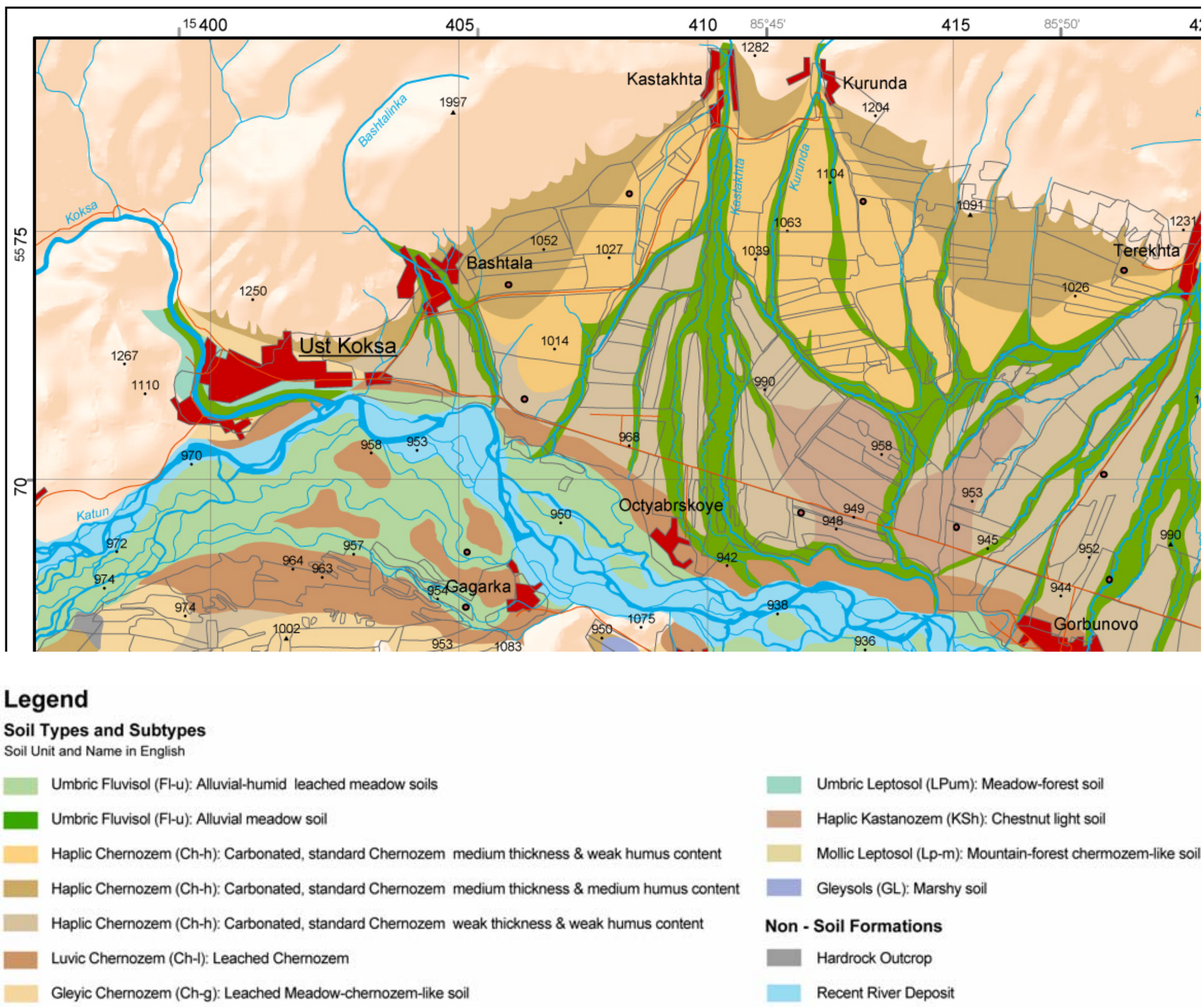


Figure 2.7: Portion of soil map of the Uimon Basin (for more details see Map A4).

Table 2.8: Distribution of soils in the Uimon Basin.

No.	Soil	Area in km^2	% of total area
1	Alluvial soils	120.12	28.0
2			
3	Standard and leached chernozems	227.10	52.9
4			
5			
6			
7			
8	Mountain forest soils	5.01	1.2
9	Chestnut soils	18.64	4.3
10	Meadow soils	23.39	5.4
11	Marschy soils	0.90	0.2
	Recent river deposits	31.08	7.2
	Hardrock outcrops	3.66	0.8
Total		429.89	100

2.7 Salinisation

There is no salinisation.

2.8 Drainage

The Katun River is the biggest river in the Gorno-Altaisk Region. It belongs to the Ob River catchment and originates from the glaciers of Beloukha. It joins the Koksa River at the village of Ust Koksa and crosses the Uimon Basin in west-east direction south of its axis (Figure 2.1). The average speed of the Katun River at its maximum annual water level is 5 m/sec (Buchtueva 2003).

According to the data recorded by the Ust Koksa Meteostation, the Katun and Koksa are completely free of ice around the middle of April. The presence of autumn ice floating begins again at the end of October, but in the case of a late autumn, it may occur as late as at the beginning of December (Buchtueva. 2003). Katun and Koksa are usually completely frozen by the end of November. The average annual water temperature is 4.5° C and the maximum water temperature occurs in July - August around 11.9 - 12.2°C. The water in the river is soft, with a total hardness of approximately 1.31 mg-eqv (Buchtueva 2003). The Okol, Big Okol and Multa rivers drain the Katun Range. These rivers which form the main tributaries are Bashtala, Kastachta, Kurunda, Terekhta, Chendek and Margala.

The depth of the ground water in the Uimon Basin varies. In the plains the water level is deeper than 7 m, but at high altitudes it is even lower. The local population uses spring water, water pumps and draw-wells for drink water supply.

2.9 Vegetation

The majority of the basin is covered by flora which can be grouped into:
i) motley grasses – gramineous meadow steppes which include cock's foot (Daktylis glomerata), siberian meadow grass (Poa sibirica), bonfire awnless (Bromus inermis), timothy grass (Phleum pratense) and cinquefoil golden (Potentilla aurea) etc. ii) bean groups: peavine (Achillea sp.) and vetch (Lathyrus pisiformis). Willows (Salix sp.) and willow-birch (Salix-Betula papyrifera) bushes can be found across the river basins.
Several works on vegetation, land and forest cover, topography, glaciology, climate and landscape animation and etc. concerning the Altai Republic have been done within the framework of Altai Project [INT-05], Habermann (1999), Mannheim (2000), Höppner (2001), Hänel (2002), Londershausen (2002), Pollack (2002), Kunert (2003), Werner (2004) and Bähr (2006).

2.10 Actual Landuse (2002)

Comprehensive information on landuse/landcover is the basic pre-requisite for land resource evaluation, assessment, utilization and management. The agricultural landuse is a function of land productivity and land utilization practices over a period of time. The agricultural land use classes identified in the study area include nine croplands (Figure 2.8).
The scope of the present study is limited to mapping the present landuse patterns, their spatial distribution, assessment and geographical extent in the basin and verification of it with

Table 2.9: Landuse types in the Uimon Basin, based on field evidences 2003.

No.	Landuse types	Area in km^2	% of total area	Sum in %
1	Summer wheat	88.10	20.6	60.1
2	Oats	33.36	7.8	
3	Barley	41.59	9.7	
4	Sunflowers with peas, Barley with sweet clover, Buckwheat (Annual)	55.09	12.8	
5	Lucerne, Red clover (Perennial)	39.58	9.2	
6	Potatoes	6.55	1.5	1.5
7	Meadow vegetation	91.31	21.2	30.2
8	Meadow and forest vegetation	38.67	9.0	
9	Not cultivated lands	0.90	0.2	0.2
	Hardrock outcrop	3.65	0.8	0.8
	Recent river deposits	31.08	7.2	7.2
Total		429.89	100	100

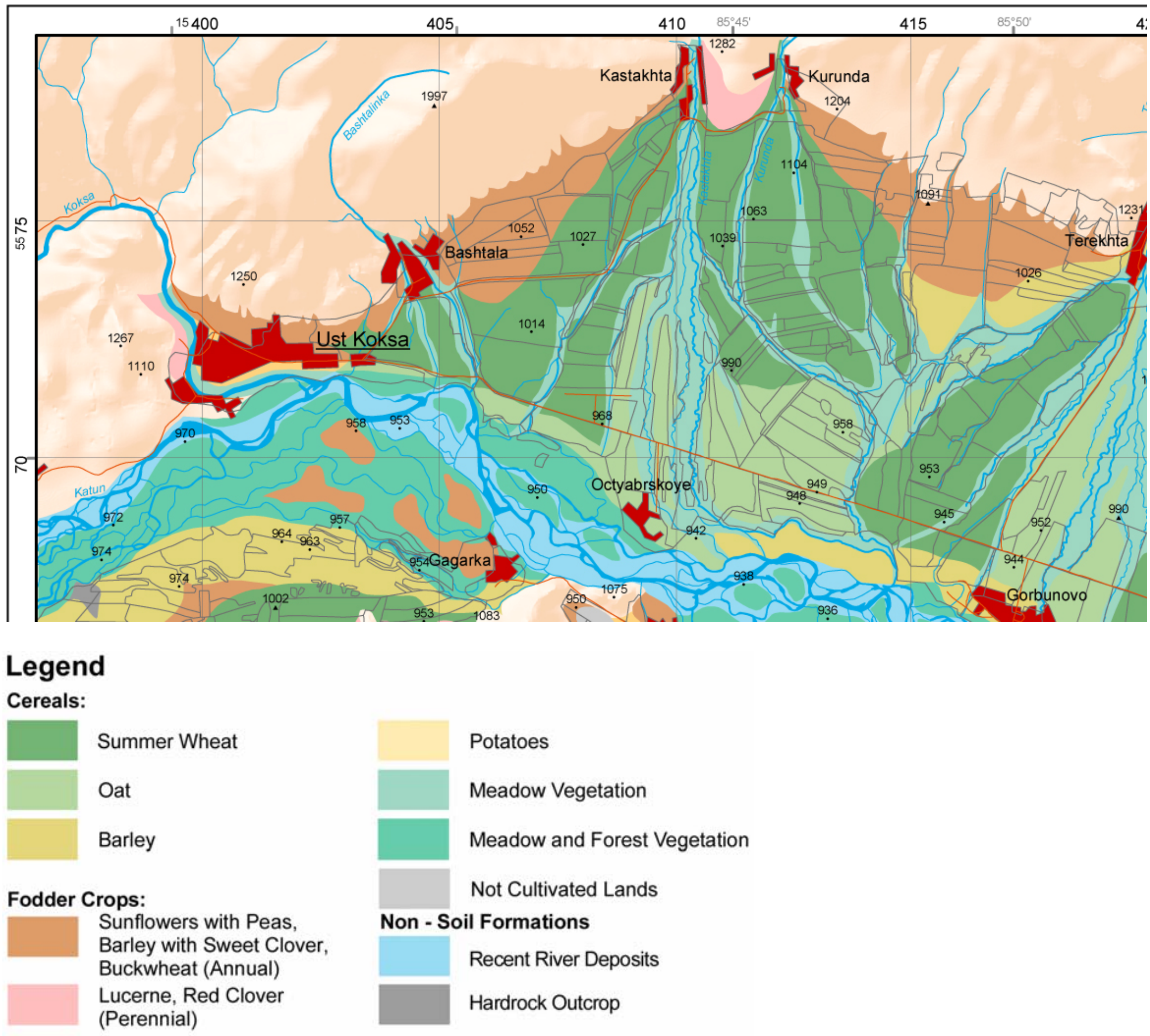


Figure 2.8: Portion of landuse map of the Uimon Basin (for more details see Map A6).

final suitability maps. The preparation of landuse map has been carried out by using field data, satellite data, remote sensing techniques and previous sources (Raichert 2004, Buchtueva 2003). The landuse map is presented in Figure 2.8 and Map A6. It is observed, cereals are the most used crops in agricultural practice.

2.10.1 Agriculture in General

The most productive branches in the state farms of the Uimon Basin are animal husbandry. Animal breeding comprehends cattle, marals (Siberian deer), pigs and sheep. Most farmers specialize in the cultivation of annual and perennial grasses for providing of a fodder base (hay and silo for winter period) for the cattle-breeding branch. At present, the basin is mostly cultivated with summer wheat, oats and barley. Sunflowers grow mixed with peas and oats as fodder crop. Usually potatoes are also grown here. The grain of summer wheat is used for the baking industry and as agricultural seeds.

2.10.2 Crop Rotation

Crop rotation is an important aspect in production of agricultural crops. Nutrient management changes are needed if farmers change from their rotational patterns. Generally, yields are boosted by changing crops rather than growing the same crop year after year. Those benefits have been known for years. Crop rotation is also most beneficial in controlling disease organisms that survive in crop residue. The increased pressure of insects can lead to an increased use of pesticides which increases cost, environmental and food safety concerns. It also means increased handling of pesticides and additional worker protection liability as well as increased equipment needs. Rotations help to control weeds and reduce the number of herbicide resistant weeds. In the Uimon Basin the following rotations are used:

Table .2.10: Rotation table for spring wheat, sunflowers and potatoes (from Yashutin 2001).

Crops	Forerunners	
	More preferrable	Permissible
Spring wheat	Winter crops, tuber (root) crops, perennial, leguminous crops, clean fallow	Millet, annual for hay
Sunflowers	Winter crops, leguminous crops	Rye, summer wheat
Potatoes	Winter crops, vegetables (cabbage, cucumber), leguminous crops	Summer cereals

2.11 Population

There are 15 villages in the Uimon Basin (Tab. 2.11). The biggest village is Ust Koksa with a population of 3.815 people (Buchtueva 2003). The villages of Chendek, Upper-Uimon and Multa are less populated and the least populated ones are Bachtala, Terekhta, Kurunda, Kastachta, Low Uimon, Tikhonkaya, Gagarka, Oktyabrskoe, Gorbunovo, Margala and Polevodka.

Table 2.11: Population of the Uimon Basin for 2002 (from Buchtueva 2003).

No.	Village name	Year of Formation	Persons	Predominant Etnos
1	Verkhni Uimon	1798 (1786)	627	Russian
2	Ust - Koksa	1807	3815	Russian, Altaian, Ukrainian and oth.
3	Nijni Uimon	1826	210	Russian
4	Tikhonkaya	1867	440	Russian
5	Gagarka	1866	224	Russian, Altaian
6	Oktyabrskoe	At the begin. of XX cent.	300	Russian
7	Gorbunovo	1875	322	Russian
8	Kurunda	1876	256	Russian, Altaian
9	Kastakhta	1884	198	Altaian
10	Margala	1900	97	Russian
11	Polevodka	At the begin. of XX cent.	96	Russian
12	Chendek	1866	1051	Russian
13	Multa	1836	1160	Russian
14	Terekhta	1850	528	Altaian
15	Bashtala	1860	433	Altaian, Russian
Total			9757	

2.12 Brief Historic Account of the Altai Republic

*By the middle of XVth century, as a result of feudal wars and political intrigues, the Altaian population fell under the influence of the western Mongols or the Oirats (the latter being also known under the name of "the Jungars", since 30-ies of XVIIIth century). Their supremacy lasted up to 1756, i.e. up to the time when the southern Altaians (the Altai-Kizhi, the Teleuts, the Telengits) became a part of Russia. Unlike the latter, the northern Altaians (the Kumandins, the Tubalars and the Tchelkans) took out Russian citizenship much earlie*r [INT-03]*. By the end of XVIIth century over 100 of their "volosts, uluses and ails" were submitted to the Russian Tzar and paid yasak-tax to his treasury. Inclusion of the Altaians to Russia protected them from foreign infringements, and even from being physically annihilated by the Tsin Army. This conditioned their further economic and cultural development on a new basis. After gaining Russian protectorate, the Altaians as well as other peoples of Russia, struggled against the existing regime. Working people of Altai took part in the Revolution of 1905-1907, in February and October Revolutions. Soviet power was established in December, 1917. From 1922 up to 1947 the Republic was called Oirot Autonomous Oblast (means Region); from 1948 up to 1990 - Gorno-Altaisk Autonomous Oblast; on July 3, 1991 the oblast was transformed to Gorno-Altaisk Republic of the Russian Federation; and on May of 1992 it was renamed to the Altai Republic. As a subject of the Russian Federation, the Altai Republic has its Constitution adopted on July 7, 1997 and state symbols - the flag and the emblem. State languages of the Republic are the equal Altaian and Russian.*

3. Preparation of Geo-Data

3.1. Remote Sensing, GIS and Cartography

3.1.1. Introduction

Remote sensing, GIS and cartography are interacting mapping fields in the sense that they - at least partly - exhibit mutual dependencies. They tend to grow closer to one another under the influence of technology. A remarkable number of papers dating from the late 1980s are also exclusively dedicated to the distinctions and relations among these three areas of interest and their separate definitions (cf. Blakemore 1988; Buchroithner 1996, Cowen 1988; Fisher and Lindenberg 1989; Fussel et al. 1986; Maguire 1991; Wel 2000). In the brief introduction, attention is paid to the definitions of remote sensing, GIS and cartography below.

3.1.2 Remote Sensing

Photogrammetry and Remote Sensing is the art, science and technology of obtaining reliable information from non-contact imaging and other sensor systems about the Earth and its environment, and other physical objects and processes through recording, measuring, analysing and representation[2].

In general, remote sensing is considered primarily a data acquisition technique that includes traditional aerial photography as well as more advanced air and spaceborne sensor technology. The extent of this is however dependent on the various disciplines that make use of the technology; remote sensing refers here to the use of electromagnetic energy sensors that derive information about the features on the Earth's surface by measuring and analysing the type and amount of energy that they emit or reflect. The type of energy refers to different parts of the electromagnetic spectrum ("wavelengths"), e.g. visible, near-infrared, thermal infrared or micro-wave bands (ordered in increasing wavelengths). Figure 3.1 presents a schematic representation of the principle of electromagnetic remote sensing of the Earth (Rees 1990); it encompasses the collection of information on a *scene object* located on or near the earth's surface without coming into physical contact with it, by using an airborne or spaceborne sensor that is more or less above and at a "substantial" distance from this object (Abkar 1999). Moreover, the information is carried by electromagnetic radiation, as stated before. Note that the above definition excludes other remote sensing techniques such as sonar which uses acoustic waves and medical imaging that indeed applies electromagnetic energy, yet not in the sense that is meant by environmental remote sensing with a sensor at a "substantial distance" from an earthbound object (Wel 2000). In order to understand the unique character of remotely sensed data, some attention will be paid to the principles of remote sensing. A more

[2]) from Wel (2000)

extended discussion on remote sensing techniques can be found in, among others, Richards (1999), Mather (1987) and Lillesand and Kiefer (1994). Gonzalez and Woods (1992) provide an introduction to the concepts and methodologies used to process the image data that is acquired by remote sensing techniques.

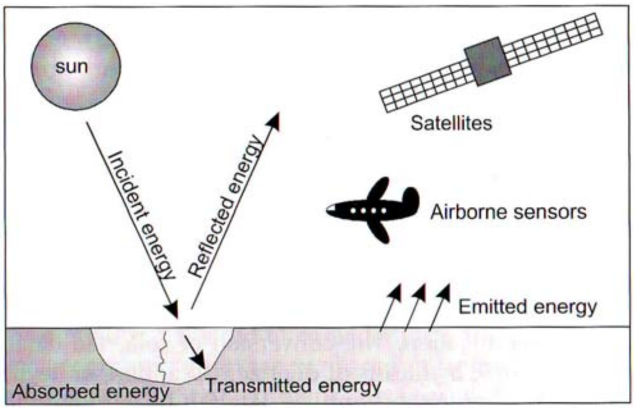


Figure 3.1: The principle of remote sensing (from Rees 1990).

The term remote sensing dates back to the early 1960s when new data acquisition techniques failed to conform to the narrow definition of aerial photography (Fussell et al.1986). Since then, satellite platforms have enabled observations from high altitude with sensors operating in the visible, infrared and thermal sections of the electromagnetic spectrum as well as in the microwave region. Fussell *et al.* (1986) state that the data acquisition process has a sound physical basis, e.g. quantum mechanics describes the behaviour of electromagnetic radiation in terms of waves as well as quanta (photons). The data acquisition process can be roughly subdivided into the following stages (Wel 2000):

- The flow of incidental solar energy and its interactions with the atmosphere such as scattering and absorption as well as the atmospheric interactions of the reflected and emitted portion of that energy.
- The interaction with earth-bound objects and the subsequent reflection, absorption and transmission of energy.
- The recording of energy values by scanner optics over an area on the ground that is observed by the sensor at a certain point in time - the Instantaneous Field of View (IFOV).
- The transformation of the photon or radiant flux into an electrical current and the subsequent sampling during which analogue photon counts are converted into digital integer numbers or DNs (quantization).

In this thesis, remote sensing imagery played a useful role due to the remoteness of the Uimon Basin. Here, it served as a tool for the interpolation of the field data, the preparation of Quaternary map and the improvement of the soil map. Digital terrain models (DTMs) allow the derivation of various useful types of terrain representations (e.g. slope gradients and aspects) or of digital illumination models for the classification of remotely sensed image data. They are going to play an increasingly significant role (Buchroithner 1996). More details about the using of satellite image will be given in Chapter 3.2.

3.1.3 Geographical Information Systems

"...The results of remote sensing processes are seen more and more as single steps in the greater context of CIS. The appropriate means of making the various streams of information provided by GIS visible[3].

Geographic information systems (GIS) emerged in the 1970-80s period. GIS represents a major shift in the cartography paradigm. In traditional (paper) cartography, the map was both the database and the display of geographic information. For GIS, the database, analysis, and display are physically and conceptually separate aspects of handling geographic data. Geographic information systems comprise of computer hardware, software, digital data, people, organisations and institutions for collecting, storing, analysing, and displaying geo-referenced information about the Earth (Nyerges 1993). Chrisman (1984) refers to it as a complicated type of software covering the whole life cycle of geographical data, from data collection to interpretation onwards. A better and more widely accepted definition of GIS is given by Burrough and McDonnell (1998) who consider GIS a complex of computer hardware and software embedded in a proper organisational context. Burrough and McDonnell (1998) distinguish the following five technical tasks (cf. Figure 3.2):

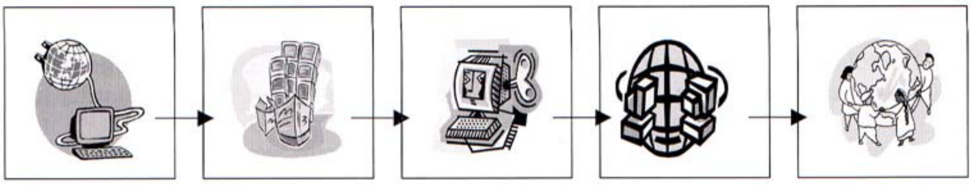


Figure 3.2: Five main of GIS software, schematically represented (from Burrough and McDonnell 1998).

- Data input and data verification. The conversion of collected data into a suitable, digital format, for example by means of digitizers, scanners or keyboard. Moreover, it involves some kind of pre-processing, as data can be subjected to generalisation or simple classification procedures.
- Data storage and database management. Once passed the input stage, data is stored in a database according to a particular data structure and database structure.
- Data manipulation. This involves all transformations being applied to the data.
- Data output and presentation. The data, processed or not, can be presented in a graphic or alphanumeric way, as hardcopy (e.g. a paper map) or softcopy (e.g. so-called ephemeral output on a computer screen).

[3]) Wel (2000)

- Interaction with a user. A user is able to communicate with the information system ("query input") in order to extract information from the stored data.

Marble and Peuquet (1983) give a well-chosen description of the functionality of a GIS that summarises the above-mentioned tasks: "... *a GIS is designed to accept large volumes of spatial data, derived from a variety of sources, including remote sensors, and to efficiently store, retrieve, manipulate, analyse and display this data according to user-*"*defined specifications...*“

In this thesis, the use of GIS tools in logical sequence (cf. Figure 3.2) helps to solve the complex spatial problems (e.g. input, process and storage of field and other data, overlay functions, etc.). The Arc/Info Macro Language (AML) was used for the modelling of land suitability maps. More details are presented in Chapter VI.

3.1.4 Cartography

Cartography is a unique facility for the creation and manipulation of visual or virtual representations of geospace maps to permit the exploration, analysis, understanding and communication of information about that space.[4]

Cartography is the science of map making, including the art and technology of map-making. As an ancient discipline it was borne from the need to represent large areas of the Earth on a manageable size [INT-07]. For many years, cartography was associated only with analogue maps and analogue map production (hard copy maps). The contributions to theoretical cartography provided by Kolacny (1969), Ratajski (1973) are well known in the cartographic community. Due to the interest in computer-assisted cartography in the 1980s, the communication theories in cartography have lost some of their influence (Wel 2000). Nowadays, cartography has grown to encompass a wider field of applications such as digital maps, digital map production, alternative forms of visualisation (of the Earth and of very small and very large phenomena), and digital geo-spatial data analysis [INT-08]. In accordance with MacEachren (1995), cartography is defined as a discipline dealing with "representation". Instead of considering maps as merely graphic messages to convey relevant geographic information, based on information theory (Shannon 1948) and semiotics (Bertin 1983), maps are viewed as spatial representations, thereby stressing cartography's function as *"...creating interpretable graphic summaries of spatial information (i.e., representations)..."* (MacEachren 1995, Wel 2000). Cartographic presentation can be realized in the form of maps or map-like products (Buchroithner 1996). Terrain relief plays a crucial role and enforces a series of measures. Detailed inventories of surface cover features (e.g. erosion marks) and, their perspective representation to enhance the relief impression, as well as graphics of remotely sensed data. (Buchroithner 1996). For instance, digital elevation models allow derivation of

[4]) International Cartographic Association (ICA): [INT-09]

various useful forms of terrain representations (e.g. slope gradients and aspects) or digital illumination models for the classification of remotely sensed image data are going to play an increasingly significant role (Buchroithner 1996). Ormeling (1995) states that *"…no one map can be considered as the only true map based on specific data, as subjective decisions regarding data thresholds, classification systems, class boundaries, or numbers of classes have been made…"*.

In this thesis, the results of satellite image and GIS works including field data were helpful in conveying the concepts of cartography to experts and non-scientists. ARCMap was used for the production of the output maps and the visualization of results to experts and non-experts.

3.2 Satellite Imagery and Topographic Data

The advantages of satellite images are well known in the cartographical community. As stated before, MK-4 multi-spectral satellite images of the study area (Table 3.1) were used in the current thesis. Collaborative long-term project between the Dresden University of Technology (Germany) and the Altai University, Barnaul (Russia) is aiming at generating a comprehensive environmental GIS for the Altai Republic (Prechtel 2000, Prechtel and Buchroithner 2001 and 2003, Prechtel 2003). The original scale of the analogue MK4 stereo-model is 1:790,000 (Prechtel and Buchroithner 2001). The greatest benefit of this image is the combination of high geometric resolution (around 12 m) and stereo-capability (60% overlap along track; Prechtel and Buchroithner 2001).

Table 3.1: MK-4 satellite image, forming part of the GIS ALTAI-100 at a scale of 1:1,000,000 (from Prechtel 2001).

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; Planimetric resolution after geometric processing: 16.667m x 16.667m	Multi-spectral ortho-images (processed at the Institute for Cartography)

The following information was derived from the above image:

- delineation of actual agricultural land (agriculture mask) = outer boundary of the study area (by visual interpretation)
- delineation of field patterns of arable lands, meadows, flood areas, main rivers, settlement and other relief features (by visual interpretation)
- location of sample points and easy visualisation of the relief of the study area during field soil sample works (by visual interpretation)

- delineation of geomorphologic features for improvement of quaternary map (by visual interpretation and geology knowledge).

For direct crop identification from imagery on a field-by-field basis, a multi-temporal image set falling within one vegetation period would be a prerequisite which is presently not available and hard to acquire as a result of cloudiness (Kelgenbaeva et al. 2003).

Official topographic maps of Russian territory are mostly difficult to access with no reliable civilian distribution system established; maps are strictly classified for scales larger than 1:200,000; and are often printed without coordinates and even without a legend for civilian use (Prechtel and Buchroithner 2001). This strict limit on the free usage of large-scale topographic maps prevents the generation of a high-quality DTM. The same restrictions prevent the use of aerial photographs. The problem was solved due to the availability of the schematic soil map 1:25 000 (total 114 A4 sheets) from which contour lines for DEM preparation were drawn. Improvements were achieved by combining and/or integrating this with the contour lines of standard 1:200,000 topographic scale maps (Figure 3.4).

To sum up, the topographic data in the present thesis was used in a twofold manner: the first one (i) is used in modelling (as a drainage factor) and for a detailed numeric description of the relief (Digital Terrain Model); the second one (ii) is used as an integrative part of the cartographic output. The latter basically contains orientation elements such as communication lines, settlements, elevation points, peaks and rivers (see Map A1). More details about the preparation of the DTM will be given in the next chapter.

3.3 DTM Generation

The Digital Terrain Model (DTM) was prepared for the visual representation, checking and analysis of the relief and in particular landforms. Value-added visualisations such as hillshading (Figure 3.5) and a perspective view of the study area (Figure 3.6) were also created using the DTM. The flow chart of the preparation of the DTM25 and the further integration of it into the DTM100 (both resampled to 16 m resolution) is presented in Figure 3.3. The DTM has been created through an interpolation with the Topogrid Tool of ERDAS Imagine. The contour line map 1:200 000 from the Altai Project was used to show the helicopter view (Katun and Terechta Ranges) and for the orientation in the Uimon Basin. For an optimised visualisation of the DTM a hillshading was used. The combination of hillshading and the colour-coded elevation is presented in Figure 3.4. In that case the hillshading is a transparency layer. A further three more parameters were calculated for geomorphometric interpretation: elevation, slope and aspect.

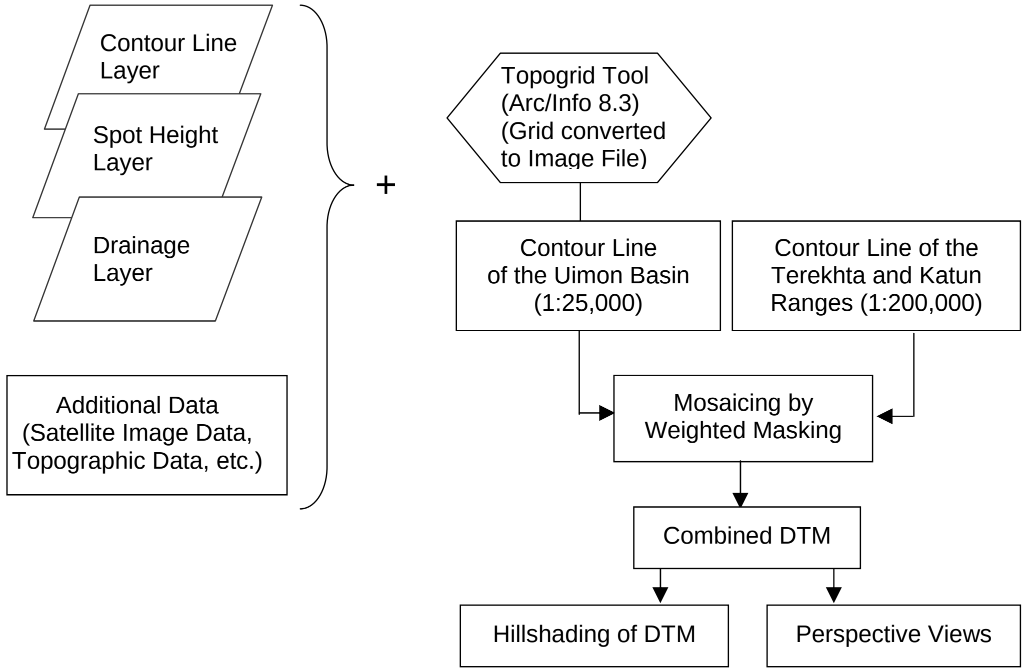


Figure 3.3: Flow chart for the DTM generation and the visualisation derivatives.

Figure 3.4: DTM of the Uimon Basin.

The relief forms the main guiding factors for soil development (directly through the displacement of particles; indirectly through the influence on the water and energy household (Kelgenbaeva et al. 2003). That is why a Digital Terrain Model (DTM) with a high accuracy was very useful to visualize relief, soil distribution and soil forming processes in this study area.

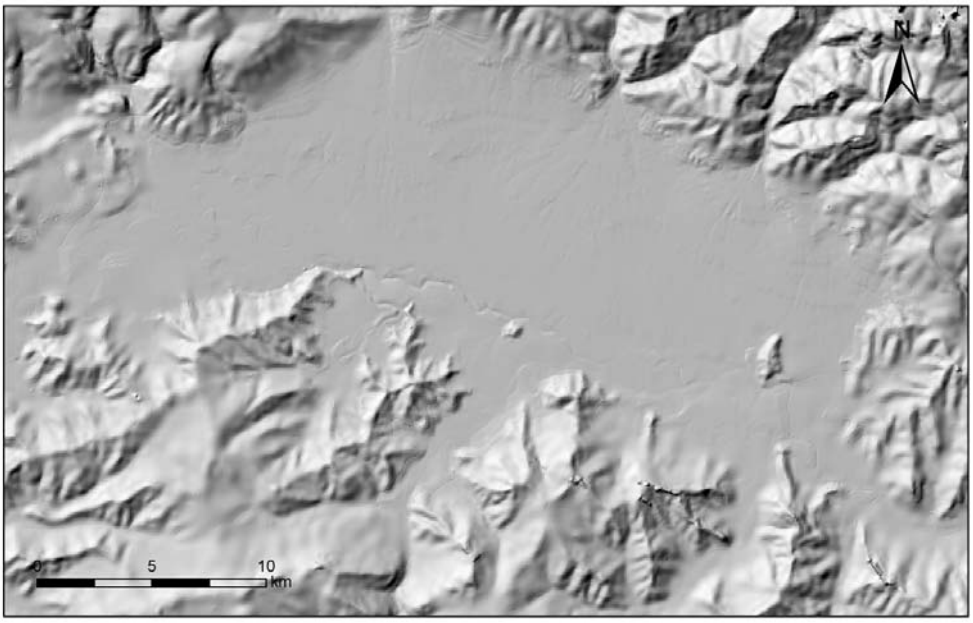


Figure 3.5: Hillshading representation of the study area.

The perspective views by means of DTMs and draped orthoimages can be developed by GIS and the image processing software Erdas Imagine. Apart from its use as a gadget or mere 'eye catcher', such products can be very useful to:

- detect geometric inconsistencies of the DEM and/or image,
- assist in the detection of correlations between surface features and patterns and the relief and helicopter view or to facilitate the orientation.

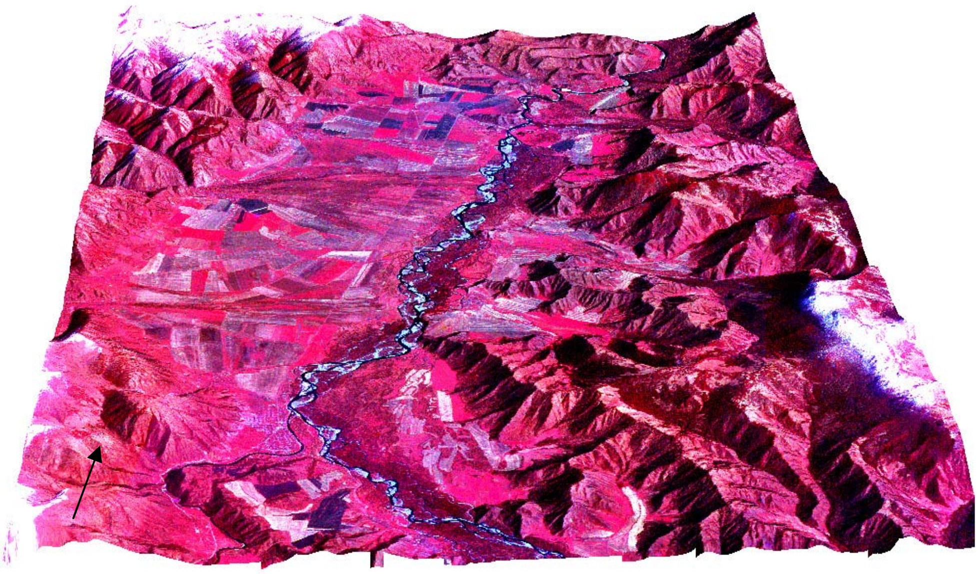


Figure 3.6: View of the Uimon Basin with a partial view of the Katun Range. The arrow in the lower left corner indicates the North direction.

4. Climatic and Soil-Fertility Indicators

4.1 Agricultural Evaluation of Climate

In agriculture, climatic data is only interesting when a crop requirement to climate conditions is required to know. This means that it is necessary to determine crop requirements regarding illumination, humidity and other climatic factors in order to compare them with those studying climate resources. Further, to determine if the climate is favourable or not favourable for those crop plantations. There is the same demand for the breeding of live-stock. The quantitatively expressed relationship between climate factors and crop development (e.g. their growth, winter hardiness, ripening and yield) are called *agroclimatic indicators*. Nowadays, there are many methods for such evaluations (cf. Chirkov 1988, Dallemand and Vossen 1994). The authors state that the following parameters should be analysed: 1) the thermal and partial light conditions of the vegetation period and its separate subperiods, 2) the humidity, including the precipitation modes and soil moisture for the same periods, 3) wintering conditions for winter crops and perennial plants characterized by the minimal temperatures of air and soil as well as height of snow cover, 4) non-favourability for agricultural phenomena (flood, cloudiness, wind and etc.). Furthermore, it is necessary to know the minimal and the optimum temperature of air and soil, the temperatures required to complete the plant growth beginning from sowing to ripening, and the amount of moisture for obtaining the required yield. This is the first principle of the methodology of the agrometeorological evaluation (cf. Chirkov 1988).

The second principal feature of the agrometeorological evaluation method is the use of meteodata, which are frequently repeated and dangerous phenomena in agriculture (e.g. flood frequency). This allows securing the development of plants and basing their yield on the climatic factors in the complete agricultural territory.

4.2. Evaluation Criteria

For the present agricultural land evaluation of the Uimon Basin the following evaluation criteria were considered: depth of humus horizon, nutrient availability of nitrogen, phosphorrous and potassium, humus content, soil pH-reaction, cation exchange capacity, flood damage and seasonal water supply: hydrothermal coefficient 1 and hydrothermal coefficient 2. Their importance to crop plantation will be discussed in detail in the following sub-chapters.

4.2.1 Definition of Classes and Ranking Tables

Depending on the gradations (ranking tables) considered for each of the criteria selected and on the different agricultural uses, five suitability classes are established. The final class definitions were adopted from the FAO classification (FAO 1976) for the present land evaluation in terms of two suitability orders (S for Suitable and N for Unsuitable) as:
S1 – High suitability, S2 – Good suitability, S3 – Moderate suitability, S4 – Marginal suitability and NS – No suitability (cf. Table 1.3). The classification ranking of classes is followed also to the criterion of maximum limitation of De la Rosa [INT-06]) and Burlakova (1988). The other experts Beek and Bennema (1972) use ranking tables (gradation matrices) indicating the minimum level at which the different variables fit a determined suitability class. A comparison is thus established between the different levels of generalization and the specific needs of each agricultural use for each criterion or soil characteristic. Cardoso (1970) states, it is not necessary that all the classification factors are present in each class - it is the most unfavorable that is determinant.

4.2.2 Hydrothermal Coefficients

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 from 2 m above ground at a meteostation 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 10°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 2001b, Yashutin et al. 1996, Chirkov 1988) and individually calculated for the relevant crops.
In particular, precipitation data were considered to calculate the Hydrothermal Coefficient (HTC), which approximately shows an excess or a lack of humidity during (1) the root growing period (May - June) - termed HTC_1 and (2) HTC_2 for the remaining vegetative period

in the area (May - September). Daily temperature and rain records are at our disposal from 1995 to 2001. The calculation of the HTC_i is based on Selyaninov's formula (Chirkov 1988).

$$HTC_i = \sum P / [0.1 * \sum T_{>X°C}] \quad [1]$$

HTC_i: *Hydrothermal Coefficient*
P: *Sum of precipitation (mm)*
$\sum T_{>X°C}$: *Sum of positive daily mean temperature (°C)*
X: *Crop-specific threshold temperature (°C).*

For the present modelling, the ranking tables of HTC_1 and HTC_2 for each crop were prepared (Table 4.2). The classification is based on the local (Altaian) ranking tables given by Burlakova (1988).

Table 4.2: Category ranking of the HTC_1 and HTC_2 for summer wheat as a determinant for water supply depending on the requirements of each crop.

Suitability Index (SI)	Ranking of Hydrothermal Coefficient (HTC_1)	
No Suitability (NS)	Dry zone	≥ 1.6
Marginal Suitability (S4)	Marginally humidified zone	< 0.8
Moderate Suitability (S3)	Not sufficiently humidified zone	≥ 1.2 - < 1.6
Good Suitability (S2)	Sufficiently humidified zone	≥ 0.8 - < 1.0
High Suitability (S1)	Over-humidified zone	≥ 1.0 - < 1.2

Suitability Index (SI)	Ranking of Hydrothermal Coefficient (HTC_2)	
No Suitability (NS)	Dry zone	≥ 1.4
Marginal Suitability (S4)	Marginally humidified zone	< 0.8
Moderate Suitability (S3)	Not sufficiently humidified zone	≥ 1.2 - < 1.4
Good Suitability (S2)	Sufficiently humidified zone	≥ 0.8 - < 1.0
High Suitability (S1)	Over-humidified zone	≥ 1.0 - < 1.2

4.2.2.1 Statistical Analyses of Climate Data

The statistical analysis of the meteorological data was performed using a normal density function in order to find the best probability distribution (also called the probability density function (pdf)) and to know the most appopriate probable vegetative year of the Uimon Basin. The sum of the days with a temperature of more than 5° ($\sum T_{>5°C}$) and of more than 10° ($\sum T_{>10°C}$) for the period from 1995 to 2002 recorded by Ust Koksa meteostation was used. The determination of the probability of the most probable vegetative year in the example of $\sum$ T>5°C and $\sum$ T>10° programmed in Matlab is shown below:

```
% Gauss-Glocke
mu = 1293;
sigma = 101.05;
a=mu-3*sigma;
b=mu+3*sigma;
d=(b-a)/100;
t=a:d:b;
for i=1:1:length(t)
 f(i)=1/(sqrt(2*pi)*sigma)*exp(-(t(i)-mu)^2/(2*sigma^2 ));
end;
figure;
grid on;
hold on;
plot(t,f);
hold off;
v = [1154,
     1208,
     1362,
     1483,
     1313,
     1290,
     1301,
     1234];
for i=1:1:length(v)
   t = v(i);
   eps = 50;
   fv(i)=2*eps*1/(sqrt(2*pi)*sigma)*exp(-(t-mu)^2/(2*sigma^2 ));
   end;
proz = fv*100
```

Based on the results (Figure 4.1 and 4.2) the years with the highest probability are 2000 and 2001 with 39.46% and 39.66% probability respectively. This means that these years can be considered as (the most) typical years for the Uimon Basin.

Table 4.3: Table of the pdf results for the $\sum T_{>5°C}$.

No.	Year	$\sum T_{>5°C}$	Probability (%)
1	1995	1154	15.33
2	1996	1208	27.71
3	1997	1362	31.27
4	1998	1483	6.74
5	1999	1313	38.71
6	**2000**	**1290**	**39.46**
7	2001	1301	39.36
8	2002	1234	33.29
mu = 1293, Σ = 101.05			

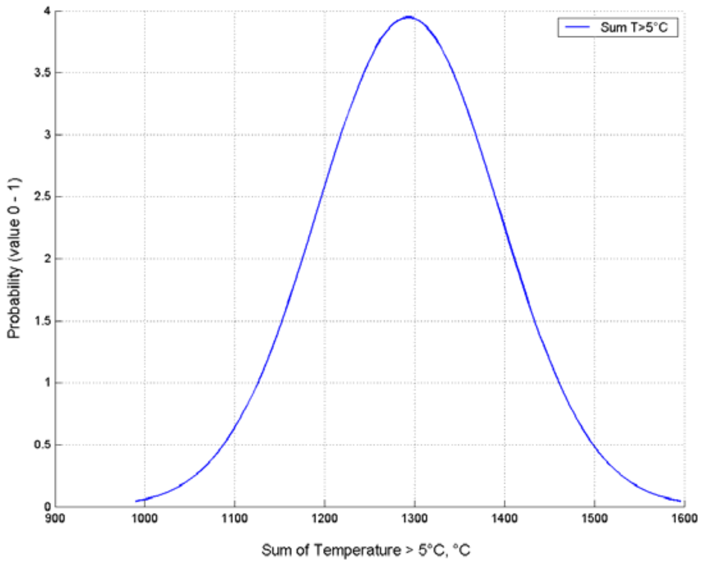


Figure 4.1: Obtained Gaussian probability density function for the $\sum T_{>5°C}$.

Table 4.4: Table of the pdf results for the $\sum T_{>10°C}$.

No.	Year	$\sum T_{>10°C}$	Probability (%)
1	1995	418	15.66
2	1996	488	31.80
3	1997	607	34.74
4	1998	753	5.68
5	1999	583	38.22
6	2000	545	39.53
7	**2001**	**561**	**39.66**
8	2002	488	31.80
mu = 555, Σ = 100.41			

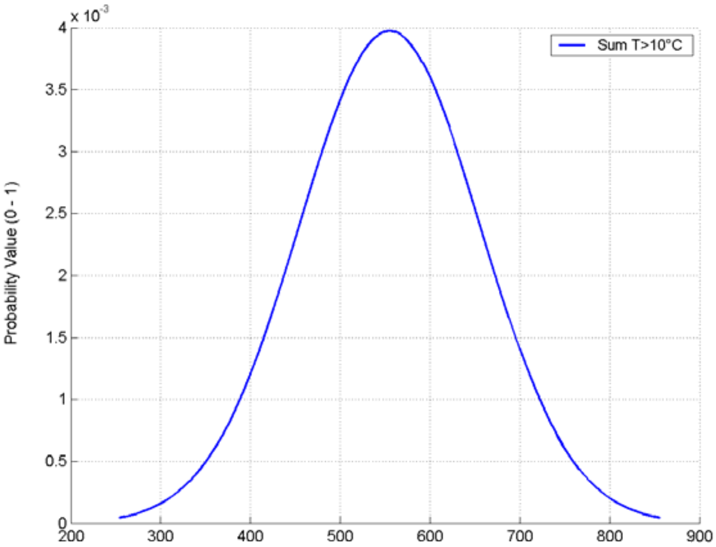


Figure 4.2: Obtained Gaussian probability density function for the $\sum T_{>10°C}$.

4.2.3 Soil Type

Each plant has its own growth stage, nutrient requirements, and ecology. Similarly, each soil type (St) has its own genetic, physical, chemical, and depth characteristics. Not all crops are suitable to all soil types; one soil type may produce several crops with a high yield and quality, but may produce poor results for other crops.

As already mentioned in Chapter 2, in the Uimon Basin the most prevailed soil is chernozems (leached and standard).

Table 4.5: Category ranking of soil types and subtypes (St) for summer wheat as a determinant of soil - crop suitability depending on the requirements of each crop.

Suitability class (SI)	Ranking of St
No Suitability (NS)	Ah, Mar, S
Marginal Suitability (S4)	A, Mofch, Gf
Moderate Suitability (S3)	Mef, K
Good Suitability (S2)	Ch^k, Ch^{ml}, Mech,
High Suitability (S1)	Ch^l, Ch^p, MoCh, Me

Legend: Ah - Alluvial-humid leached meadow soils, A - Alluvial meadow soil, Ch^k - Standard carbonated Chernozem, Ch^l - Leached Chernozem, Ch^{ml} - Meadow–leached Chernozem, Ch^p – podsolized Chernozem, MoCh - Mountain Chernozem, Mef - Meadow–forest soil, K - Chestnut soil, Mofch - Mountain-forest-chernozemic soil, Mar - Marshy soil, S - Solonetz, Gf – Grey forest soil, Mech - meadow chernozem soils and Me -Meadow soils.

4.2.4 Depth of Humus Horizon

The depth of the humus horizon refers to the thickness of the humus layer for the best root development and is a very important indicator of soil suitability for crops and vegetation growth. For the present modelling, ranking tables of the depth of the humus horizon were prepared for each crop (Table 4.6). The classification is based on the local (Altaian) ranking tables given by Burlakova (1988).

Table 4.6: Category ranking of the depth of the humus horizon for summer wheat as a determinant for the seasonal water supply depending on the requirements of each crop (from Burlakova 1988).

Suitability class (SI)	Ranking of depth of humus horizon in %	
No Suitability (NS)	very weak	< 30
Marginal Suitability (S4)	weak	>= 30 - < 40
Moderate Suitability (S3)	moderate	>= 40 - < 50
Good Suitability (S2)	good	>= 50 - < 60
High Suitability (S1)	high	>= 60

4.2.5 Humus

Humus is often described as the life-force of the soil. It is a complex organic substance resulting from the breakdown of plant material during a process called humification. This process can occur naturally in the soil, or in the production of compost. Humus is extremely important to the fertility of soils in both a physical and chemical sense. Physically it helps the soil to retain moisture and encourages the formation of a good soil structure. Chemically, it has many active sites which could bind to ions of plant nutrients, making them better available. Humus has many functions and benefits in the soil [INT-10] as outlined below:

- The mineralisation process that converts raw organic matter to the relatively stable substance that is humus feeds the soil population of micro-organisms and other creatures thus maintaining high and healthy levels of soil-life.
- Effective and stable humus are further sources of nutrients to microbes, the former providing a readily available supply whilst the latter acts as a more long term storage reservoir.
- Humification of dead plant material causes complex organic compounds to break down into simpler forms which are then made available to growing plants for the uptake through their root systems.
- Humus is a colloidal substance, and increases the soil's cation exchange capacity, hence its ability to store nutrients on clay particles, thus, whilst these nutrient cations are

accessible to plants, and they are held in the soil safe from leaching away by rain or irrigation.

- Humus can hold the equivalent of 80-90% of its weight in moisture and thus increases the soil's capacity to withstand drought conditions.
- The biochemical structure of humus enables it to moderate- or buffer- excessive acidic or alkaline soil conditions [INT-10].
- The dark colour of humus helps to warm up cold soils in the spring

For the present modelling, ranking tables of humus content for each crop were prepared (Table 4.7). The classification is based on the local (Altaian) ranking tables given by Burlakova (1988).

Table 4.7: Category ranking of the humus of summer wheat as a determinant for nutrients depending on the requirements of each crop (from Burlakova 1988).

Suitability class (SI)	Ranking of humus content in %	
No Suitability (NS)	very weak	< 1
Marginal Suitability (S4)	weak	>= 1 - < 2
Moderate Suitability (S3)	moderate	>= 2 - < 4
Good Suitability (S2)	good	>= 4 - < 6
High Suitability (S1)	high	>= 6

4.2.6 Nitrogen

In order to grow and thrive plants need a number of different chemical elements. The most important ones are:

- Carbon, hydrogen and oxygen - Available from air and water and therefore in plentiful supply.
- Nitrogen, phosphorus, potassium - These three elements and macronutrients are the most packaged fertilizers.
- Sulfur, calcium, and magnesium - Secondary nutrients.
- Boron, cobalt, copper, iron, manganese, molybdenum and zinc - Micronutrients

The most important of these (the ones that are needed in the largest quantity by a plant) are nitrogen, phosphorus and potassium. They are important because they are basic building blocks for leaves, growth and ripening of plant. Some examples are here:

- Every amino acid contains nitrogen.
- Every molecule making up every cell's membrane contains phosphorous (the membrane molecules are called phospholipids), and so does every molecule of adenosine triphosphate (ATP; the main energy source of all cells).

- Potassium makes up 1 percent to 2 percent of the weight of any plant and, as an ion in cells, is essential to metabolism.

Nitrogen affects the healthy growth of crop and the high productivity of most agricultural crops. It is most responsible for green lawns, since it is an important constituent of chlorophyll [INT-11]. If the nitrogen content in soil is low, leaves of the crops become smaller, of light green colour or yellow colours; thin stems and weak ramification are observed. The formation and development of the reproductive organs and ripening of grain deteriorated. (Raichert 2004).

Nitrogen fertilizers give fairly predictable yields where lack of nitrogen is the principal factor limiting yields. The main considerations in deciding how much nitrogen should be applied to obtain a given yield are:

i) the initial nitrogen content of the soil

ii.) the amounts of nitrogen removed by the crop

iii.) the contribution from nitrogen fixation

iv) the losses of nitrogen from leaching, denitrification, etc.

For the present modelling, ranking tables of nitrogen content for each crop were prepared (Table 4.8). The classification is based on the local (Altaian) ranking tables given by Burlakova (1988).

Table 4.8: Category ranking of the nitrogen for summer wheat as a determinant for nutrients depending on the requirements of each crop (from Burlakova 1988).

Suitability class (SI)	Ranking of NO_3 content in %	
No Suitability (NS)	very weak	< 3
Marginal Suitability (S4)	weak	>= 3 - < 10
Moderate Suitability (S3)	moderate	>= 10 - < 15
Good Suitability (S2)	good	>= 15 - < 20
High Suitability (S1)	high	>= 20

4.2.7 Phosporus

As already mentioned, phosphorus belongs to the macronutients group which is necessary for the healthy development of crops. Plants use phosphorus in soluble form (P_2O_5) that is readily available for them in the soil. The lack of phosphorus may cause a blue-green colour of the leaves, often with a purple or bronze tint. Often, the leaves become smaller and narrower, the growth of plants slows down the ripening of grains (for instance in grain crops). A good phosphorus nutrition of the crops not only significantly increases the yield of crops, but also noticeably improves its quality. There is an increased number of grain in the total mass. Crops in the early periods of their growth absorb phosphates more intensively than later on. A lack of phosphate in the early period of crop growth causes depression, which cannot be overcome even by following with a normal application as it affects the formation of the root system of crops. Acidic soils usually require more added phosphorus than neutral soils. Grasses and cereals usually have a lower requirement than crops such as potatoes, sugarbeet, and leafy vegetable crops which may respond to two or three times more than the application rate for the former [Bingham 1973]. In general, the phosphorus fertilizer or manurial requirement for rice is less than for other cereals. Wherever possible, such generalizations should be confirmed by experiments which also examine the optimal sources and inputs of phosphorus fertilizers in their various forms as rock phosphate, superphosphate, triple superphosphate, etc.

For the present modelling, ranking tables of phosphorus for each crop were prepared (Table 4.9). The classification is based on the local (Altaian) ranking tables given by Burlakova (1988).

Table 4.9: Category ranking of the phosphorus for summer wheat as a determinant for nutrients depending on the requirements of each crop (from Burlakova 1988).

Suitability class (SI)	Ranking of P_2O_5 content in mg/100 g soil	
Marginal Suitability (S4)	very weak	< 5
Moderate Suitability (S3)	weak	>= 5 - < 10
Good Suitability (S2)	good	>= 10 - < 15
High Suitability (S1)	high	>= 15 - < 20
Moderate Suitability (S3)	moderate	>= 20

4.2.8 Potassium

Potassium makes up 1 to 2 percent of the weight of any plant and, as an ion in cells, is essential to its metabolism. Insufficient potassium nutrition in plants may affect their leaves and lead to yellowness and drying out from the edge of the leaf. Potassium affects the water regime of plants e.g. it increases the drought- and coldness resistance of plants (as a result of the increase of osmotic pressure of the cell sap), the sustainability of the plants to bacterial diseases (Raichert 2004). It increases the synthesis of high molecular carbohydrates, which results in a thickening of the cell walls of cereals and ensures a greater stability of the leaves. The temperature and soil moisture play a significant role in the mobility and accessibility of nutrients to plants. Plants use phosphorus also in soluble form (K_2O) which is readily available.

For the present modelling, ranking tables of potassium for each crop were prepared (Table 4.10). The classification is based on the local (Altaian) ranking tables given by Burlakova (1988).

Table 4.10: Category ranking of the potassium for summer wheat as a determinant for nutrients depending on the requirements of each crop (from Burlakova 1988).

Suitability class (SI)	Ranking of K_2O content in mg/100 g soil	
Marginal Suitability (S4)	very weak	< 10
Moderate Suitability (S3)	moderate	>= 10 - < 15
Good Suitability (S2)	good	>= 15 - < 20
High Suitability (S1)	high	>= 20 - < 25
Moderate Suitability (S3)	moderate	>= 25

4.2.9 Cation Exchange Capacity

The quantity of cation exchange is measured per unit of soil weight and is termed Cation Exchange Capacity (CEC). CEC is the ability of the soil to hold onto nutrients and prevent them from leaching beyond the roots. The more cation exchange capacity a soil has, the more likely the soil will have a higher fertility level. When combined with other measures of soil fertility, CEC is a good indicator of soil quality and productivity [INT-12]. The cation exchange capacity of a soil is simply a measure of the quantity of sites on soil surfaces that can retain positively charged ions by electrostatic forces. Cations retained electrostatically are easily exchangeable with other cations in the soil solution and are thus readily available for plant uptake. Thus, CEC is important for maintaining adequate quantities of plant available calcium (Ca++), magnesium (Mg++) and potassium (K+) in soils. Other cations include Al+++(when pH < 5.5) , Na+, and H+.

Soil CEC is normally expressed in units of charge per weight of soil. There are two different sets of units, but numerically they are equivalent: meq/100 g (milliequivalents of element per 100 g of dry soil) and cmolc/kg (centimoles of charge per kilogram of dry soil).

For the present modelling, ranking tables of phosphorus for each crop were prepared (Table 4.11). The classification is based on the local (Altaian) ranking tables given by Burlakova (1988).

Table 4.11: Category ranking of the CEC for summer wheat as a determinant for nutrient availability depending on the requirements of each crop (from Burlakova 1988).

Suitability class (SI)	Ranking of CEC in meq/100 g	
No Suitability (NS)	very weak	< 6
Marginal Suitability (S4)	weak	>= 6 - < 12
Moderate Suitability (S3)	moderate	>= 12 - < 25
Good Suitability (S2)	good	>= 25 - < 40
High Suitability (S1)	high	>= 40

4.2.10 Soil pH

The pH of soil or more precisely the pH of the soil solution is very important because soil solution carries in it nutrients such as nitrogen (N), potassium (K), and phosphorus (P) that plants need in specific amounts to grow and fight diseases [INT-13].

If the soil's pH is too high or too low, some nutrients become insoluble, limiting the availability of these nutrients to the plant root system. So, if the pH of the soil solution is increased above 5.5, Nitrogen (in the form of nitrate) is made available to plants. Phosphorus, on the other hand, is available to plants when soil pH is between 6.0 and 7.0.

The acidity-alkalinity scale ranges from 0 to 14. Soils are referred to as being acid, neutral, or alkaline, depending on their pH levels. A pH of 7 is neutral, while a pH lower than 7 is acid, and a pH higher than 7 is alkaline (basic) [INT-13].

Certain bacteria help plants obtain N by converting atmospheric nitrogen into a form of N that plants can use.These bacteria live in the root nodules of legumes (like alfalfa and soybeans) and function best when the pH of the plant they live in grows in soil within an acceptable pH range. For instance, alfalfa grows best in soils having a pH of 6.2 - 7.8 while wheat and corn grow best in soils with a pH between 5.5 and 7.5 and potatoes prefers a pH of 4.8 – 6.5. Peanuts grow best in soils that have a pH of 5.3 to 6.6 [INT-13]. Many other crops, vegetables, flowers and shrubs, trees, weeds and fruit are pH- dependent and rely on the soil solution to obtain nutrients.

If the soil solution is too acidic, plants cannot utilize N, P, K and other nutrients they need. In acidic soils, plants are more likely to take up toxic metals and some plants eventually die of toxicity (poisoning). Herbicides, pesticides, fungicides and other chemicals are used on and around plants to fight off plant diseases and get rid of bugs that feed on plants and kill plants. Knowing whether the soil pH is acidic or basic is important because if the soil is too acidic the applied pesticides, herbicides, and fungicides will not be absorbed (held in the soil).

For the present modelling, ranking tables of soil pH-reaction for each crop were prepared (Table 4.12). The classification is based on the local (Altaian) ranking tables given by

Burlakova (1988), which, however does not coincide with the international classification. Reasons for the choice of Burlakova's approach are given on page 3.

Table 4.12: Category ranking of the depth of pH-reaction for summer wheat as a determinant for asidity depending on the requirements of each crop (from Burlakova 1988).

Suitability class (SI)	Ranking of soil pH	
Marginal Suitability (S4)	Strong acidity (S4)	< 6.3
High Suitability (S1)	Very slight acidity (S1)	>= 6.4 - < 6.5
Good Suitability (S2)	Slight acidity (S2)	>= 6.6 - < 7.0
Moderate Suitability (S3)	Moderate alcalinity (S3)	>= 7.1 - < 7.5
Marginal Suitability (S4)	Strong alcalinity (S4)	>= 7.6 - < 8.0
No Suitability (NS)	Very strong alcalinity (NS)	>= 8.1

4.2.11 Flood Frequency

Flood damage is most likely to occur on river flood plains, alluvial and coastal plains, regions with large seasonal variations in rainfall and liable to intensive rain over hours or days. The detailed pattern of incidence is thus related to landforms. The *flood frequency* is the probability of occurrence of damaging floods during the year. A damaging flood is one that destroys or causes severe damage to the crop, land or infrastructure. Where required, a damaging flood may be defined quantitatively in terms of period of inundation and/or speed of flow or volume of discharge of moving water [INT-14].

For the present modelling, ranking tables of flood frequency for each crop were prepared. Table 4.13 gives the example of the summer wheat. The classification is based on the FAO lecture notes on land evaluation [cf. INT-14].

Table 4.13: Category ranking of the flood frequency for summer wheat as a determinant for damage depending on the requirements of each crop (from [INT-14]).

Suitability class (SI)	Ranking of flood frequency in %
No Suitability (NS)	>= 80
Marginal Suitability (S4)	>= 60 - < 80
Moderate Suitability (S3)	>= 40 - < 60
Good Suitability (S2)	>= 20 - < 40
High Suitability (S1)	< 20

4.3 Altai Crop Requirements

4.3.1 Summer wheat

Wheat (*Triticum aestivum Linné*) can be classified as winter or spring growth habit based on the flowering responses to cold temperatures. Winter wheat development is promoted by an exposure of the seedlings to temperatures in the +3 degrees to +8 degrees C (38 degrees to 46 degrees F) range [INT-15]. Such types are usually planted in autumn which exposes the seedlings to cold temperatures during late autumn and winter. Spring types, however, do not require exposure to cold temperatures for normal development and can be planted in spring. Both winter- and spring types, when properly grown, can be harvested in the Uimon Basin in August. In the Uimon Basin spring sowing dominates. This is because the short vegetative period of the Uimon Basin allows the plants to grow only in spring and to produce a higher yield than a winter-sown alternative. The duration of the vegetative period for summer wheat depends on weather conditions and type of crops. The mean vegetative period for summer wheat is 90 - 115 days and, for instance, for barley 85 – 95 days. Optimum conditions for crop sowing start in spring when the temperature is higher than +5°C at a depth of 10 cm. Grain sowing can begin 8 - 12 days earlier or later than these optimum periods (Grigoryeva 2001a and 2001b, Yashutin 2001). Productive moisture is absorbed by the soil during autumn and early spring precipitation. This moisture is of high value to the initial growth of crops and also during the vegetation period. In a 20 cm soil layer, 20 mm or more of productive moisture is a satisfactory condition for seed growth and further crop formations. When the moisture reserve in the soil layer is less than 10 mm, normal seed germination is not ensured. Generally, if the moisture reserve is less than 5 mm, the shoots do not appear at all (Burlakova 1988, Grigoryeva 2001, Yashutin 2001). Summer wheat roots appear in early spring during the phase of the third leaf, which occurs in most regions at the end of May - beginning of June (Grigoryeva 2001). The second main roots begin to grow during sufficient moistening of the upper soil layer almost simultaneously with the third leaf.

A prolonged lack of rain delays the growth of the second main roots until the next precipitation. The main roots generally do not grow during a prolonged drought. During favourable weather conditions and good soil moistening, the summer wheat begins to grow simultaneously with the growth of the third leaf or several days later. According to the long-time mean data, in the major part of the Altai Republic the productive moisture reserves amount to 25 - 45 mm in 20 cm of soil layer in this period. After the optimal periods for sowing (the first period is the beginning of the second ten days of May), sprouting of summer wheat begins from the end of the third ten days of June to the first ten days of July. In any given year, sprouting can begin up to 10 days earlier or later, depending on the weather conditions.

In the Uimon Basin, the sprouting (heading) period lasts 19 – 23 days on average. In this period, the moisture requirement for summer wheat reaches its maximum values; because the plant grows intensively, it produces a grain and a flower. The mean long-standing reserves of the productive moisture in a soil layer of 1 m are 150 – 170 mm in foothill regions, and 100 – 130 mm in the remaining territories during the heading period.

From the beginning of the second ten days of June, a significant reduction in moisture can be observed. According to the long-standing meteodata, the productive moisture reserve in a soil layer of 1 m varies from 125 - 150 mm in the north-east, east and foothill regions to 50 - 25 mm in the south-west during this period. The "heading to flowering" period lasts 3 to 8 days on average and occurs in the first ten days of July for medium-ripe crop types and in the second ten days of July for late-ripening crops. The formation of grain in the flowering period occurs to wax ripeness. The grain pouring time lasts 12 - 17 days on the average. A lack of moisture during this time may lead to a reduction of grain quantity. The milk ripeness of summer wheat depends on each type and is noted during the second and third ten days of July. Depending on weather conditions, the wax ripeness occurs during the third ten days of July through to the second ten days of August (Yashutin et. al. 2001, Grigoryeva 2001).

For the present modelling, a ranking table of land attributes depending on the requirements of summer wheat was prepared (Table 4.14):

Table 4.14: Category ranking of land attributes for summer wheat given in an ordinal scale.

No.	Criteria	Parameter (for upper soil layer, 0 - 20 cm, and 0 - 40 cm only)	Rating table for land characteristics				
			Suitability class				
			S1	S2	S3	S4	NS
1	Soil type	St*	Ch^l, Ch^p, MoCh, Me	Ch^k, Ch^{ml}, Mech,	Mef, K	A, Mofch, Gf	Ah, Mar, S
2	Depth of humus horizon	$H_{(A+AB)}$ (cm)	≥ 60	≥50 - < 60	≥ 40 - < 50	≥ 30 - < 40	< 30
3	Nutrients	NO_3 (mg/100g soil) *	≥ 20	≥15 - < 20	≥ 10 - < 15	≥ 3 - < 10	< 3
4		P_2O_5 (mg/100g soil) *	≥ 10 - < 15	≥15 - < 20	≥ 5 - < 10; ≥ 20	< 5	-
5		K_2O (mg/100g soil) *	≥ 20 - < 25	≥15 - < 20	≥ 10 - < 15; ≥ 20	< 5	-
6		Humus (%)	≥ 6	≥ 4 - < 6	≥ 2 - < 4	≥ 1 - < 2	< 1
7	Acidity	pH	≥ 6.4 - < 6.5	≥ 6.6 - < 7.0	≥ 7.1 - < 7.5	≥ 7.6 - < 8.0; < 6.3	≥ 8.1
8	Nutrient availability	CEC (meq 100 g)	≥ 40	≥25 - < 40	≥ 12 - < 25	≥ 6 - < 12	< 6
9	Flood damage	Flood frequency (%)	< 20	≥20 - < 40	≥ 40 - < 60	≥ 60 - < 80	≥ 80
10	Seasonal water supply	HTC_1	1.0- < 1.2	≥ 0.8 - < 1.0	≥ 1.2 - < 1.6	< 0.8	≥ 1.6
11		HTC_2	1.0- < 1.2	≥ 0.8 - < 1.0	≥ 1.2 - < 1.4	< 0.8	≥ 1.4

** - The abbreviations of the soil types see in Table 4.5*

4.3.2 Sunflowers

The sunflowers *(Helianthus annuus Linné)* are a warmth loving and drought-resistant crops. The vegetation period for early types of sunflowers is within 80 to 100 days when the sum of positive temperatures is more than +10°C is 1400 - 1500°C; for medium-ripe sorts it takes 100 - 130 days at a sum of positive temperatures of 1500 - 2000°C; for late-ripening sorts it is 130 - 160 days at a sum of positive temperatures of 2000 - 2500°C (Yashutin et al 2001). The duration of the vegetation period depends not only on the type of crop but also on the year. It is noticeably reduced at high temperatures and lowered soil moisture and, in contrast, is extended at low temperatures and increased soil moisture. The capability of the sunflower seeds to grow at low temperatures (+5° to +7°C) and relatively good hardness of shoots to frost (-3° to -5°C) makes it possible for its sowing (to be carried out) at the same time as for early cereal crops. Early sowing provides a better opportunity for using spring soil moisture reserves as a result of which the yield and a percentage of the seed oil is increased. In the Altai, sunflowers are first planted during the end of April and the first ten days of May. The mean daily temperature during this period lies between +8° and +12°C. The mean long-standing moisture reserves in the extreme western and south-western regions at the time of sowing (in the arable layer of 0 - 20 cm) are 10 – 20 mm, and in the remaining areas the figure is between 25 - 50 mm. The appearance of sunflower shoots with a suitable moisture supply depends on the mean daily temperature. Shoots appear on average 16 - 22 days after sowing (in the second to third ten days of May), but during a cold spring, shoots may only appear from the end of the first ten days to the beginning of the second ten days of June. The formation of sunflower inflorescence starts from the end of June through the first ten days of July, and flowering begins from the end of the second to the beginning of the third ten days of July. Sunflower growth is intensive from the formation of inflorescence through the flowering periods and, as a result, requires increased soil moisture. This period coincides with the maximum summer precipitation which comes in July. The precipitation is well used by plants as it is needed by the sunflower root system to be able to form the secondary roots in the upper soil layer.

Sunflowers start to bloom in the third ten days of August until the beginning of September. The harvest starts from the second ten days of September. The agro-climatic conditions for yield harvesting during September are in essence, completely favourable. In October they deteriorate, and sunflower heads freeze during this period (Yashchutin et. al. 2000).

For the present modelling, a ranking table of land attributes depending on the requirements of sunflower was prepared (Table 4.15):

Table 4.15: Category ranking of land attributes for sunflowers given in an ordinal scale.

No.	Criteria	Parameter (for upper soil layer, 0 - 20 cm, and 0 - 40 cm only)	Rating table for land characteristics				
			Suitability class				
			S1	S2	S3	S4	NS
1	Soil type	St*	Ch^{l}, Ch^{p}, MeCh, Me	Ch^{k}, Ch^{ml}, K	A, Mef, Moch	Mofch, Gf	Ah, Mar, S
2	Depth of humus horizon	$H_{(A+AB),}$ (cm)	≥ 70	≥ 60 - < 70	≥ 50 - < 60	≥ 40 - < 50	< 40
3	Nutrients	NO_3 (mg/100g soil) *	≥ 18	≥ 13 - < 18	≥ 8 - < 13	≥ 5 - < 8	< 5
4		P_2O_5 (mg/100g soil) *	≥ 20	≥ 15 - < 20	≥ 10 - < 15	< 10	-
5		K_2O (mg/100g soil) *	≥ 30	≥ 20 - < 30	≥ 10 - < 20	< 10	-
6		Humus (%)	≥ 6	≥ 5 - < 6	≥ 3.5 - < 5	≥ 2 - < 3.5	< 2
7	Acidity	pH	≥ 6.1 - < 6.8	≥ 6.8 - < 7.5	≥ 7.5	< 6	
8	Nutrient availability	CEC (meq 100 g)	≥ 35	≥25 - < 35	≥ 15 - < 25	≥ 8 - < 15	< 8
9	Flood damage	Flood frequency (%)	< 20	≥20 - < 40	≥ 40 - < 60	≥ 60 - < 80	≥ 80
10	Seasonal water supply	HTC_1	≥ 0.7- < 1.0	≥ 1.0 - < 1.2	≥ 1.2 - < 1.6	< 0.7	≥ 1.6
11		HTC_2	≥ 0.7- < 1.0	≥ 1.0 - < 1.2	≥ 1.2 - < 1.6	< 0.7	≥ 1.6

** - Abbreviations of soil type see in Table 4.5*

4.3.3 Potatoes

The areas where most potatoes *(Solanum tuberosum Linné)* are planted in the Altai are the forest-steppe and the foothill regions (Grigoryeva 2001 and 2001a, Yashutin 2001). In these regions, almost every year all types of potatoes are provided with 80 – 100% of adequate warmth, with the exception of late-ripening varieties, of which only with 70% receive adequate warmth in the lowest parts of the eastern and foothill regions. Potatoes require a deeply cultivated soil in autumn and must be well fertilised. The tuber of a potato begins to grow at +5°C, but the optimum temperature for growth is +15° to +16°C and optimum temperature for tuberization is +17°C (Grigoryeva 2001). The optimum temperature for the assimilation of carbonic acid (carbon dioxide) is +21°C, and at temperatures above +40°C, the accumulation of assimilation products is stopped (Grigoryeva 2001, Yashutin 2001).

In the sowing period, the soil depth (up to 10 cm) is warmed up to +10° to +12°C in the eastern and foothill regions and up to +12° to +14°C in the steppe and arid regions. This temperature level is optimal for the tuber growth of potatoes. In this period, the level of precipitation is insignificant, i.e. it does not exceed 10 - 15 mm per ten days in any region (Yashutin et al 2000). The productive moisture reserves in the arable soil layer are within the limits of 20 - 30 mm in the major regions.

A high water requirement for the period of budding and the beginning of tuber formation can be observed. The moisture reserves contained in tubers are sufficient for potato development during the period of tuber growth. Potato shoots appear on average 20 - 25 days after planting at the end of the first or at the beginning of the second ten days of June. The duration of the period between planting and the arrival of shoots essentially depends on temperature conditions. The mean ten-day temperature in the period when the shoots appear reaches 18 - 20°C. At this time, the productive moisture reserves on the level of 45 - 65 mm in the soil layer from 0 to 50[2] cm.

Floscules form on average 20 – 25 days after the potato shoots. This time coincides with the beginning of tuber formation which lasts until vegetable tops start to disappear. Intensive tuber formation starts from the beginning of potato shooting. In the Altai, this period begins in the second ten days of July and continues on average until the middle of the first ten days of September.

Temperature and soil moisture factors have high values during the period of tuber formation. The optimum temperature for tuber formation is 17 - 18°C, a reduction in the level of tuber formation occurs at 20°C, and formation stops completely at 29°C (Grigoryeva 2001a). During the periods when the tubers are lying and being formed, the long-standing mean ten-day temperature is 17 - 19°C in the eastern and foothill regions, and 19 – 20°C in the south-west steppe regions, i.e. it is higher than the optimal temperature by 1 - 2°C. In the period of tuber formation in the south-west, there are, on average, 30 – 35 days with a mean daily temperature higher than 20°C.

HTC_2 of 1.5 to 2.0 is conducive to a maximum potato yield. In conditions of unreliable moistening (HTC_2 = 1.0 – 1.4) and excessive moistening (HTC_2 > 2.0) the harvest yield may be reduced, and the yield drops sharply when HTC_2 < 1.0 (Grigoryeva 2001a and 2001b, Yashutin 2001).

The natural fading of the vegetable tops signals the end of plant vegetation and technical ripeness for potatoes. In the case of potatoes, the fading of vegetable tops occurs in the first ten days of September. The start of the removal of early varieties of potatoes precedes the fading of vegetable tops.

For the present modelling, a ranking table of land attributes depending on the requirements of potato was prepared (Table 4.16):

Table 4.16: Category ranking of land attributes for potatoes given in an ordinal scale.

No.	Criteria	Parameter (for upper soil layer 0 - 20 cm and 0 - 40 cm only)	Rating table for land characteristics				
			Suitability class				
			S1	S2	S3	S4	NS
1	Soil type	St*	Ch^l, Ch^p, Moch	Ch^k, Ch^{ml}, Me	Mef, Mech, K	A, Mofch, Gf	Ah, Mar, S
2	Depth of humus horizon	$H_{(A+AB)}$ (cm)	≥ 60	≥50 - < 60	≥ 40 - < 50	≥ 30 - < 40	< 30
3	Nutrients	NO_3 (mg/100g soil) *	≥ 20	≥15 - < 20	≥ 10 - < 15	< 10	
4		P_2O_5 (mg/100g soil) *	≥ 25	≥10 - < 25	≥ 5 - < 10	< 5	-
5		K_2O, (mg/100g soil) *	≥ 40	≥ 30 - < 40	≥ 20 - < 30	< 20	-
6		Humus (%)	≥ 6	≥ 5 - < 6	≥ 4 - < 5	≥ 2 - < 4	≥ 2
7	Acidity	pH	≥ 4.5 - < 6.3	≥ 6.3 - < 7.6	≥ 4.0 - < 4.5	< 4; ≥ 7.6	
8	Nutrient availability	CEC (meq 100 g)	≥ 40	≥30 - < 40	≥ 20 - < 30	≥ 10 - < 20	< 10
9	Flood damage	Flood frequency (%)	< 20	≥20 - < 40	≥ 40 - < 60	≥ 60 - < 80	≥ 80
10	Seasonal water supply	HTC_1	≥ 1.0 - < 1.1	≥ 0.8 - < 1.0 ≥ 1.1 - < 1.2	≥ 1.2 - < 1.4	≥ 0.6 - < 0.8	< 0.6; ≥ 1.4
11		HTC_2	≥ 1.0 - < 1.1	≥ 0.8 - < 1.0 ≥ 1.1 - < 1.2	≥ 1.2 - < 1.4	≥ 0.6 - < 0.8	< 0.6; ≥ 1.4

** - Abbreviations of soil type see in Table 4.5*

5. Determination of Land Suitability

5.1 Discussion of Previous Work

In this Chapter a review of the local (Altaian) as well as Mediterranean and other international methods on soil and land evaluation will be discussed. For details see the following sub-chapters.

5.1.1 Soil Evaluation by Burlakova (1974)

Lidia Burlakova (Soil Science Faculty of the State Agricultural University of Barnaul, Russia) in her previous research (Burlakova 1974) studied different subtypes of Altai chernozems (podsolized, leached and standard), and carried out detailed research on fertility factors (humidity and NPK) and their influence on soil fertility in the Altai Region of the Ob River (Russia).

5.1.2 Yield Forecasting Model of Burlakova (1988)

Burlakova developed crop yield forecasting models for summer wheat, maize, sugar beet and perennial (e.g. lucerne) in 1988 (cf. Burlakova 1974 and 1988). The models were specifically developed for Altai conditions and were based on the method of weighted means. The author uses ranking (classification) tables which evaluate each factor on a scale from the minimum to the maximum level (see Table 1.1) and also their corresponding crop productivity. A determined suitability class corresponds to each classified yield variable.

Table 5.1: Classification of yield forecasting for summer wheat as an example for the approach of weighted means (Burlakova 1988).

Factor	Ranking	Summer wheat yield	
		0.1*t/ha	Suitability class
Humus content (for soil upper layer 0 - 20 cm only) in %	< 4	< 5	1
	4.1 – 5.0	6 - 8	2
	5.1 – 6.0	15 - 17	4 - 5
	6.1 – 7.0	15 - 17	5 - 6
	7.1 – 8.0	18 - 20	6
	8.1 – 9.0	21 - 23	7
	> 9.0	15 - 17	5

The evaluation of crop forecasting is based on soil and climatic factors. An example of the calculation of the yield forecasting index for summer wheat is presented below:

$$Yield\ Index\ (wheat) = HTC_1 * HTC_2 * (M * pH * (Hu * K_2O * (N * NO_3 * (P_20_5 * P)))) \quad [2]$$

HTC_1 - hydrothermal coefficient for May – June,
HTC_2 - hydrothermal coefficient for May – September,
M – thickness of humus horizon,
pH - soil pH,
Hu - humus content,
K_2O – soluble potassium,
N and NO_3 – total nitrogen and nitrate,
P and P_20_5 - total phosphorus and phosphorus pentoxide.

The main advantage of Burlakova's models is that they are easily calculable and their workings are transparent; the main disadvantage is that remote sensing cannot be integrated and that there is no linkage to a GIS.

5.1.3. Soil Evaluation Model of Raichert (2004)

This chapter sets forth a recent research on soil fertility evaluation for the Uimon Basin developed by Raichert (2004). Hence, it makes sense to discuss it here.
In his study Raichert considers only the northern part of the Uimon Basin with emphases on standard chernozems. Other soils which are distributed along the southern part of the Katun River, e.g. leached chernozem, is not studied by the author. Out of 22 soil profiles, 80 soil samples for soil-physical analyses were collected in 2001. The same work was done in 1971 by the Soil Science Faculty of the Lvov State University (Belarussia). The analysis was carried out in order to check whether there have been any changes in the soil-physical properties of the Uimon Basin over the last 30 years. Raichert (2004) found that the:

- contents of silt and clay (in A_1 horizon) decreased by 10%,
- humus thickness (for A+AB horizon) decreased by 2.8 cm,
- soluble potassium K_2O decreased by 7%,
- other factors (e.g. humus content, pH-soil reaction, content of Ca, Mg, S, P_2O_5 in A_1 horizon) did not show any significant changes.

Raichert developed a crop yield forecasting model based on the weighted means of a factor set. Three relevant crops, summer wheat, oats and barley, were considered. 5 soil factors were taken as evaluation factors (more details see below). Examples of the calculation of the yield index (class) for summer wheat, oats and barley are presented below:

$$Yield\ Index\ (wheat) = Hu * N/NO_3 * (P_2O_5 * (K_2O * M))$$
$$Yield\ Index\ (oats) = Hu * P_2O_5 * (M * (N/NO_3 * K_2O)$$
$$Yield\ Index\ (barley) = Hu * M * (N/NO_3 * (P_2O_5 * K_2O)) \quad [3]$$

where: Hu – humus index, P_2O_5 – soluble phosphorus index, M – humus thickness index, N/NO_3 – nitrogen nitrate index and K_2O – soluble potassium.

The following maps were prepared in a GIS (Map/Info) environment: (i) map of humus content, (ii) map of humus thickness, (iii) map of nitrogen nitrate, (iv) map of soluble potassium and (v) map of soluble phosphorus. The advantage of the models is that they are easy to calculate, and the disadvantage is that they are not linked to a Geographic Information System (GIS). Cartographic representations of crop yield forecasting models are absent.

Raichert also studied the susceptibility of the Uimon Basin to water erosion. Two parameters, (i) slope angle and (ii) the state of down-washed soils (e.g. high down-washed soil, moderate down-washed soil etc.) were taken as evaluation criteria. The latter was defined based on the amount of the reduction of both humus thickness and humus content on the observed soils. In result, the area has been generalized into 5 classes of erodability: 1) not eroded, 2) weak down-washed, 3) moderate down-washed, 4) strong down-washed and 5) mixed both weak and moderate down-washed (ca. 5-10%). Based on statistical analyses, the author states that the lower the erodability of area, the higher the yield productivity of summer wheat, oat and barley. As also stated by other authors, the erodability of an area has to be considered as an important factor for soil suitability and crop yield forecasting. Raichert also developed an additional soil loss model which takes into account different soils and relief ranks using the following formula:

$$S = C * W * Wa * Slg * Sgr * Slp * Sd * Sf \quad [4]$$

where: S – rank of down-washed soil, C – rank of down-washed soil based on physical clay content, W – rank of down-washed soil on water permeability, Wa - rank of down-washed soil based on the content of waterproof aggregates, Slg - rank of down-washed soil based on slope length, Hu - rank of down-washed soil based on humus content, Sgr - rank of down-washed soil based on slope gradient, Slp - rank of down-washed soil based on slope part, Sd - rank of down-washed soil based on soil density, Sf - rank of down-washed soil based on silted fraction content.

The model gives a probability of 62 % under the following conditions: winter rainfall of 203 mm (from November through to March) and 38 % in cases where one rank deviates from the norm for 1 class. Long-term precipitation data are not available, and that is why they were not included in the model. As with the previous yield forecasting model, this model cannot integrate remote sensing and has no link to a GIS. A cartographic presentation of the digital soil loss is missing.

In conclusion, the author has prepared a map of the ecological states of the Uimon Basin based on Vinogradov’s classification and gives recommendations on how to differentiate land categories. Table 5.2 presents some of Rachert’s results.

Table 5.2: Classification of ecological states using the “Joint-Producers Cooperative Terek” as an example (from Raichert 2004 shortened version).

<table>
<tr><th rowspan="2">No.</th><th rowspan="2">Slopes in gradients and responsible land categories</th><th colspan="2">Area, ha</th><th rowspan="2">Land degradation in %</th><th rowspan="2">Reduction of productivity in %</th><th rowspan="2">Ecological state</th></tr>
<tr><th>total</th><th>eroded soil</th></tr>
<tr><td>1</td><td>< 1 - I cat.</td><td>403</td><td>No</td><td>No</td><td>No</td><td>Risk absent</td></tr>
<tr><td>2</td><td>1 – 2 – II cat.</td><td>368</td><td>40</td><td>11</td><td>17</td><td>Very low risk</td></tr>
<tr><td>3</td><td>2 – 3 - III cat.</td><td>456</td><td>105</td><td>23</td><td>28</td><td>Moderate crisis</td></tr>
<tr><td>4</td><td>3 – 5 – IV cat.</td><td rowspan="2">507</td><td rowspan="2">237</td><td rowspan="2">47</td><td rowspan="2">31</td><td>High crisis</td></tr>
<tr><td>5</td><td>5 – 7 – V cat.</td><td>Very high</td></tr>
<tr><td>6</td><td>7 – 10 - VI cat.</td><td>195</td><td colspan="4">meadow formation</td></tr>
</table>

In accordance with the above land categories, Raichert (2004) proposed recommendations for a rational land use which focuses on soil protection against water erosion and the re-production of soil fertility.

5.1.4 Mediterranean MicroLEIS Models (1992 and 1998)

The particular interest was put on the well-known Microcomputer-based Land Data Transfer and Evaluation Information System 4.1 (MicroLEIS 4.1) which was developed for optimal use of agricultural and forestry land systems under Mediterranean conditions by De la Rosa (cf. De la Rosa et al. 1992 and 1998 [INT-06]). The part “Production and Ecosystem Modelling” (Pro&Eco) of the MicroLEIS Integrated Package provides a series of computerized models for agro-ecological evaluation based on productivity-related aspects [INT-06]. In general, the models making up Pro&Eco follow the criteria of FAO (1976, 1981) for land evaluation as adapted by the European Community, and fit evaluation methods previously developed by the authors [INT-06]. The models have been recalibrated and validated using benchmark data from various regions of Andalucia (Spain) and other sites. Software have been developed to automate the application of these models, and they are documented in Spanish and English. Figure 5.1 shows the general outline of the MicroLEIS programs.

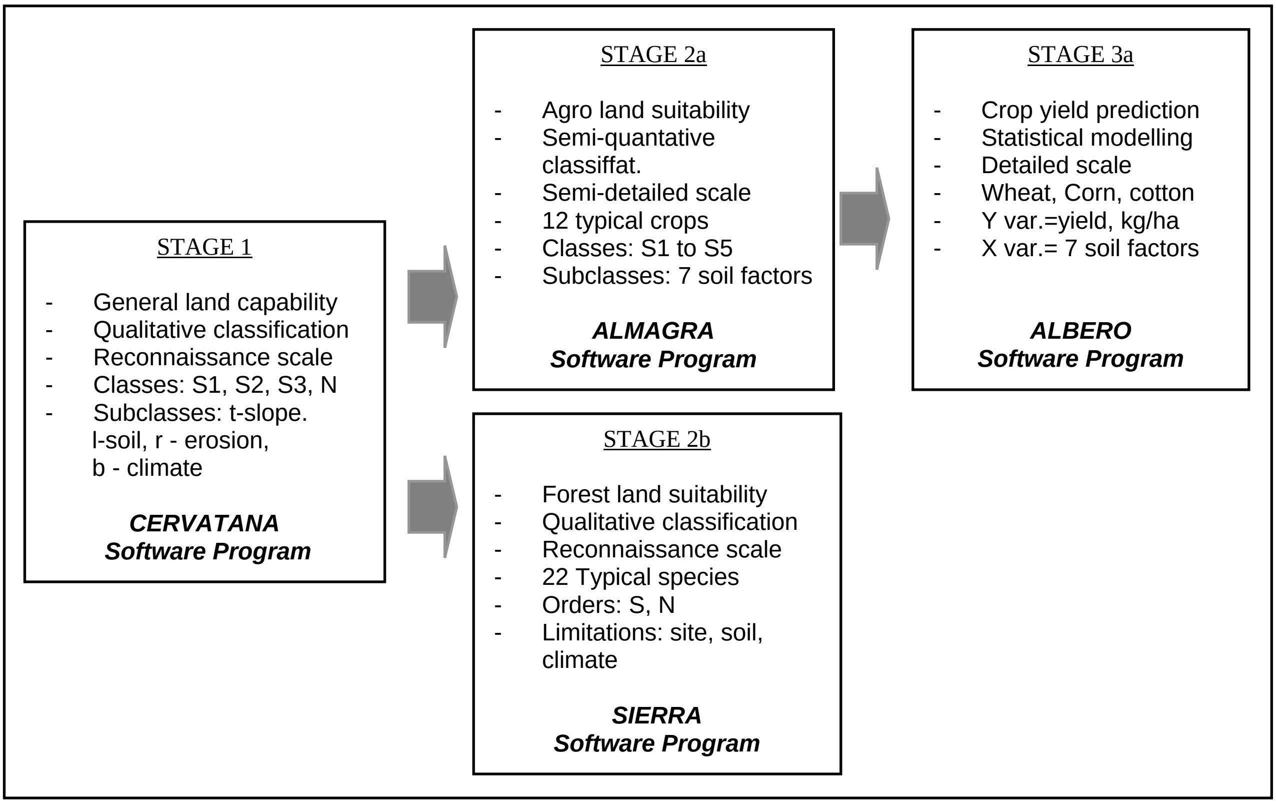


Figure 5.1. General outline of the land evaluation system MicroLEIS (from Dela Rosa: [INT-06]).

5.1.4.1 Agricultural Soil Suitability Model "Almagra" (1998)

The Almagra soil suitability method was based on an analysis of soil characteristics which influence the productive growth of twelve traditional mediterranean crops (Figure 5.2*):* wheat, corn, melon, potato, soybeans, cotton, sunflower, sugar-beet, alfalfa, peach, citrus and olive [INT-06]. Effective depth (p), texture (t), drainage (d), carbonate content (c), salinity (s), sodium saturation (a), and degree of profile development (g) are the soil characteristics used as diagnostic criteria. Following the maximum limitation procedure, five suitability classes were determined: *Class S1: Very High, Class 2: High, Class 3: Moderate, Class 4: Marginal and Class 5: Null.* The subclasses are indicated by the letters corresponding to the main limiting soil criteria.

The Almagra microcomputer-based program is an atomized application of this soil suitability method, which matches soil characteristics of the soil-units with growth requirements of each particular crop; and results in the crop growth limitations being provided by the computer.

Once the land unit data have been entered, Almagra gives an on-screen evaluation. If the main menu option "Save results to file" is selected, Almagra saves the results in the format appearing on the screen (Figure 5.2).

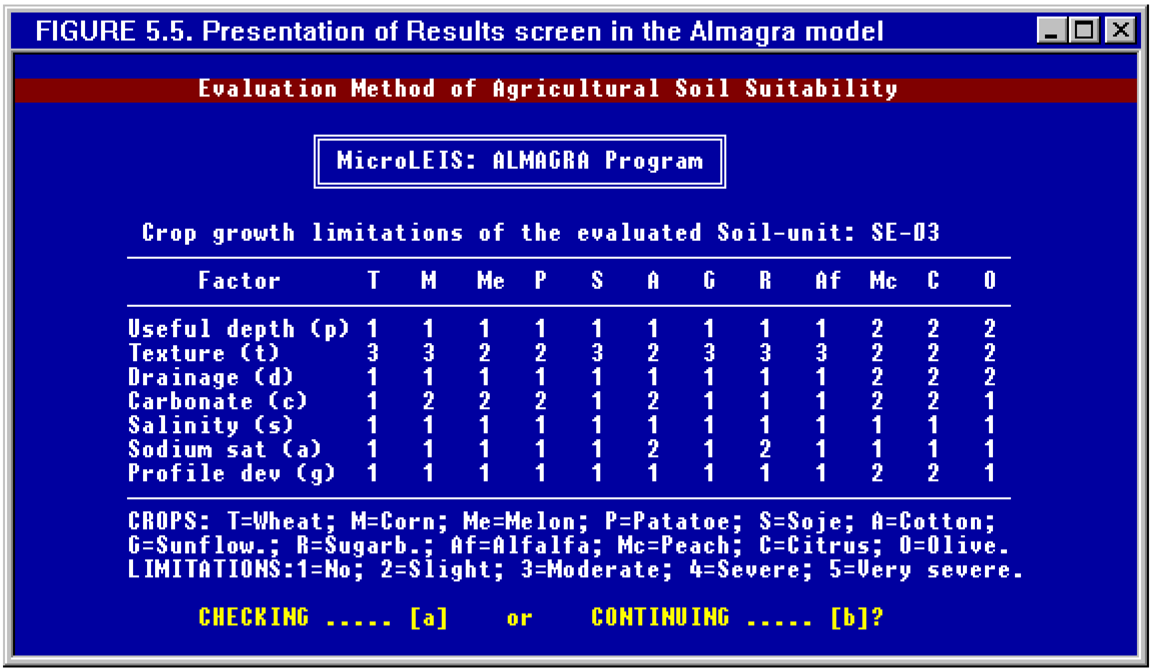


Figure 5.2: Screen shot: presentation of results in the Almagra Model (from De la Rosa [INT-06]).

5.1.4.2 Land Capability Model “Cervatana” (1998)

The Cervatana Model, is qualitative land capability module which is considered as a first stage to screen the land-units, favourable and excluded, for agricultural uses in Mediterranean regions within the qualitative/quantitative agroecological land evaluation procedure which automatizes MicroLEIS [INT-06]. The prediction of general land use capability is the result of a qualitative evaluation process or overall interpretation of the following biophysical factors: relief, soil, climate, and current use or vegetation. The approach was developed by De la Rosa [INT-06], grouping the lands into four Capability Classes: S1 Excellent, S2 Good, S3 Moderate and N Marginal or Nule, in general accordance with the FAO-Framework for Land Evaluation (1976). Following the generally accepted norms of land evaluation (USDA 1961, FAO 1976, Dent and Young 1981, Onern 1982), the Cervatana Model forecasts the general land use capability or suitability for a broad series of possible agricultural uses. The procedure of maximum limitation is used, with matrices of degree, to relate the land characteristics directly with the classes of use capability [INT-06]. The example of results is shown in Table 5.3.

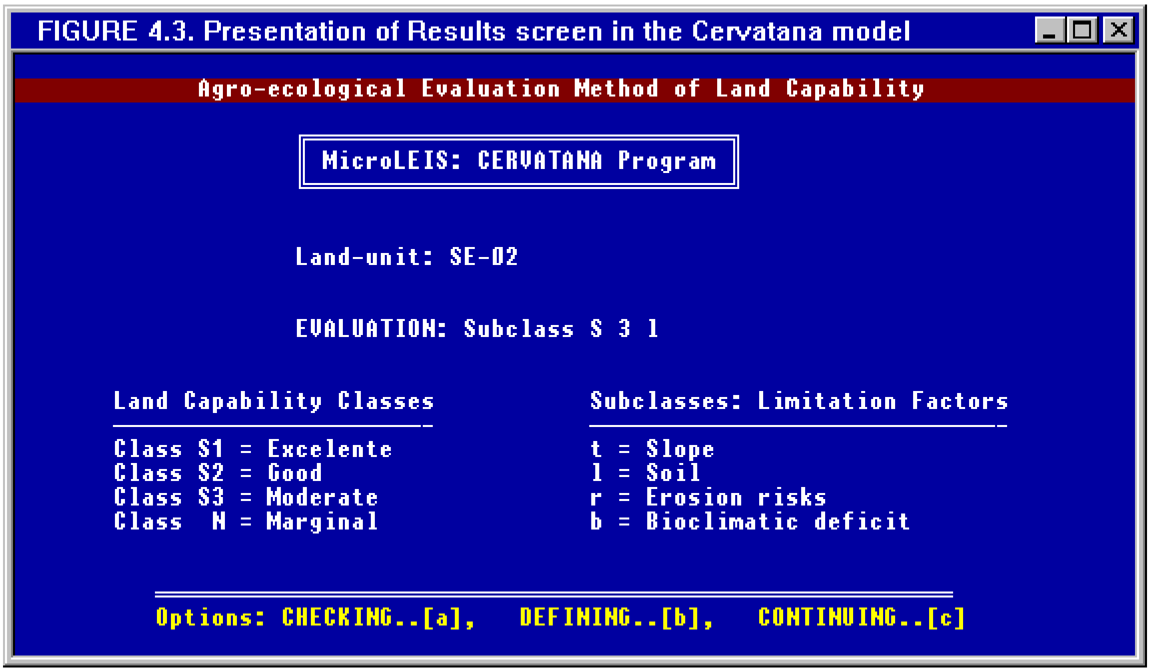


Figure 5.3: Screen shot: presentation of results in the Cervatana Model (from De la Rosa [INT-06]).

5.1.4.3 Albero Model (1998)

Albero deals with the characteristics of a quantitative system of evaluation of soil productive capability, making use of computerized multiple regression techniques ([INT-06]). It is a first approach to predict the productivity of the following crops: maize, wheat and cotton, based on a limited number of soil properties. Without analyzing the effect of climatic characteristics, and considering a high level of agricultural management practices, it attempts to explain the variability in productivity exclusively due to edaphic characteristics. Following the conventionally accepted criteria on soil evaluation (e.g. Simonson, 1938; Storie, 1950; Sys, 1964). Albero is a statistical procedure of productivity prediction.

Twenty-five soils under cultivation in a representative reference zone of 35,000 ha in the lower Guadalquivir Valley in the Province of Sevilla were studied. The characteristics of this zone are those typical of the Mediterranean climate: wet winters and hot, dry summers. The soils were classified into the following main groups: Haploxeralfs (3), Rhodoxeralfs (3), Xerofluvents (7), Xerochrepts (3), and Chromoxererts (9), in accordance with the Soil Taxonomy classification system ([INT-06]). The information on productivity of the crops analyzed was obtained by means of surveys with land workers and technicians of the zone for harvests between 1970 and 1975 (Cebac 1976, [INT-06]).

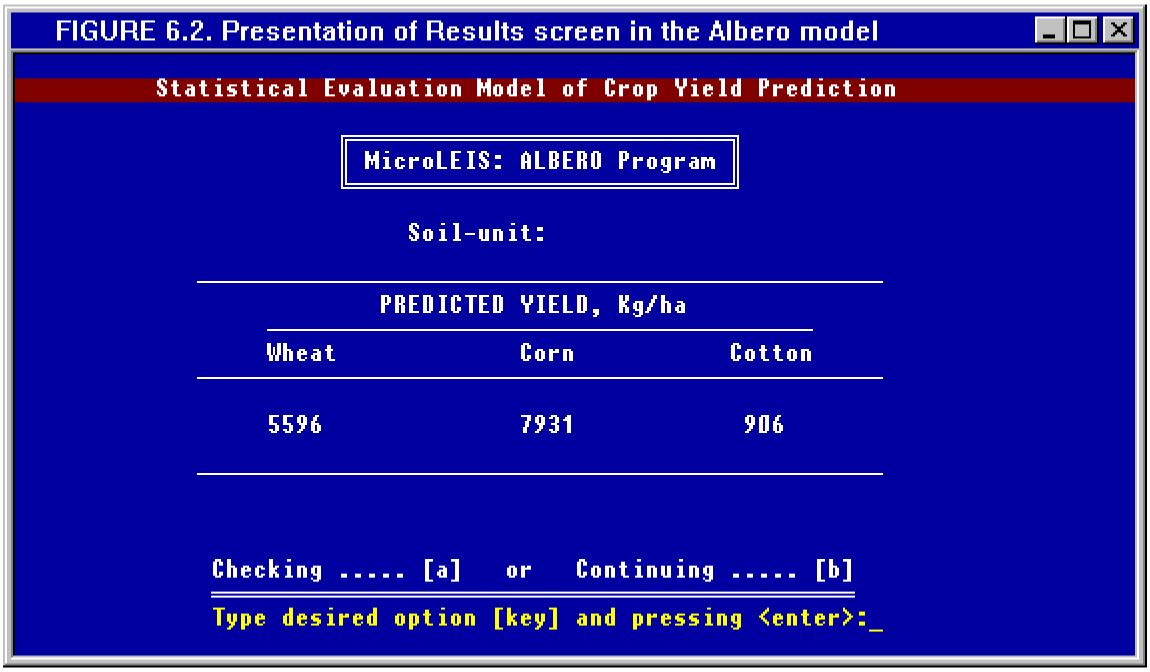


Figure 5.4: Screen shot: presentation of results in the Albero Model (after De la Rosa [INT-06]).

5.1.4.4 Sierra Model (1998)

A first approximation to the land requirements of 22 selected representative forest species has been established in this module of MicroLEIS [INT-06]. Position, climatic and adaphic requirements were estimated for each species as the minimum conditions necessary for their successful and sustained growth. The land characteristics selected were latitude, altitude, physiographic position, useful soil depth, texture, drainage, pH, mean minimum and maximum temperatures of the coldest and warmest months, and cumulative yearly precipitation. These provisional land requirements were structured so that a land unit was assessed as suitable (Class S) or not suitable (Class N) for each of the forest species. Qualitative land evaluation for forest use was based upon the maximum limitation method. The Sierra microcomputer-based program in MicroLEIS is an automated application of this qualitative land suitability procedure; it selects suitable species for each unit evaluated, and also offers a descriptive option presenting the land characteristic values most appopriate for each forest species.

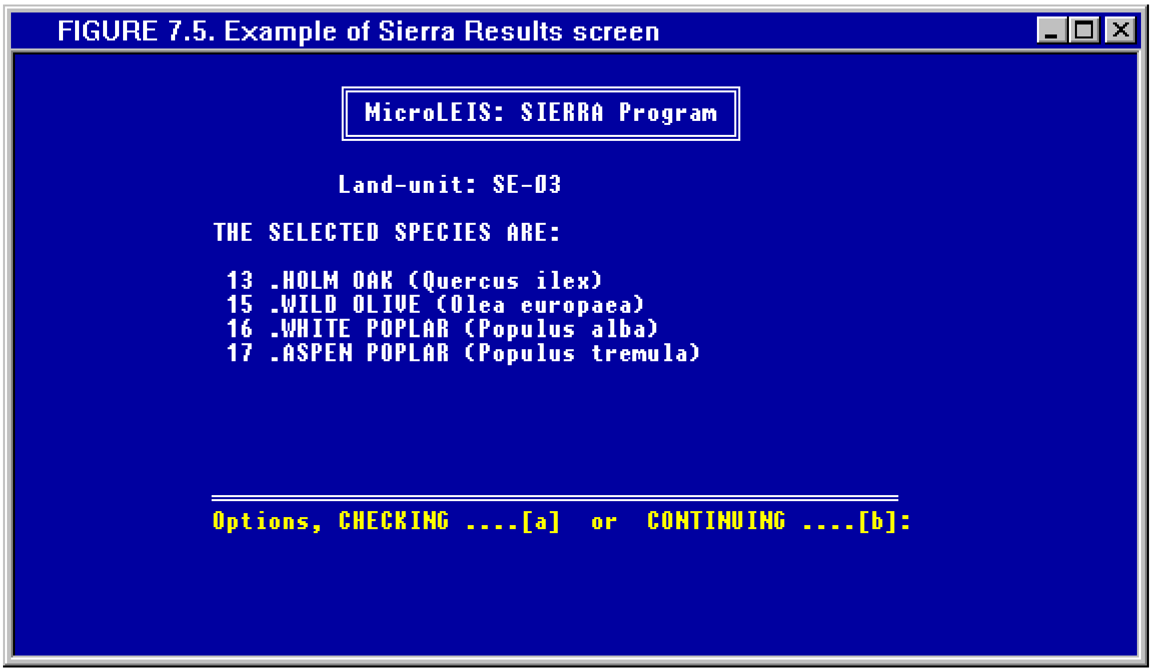


Figure 5.5: Screen shot: presentation of results in the Sierra Model (from De la Rosa [INT-06]).

5.1.5 International Review of Previous Work

Most traditional forms of land evaluation involve ratings of the relative favourableness of each of a selected set of soil properties. In contrast, soil potentials centre on the impacts of soil properties on yields or on other aspects of soil performance (McCormack 1987). "Black-box models" based on measured performance of well-characterised mapping units are limited to known land uses and local areas. More fundamental models, based on physical processes are limited by our understanding of the processes, the availability of data and the complexity of the real world, in particular the ability of crops and crop management to make dynamic adjustments to changing conditions (Dent and Cook 1987).

With the increasing application and capacity of computers to handle spatially distributed data sets there was growing need for more quantified predictions of land performance (Teach and Burt 1974, Diepen et al. 1991). Yet, quantified methods require more detailed models of land performance, which usually have high data requirements. In areas of the world where adequate data is scarce, or in application areas with knowledge gaps, qualitative and semi-qualitative models based partly on expert judgment still have to play an important role (Rossiter 1996). Sys (1985) gives a general view on qualitative approaches of physical land evaluations. Sharma (1987) gives a comparison of qualitative and quantitative land evaluation for rainfed maize in subhumid tropical and subtropical climates.

The current trend is to include social and economical variables in prediction models, as most problems to achieve the integration of land use planning and land management which related to human factors (Pieri 1997). Moreover, prediction models are designed to deliver several alternative options from which the stakeholder can choose, rather than to provide single clear-cut solutions (Bouma 1997, Larson 1986).

MicroLEIS (a Microcomputer-Based Mediterranean Land Evaluation Information System) developed by De la Rosa et al. (1992, [INT-06]) is an interactive tool for the optimal use of agricultural and forestry land systems with special reference to Mediterranean regions.

Mourik (1987) presents a land evaluation model for a livestock project in north-western Tunisia where agro-economic, socio-economic and environmental data are combined in a program using GIS. The increasing application of information technology to land evaluation procedures has led to the development of land evaluation information systems (LEIS). LEIS integrates experimental information using simulation modelling and GIS (Lanen et al. 1992a). Land evaluation procedures have also been improved by the use of expert systems (Wood and Dent 1983, Shrover et al. 1987, Puentes 1987). The automated Land Evaluation System (ALES) developed by Rossiter (1990) is a framework for evaluators to build their own expert system, and has many possible applications (Lanen and Wopereis 1992). Huddleston (1984) provides a historical documentation of major U.S. efforts to develop qualitative and quantitative methods for evaluating soil productivity. Zinck (1990) gave a general view of soil survey and land evaluation with special reference to developing countries. Diepen et al. (1991) discussed quantitative land evaluation methods simulating both soil water flow and associated crop production. Bouma et al. (1993) shows a hybrid land evaluation approach according to FAO framework criteria using decision trees and a simulation model of the soil-water regime. Driessen and Konijn (1992) discuss established qualitative and semi-quantitative procedures and modern quantified methods for assessing the biophysical suitability of land for crop production. Robert et al. (1993) present the results of a workshop with the objective of reviewing current knowledge and application technologies related to farming. Bullock et al. (1999) provide a set of European country reports on soil survey, monitoring and applications. Sanchez et al. (2003) used the fertility capability soil classification (FCC) system. As author states, the FCC it does not deal with soil attributes that can change in less than 1 year, but those that are either dynamic at time scales of years or decades with management, as well as inherent ones that do not change in less than a century.

Many papers also discuss the advantages of GIS and the FAO Framework in assessing soil productivity (Batjes et al. 1987, Comerma and De Guenni 1987, Driessen and Diepen 1987, Jones and Thomasson 1987, Karnchanasutham 2002, Kelgenbaeva 2002, Kelgenbaeva, Prechtel and Buchroithner 2003, Mausbach and Reybold 1987, Steeg 2003).

The use of the fuzzy set methodology by several authors (Burrough 1989 and 1991, Burrough et al. 1992, Davidson et al. 1994, Hall et al. 1992, Sasikala et al. 1996, Stolz 1998, Syrbe 1998a and 1998b, Tang et al. 1991, Wang et al. 1990) has made a significant contribution to the improvement of land suitability analyses. Burrough et al. (1992) use fuzzy classification to determine land suitability from (i) multivariate point observations of soil attributes, (ii) topographically controlled drainage conditions, and (iii) minimum contiguous areas, and compare the results obtained with conventional Boolean methods. In their study Boolean methods reject larger numbers of cells than fuzzy classification, and select cells that are insufficiently contiguous to meet the aims of the land classification. Burrough (1989) explains the basic principles of fuzzy sets, operations on fuzzy sets and the derivation of membership functions according to the Semantic Import Model with data for case studies in Venezuela and Kenia. Tang et al. (1991 and 1992) describe the application of the fuzzy set theory to the determination of land indices and suitability classes for maize production in Aitai County (China). The accuracy of this approach has been tested by comparing the land indices calculated by the fuzzy set theory with those obtained by two other evaluation procedures: the multiplicative parametric and the maximum limitation methods. The respective land indices were then correlated with the crop yields observed in the area: the best correlation was achieved by the fuzzy set approach. The result demonstrates the promising use of this theory in land evaluation. Lok and Phipps (1981) use vectors and matrices to represent soil conditions and land use requirements. Through a series of simple applications of matrix algebra, the technique combines site conditions and land use requirements, flexibly accounting for both positive and negative interactions, to calculate indices of site suitability for a defined land use. A test of the model in a region of Carleton County, Ontario, produced encouraging results.

Pierce et al. (1983) present an approach for evaluating the long-term effects of erosion on the productive potential of the U.S. soil resource base. The productivity of soils in the Major Land Resource Area (MLRA) 105 in Minnesota now and after 25, 50 and 100 years of erosion is calculated using erosion rates reported in the 1977 National Resource Inventory. The results indicate that the weighted average reduction in soil productivity is less than 5 percent for soils in this MLRA, with the biggest reduction occurring on soils with slopes steeper than 6 percent. Giordano et al. (1991) describe the first genuine attempt to provide consistent information on soil erosion risk and land quality for policy applications at the European level. As such it both helps to highlight future research needs and forms a basis for a better informed policy on land resources conservation.

Davidson et al. (1994) make a comparison of land evaluation results from Boolean and fuzzy set methodologies and highlight the advantages of them. As stated, the choice of membership functions and weights has a major effect on the results.

Sasikala et al. (1996) show how fuzzy membership functions to particular classes can be computed for regions composed of lots of smaller regions belonging to different classes and how variables taking values in ranges with different boundary conditions can be handled in a mathematically rigorous way. Their methodology demonstrates the problem of assessing the risk of desertification of burned forest areas in the Mediterranean region.

Syrbe (1998b) develops an evaluation technique within a GIS (Arc/Info). The methodology combines several known methods with fuzzy approaches to catch the intrinsic fuzziness of ecological systems as well as the heterogeneity of the landscape. As Syrbe states fuzzy logic can be well used to process the data uncertainty, to simulate the vagueness of knowledge about ecological functionality, and to model the spatial structure of the landscape. The fuzzy operations were executed by Arc/Info Macro Language (AML) where it is possible to use the geographical functions (neighbourhoods, distances, etc.) of GIS within the fuzzy system directly (Syrbe 1998b).

5.1.6 Critical Discussions

The MicroLEIS models developed for Mediterranean regions has the following *advantages:* it runs under MS-Dos, interactive and it freely available in internet; *disadvantages:* it is a closed system, it doesn't integrate RS data and it has no links to GIS. The most related to the present thesis, Almagra and Cervatana models are based on the maximum limitation procedure.

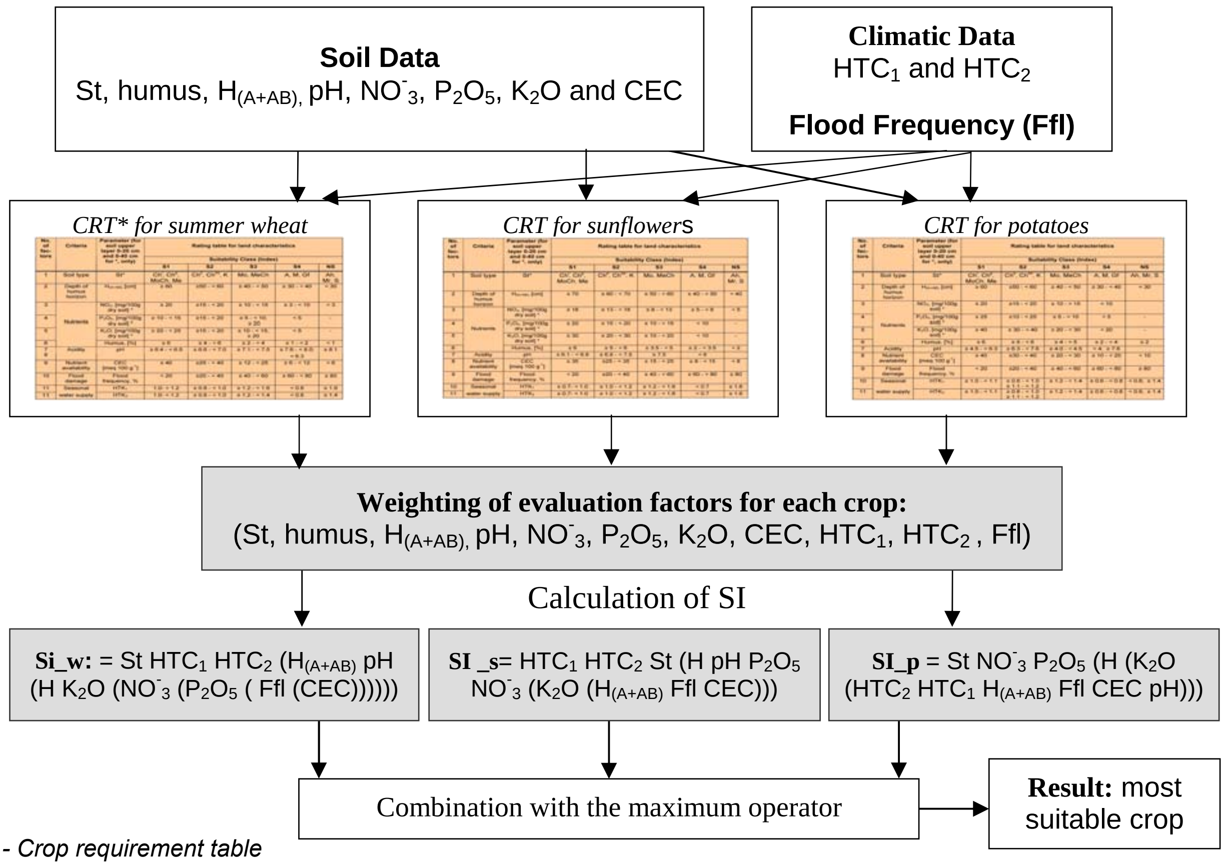
The crop-yield forecasting models which are specifically developed for the Altai conditions by Burlakova L. (cf. Burlakova 1974 and 1988, Raichert 2004) use the method of weighted means. *The advantages* of the Burlakova's model are transparent and easy to use and with likewise *disadvantages* as above. The problem of the weighted means 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 of all factors 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 for the Altai Land Suitability Model. The choice of weights for each factor and each individual species given by Burlakova (1988) were useful.

6. Modelling

6.1. Modelling of ALSM using the Weighted Means Approach

The Altai Landuse Suitability Model (ALSM) was derived using the following models: i) the Soil Suitability Model „Almagra" and the Land Capability Model "Cervatana"/MicroLEIS System and ii) the Burlakova's approach (for details refer the Chapter 5). The following improvements are suggested and discussed in final ALSM which is based on weighted means of a factor set:

- to use field data and MK-4 satellite imagery,
- to prepare new databases (geology, quaternary, soil map, DTM, drainage and other GIS layers),
- to integrate the data into a GIS (Arc/Info) environment,
- to increase the number of evaluation factors,
- to present the outputs cartographically,
- to consider three relevant crops from different crop categories (summer wheat, sunflowers and potatoes).



** - Crop requirement table*

Figure 6.1.1: Generalised flow chart showing the modelling of ALSM using Weighted Means Approach (largely based on Burlakova 1988).

6.1.2. Calculation of Altaian Summer Wheat Suitability

In 1988, Lidia Burlakova (Barnaul Agricultural University, Altai, Russia) developed a soil evaluation method based on weighted means for several agricultural crops based on agro-chemical and soil-science criteria. The method provides a possibility to forecast the crop yield without the application of fertilizers (cf. Burlakova 1988). Below an example for summer wheat (changed after Burlakova) is given where the following evaluating factors for the ALSM are determined:

$$St,\ H_{(A+AB)},\ pH,\ Hu,\ K_2O,\ NO_3,\ P_2O_5,\ HTC1,\ HTC2,\ CEC,\ Ffl \qquad [5]$$

St – soil type or sybtype, $H_{(A+AB)}$ - depth of humus horizon (cm), pH – soil pH, Hu – humus (%), K_2O – soluble potassium (mg/100g soil), NO_3 – soluble nitrogen (mg/100g soil), P_2O_5 – soluble phosphorus (mg/100g soil), HTC_1 – hydrothermal coefficient for May - June, HTC_2 – hydrothermal coefficient for May – September, Ffl – frequency to flooding and CEC – cation exchange capacity (meq/100g).

The weakly humused chernozems are characterised by the lowest productivity 0.8 0.1*t/ha) that corresponds to the 5th or NS (for details refer to Table 1.3). Alluvial-humid leached meadow soils show the minimum productivity of yield (0.3 0.1*t/ha) (Table 6.1.1). Leached chernozems shows the maximum soil productivity (26 0.1*t/ha). Burlakova (1988) states that with the increase of the humus content in the soil layer, the productivity of summer wheat also increases because every centimetre of the humus layer is of vital importance for increasing summer wheat yield. The latter may be reduced in cases where the humus soil layer is too high and other factors which limit yield formation in chernozem and other similar soils (Burlakova 1988). These factors are a lack of warmth in the soil of the foothills and a lack of nutrient elements (for instance, phosphorus).

Very weak humused chernozems as well as soils with weakly developed horizons have the lowest productivity (Table 6.1.1). For example, in standard chernozem, with an increase in the humus content of the soil from 4 to 6%, the productivity reaches up to the S2 class, which corresponds to 1.6 – 1.9 0.1*t/ha of summer wheat grain. The highest productivity – 2.0 0.1*t/ha (S1class) ensures a humus layer of 6 – 9%. The most favourable soil pH is 6.4 – 7.0, where the yield productivity is 1.6 – 2.0 0.1*t/ha (S1 and S2 class). Decreases or increases in the pH also reduce the productivity of summer wheat. Correlations between yield and nitrogen as well as humus content have shown a curvilinear nature. Based on Burlakova's research for the Altai Region, the minimum values of the total nitrogen in the soil correspond to a high yield, the maxima to an average yield, and the average values to the highest yield. The same applies to the correlation between yield and the total phosphorus contents in chernozem.

The soluble forms of nutrient elements influence the summer wheat yield to a marked degree. As known, the soluble forms are changeable during the vegetation period. Therefore, during the period of the bushing the content of nitrogen nitrates (NO_3), the content of the soluble phosphorus (P_2O_5) and the content of soluble potassium (K_2O) in the soil have a large influence on the formation of the summer wheat yield (Burlakova 1974, 1988, Yashutin et al. 2001). A lack or a surplus of potassium in the soil also decreases the productivity of the summer wheat yield (Burlakova 1988).

The summer wheat yield is determined not only by soil factors, but also by the climate. There is a positive correlation between the yield and both the hydrothermal coefficient for May - June (HTC_1) and the whole vegetation period of May - August (HTC_2). The explanation of hydrothermal coefficients is given in sub-chapter 4.2.2.

The optimum parameters for chernozem soils and hydrothermal properties are determined for the formation of the maximum summer wheat yield (2.0 0.1*t/ha) without applying any fertilisers. The corresponding parameters are a humus horizon of 50 - 60 cm, a content of humus in the arable layer of 6 - 8%, a pH of 6.4 - 7.0, a total nitrogen content of 0.3 – 0.4%, a phosphorus content of 0.18 – 0.20%, nitrogen nitrates equalling 15 - 20 mg/100g soil for the period of bushing out, soluble phosphorus amounting to 10 - 20 mg/100g soil and exchangeable potassium of 25 - 40 meq/100g before sowing. The hydrothermal coefficients for May - June (HTC_1) are 1.0 - 1.2 and 1.0 – 1.2 for May - August (HTC_2), with the precipitation for May - June amounting to 90 - 120 mm and soil moisture in the layer between 0 - 50 cm during the period of bushing out equalling 20 - 25%.

As can be seen in Table 6.1.1 the minimum yield comes from alluvial-humid meadow soil (0.3 0.1*t/ha). Standard chernozem is the prevailing soil in the Uimon Basin (cf. Map A4). Therefore, to obtain the minimum yield of summer wheat (less than 0.8 0.1*t/ha) on this soil the following values for soil and meteorological factors are required: a humus horizon of less than 30 cm, a humus content of less than 1%, total nitrogen and phosphorus levels of less than 0.2 and 0.13%, respectively, nitrogen nitrates equalling less than 3 mg/100g soil, soluble phosphorus amounting to less than 5 mg/100g soil and exchangeable potassium of less than 6 meq/100g. The hydrothermal coefficients for May - June and May - August are less than 0.4 and 0.5, respectively; the precipitation for May - June is less than 30 mm and soil moisture is less than 10 cm and more than 35% for medium loamy soils.

It is rare in nature to have a combination of all the factors at the levels defined as either the minimum or the optimum. Mostly, a varied combination frequently occurs, which in interaction determines one or another level of soil fertility and the corresponding summer wheat yield level (Burlakova 1988). To determine the standards and the relationships of the mineral fertilisers for the planned yield, it is necessary to know the crop yields. Based on Burlakova (1988), the suitability class for summer wheat can be calculated by the following formula, including the above mentioned soil and climatic factors:

$$SI = St*HTC_1*HTC_2*(H_{(A+AB)}*pH*(H*K_2O*(NO_3*(P_2O_5*(Ffl*(CEC)))))) \quad [6]$$

St – soil type or sybtype, $H_{(A+AB)}$ - depth of humus horizon (cm), pH – soil pH, Hu – humus (%), K_2O – soluble potassium (mg/100g), NO_3 – soluble nitrogen (mg/100g), P_2O_5 – soluble phosphorus (mg/100g), HTC_1 – hydrothermal coefficient for May – June, HTC_2 – hydrothermal coefficient for May – September, Ffl – frequency to flooding and CEC – cation exchange capacity (meq/100g).

By adopting this formula it is possible to take a soil moisture measurement instead of using HTC_1 and HTC_2 for a layer of 0 - 50 cm during the bushing out phase (Burlakova 1988). Then, the accuracy of the forecast will be less than 8%. Standard and leached chernozems are the prevalent soils throughout the studied region. The suitability indices using weighted means have the following general form:

$$SI = round[\sum_{1}^{n}(X_i * w_i)] \quad [7]$$

where 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.

*Table 6.1.1: Maximum and minimum yield of crops (in 0.1*t/ha) based on soil and climatic characteristics (changed after Burlakova 1988).*

Soil type	Summer wheat		Sunflowers		Potatoes	
	Yield (0.1*t/ha)					
	Max	Min	Max	Min	Max	Min
Alluvial-humid leached meadow soils	> 4	< 0.3	> 2	< 1	>16	<10
Alluvial meadow soil	> 12	< 0.5	> 4	< 2.5	>50	<30
Carbonated standard Chernozem	> 20	< 0.8	> 7	< 4	>80	<50
Leached Chernozem	> 26	< 1.0	> 5	< 3	>90	<57
Meadow Chernozem leached soil	> 15	< 0.6	> 4.5	< 3	>60	<40
Meadow forest soil	> 13	< 0.4	> 3	< 1.7	> 20	< 11
Chestnut soil	> 16	< 0.6	> 5	< 3	>55	<35
Mountain-forest chernozemic soil	> 7	< 0.4	> 3	< 2	>18	<15
Marschy soil	no data					

6.1.3 Calculation of Altaian Sunflowers Suitability

The same factors as for summer wheat have been taken into consideration to obtain a sunflower yield for full matured seeds. Every condition is considered essential, however, each affects the formation of the sunflower yield in a different way. The calculation of the suitability class for the sunflower yield can generally be represented by the following formula:

$$SI = HTC_1*HTC_2*St*(H*pH*P_2O_5*NO_3*(K_2O*(H_{(A+AB)}*Ffl*CEC))) \quad [8]$$

St – soil type or sybtype, $H_{(A+AB)}$ – depth of humus horizon (cm); pH – soil pH; Hu – humus (%); K_2O – soluble potassium (mg/100g soil); NO_3 – soluble nitrogen (mg/100g soil); P_2O_5 – soluble phosphorus (mg/100g soil); HTC_1 – hydrothermal coefficient for May - June; HTC_2 – hydrothermal coefficient for May – September; Ffl – frequency to flooding and CEC – cation exchange capacity (meq/100g).

In an order from the highest to least importance, hydrothermal conditions, presence of humus, phosphorous, and nitrates, are essential for a sunflower yield (Burlakova 1988, Grigoryeva 2001a and 2001b). The calculation procedure is the same as the one for the summer wheat.

The yield condition was determined specifically for each soil and climate factor in the Altai region. In order to obtain the maximum sunflower yield (Table 6.1.1), the soil humidity should not be less than 20 – 25% during the blooming phase, and the hydrothermal coefficient for May – June should be within the range of 0.7 - 1.0. Such a yield can be obtained under the following conditions: a soil with a humus layer thickness above 40 cm; a humus content in the arable layer of more than 6%; a phosphorus content of more than 0.23%; soluble phosphorus of more than 20 mg/100g soil; a potassium content of more than 30 mg/100 g soil; and a nitrogen nitrate of 18 - 20 mg/100 g soil.

A minimum sunflower yield (Table 6.1.1) can be achieved under the following conditions: a humus layer thickness below 40 cm; humus content of below 2%; nitrogen and phosphorous contents below 0.26% and 0.23% respectively; nitrate nitrogen of below 5 mg/100g of soil in a soil layer ranging from 0 - 60 cm during the blooming phase; solable phosphorous and potassium contents below 8 – 10 mg/100g of soil during the same phase and a hydrothermal coefficient during May – August of below 0.5.

However, despite the present suitability investigation in the Uimon Basin, it is assumed that sunflower plants are mixed with pea, which are then cut before the formation of inflorescence and used as fodder for animal husbandry.

6.1.4 Calculation of Altaian Potatoes Suitability

Potatoes have many requirements in relation to environmental conditions. The crop capacity is often limited by soil factors. These factors are of great significance. In order to clarify the role of each soil, climate and drainage factor, their importance for crop yields under the conditions of the chernozem zone in the Altai has been determined.
The formula for the determination of the suitability index for potato yields has been derived from the set of the above mentioned factors according to the same principles as for the previously described crops:

$$SI = St\ NO_3\ P_2O_5\ (H\ (K_2O\ (HTC_2\ HTC_1\ H_{(A+AB)}\ Ffl\ CEC\ pH))) \qquad [9]$$

St – soil type or sybtype, $H_{(A+AB)}$ – depth of humus horizon (cm); pH – soil pH; Hu – humus (%); K_2O – soluble potassium (mg/100g soil); NO_3 – soluble nitrogen (mg/100g soil); P_2O_5 – soluble phosphorus (mg/100g soil); HTC_1 – hydrothermal coefficient for May - June; HTC_2 – hydrothermal coefficient for May – September; Ffl – frequency to flooding and CEC – cation exchange capacity (meq/100g).

What is most important for potatoes is the content of nitrogen and phosphorous during the sprouting phase. The thickness of the humus layer and the hydrothermal conditions in May – August are less important in this case due to the large reserves of water after fallowing (Yashutin et al. 2001).
A maximum potato yield (80 – 90 0.1*t/ha) in the layer of 0 - 40 cm during the sprouting phase is formed using the following conditions (Table 6.1.1): a nitrate nitrogen content (NO_3) of 20 - 25 mg/100g soil; a humus content of more than 6% in the plough layer; total nitrogen content of more than 0.20%; P_2O_5 equalling 25 mg/100 g soil and total potassium content amounting to more than 40 mg/ 100 g soil.
A minimum potato yield (less than 50 0.1*t/ha) in the layer of less 30 cm during the sprouting phase is formed using the following conditions (Table 6.1.1): a nitrate nitrogen content (NO_3) of 10 mg/100g soil; a humus content of less than 2% in the plough layer; total nitrogen content of more than 0.10%; P_2O_5 equalling less than 5 mg/100 g soil; and total potassium content amounting to less than 20 mg/100 g soil.

6.1.5 Generation of Suitability Maps

6.1.5.1 Summer Wheat

Knowing is not enough; we must apply.
Willing is not enough; we must do…
Johann Wolfgang von Goethe
(1749-1832)

As is well known, GIS offers the possibility to analyse and evaluate spatial data. In the present study, GIS was used to integrate input data for the land suitability models to then develop a modelling procedure for the land suitability evaluation. Digitised maps, the geographical distributions of soils, topography, results of soil chemical analyses and agro-climatic indicators were compiled together with attribute data (e.g. humus thickness, soil depth and etc. for each soil unit). The classification for each factor (11 in total) and each soil (also 11) and the calculation of suitability classes were carried out using Arc/Info Macro Language (AML) in ArcGIS. The AML calculations are presented below (for more details see Appendix B1).

```
&ty *** AML to Calculate the SI for wheat
/*Name of the Coverage
&sv incov = data_1m
&sv outcov = out_weam1
&ty *** Kill old datasets
&if [EXISTS  %outcov % -COVER] &then kill  %outcov % all

&ty *** Create working coverage  %outcov %
copy  %incov %  %outcov %

/*Name of the Types
&sv item1 = HUMUS
&sv item2 = H_A_AB_
&sv item3 = PH
&sv item4 = N
&sv item5 = P2O5
&sv item6 = K2O
&sv item7 = CEC
&sv item8 = HTC1
&sv item9 = HTC2
&sv item10 = FFL
&sv item11 = St

ae
edit  %outcov % POLY

&ty *** Adding the Items to cover  %outcov %
additem C %item1 % 2 4 b
additem C %item2 % 2 4 b
additem C %item3 % 2 4 b
additem C %item4 % 2 4 b
additem C %item5 % 2 4 b
additem C %item6 % 2 4 b
additem C %item7 % 2 4 b
additem C %item8 % 2 4 b
additem C %item9 % 2 4 b
additem C %item10 % 2 4 b
additem C %item11 % 2 4 b
additem SI 2 4 b

select all
&sv numb = [show number select]
&sv x = 0
&ty *** Starting the Calculation of HUMUS,H_A_AB_,PH,P2O5,K2O,N,CEC,HTC1,HTC2,FFL,St
CURSOR OPEN

&do &while  %:edit.aml$next %

&sv x =  %x % + 1

&sv temp1 = 0
&sv temp2 = 0
&sv temp3 = 0
```

```
&sv temp4 = 0
&sv temp5 = 0
&sv temp6 = 0
&sv temp7 = 0
&sv temp8 = 0
&sv temp9 = 0
&sv temp10 = 0
&sv temp11 = 0

/*_______________________ITEM1-Classification

&sv temp1 =  %:edit.HUMUS %
&if  %temp1 % <  1                  &then &sv class1 = 5
&if  %temp1 % >= 1 AND  %temp1 % < 2   &then &sv class1 = 4
&if  %temp1 % >= 2 AND  %temp1 % < 4   &then &sv class1 = 4
&if  %temp1 % >= 4 AND  %temp1 % < 6   &then &sv class1 = 2
&if  %temp1 % >= 6                  &then &sv class1 = 1
calc C %item1 % =  %class1 %

/*_______________________ITEM2-Classification

&sv temp2 =  %:edit.H_A_AB_ %
&if  %temp2 % <  30                 &then &sv class2 = 5
&if  %temp2 % >= 30 AND  %temp2 % < 40 &then &sv class2 = 4
&if  %temp2 % >= 40 AND  %temp2 % < 50 &then &sv class2 = 3
&if  %temp2 % >= 50 AND  %temp2 % < 60 &then &sv class2 = 1
&if  %temp2 % >= 60                 &then &sv class2 = 2
calc C %item2 % =  %class2 %
```

The overall suitability was evaluated using Formula [6]. The AML calculations are presented below:

```
&sv a =  %class8 %
&sv b =  %class9 %
&sv c =  %class2 %
&sv d =  %class3 %
&sv e =  %class1 %
&sv f =  %class6 %
&sv g =  %class4 %
&sv h =  %class5 %
&sv i =  %class7 %
&sv j =  %class10 %
&sv k =  %class11 %

&sv si1 = [calc [calc  %i % +  %j %] / 2]
&sv si2 = [calc [calc  %g % +  %h % +  %si1 %] / 3]
&sv si3 = [calc [calc  %e % +  %f % +  %si2 %] / 3]
&sv si4 = [calc [calc  %c % +  %d % +  %si3 %] / 3]
&sv si5 = [calc [calc  %a % +  %b % +  %si4 %] / 3]
&sv si = [calc [calc  %k % +  %si5 %] / 2]

&if  %si % eq 0                     &then &sv si = 0
&if  %si % <= 1.5                   &then &sv si = 1
&if  %si % >  1.5 AND  %si % <= 2.5 &then &sv si = 2
&if  %si % >  2.5 AND  %si % <= 3.5 &then &sv si = 3
&if  %si % >  3.5 AND  %si % <= 4.5 &then &sv si = 4
&if  %si % >  4.5 AND  %si % <= 5.5 &then &sv si = 5
```

The obtained results are presented as tables and maps (Table 6.1.2 and Figure 6.1.2).

Table 6.1.2: SI for summer wheat based on the WM Approach.

Soil type (St*)	Suitability class (SI**) for summer wheat based on the WM Approach	Limitation classes (LC***)
St1	S4	LC4
St2	S4	LC4
St3	S1	LC1
St4	S2	LC2
St5	S3	LC3
St6	S2	LC2
St7	S3	LC3
St8	S3	LC3
St9	S2	LC2
St10	S4	LC4
St11	NS	LC5

**- the location of the various soil type can be determined in the Map B1 using the enclosed transparency (cf. Appendix C),*
*** - for details refer to Table 1.3,*
**** - for details refer to Table 6.1.3.*

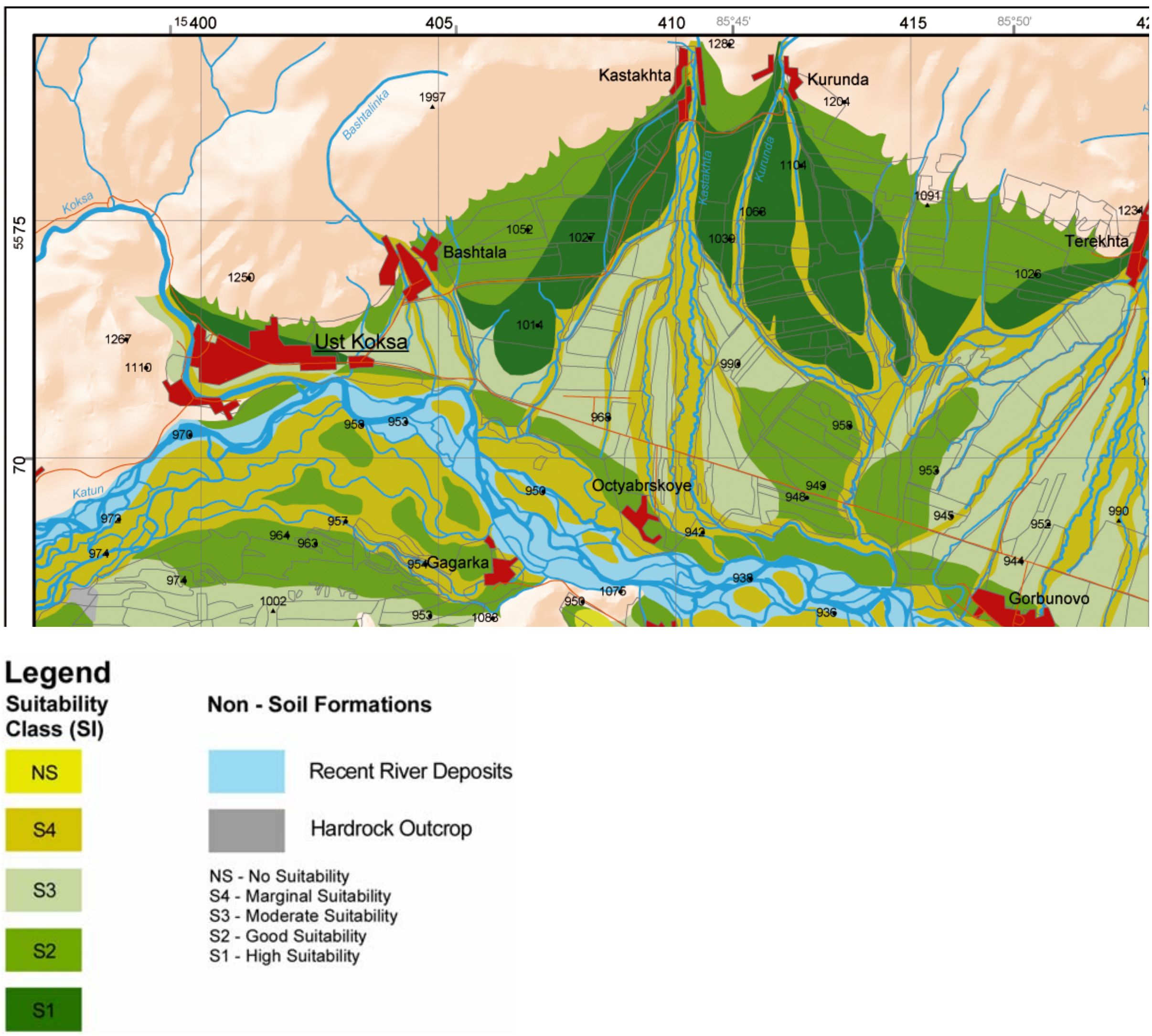


Figure 6.1.2: Portion of land suitability map for summer wheat (for more details see Map B1).

Table 6.1.3: Limiting factors.

Limitation class	Limiting factors
LC1	No significant limitations. All factors are in favour of high suitability.
LC2	Slight limitations through soil nutrient elements like P_2O_5, NO_3, K_2O and humus.
LC3	Moderate limitations of soil factors in the rooting zone: $H_{(A+AB)}$, CEC and a moderate content of LC2 factors.
LC4	Severe limitations in HTC_1, HTC_2, pH and a high content of LC3 factors.
LC5	A very severe limitation due to flooding risk, erodability and salinisation- the latter one was excluded for the present study area. Very severe limitations of LC4.

Table 6.1.4: SI for summer wheat based on the WM Approach.

SI for summer wheat (Model I)	Area in km^2	% of total area
5	2.43	0.6
4	143.04	33
3	109.27	25
2	90.88	21
1	49.54	12
Recent river deposits	31.08	7.2
Hardrock outcrops	3.65	0.8
Total	429.89	100

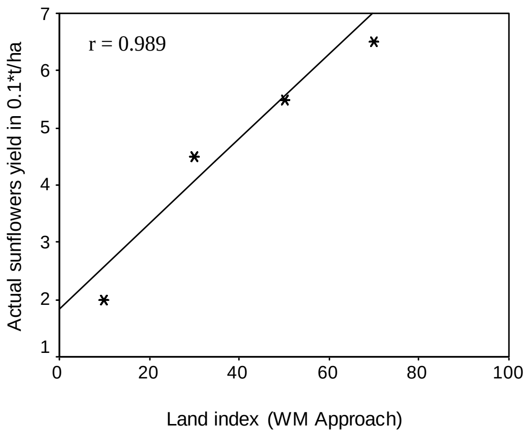


Figure 6.1.3: Linear regression of the land indices and the actual summer wheat yield.
Note: some asterisks are superimposed due to same values.

The results show that 12% of the area have a high suitability for growing and developing summer wheat. About 21% of the total area show a good suitability. Based on the soil map (cf. Map A4), both of these areas occur under standard and leached chernozem. However, 25% of the total area shows a moderate suitability. This area shows weak humused standard chernozem and is located in the fluvial-semiarid zone (see Map A3). It represents 33% of the total area with marginal suitability. The reason for being marginally suitable is due to its location in the flood lands of the river basins (Katun, Kastachta, Terekhta, Chendyk, Multa, Tikhonkaya and Verkhyi Uimon). The recent proluvium and alluvium deposits are characterised by their quaternary sediments. Out of the total area, 0.6% show no suitability at all, since the type of soil is marshy. Summing up, the different areas of standard and leached chernozem show a good to high suitability for summer wheat and represent the most used soil for agriculture.

In order to judge the efficiency of the classification methods, the land indices data (see Table 1.3) were compared with the actual yield data of standard chernozem (due to their majority in the Uimon Basin). The correlation coefficient shows a high agreement (r = 0.989) of yields and land index data.

6.1.5.2 Sunflowers

The same procedure as for summer wheat was performed for sunflowers (cf. Chapter 6.1.5.1). The AML calculations are given below:

&ty *** AML to Calculate the SI for wheat

```
/*Name of the Coverage
&sv incov = data_1m
&sv outcov = out_sunm1
&ty *** Kill old datasets

&if [EXISTS  %outcov % -COVER] &then kill  %outcov % all
/*kill  %outcov % all

&ty *** Create working coverage  %outcov %
copy  %incov %  %outcov %

/*Name of the Types
&sv item1 = HUMUS
&sv item2 = H_A_AB_
&sv item3 = PH
&sv item4 = N
&sv item5 = P2O5
&sv item6 = K2O
&sv item7 = CEC
&sv item8 = HTC1
&sv item9 = HTC2
&sv item10 = FFL
&sv item11 = ST

ae
edit  %outcov % POLY

&ty *** Adding the Items to cover  %outcov %
additem C %item1 % 2 4 b
additem C %item2 % 2 4 b
additem C %item3 % 2 4 b
additem C %item4 % 2 4 b
additem C %item5 % 2 4 b
additem C %item6 % 2 4 b
additem C %item7 % 2 4 b
additem C %item8 % 2 4 b
additem C %item9 % 2 4 b
additem C %item10 % 2 4 b
additem C %item11 % 2 4 b
additem SI 2 4 b

select all
&sv numb = [show number select]
&sv x = 0
&ty *** Starting the Calculation of St, HUMUS,H_A_AB_,PH,P2O5, K2O,N,CEC,HTC1,HTC2,FFL
CURSOR OPEN

&do &while  %:edit.aml$next %

&sv x =  %x % + 1

&sv temp1 = 0
&sv temp2 = 0
&sv temp3 = 0
&sv temp4 = 0
&sv temp5 = 0
&sv temp6 = 0
&sv temp7 = 0
&sv temp8 = 0
&sv temp9 = 0
&sv temp10 = 0
&sv temp11 = 0

/*_______________________ITEM1-Classification

&sv temp1 =  %:edit.HUMUS %
&if  %temp1 % < 2.0                    &then &sv class1 = 5
```

```
&if  %temp1 % >= 2.0 AND  %temp1 % < 3.5 &then &sv class1 = 4
&if  %temp1 % >= 3.5 AND  %temp1 % < 5.0 &then &sv class1 = 3
&if  %temp1 % >= 5.0 AND  %temp1 % < 6.0 &then &sv class1 = 2
&if  %temp1 % >= 6                       &then &sv class1 = 1
calc C %item1 % =  %class1 %

/*_______________________ITEM2-Classification

&sv temp2 =  %:edit.H_A_AB_ %
&if  %temp2 % <  40                          &then &sv class2 = 5
&if  %temp2 % >= 40 AND  %temp2 % < 50 &then &sv class2 = 4
&if  %temp2 % >= 50 AND  %temp2 % < 60 &then &sv class2 = 3
&if  %temp2 % >= 60 AND  %temp2 % < 70 &then &sv class2 = 2
&if  %temp2 % >= 70                    &then &sv class2 = 1
calc C %item2 % =  %class2 %
```

…………..and so on for all factors.

```
&sv a =  %class8 %
&sv b =  %class2 %
&sv c =  %class3 %
&sv d =  %class5 %
&sv e =  %class1 %
&sv f =  %class4 %
&sv g =  %class6 %
&sv h =  %class7 %
&sv i =  %class9 %
&sv j =  %class10 %
&sv k =  %class11 %

&sv si1 = [calc [calc  %i % +  %a %] / 2]
&sv si2 = [calc [calc  %e % +  %k % +  %si1 %] / 3]
&sv si3 = [calc [calc  %d % +  %c % +  %si2 %] / 3]
&sv si4 = [calc [calc  %g % +  %f % +  %si3 %] / 3]
&sv si5 = [calc [calc  %j % +  %b % +  %si4 %] / 3]
&sv si = [calc [calc  %h % +  %si5 %] / 2]

&if  %si % eq 0                &then &sv si = 0
&if  %si % <= 1.5              &then &sv si = 1
&if  %si % >  1.5 AND  %si % <= 2.5 &then &sv si = 2
&if  %si % >  2.5 AND  %si % <= 3.5 &then &sv si = 3
```

The obtained results are presented in Table 6.1.5, Figure 6.1.4 and Map B2.

Table 6.1.5: SI for sunflowers based on the WM Approach.

Soil type (St*)	Suitability class (SI**) for sunflowers based on the WM Approach	Limitation class (LC***)
St1	NS	LC5
St2	NS	LC5
St3	S2	LC2
St4	S3	LC3
St5	S4	LC4
St6	S3	LC3
St7	S4	LC4
St8	S4	LC4
St9	S3	LC3
St10	NS	LC5
St11	S4	LC4

**- the location of the various soil type can be determined in the Map B2 using the enclosed transparency (cf. Appendix C),*
*** - for details refer to Table 1.3,*
**** - for details refer to Table 6.1.6.*

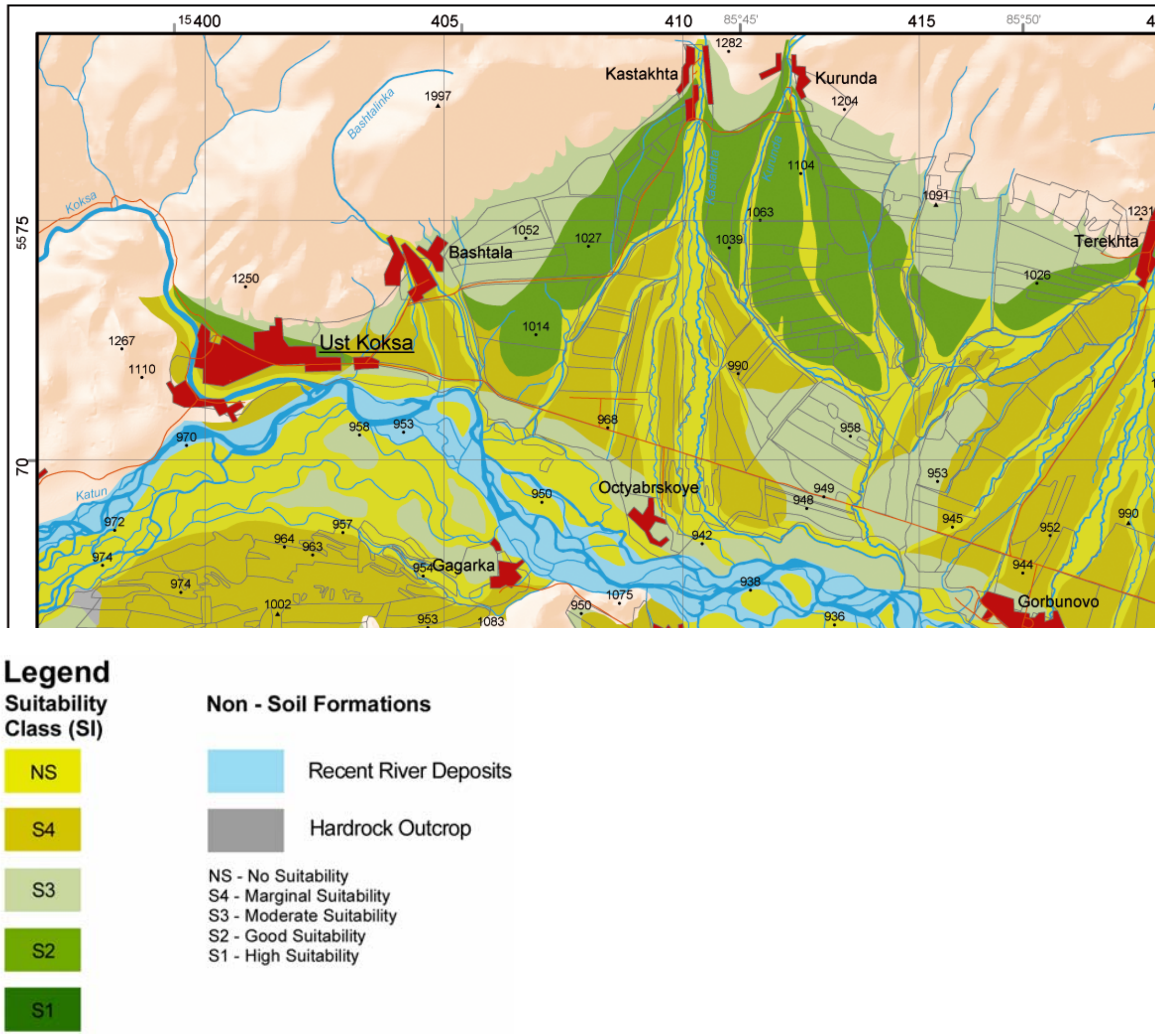


Figure 6.1.4: Portion of land suitability map for sunflowers (for more details see Map B2).

Table 6.1.6: Limiting factors.

Limitation class	Limiting factors
LC1	No significant limitations. All factors are in favour of high suitability.
LC2	Slight limitations through soil nutrient elements like P_2O_5, NO_3, K_2O and humus.
LC3	Moderate limitations of soil factors in the rooting zone: $H_{(A+AB)}$, CEC and a moderate content of LC2 factors.
LC4	Severe limitations in HTC_1, HTC_2, pH and a high content of LC3 factors.
LC5	A very severe limitation due to flooding risk, erodability and salinisation-the latter one was excluded for the present study area. Very severe limitations of LC4.

Table 6.1.7: SI for sunflowers based on the WM Approach.

SI for sunflowers (Model I)	Area in km^2	% of total area
5	142.44	33.1
4	109.27	28.0
3	82.78	19.3
2	49.54	11.6
Recent river deposits	31.08	7.2
Hardrock outcrops	3.65	0.8
Total	429.89	100

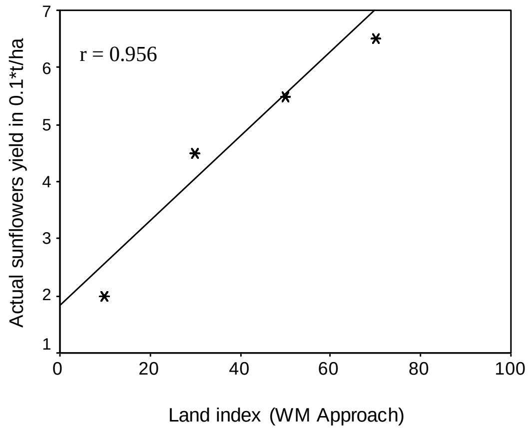


Figure 6.1.5: Linear regression of the land indices and the actual sunflowers yield.
Note: some asterisks are superimposed due to same values.

The results show that 11.6% of the area have a good suitability for growing and developing sunflowers. This area is mostly located on the northern parts of the Uimon Basin where standard chernozem prevail (cf. Map B2). About 19.3% of the total area shows a moderate suitability. It is located close to the foothill zones of the basin. Most of the area shows a marginal and no suitability i.e. 28% and 33.1%, respectively. This is due to their location in fluvial-humid zones under less fertile soils like alluvial-humid leached and alluvial meadow soil. Weakly humused standard chernozems, which are distributed under fluvial-humid zone, also show a marginal suitability. Summing up, the area has only a moderately and marginal suitability for the fully mature sunflower seeds.

In order to judge the efficiency of the classification methods the land indices data (see Table 1.3) were compared with the actual yield data of standard chernozem (due to their majority in the Uimon Basin). The correlation coefficient shows a high agreement (r = 0.956) of yields and land index data.

6.1.5.3 Potatoes

For potatoes, the same procedure was used as for summer wheat (Chapter 6.1.5.1). The AML calculation is shown below:

```
&ty *** AML to Calculate the SI for wheat
/*Name of the Coverage
&sv incov = data_1m
&sv outcov = out_potm1

&ty *** Kill old datasets

&if [EXISTS  %outcov % -COVER] &then kill  %outcov % all
/*kill  %outcov % all

&ty *** Create working coverage  %outcov %
copy  %incov %  %outcov %
```

```
/*Name of the Types
&sv item1 = HUMUS
&sv item2 = H_A_AB_
&sv item3 = PH
&sv item4 = N
&sv item5 = P2O5
&sv item6 = K2O
&sv item7 = CEC
&sv item8 = HTC1
&sv item9 = HTC2
&sv item10 = FFL
&sv item11 = St

ae
edit  %outcov % POLY

&ty *** Adding the Items to cover  %outcov %
additem C %item1 % 2 4 b
additem C %item2 % 2 4 b
additem C %item3 % 2 4 b
additem C %item4 % 2 4 b
additem C %item5 % 2 4 b
additem C %item6 % 2 4 b
additem C %item7 % 2 4 b
additem C %item8 % 2 4 b
additem C %item9 % 2 4 b
additem C %item10 % 2 4 b
additem C %item11 % 2 4 b
additem SI 2 4 b

select all
&sv numb = [show number select]
&sv x = 0
&ty *** Starting the Calculation of St,HUMUS,H_A_AB_,PH,P2O5, K2O,N,CEC,HTC1,HTC2,FFL
CURSOR OPEN

&do &while  %:edit.aml$next %

&sv x =  %x % + 1

&sv temp1 = 0
&sv temp2 = 0
&sv temp3 = 0
&sv temp4 = 0
&sv temp5 = 0
&sv temp6 = 0
&sv temp7 = 0
&sv temp8 = 0
&sv temp9 = 0
&sv temp10 = 0
&sv temp11 = 0

/*________________________ITEM1-Classification

&sv temp1 =  %:edit.HUMUS %
&if  %temp1 % <  2.0                                   &then &sv class1 = 5
&if  %temp1 % >= 2.0 AND  %temp1 % < 4.0 &then &sv class1 = 4
&if  %temp1 % >= 4.0 AND  %temp1 % < 5.0 &then &sv class1 = 3
&if  %temp1 % >= 5.0 AND  %temp1 % < 6.0 &then &sv class1 = 2
&if  %temp1 % >= 6.0                          &then &sv class1 = 1
calc C %item1 % =  %class1 %

/*________________________ITEM2-Classification

&sv temp2 =  %:edit.H_A_AB_ %
&if  %temp2 % <  30                          &then &sv class2 = 5
&if  %temp2 % >= 30 AND  %temp2 % < 40 &then &sv class2 = 4
&if  %temp2 % >= 40 AND  %temp2 % < 50 &then &sv class2 = 3
&if  %temp2 % >= 50 AND  %temp2 % < 60 &then &sv class2 = 2
&if  %temp2 % >= 60                          &then &sv class2 = 1
calc C %item2 % =  %class2 %
```

Table 6.1.8: SI for potatoes based on the WM Approach.

Soil type (St*)	Suitability class (SI**) for potatoes based on the WM Approach	Limitation class (LC***)
St1	NS	LC5
St2	S4	LC4
St3	S2	LC2
St4	S2	LC2
St5	S4	LC4
St6	S3	LC3
St7	S4	LC4
St8	S4	LC4
St9	S3	LC3
St10	NS	LC5
St11	S4	LC4

**- the location of the various soil type can be determined in the Map B3 using the enclosed transparency (cf. Appendix C),*
*** - for details refer to Table 1.3,*
**** - for details refer to Table 6.1.9.*

Table 6.1.9: Limiting factors.

Limitation class	Limiting factors
LC1	No significant limitations. All factors are in favour of high suitability.
LC2	Slight limitations through soil nutrient elements like P_2O_5, NO_3, K_2O and humus.
LC3	Moderate limitations of soil factors in the rooting zone: $H_{(A+AB)}$, CEC and a moderate content of LC2 factors.
LC4	Severe limitations in HTC_1, HTC_2, pH and a high content of LC3 factors.
LC5	A very severe limitation due to flooding risk, erodability and salinisation- the latter one was excluded for the present study area. Very severe limitations of LC4.

Table 6.1.10: SI for potatoes based on the WM Approach.

SI for sunflowers (Model I)	Area in km^2	% of total area
5	58.67	13.6.
4	196.08	45.6
3	54.68	12.7
2	85.73	19.9
Recent river deposits	31.08	7.2
Hardrock outcrops	3.65	0.8
Total	429.89	100

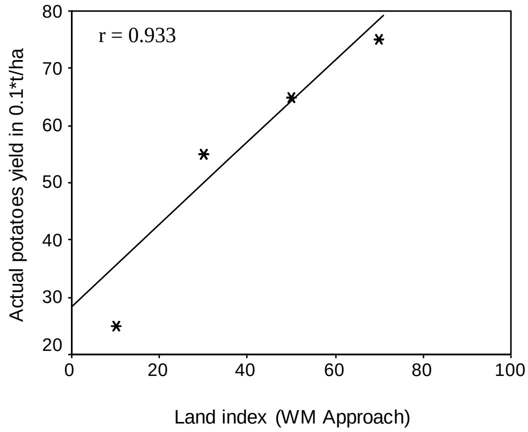


Figure 6.1.7: Linear regression of the land indices and the actual potatoes yield.
Note: some asterisks are superimposed due to same values.

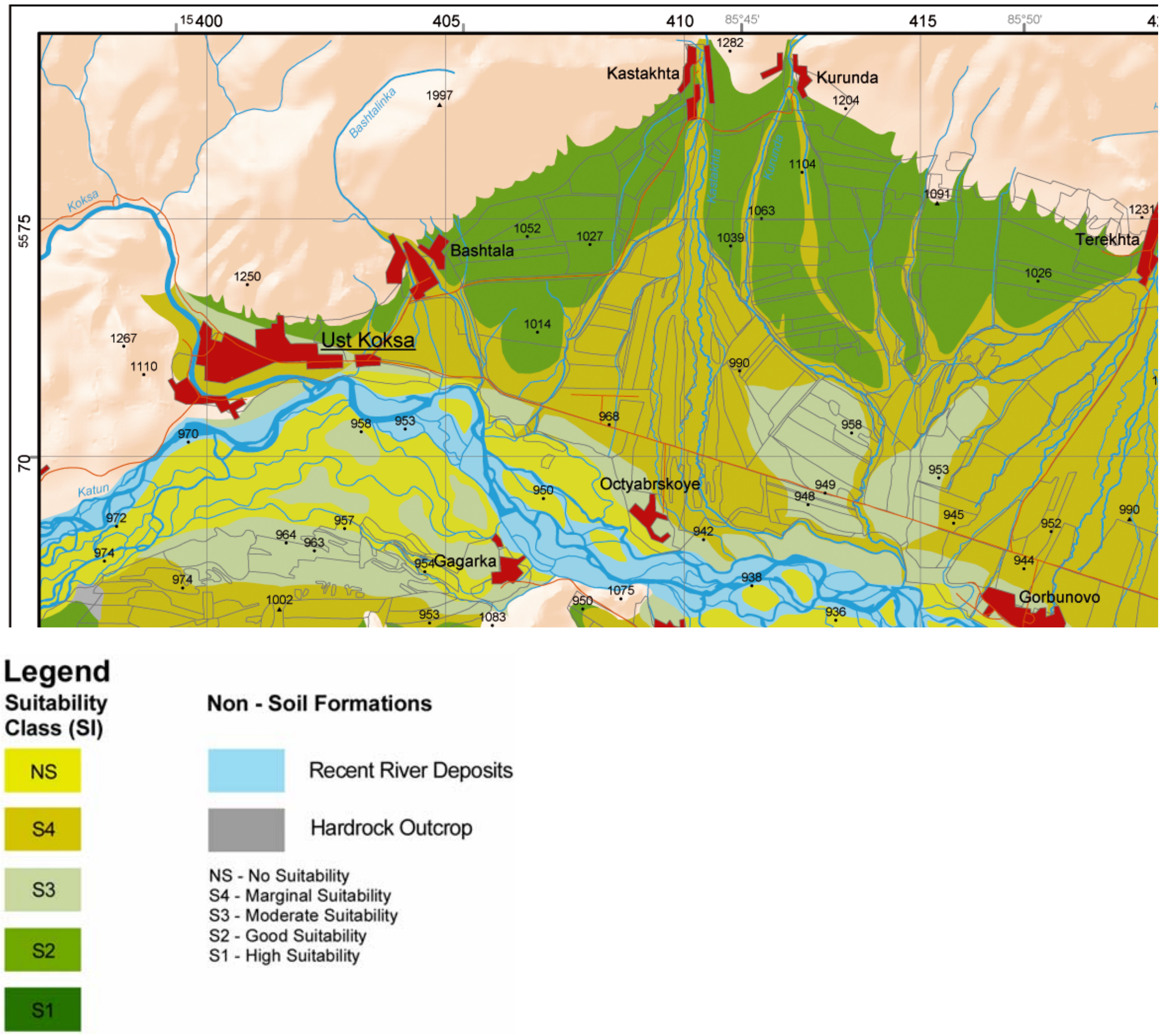


Figure 6.1.6: Portion of land suitability map for potatoes (for more details see Map B3).

The results show that 19.9% of the area have a good suitability for growing and developing potatoes (cf. Figure 6.1.6 and Map B3). Based on the soil map, these areas occur in medium humused standard chernozem which is mostly distributed in the northern part of the Uimon Basin. About 12.7% of the total area show a moderate suitability. The highest percentage, i.e. 45.6% of the total area show marginal suitability for potatoes. The reason for their marginal suitability is their location in the flood lands of the river basins (Katun, Kastachta, Terekhta, Chendyk, Multa, Tikhonkaya and Verkhnyi Uimon) which belong to the fluvial-humid zones. Less fertile soils such as alluvial-humid meadows with leached and alluvial meadow soil occur there. Summing up, the area which belongs to the standard chernozem shows their good suitability for potatoes. The more humused leached chernozem shows moderate suitability due to the limitation of climate factors in the southern part of the Uimon Basin.

In order to judge the efficiency of the classification methods the land indices data (see Table 6.1.3) were compared with the actual yield data of standard chernozem (due to their predominance in the Uimon Basin). The correlation coefficient shows a high agreement (r = 0.933) of yields and land index data.

6.1.5.4 Combination: One Map with Most Suitable Crops

It is essential for the farmers to know which crop is profitable to grow. Combining three maps into one map allows to find out the most favourable crop. Figure 6.1.8 explains this procedure:

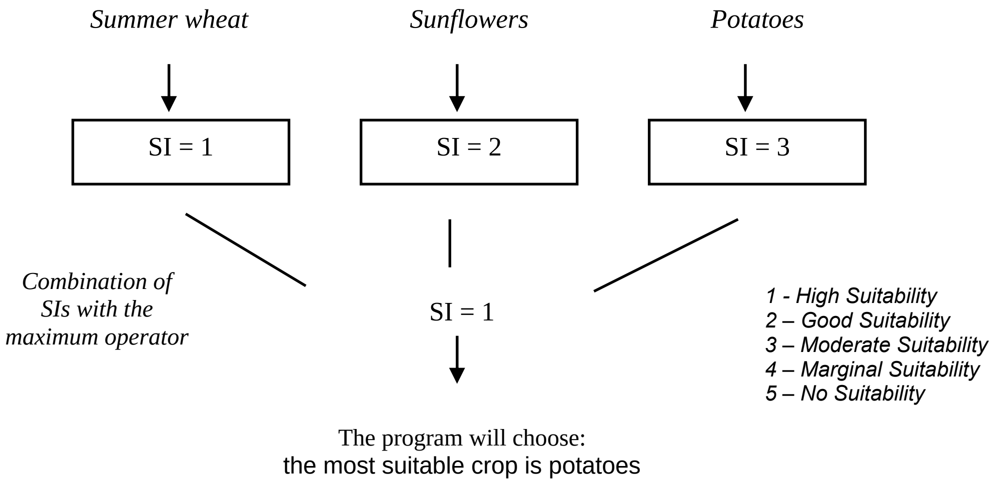


Figure 6.1.8: Example of the process for selection of the most suitable crop and suitability index.

```
/* AML to determine WSP

&if [exists wspcalc -cover] &then kill wspcalc all

&sv input1 = out_weam1
&sv input2 = out_potm1
&sv input3 = out_sunm1

copy  %input1 % wspcalc

additem wspcalc.pat wspcalc.pat W_SI 4 2 f 3
additem wspcalc.pat wspcalc.pat S_SI 4 2 f 3
additem wspcalc.pat wspcalc.pat P_SI 4 2 f 3
additem wspcalc.pat wspcalc.pat WSPC 4 2 f 3
additem wspcalc.pat wspcalc.pat WSP 7 7 C

relate add rel1  %input1 %.pat info wspcalc#  %input1 %# linear rw
relate add rel2  %input2 %.pat info wspcalc#  %input2 %# linear rw
relate add rel3  %input3 %.pat info wspcalc#  %input3 %# linear rw

tables
sel wspcalc.pat
calc W_SI = rel1//SI
calc S_SI = rel2//SI
calc P_SI = rel3//SI
q

ap
cursor ptcur declare wspcalc.pat info rw
cursor ptcur open
&do &while  %:ptcur.aml$next %

  /* Case if W=S=P
  &if [value :ptcur.W_SI] eq [value :ptcur.P_SI] and [value :ptcur.P_SI] eq [value :ptcur.S_SI] &then
  &do
   &sv :ptcur.WSP = WSP
   &sv :ptcur.WSPC = [value :ptcur.W_SI]
```

```
&end

/* Case if W
&if [value :ptcur.W_SI] lt [value :ptcur.S_SI] and [value :ptcur.W_SI] lt [value :ptcur.P_SI] &then
&do
 &sv :ptcur.WSP = W
 &sv :ptcur.WSPC = [value :ptcur.W_SI]
&end

/* Case if S
&if [value :ptcur.S_SI] lt [value :ptcur.W_SI] and [value :ptcur.S_SI] lt [value :ptcur.P_SI] &then
&do
 &sv :ptcur.WSP = S
 &sv :ptcur.WSPC = [value :ptcur.S_SI]
&end
```

The obtained results are presented in Table 6.1.11 and Figure 6.1.9.

Table 6.1.11: SI for summer wheat, sunflowers and potatoes (WSP) based on the WM Approach.

Soil type (St*)	Combined SI** of the WSP based on the WM Approach	LC***
St1	S4/W	LC4
St2	S4W/P	LC4
St3	S1/W	LC1
St4	S2/W/P	LC2
St5	S3/W	LC3
St6	S2/W	LC2
St7	S3/W/P	LC3
St8	S3/W	LC3
St9	S2/W	LC2
St10	S4/W	LC4
St11	S4/S/P	LC4

**- the location of the various soil types and subtypes can be determined in the Map B4 using the enclosed transparency (cf. Appendix C),*
*** - for details refer to Table 1.3,*
**** - for details refer to Table 6.1.12.*

Table 6.1.12: Limiting factors.

Limitation class	Limiting factors
LC1	No significant limitations. All factors are in favour of high suitability.
LC2	Slight limitations through soil nutrient elements like P_2O_5, NO_3, K_2O and humus.
LC3	Moderate limitations of soil factors in the rooting zone: $H_{(A+AB)}$, CEC and a moderate content of LC2 factors.
LC4	Severe limitations in HTC_1, HTC_2, pH and a high content of LC3 factors.
LC5	A very severe limitation due to flooding risk, erodability and salinisation-the latter one was excluded for the present study area. Very severe limitations of LC4.

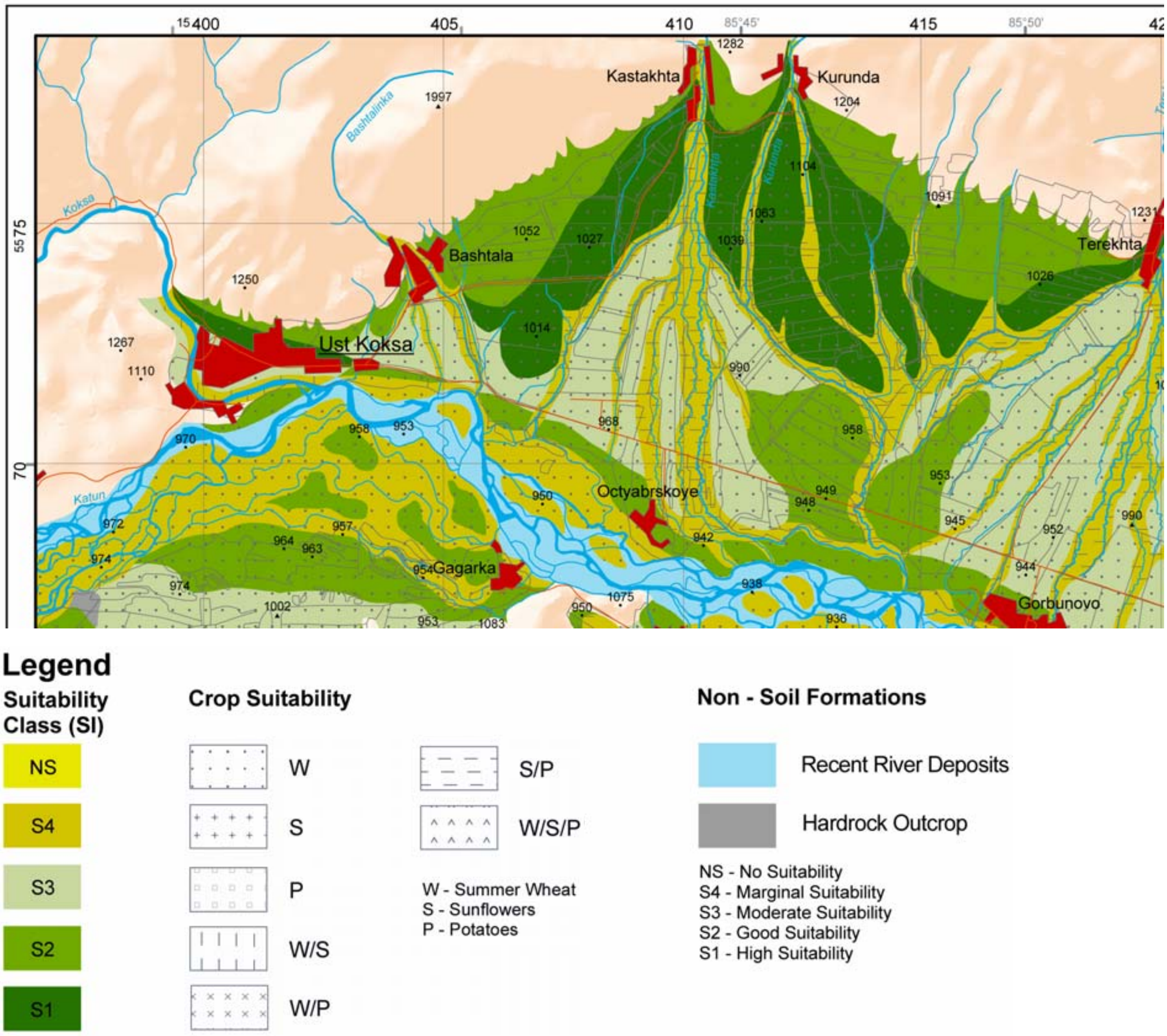


Figure 6.1.9: Portion of land suitability map for WSP (for more details see Map B4).

Table 6.1.13: Combined SI for WSP based on the WM Approach.

SI	Prevailed crop	Area in km^2	% of total area
4	W	38.25	20.08
	W/S	10.14	
	S/P	9.34	
	W/S/P	25.40	
3	W	50.42	13.23
	P	3.74	
2	W	79.36	32.8
	W/S	65.08	
1	W	113.36	25.9
Recent river deposits		31.08	7.23
Hardrock outcrops		3.65	0.85
Total		429.89	100

The results show that summer wheat is most suitable among the other crops, which covers 25.9% of the area with a high suitability for growing it (cf. Map B4). About 32.8% of the total area show a good suitability for summer wheat and sunflowers. The moderate suitability area amounts to 13.2% of the total area in which sunflowers and potatoes prevail. Marginal suitability areas make up 20.08% of the total area for all three crops. Summing up, summer wheat is the prevailing suitable crop in the Uimon Basin. It is used for the baking industry and for agricultural seeds. The second place takes sunflowers, which are used as fodder crops. Finally, potatoes are used as food for the population.

6.1.6 Conclusion

The method of weighted means of a factor set shows a high agreement of the classification results for summer wheat, sunflowers and potatoes with the values of 0.989, 0.956 and 0.933 respectively. The determination of weights for each variable was vital also because they affect the evaluation result in WM Approach. The locally adapted method developed by Burlakova (1988) turned out to be rather suitable. It was found that the method of weighting means in combination with the method of the maximum of limitation (cf. Dela Rosa 1992 and [INT-06]) improve the modelling of the newly developed ALSM. Cartographic presentations of the results on paper and in digital form give not only visualization of their land for farmers, but can also be used for further research. The advantages of this method are: it is easy to calculate. The main disadvantage of this method is the inability to take into the account the effect of crop properties which happen to have values near to class boundaries, the masking of positive key land-properties by less important ones which may depress the overall suitability class.

6.2 Modelling of the ALSM Using the Fuzzy Logic - SOM[5] Approach

6.2.1. Theory of Fuzzy Logic

Everything is vague to a degree you do not realize
till you have tried to make it precise.
Bertrand Russel[6]
(1872 - 1970)

Conventional logic deals with *true* or *false*, with nothing in between. The answer to every mathematical question is either yes or no. The principle of true or false was formulated by Aristotle some 2000 years ago as the “Law of the Excluded Middle” [INT-17]. He considered that there were degrees of *true* or *false*, particularly in making statements about possible future events. The real breakthrough was made by Prof. Lotfi Zadeh of the University of California in Berkeley. In 1965 he published a paper on the theory of fuzzy sets; that paper has given rise to thousands of papers on fuzzy mathematics and fuzzy systems theory. Of course, the idea that things must be either true or false is in many cases nonsense. Maier (2006) explains this with the following example:

Martin is tall.

With conventional logic it is not possible to describe this statement without losing information implied by the statement. Apparently, it is possible to formulate a statement "Martin is taller than 160 cm" which can be simply solved by measuring and comparing the height. However, the first statement relies on natural language. Such statements are difficult to translate into more a precise language without losing some of their semantic value. Clearly, "tall" means taller than the average height, which strongly depends on the context in which the statement was used. Being tall in a basketball team means something different than in other groups of people. Furthermore, if it is a children's basketball team, it is different again. Also, being tall in Asia might have a different flavour than in Europe.

Therefore, the semantic value cannot be measured easily with normal (crisp) logic. Clearly, it is possible to use crisp logic to approach the statements by formulating limitations like:

Martin is taller than 160 cm.

Martin is not taller than 200 cm.

Martin's height is higher than the average height of all men in the UK.

Other crisp statements to identify the semantics in the first statement can be continued. Fuzzy logic allows quantifying the statement with a single function [INT-18]. Fuzzy Logic is

5) SOM: Smallest of Maximum

6) Russell Bertrand (1918): The Philosophy of Logical Atomism, B. Russell Ed. & with an introd. by David Pears. 4th print. Open Court Publ. 1993, 188 p.

the counterpart of Boolean Logic (Maier 2006; Stolz 1998, Davidson 1994). Where Boolean or crisp logic only allows truth-values of *true* and *false*, fuzzy logic allows partial truth. In comparison to conventional logic fuzzy logic offers a better way of representing reality. In fuzzy logic, a statement is true to various degrees, ranging from completely true through half-true to completely false [INT-18]. Chapter 6.2.1 also introduces the fuzzy set theory and discusses the success and objectives of fuzzy logic.

These assets are the basic elements of the Fuzzy Logic:

- Fuzzy Sets
- Membership Functions
- Logical Operations
- If-Then-Rules

The following sub-chapters briefly introduce them.

6.2.1.2. Fuzzy Sets

The best way to understand fuzzy logic is in the context of fuzzy sets. A fuzzy set is a set that "knows" to what extend the elements are members of the set. With conventional sets the original statement describe above as:

Martin is a member of the set of tall people or

Martin is not a member of the set of tall people.

Conventional set theory only allows *true* or *false* memberships. With the fuzzy set theory it is possible to use fuzzy memberships to describe the content of a set. To describe that Martin is tall, but not very tall, can be transformed to:

Martin is a slightly strong member of the set of tall people.

With fuzzy sets it is possible to scale the degree of memberships. Fuzzy sets allow using a value that describes the memberships, for instance:

Martin is 80% member of the set of tall people.

A fuzzy set in fuzzy set theory permits the gradual assessment of the membership of elements in relation to a set. This is described with the help of membership values from 0 to 1; the higher the number, the stronger the membership. The full membership (1.0) in a conventional set in a fuzzy set can therefore be regarded as a special case of the fuzzy set. (Maier 2006). It is important to note the distinction of fuzzy memberships and probability. Both operate over the same numeric range, and at first glance both seem similar. However, there is a distinction to be made between the two statements: The probabilistic approach yields the natural-language statement, "There is an 80% chance Martin is tall", while the fuzzy terminology corresponds to "Martin's degree of membership within the set of tall people is 0.80." The semantic difference is significant. Martin is and always is a member of the set of tall people (to a degree of 80%). The probability of Martin being tall is irrelevant for his membership degree within the set [INT-18].

Values strictly between 0 and 1 characterise the fuzzy members. Figure 6.2.1 shows the membership of element x within the set X ($mf_A(x)$) and the function for conventional sets.

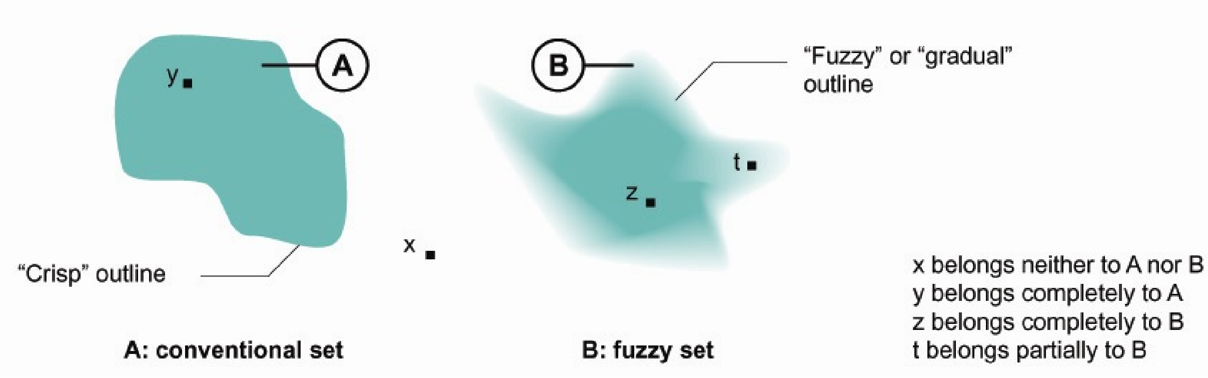


Figure 6.2.1: A comparison of a conventional set and a fuzzy set (after Chievrie and Guely 1998).

6.2.1.3 Membership Functions

In 1965 Lotfi Zadeh proposed that a fuzzy set is one to which objects can belong to different degrees, called *grades of membership.* A *membership function* (*mf)* is a curve that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1. The input space is sometimes referred to as the *universe of discourse*, a fancy name for a simple concept. The only condition a membership function must really satisfy is that it must vary between 0 and 1. The function itself can be an arbitrary curve whose shape can be defined as a function that suits from the point of view of simplicity, convenience, speed, and efficiency.

The Fuzzy Logic Toolbox software includes 11 built-in membership function types [INT-16]. These 11 functions (Figure 6.2.2) are, in turn, built from several basic functions: piecewise linear functions, the Gaussian distribution function, the sigmoid curve, and quadratic and cubic polynomial curves. For detailed information on any of the membership functions refer to the Fuzzy Toolbox in Matlab [INT-16]. By convention, all membership functions have the letters mf at the end of their names.

The simplest membership functions are formed using straight lines. Of these, the simplest is the *triangular* membership function, and it has the function name trimf. It is nothing more than a collection of three points forming a triangle. The *trapezoidal* membership function, trapmf, has a flat top and really is just a truncated triangle curve. These straight line membership functions have the advantage of simplicity.

Two membership functions are built on the *Gaussian* distribution curve: a simple Gaussian curve and a two-sided composite of two different Gaussian curves.

The *generalised bell* membership function is specified by three parameters and has the function name gbellmf. The bell membership function has one more parameter than the Gaussian membership function, so it can approach a non-fuzzy set if the free parameter is tuned. Because of their smoothness and concise notation, Gaussian and bell membership

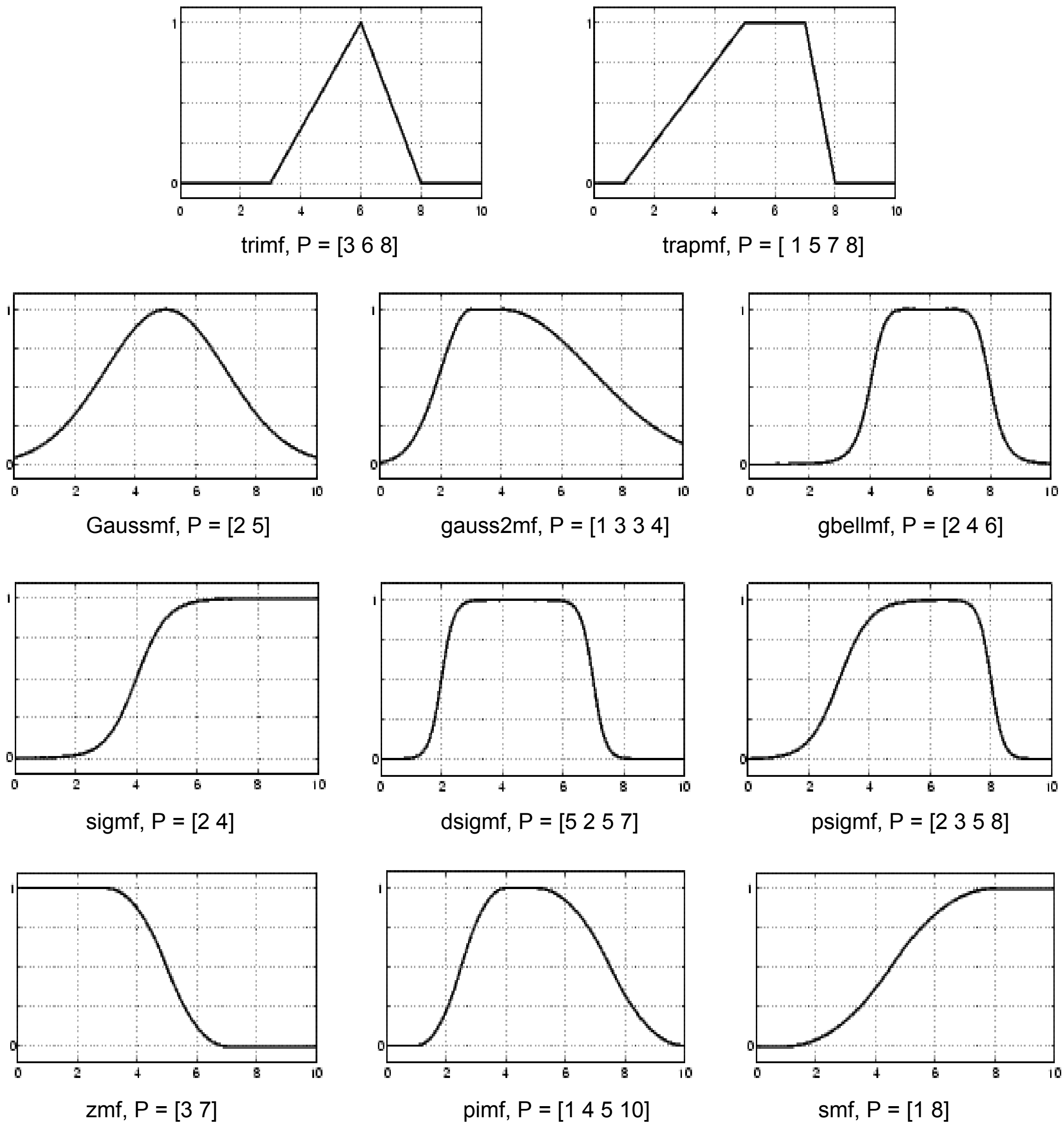


Figure 6.2.2: Membership functions in the Fuzzy Logic Toolbox software ([INT-16]).

functions are popular methods for specifying fuzzy sets. Both of these curves have the advantage of being smooth and nonzero at all points.

Although the Gaussian membership functions and bell membership functions achieve smoothness, they are unable to specify asymmetric membership functions, which are important in certain applications. The *sigmoidal* membership function is either open left or right. Asymmetric and closed (i.e. not open to the left or right) membership functions can be synthesized using two sigmoidal functions, so in addition to the basic sigmf, we also have the difference between two sigmoidal functions, dsigmf, and the product of two sigmoidal functions psigmf.

Polynomial-based curves account for several of the membership functions in the toolbox. Three related membership functions are the *Z, S*, and *Pi curves*, all named because of their shape. The function zmf is the asymmetrical polynomial curve open to the left, smf is the mirror-image function that opens to the right, and pimf is zero on both extremes with a rise in the middle. The Fuzzy Logic Toolbox also allows to use just one or two types of membership functions at the same time.

6.2.1.4 Logical Operations

The most important thing to realize about fuzzy logical reasoning is the fact that it is a superset of standard Boolean logic. In other words, if we keep the fuzzy values at their extremes of 1 (completely true), and 0 (completely false), standard logical operations will hold. In fuzzy logic the truth of any statement is a matter of degree [INT-16].

Three important operations in fuzzy logic are intersection or conjunction (AND), fuzzy union or disjunction (OR), and fuzzy complement (NOT). The AND operation is used for *min operator,* OR for *max operator* and NOT for additive complement. Figure 6.2.3 gives a graphic explanation of this:

A	B	min(A,B)
0	0	0
0	1	0
1	0	0
1	1	1

AND

A	B	max(A,B)
0	0	0
0	1	1
1	0	1
1	1	1

OR

A	1 - A
0	1
1	0

NOT

Figure 6.2.3: Logical operations in Fuzzy Logic Toolbox [INT-16].

The input values can be real numbers between 0 and 1. As shown in the Figure 6.2.3, the *min* operation accepts the statement *A* AND *B*, where *A* and *B* are limited to the range (from 0 to 1), by using the function *min* (*A*,*B*). If we replace the OR operation with the *max* function, *A* OR *B* becomes equivalent to *max* (*A, B*). Finally, the operation NOT *A* becomes equivalent to the operation $1-A$ [INT-16].

6.2.1.5 If-Then-Rules

Fuzzy sets and fuzzy operators are the subjects and verbs of fuzzy logic [INT-16]. These *if-then rule* statements are used as combined fuzzy sets with fuzzy operations to formulate the conditional statements that comprise fuzzy logic. A single fuzzy *if-then rule* assumes the form:

if *x* is *A* **then** *y* is *B*

where *A* and *B* are linguistic values defined by fuzzy sets on the ranges (universes of discourse) X and Y, respectively. The if-part of the rule "*x* is *A*" is called the *antecedent* or *premise,* while the then-part of the rule "*y* is *B*" is called the *consequent* or *conclusion*. An example of such a rule might be:

***If** service is good,* ***then** tip is average.*

A graphic visualisation of a combined use of fuzzy sets and fuzzy operators is shown below:

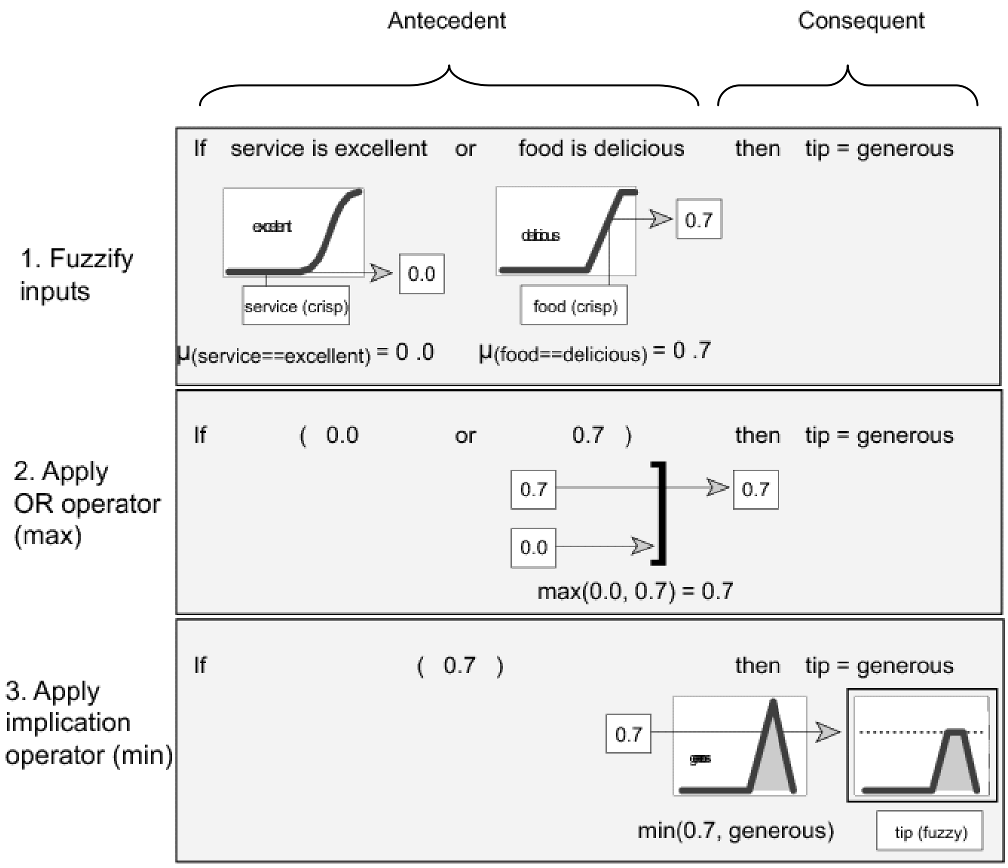


Figure 6.2.4: Logical operations in the Fuzzy Logic Toolbox [INT-16].

The output of each rule is a fuzzy set. The output fuzzy sets for each rule are then *aggregated* into a single output fuzzy set. Finally the resulting set is *defuzzified*, or resolved to a single number [INT-16]. The next section shows how the whole process works from beginning to end for a particular type of a fuzzy inference system called a Mamdani Type.

6.2.1.6 Fuzzy Inference Process

Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic [INT-16]. The mapping then provides a basis from which decisions can be made, or patterns discerned. The process of fuzzy inference involves all of the pieces that are described in the previous subchapters: membership functions, fuzzy logic operators, and if-then rules and combined into the following five steps:

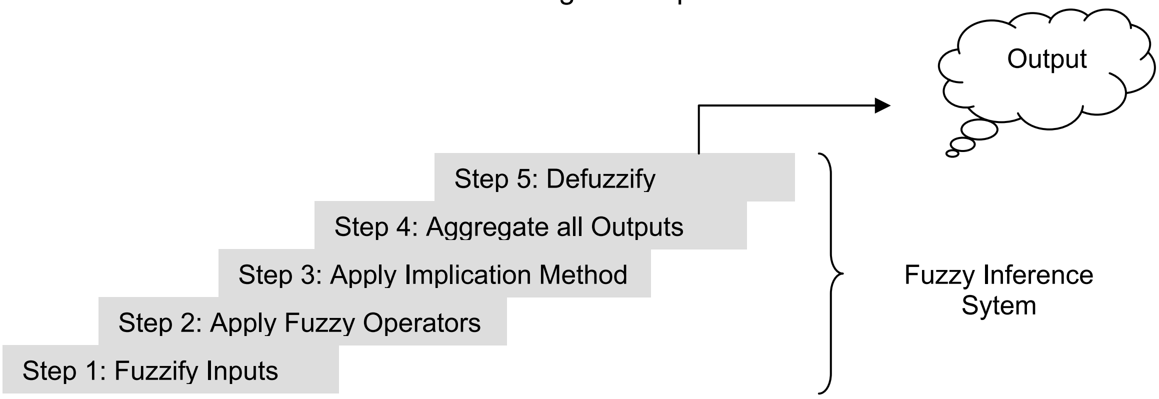


Figure 6.2.5: Process of building of Fuzzy Inference Systems [from INT-16].

There are two types of fuzzy inference systems that can be implemented in the Fuzzy Logic Toolbox: the Mamdani Type and the Sugeno Type. These two types of inference systems vary some-what in the way their outputs are determined. Below an example of the Mamdani Type will be shown. For more details refer to the website of Matworks [INT-16]. A short introduction of each step presented by Matworks is given below:

Step 1: *Fuzzify Inputs*

The first step is to take the inputs and determine the degree to which they belong to each of the appropriate fuzzy sets via membership functions. In the Fuzzy Logic Toolbox, the input is always a crisp numerical value and the output is a fuzzy degree of membership in the qualifying linguistic set (always the interval between 0 and 1).

Step 2: *Apply Fuzzy Operator*

Once the inputs have been fuzzified will be know the degree to which each part of the antecedent has been satisfied for each rule. If the antecedent of a given rule has more than one part, the fuzzy operator is applied to obtain one number that represents the result of the antecedent for that rule. This number will then be applied to the output function. The input to the fuzzy operator is two or more membership values from fuzzified input variables. The output is a single truth value. As described in Subchapter 5.2.10, any number of well-defined methods can fill in for the AND operation or the OR operation. In the Fuzzy Logic Toolbox, two built-in AND methods are supported: *min* (minimum) and *prod* (product). Two built-in OR methods are also supported: *max* (maximum), and the probabilistic OR method *probor*. The probabilistic OR method (also known as the algebraic sum) is calculated according to the equation *probor(a,b) = a + b, result is ab.* Own methods for AND and OR by writing any function are also possible.

Figure 6.2.6 shows an example of the OR operator *max* at work. The two different pieces of the antecedent (service is excellent and food is delicious) yielded the fuzzy membership values 0.0 and 0.7 respectively. The fuzzy OR operator simply selects the maximum of the two values, 0.7. If the probabilistic OR method will be used, then the result in this case would still be 0.7.

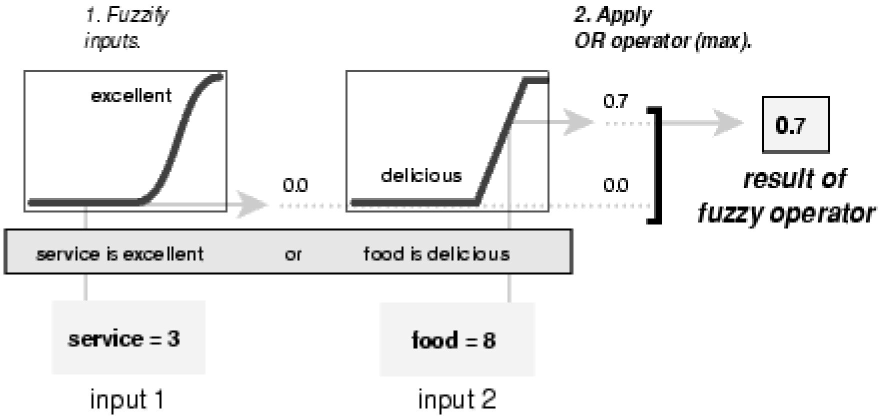


Figure 6.2.6: An example of the OR operator max at work (after Matworks 2007 [INT-16]).

Step 3. *Apply Implication Method*

Before applying the implication method, the rule's weight should be taken into account. Every rule has a *weight* (a number between 0 and 1), which is applied to the number given by the antecedent. Generally this weight is 1 (as it is for this example) and so it has no effect at all on the implication process. Once proper weighting has been assigned to each rule, the implication method is implemented. A consequent is a fuzzy set represented by a membership function, which weights appropriately the linguistic characteristics attributed to it [INT-16]. The consequent is reshaped using a function associated with the antecedent (a single number). The input for the implication process is a single number given by the antecedent, and the output is a fuzzy set. Two built-in methods are supported, the same functions that are used by the AND method: *min* (minimum), which truncates the output fuzzy set, and *prod* (product), which scales the output fuzzy set.

Step 4: *Aggregate All Outputs*

Since decisions are based on the testing of all of the rules in fuzzy inference system (FIS), the rules must be combined in some manner in order to make a decision. Aggregation

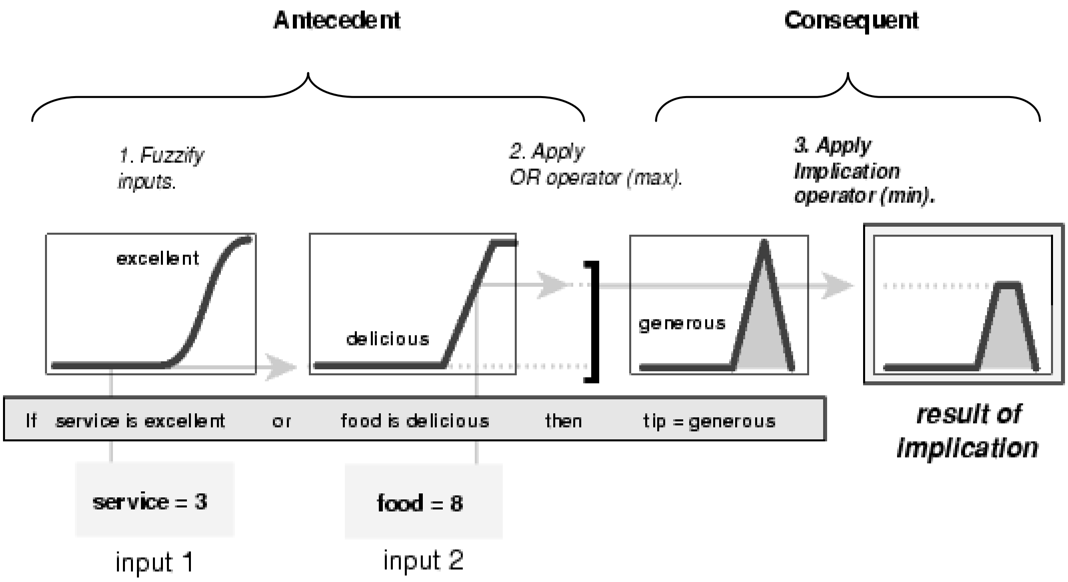


Figure 6.2.7: An application example of the implication method (after Matworks 2007 [INT-16]).

is the process by which the fuzzy sets that represent the outputs of each rule are combined into a single fuzzy set. Aggregation only occurs once for each output variable, just prior to the fifth and final step, the defuzzification. The input of the aggregation process is the list of truncated output functions returned by the implication process for each rule. The output of the aggregation process is one fuzzy set for each output variable.

Three built-in methods are supported: *max* (maximum), *probor* (probabilistic OR), and *sum* (simply the sum of each rule's output set).

In Figure 6.2.8 all three rules have been placed together to show how the output of each rule is combined, or aggregated, into a single fuzzy set whose membership function assigns a weighting for every output (tip) value.

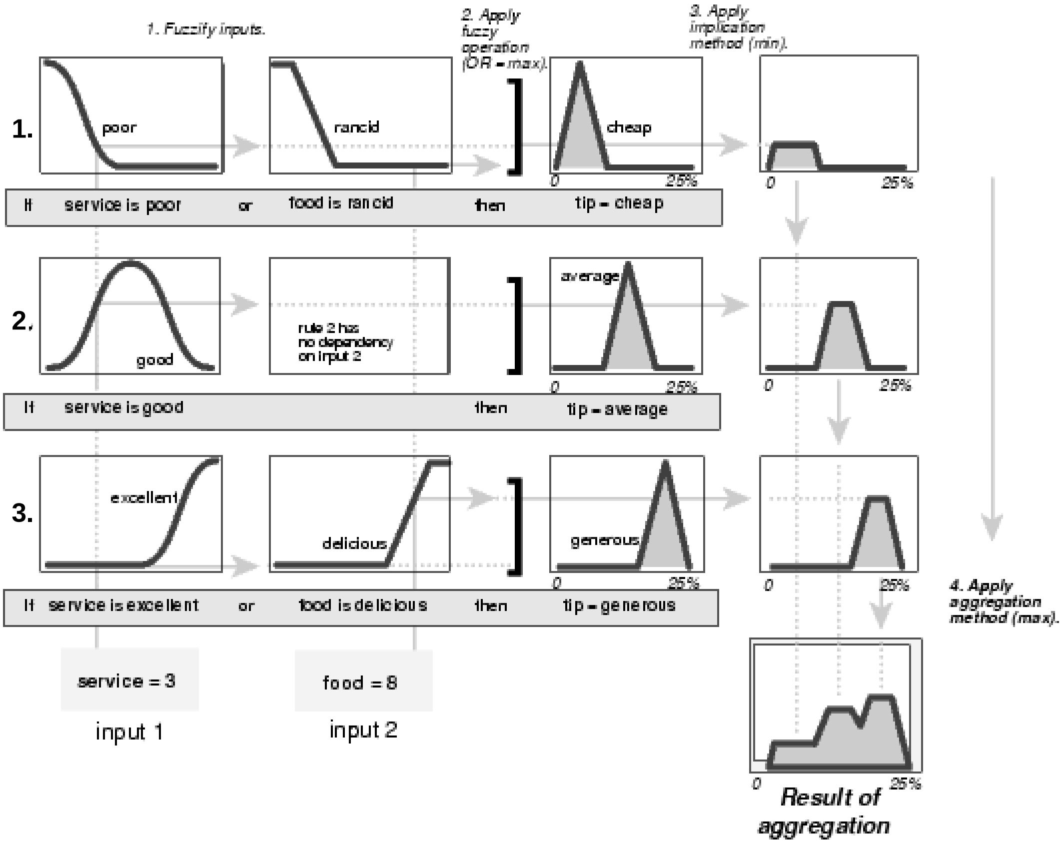


Figure 6.2.8: An application example of the aggregation method (from [INT-16]).

Step 5: *Defuzzify*

The input for the defuzzification process is a fuzzy set (the aggregate output fuzzy set) and the output is a single number. As much as fuzziness helps the rule evaluation during the intermediate steps, the final desired output for each variable is generally a single number. However, the aggregate of a fuzzy set encompasses a range of output values, and so must be defuzzified in order to resolve a single output value from the set [INT-16]). There are 5 well-known defuzzification operators as:

- Centroid Average (CA)
- Maximum Center Average (MCA)
- Mean of Maximum (MOM)
- Smallest of Maximum (SOM)
- Largest of Maximum (LOM)

Centroid Average and Maximum Center Average methods belong to the continuous ones and are frequently used in control engineering and process Modelling. The rest represents discontinuous methods, which are mainly used in decision making and pattern recognition applications for selecting the alternative.

Figure 6.2.9 shows an example of the centroid calculation, which returns the center of area under the curve.

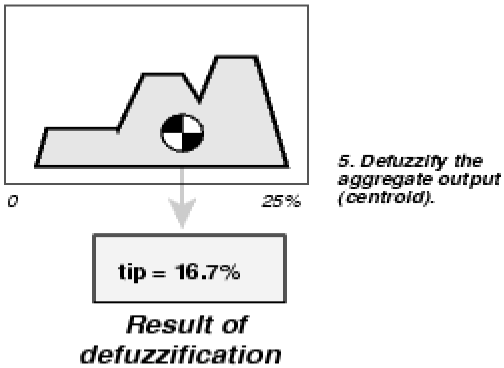


Figure 6.2.9: An application example of the aggregation method (from Matworks 2007 [INT-16]).

6.2.1.7 Fuzzy Approach to Ecological Modelling and Data Analysis

Heterogeneous and imprecise ecological data and vague expert knowledge can be integrated more effectively using fuzzy approaches (Salski 2006). Fuzzy logic can be used to handle inexact reasoning and fuzzy sets to handle data uncertainty (Zimmermann 1999). Fuzzy logic provides the means to combine numerical data and linguistic statements and to process both of them in one simulation step (Salski 2006). Ecological data or classes of ecological objects can be defined as fuzzy sets with not sharply defined boundaries, which better reflect the continuous character of nature (Zimmermann 1999).

Data analysis and *ecological modelling / expert systems* are the main application areas of the fuzzy set theory in ecological research. The problem of classifying a number of objects into classes is one of the main problems of *data analysis* and arises in many areas of ecology. Conventional classification methods based on Boolean logic ignore the continuous nature of ecological parameters and the uncertainly of data, which can result in misclassification. *Fuzzy classification,* which means the division of objects into classes that do not have sharply defined boundaries, can be carried out in various ways (Zimermann 1999), for example:

- application of fuzzy arithmetical and logical operations, e.g. to determine land suitability (Burrough el al. 1989 and 1992, Davidson 1994, Sasikala et.al. 1996, Stolz 1998, Hall et.al. 1992, Huajun et.al. 1991, Wel 2000, Fischer et al. 2002, Peisker 2006, landscape heterogenity (Syrbe 1998b), climate suitability (Fischer et.al 2002), visual decision support (Hootsmans 1996),
- fuzzy clustering, e.g. to classify some crop growth parameters (Marsili-Libelli 1989 in Zimermann 1999), to identify fuzzy soil classes (Odeh et al. 1992).

Compared with conventional classification methods fuzzy clustering method: enable a better interpretation of the data structure (Zimmermann 1999, Salski 1999).

Spatial data is an essential part of ecological data. The fuzzy extension of the interpolation procedure for spatial data, the so-called *fuzzy kriging,* can be mentioned here as an example of fuzzy approach to spatial data analysis (Piotrowski et al. 1996). Fuzzy kriging is a modify-cation of the conventional kriging procedure; it utilizes exact (crisp) measurement data as well as imprecise estimates obtained from an expert, which are defined as fuzzy numbers (Zimmermann 1999). In comparison to the conventioanal interpolation methods the results of the regionalisation based on this modified kriging procedure reflect better the imprecision of input data (Piotrowski et al. 1996).

Modelling is the next main application area of fuzzy sets and fuzzy logic in ecology (Zimmermann 1999, Salski 1999). Tlie integration of the fuzzy inference mechanisms and the expert system technique provides development tools *tor fuzzy expert systems* and *fuzzy knowledge-based models* of ecological processes. Fuzzy knowledge-based modelling can be particularly useful where there is no analytical model of the relations to be examined or where there is an insufficient amount of data for statistical analysis (Zimmermann 1999, Salski 1999). In these cases the only basis for modelling is the expert knowledge, which is often uncertain and imprecise. The evolution of expert systems into fuzzy expert systems (adding imprecision or uncertainty handling to expert systems) makes the extension of their application area for complex ecological problems possible (Zimmermann 1999, Salski 1999).

The number of applications of hybrid systems which combine the fuzzy techniques with other techniques, e.g. probabilistic approach, linear programming, neural networks, cellular automata or GIS technique (Lak et.al. 2006, EARSeL 2006 and 2007) is also increasing. As an example of an ecological use of fuzzy classification for land-suitability evaluation is presented in this monograph.

6.2.2 Modelling of ALSM Using the Fuzzy Logic - SOM Approach (Model II)

Numerous studies demonstrated that most landscape features do not conform to crisp, mutually exclusive classes (Hall et.al 1992). In the present case the fuzzy logic approach was chosen to show that the use of fuzzy information and processing offers more realistic information for landuse decision-making than the WM approach (cf. Chapter 6.1). Fuzzy techniques were used to provide realistic results by obtaining membership functions (mf) for 183 unique areas of the Uimon Basin in 5 land suitability classes, S1: High Suitability, S2: Good Suitability, S3: Moderate Suitability, S4: Marginally Suitability, NS: No Suitability. Fuzzy concepts such as “somewhat high suitability” or “very high suitability” determine the extent to which a particular area belongs the suitability class for a given crop rather than simply whether or not the area belongs to the suitability class for that crop. The crux of any fuzzy logic problem lies in deriving the membership functions (Sasikala et.al 1996). In the present study, the membership functions (mf) have been derived using Gaussian shapes. The Fuzzy

Logic Toolbox available with the Matlab package 6.1 was used for developing these shapes and mf calculations. Arc/Info GIS was used to store these data together with other GIS layers and to process fuzzy evaluations. Finally, the results were presented in the form of maps.
The deffuzification method “smallest of maximum (SOM)” was used for the defuzzification procedure. It was chosen to show the minimum suitability index for land units, so farmers can imagine the expected minimum suitability and minimum yield for their land. Below is the flow chart showing the *Fuzzy Logic - SOM Approach (Model II).*

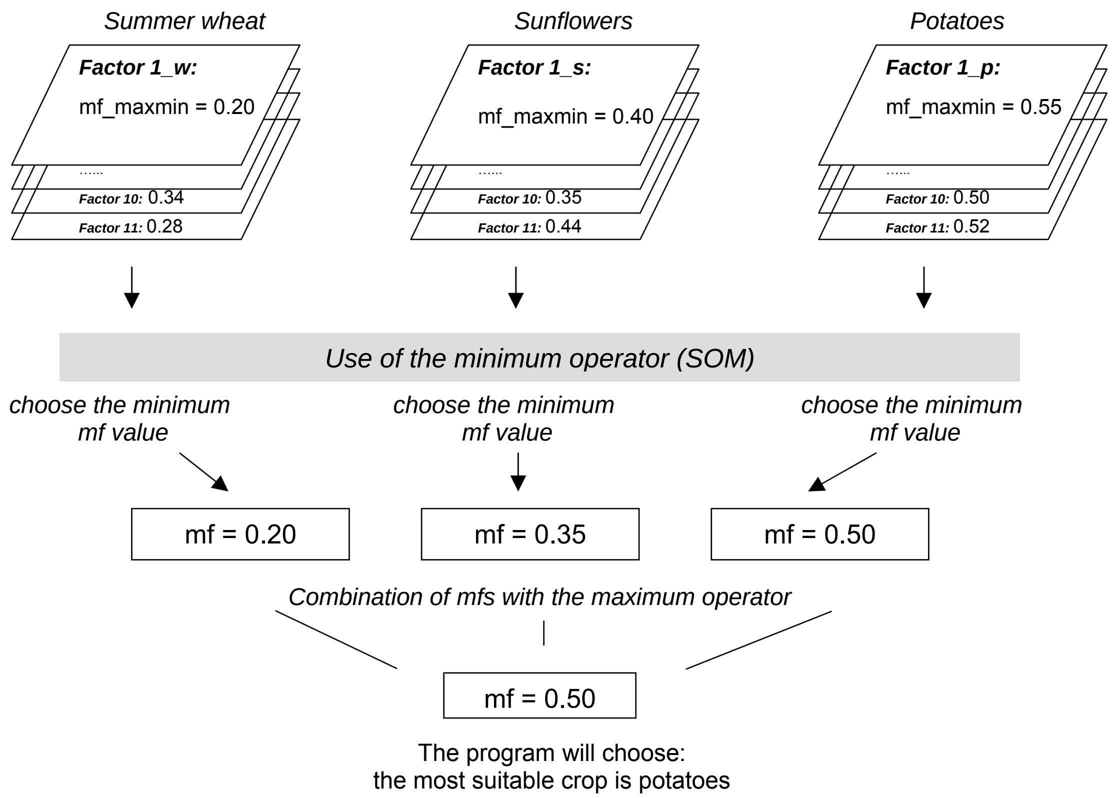


Figure 6.2.10: Flow chart for the modelling of the ALSM using Fuzzy Logic - SOM Approach.

6.2.2.1 Membership functions

A membership function of a certain class to be used within the framework of fuzzy logic is a function which inputs a certain measurement and returns the probability with which the variable can be assigned to that particular class (Sasikala et al. 1996). Therefore, each membership function for each class should be a function of the measurement value. It should also parametrically depend on the limiting values that define the class. Equation [10] is used to define the Gaussmf shapes:

$$f(x;\sigma,c) = \lambda^{\frac{-(x-c)^2}{2\sigma^2}} \qquad [10]$$

where: c is the centre of the mf, σ is the width of the mf, ℓ is the exponential function. The Gaussian approach does not work with negative values or values of zero; so the user must transform the data into positive values before fuzzification.

An example of the calculation of the Gaussmf in Matlab is given below:

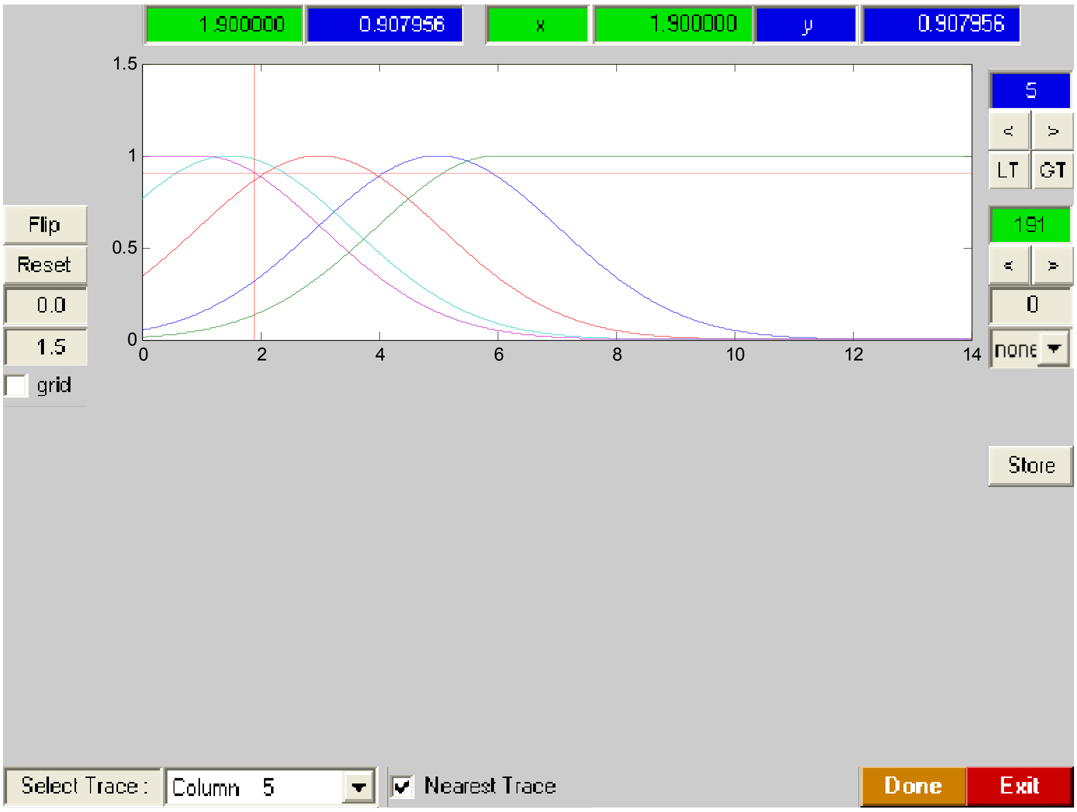


Figure 6.2.11: Visualisation of membership functions for humus in Matlab.

An example of mf output:

mf1= 0.32
mf2 = 0.13
mf3 = 0.86
mf4= 0.98
mf5= 0.91

Since fuzzy outputs vary in the present study due their own peculiarities when it comes to defining class boundaries, each factor will be discussed separately below.

6.2.2.2 Hydrothermal Coefficient 1 (HTC_1)

The hydrothermal coefficient 1 (HTC_1) for May to June, classified into the 5 classes (cf. Chapter 4), was used for the preparation of the Gauss curves (cf. Figure 6.2.12). If NS (mf), S4 (mf), S3 (mf), S2 (mf) and S1 (mf) are the membership functions for the classes no, marginal, moderate, good and high suitability, respectively, then the calculation of them in Matlab will be presented as:

S4 (mf) = Gauss2mf (x, [σ 0 σ 0.80])

S2 (mf) = Gaussmf (x, [σ 0.90])

S1 (mf) = Gaussmf (x, [σ 1.10])

S3 (mf) = Gaussmf (x, [σ 1.40])

NS (mf) = Gauss2mf (x, [σ 1.60 σ 4.0])

where the function mf (σ c (c1, c2)) is defined by Equation [10] with xmin = 0 and xmax = ∞. These functions are plotted in Figure 6.2.12 for σ = 0.216.

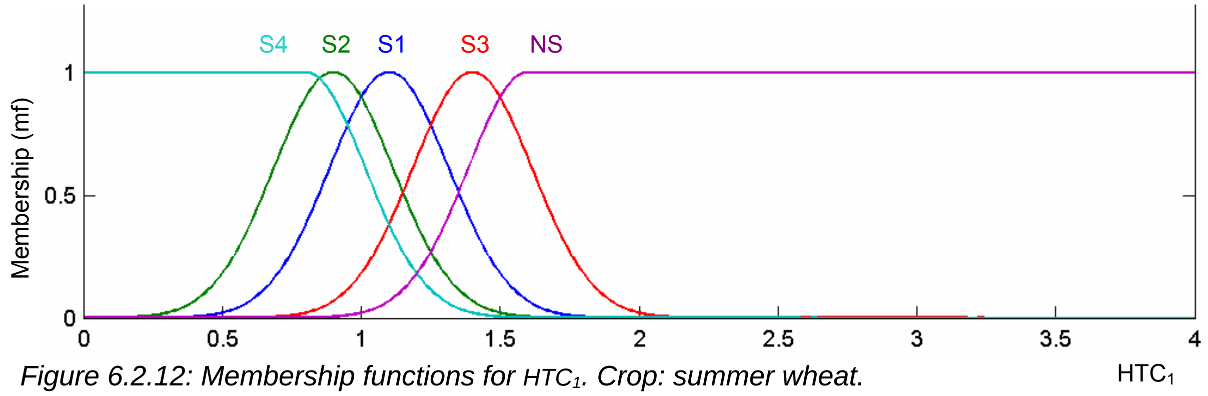


Figure 6.2.12: Membership functions for HTC_1. Crop: summer wheat.

6.2.2.3 Hydrothermal coefficient 2 (HTC_2)

The hydrothermal coefficient 2 (HTC_2) for May to September, classified into the 5 classes (cf. Chapter 4), was used for the preparation of the Gauss curves (cf. Figure 6.2.13). If NS (mf), S4 (mf), S3 (mf), S2 (mf) and S1 (mf) are the membership functions for the classes no, marginal, moderate, good and high suitability, respectively, then:

S4 (mf) = Gauss2mf (x, [0 sigma 0.80])

S2 (mf) = Gaussmf (x, [sigma 0.90])

S1 (mf) = Gaussmf (x, [sigma 1.10])

S3 (mf) = Gaussmf (x, [sigma 1.30])

NS (mf) = Gauss2mf (x, [sigma 1.40 sigma 4.0])

where this function is again defined by Equation [10] with xmin = 0 and xmax = ∞. These functions are plotted in Figure 6.2.13 for σ = 0.163.

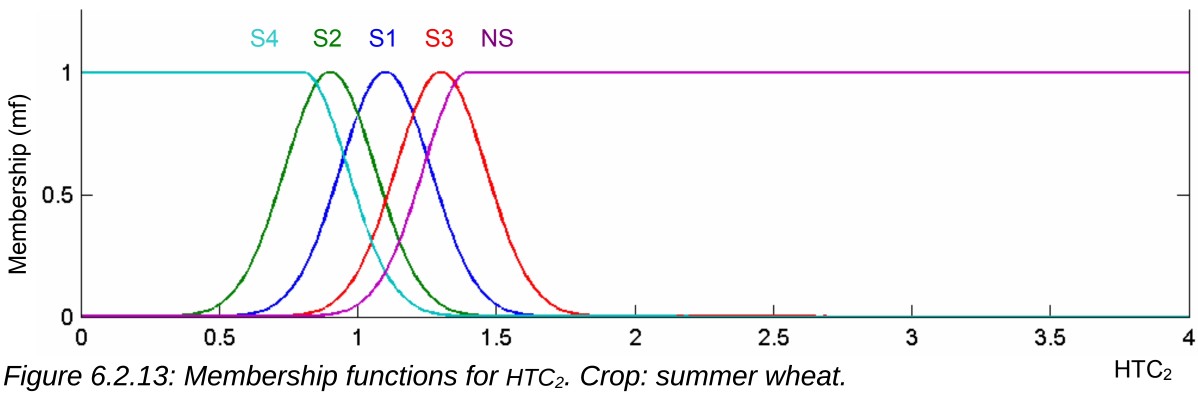


Figure 6.2.13: Membership functions for HTC_2. Crop: summer wheat.

6.2.2.4 Soil Type

The soil type, classified into the 5 classes (cf. Chapter 4), was also used for the preparation of the Gauss curves (cf. Figure 6.2.14). The advantage of using of Gaussmf here, it implies infinite tails which must influence all membership functions. In practice, if NS (mf), S4 (mf), S3 (mf), S2 (mf) and S1 (mf) indicate the membership functions for the classes no, marginal, moderate, good and high suitability, respectively, are:

NS (mf) = Gauss2mf (x, [0 sigma 30])
S4 (mf) = Gaussmf (x, [sigma 34])
S3 (mf) = Gaussmf (x, [sigma 44])
S2 (mf) = Gaussmf (x, [sigma 54])
S1 (mf) = Gauss2mf (x, [sigma 60 sigma 120])

where the functions are defined by Equation [10]. These functions are plotted in Figure 6.2.14 for σ = 16.90.

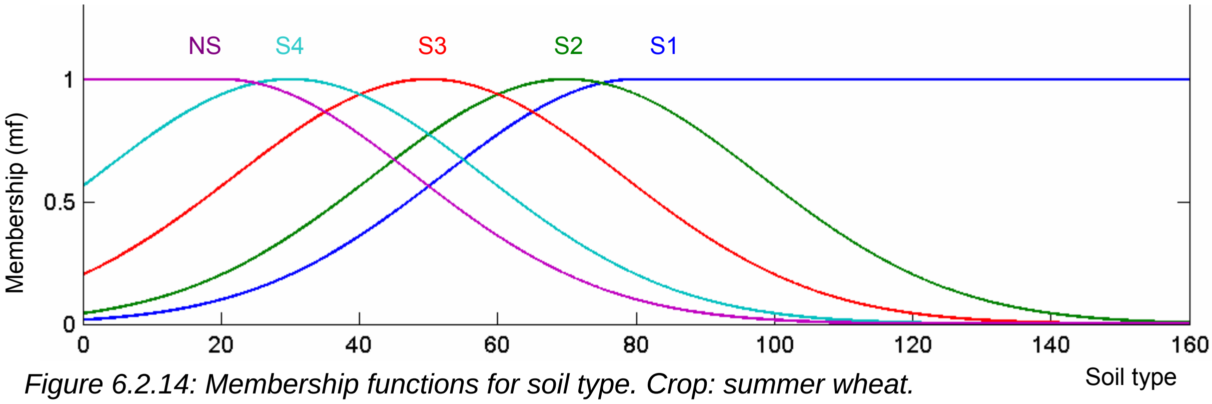


Figure 6.2.14: Membership functions for soil type. Crop: summer wheat.

6.2.2.5 Depth of Humus Horizon

The depth of humus horizon, classified into the 5 classes (cf. Chapter 4), was also used for the preparation of the Gauss curves (cf. Figure 6.2.15). If NS (mf), S4 (mf), S3 (mf), S2 (mf) and S1 (mf) are the membership functions for the classes no, marginal, moderate, good and high suitability, respectively, then:

NS (mf) = Gauss2mf (x, [sigma 0 sigma 30])
S4 (mf) = Gaussmf (x, [sigma 35])
S3 (mf) = Gaussmf (x, [sigma 45])
S2 (mf) = Gaussmf (x, [sigma 55])
S1 (mf) = Gauss2mf (x, [sigma 60 sigma 120])

where the functions are defined by Equation [10] with xmin = 0 and xmax = ∞. These functions are plotted in Figure 6.24 for σ = 17.1904

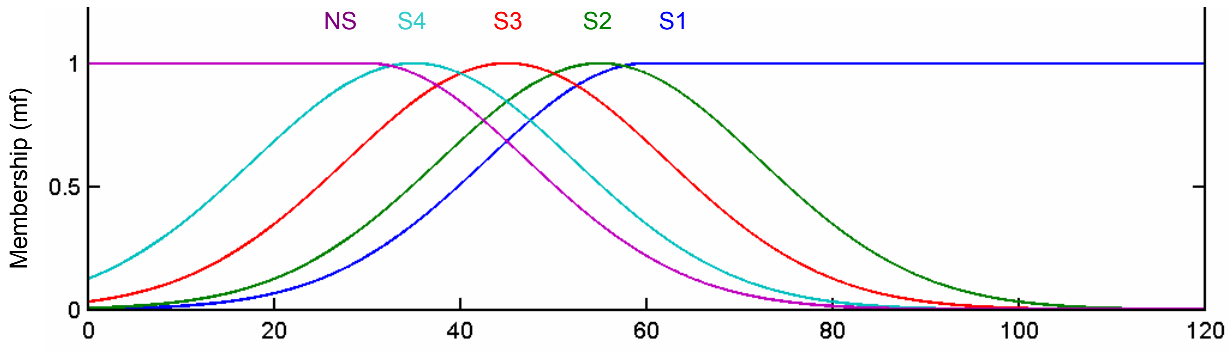


Figure 6.2.15: Membership functions for depth of humus horizon. Crop: summer wheat.

6.2.2.6 Humus

The humus, classified into the 5 classes (cf. Chapter 4), was also used for the preparation of the Gauss curves (cf. Figure 6.2.16). If NS (mf), S4 (mf), S3 (mf), S2 (mf) and S1 (mf) are the membership functions for the classes no, marginal, moderate, good and high suitability, respectively, then:

NS (mf) = Gauss2mf (x, [sigma 0 sigma 1.0])
S4 (mf) = Gaussmf (x, [sigma 1.5])
S3 (mf) = Gaussmf (x, [sigma 3])
S2 (mf) = Gaussmf (x, [sigma 5])
S1 (mf) = Gauss2mf (x, [sigma 6 sigma 14])

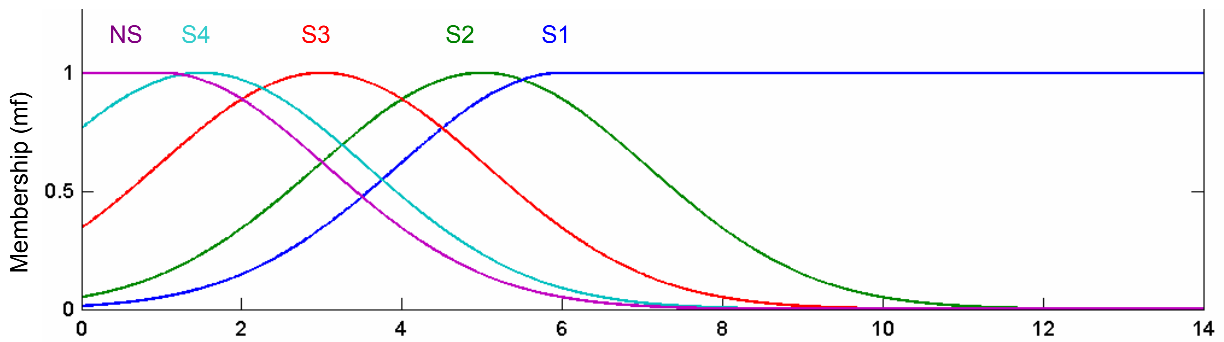


Figure 6.2.16: Membership functions for humus. Crop: summer wheat.

where the functions are defined by Equation [10] with xmin = 0 and xmax = ∞. These functions are plotted in Figure 6.2.16 for sigma (σ) = 2.048.

6.2.2.7 Nitrogen

Nitrogen, classified into the 5 classes (cf. Chapter 4), was also used for the preparation of the Gauss curves (cf. Figure 6.2.17). If NS (mf), S4 (mf), S3 (mf), S2 (mf) and S1 (mf) are the membership functions for the classes no, marginal, moderate, good and high suitability, respectively, then:

NS (mf) = Gauss2mf (x, [sigma 0 sigma 3])
S4 (mf) = Gaussmf (x, [sigma 6.5])
S3 (mf) = Gaussmf (x, [sigma 12.5])
S2 (mf) = Gaussmf (x, [sigma 17.5])
S1 (mf) = Gauss2mf (x, [sigma 20 sigma 50])

where the functions are defined by Equation [10] with xmin = 0 and xmax = ∞. These functions are plotted in Figure 6.2.17 for σ = 8.944.

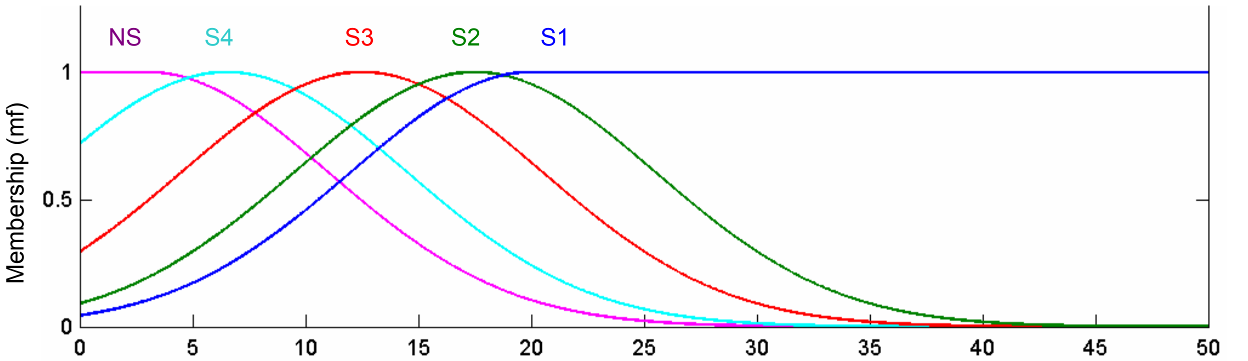


Figure 6.2.17: Membership functions for NO_3. Crop: summer wheat.

6.2.2.8 Phosphorus

Phosphorus, classified into the 5 classes (cf. Chapter 4), was also used for the preparation of the Gauss curves (cf. Figure 6.2.18). If NS (mf), S4 (mf), S3 (mf), S2 (mf) and S1 (mf) are the membership functions for the classes no, marginal, moderate, good and high suitability, respectively, then:

NS (mf) = Gauss2mf (x, [sigma 0 sigma 5])
S4 (mf) = Gaussmf (x, [sigma 7.5])
S3 (mf) = Gaussmf (x, [sigma 12.5])
S2 (mf) = Gaussmf (x, [sigma 17.5])
S1 (mf) = Gauss2mf (x, [sigma 20 sigma 35])

where the functions are defined by Equation [10] with xmin = 0 and xmax = ∞. These functions are plotted in Figure 6.2.18 for σ = 4.5923.

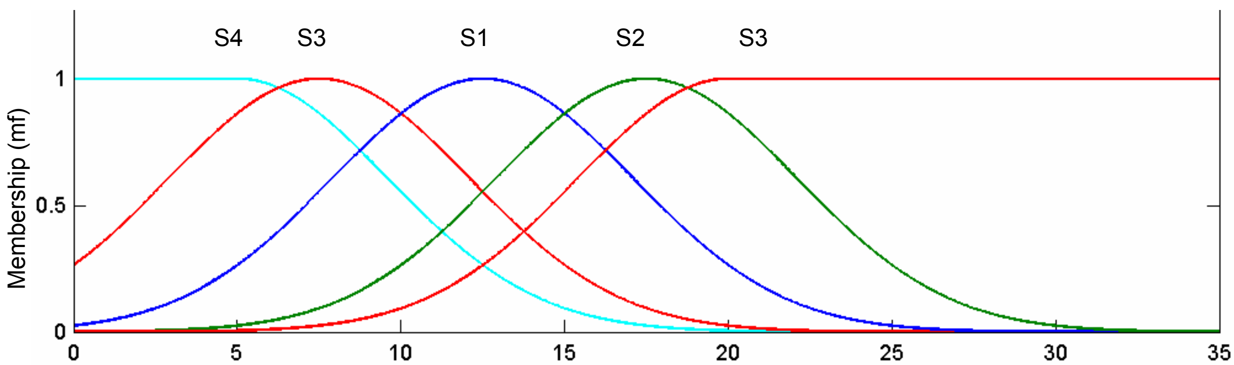


Figure 6.2.18: Membership functions for P_2O_5. Crop: summer wheat.

6.2.2.9 Potassium

Potasium, classified into the 5 classes (cf. Chapter 4), was also used for the preparation of the Gauss curves (cf. Figure 6.2.19). If NS (mf), S4 (mf), S3 (mf), S2 (mf) and S1 (mf) are the membership functions for the classes no, marginal, moderate, good and high suitability, respectively, then:

NS (mf) = Gauss2mf (x, [sigma 0 sigma 10])
S4 (mf) = Gaussmf (x, [sigma 12.5])
S3 (mf) = Gaussmf (x, [sigma 17.5])
S2 (mf) = Gaussmf (x, [sigma 22.5])
S1 (mf) = Gauss2mf (x, [sigma 25 sigma 70])

where the functions are defined by Equation [10] with xmin = 0 and xmax = ∞. These functions are plotted in Figure 6.2.19 for σ = 9.46.

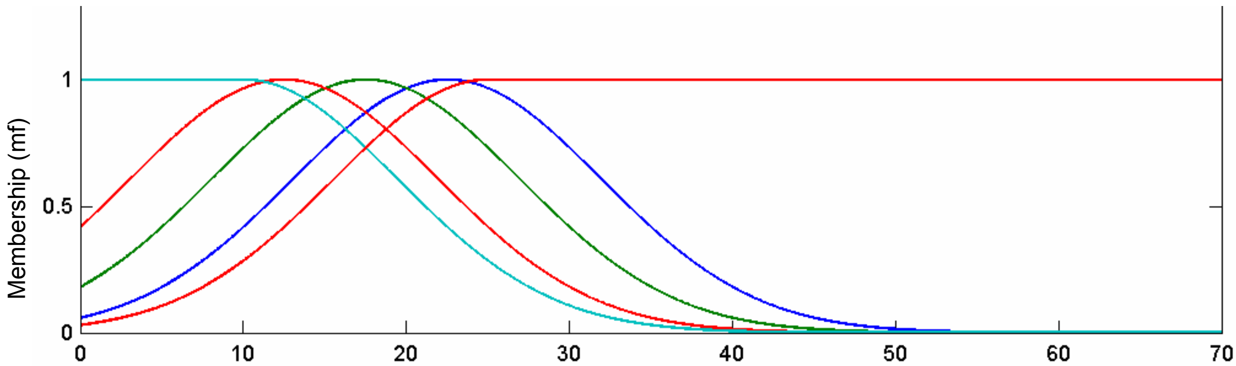


Figure 6.2.19: Membership functions for K_2O. Crop: summer wheat.

6.2.2.10 Cation Exchange Capacity

The cation exchange capacity (CEC), also classified into the 5 classes (cf. Chapter 4), was used for the preparation of the Gauss curves (cf. Figure 6.2.20) too. If NS (mf), S4 (mf), S3 (mf), S2 (mf) and S1 (mf) are the membership functions for the classes no, marginal, moderate, good and high suitability, respectively, then:

NS (mf) = Gauss2mf (x, [sigma 0 sigma 6])
S4 (mf) = Gaussmf (x, [sigma 9])
S3 (mf) = Gaussmf (x, [sigma 18.5])
S2 (mf) = Gaussmf (x, [sigma 32.5])
S1 (mf) = Gauss2mf (x, [sigma 40 sigma 80])

where the functions are defined by Equation [10] with xmin = 0 and xmax = ∞. These functions are plotted in Figure 6.2.20 for σ = 13.91.

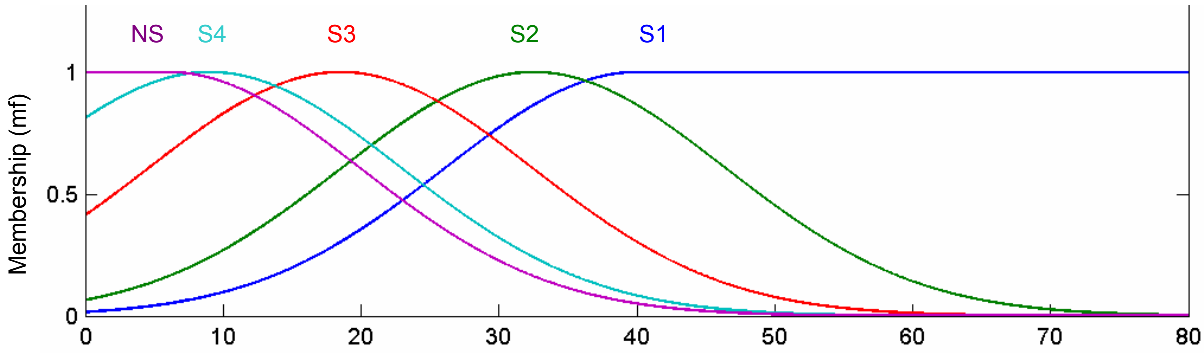


Figure 6.2.20: Membership functions for CEC. Crop: summer wheat.

6.2.2.11 Soil pH

The soil pH was classified into the 5 classes (cf. Chapter 4) and also used for the preparation of the Gauss curves (cf. Figure 6.2.21). If NS (mf), S4 (mf), S3 (mf), S2 (mf) and S1 (mf) are the membership functions for the classes no, marginal, moderate, good and high suitability, respectively, then:

NS (mf) = Gauss2mf (x, [sigma 0 sigma 6.30])
S4 (mf) = Gaussmf (x, [sigma 6.45])
S3 (mf) = Gaussmf (x, [sigma 6.65])
S2 (mf) = Gaussmf (x, [sigma 7.3])
S2 (mf) = Gaussmf (x, [sigma 7.8])
S4 (mf) = Gauss2mf (x, [sigma 8.1 sigma 14])

where the functions are defined by Equation [10] with xmin = 0 and xmax = ∞. These functions are plotted in Figure 6.2.21 for σ = 1.4359.

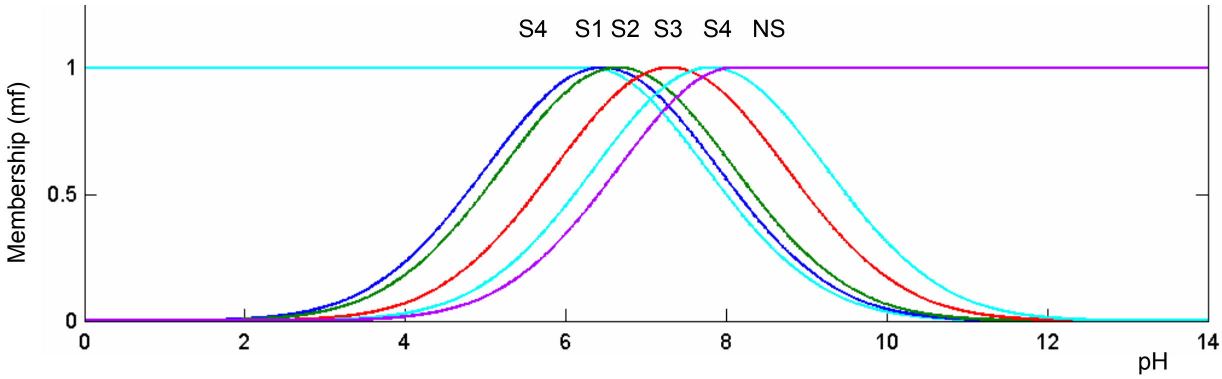


Figure 6.2.21: Membership functions for pH. Crop: summer wheat.

6.2.2.12 Flood Frequency

The flood frequency was classified into the 5 classes (cf. Chapter 4) and used the preparation of the Gauss curves (cf. Figure 6.2.22), too. If NS (mf), S4 (mf), S3 (mf), S2 (mf) and S1 (mf) are the membership functions for the classes no, marginal, moderate, good and high suitability, respectively, then:

NS (mf) = Gauss2mf (x, [sigma 80 sigma 180])

S4 (mf) = Gaussmf (x, [sigma 70])

S3 (mf) = Gaussmf (x, [sigma 50])

S2 (mf) = Gaussmf (x, [sigma 30])

S1 (mf) = Gauss2mf (x, [sigma 0 sigma 20])

where the functions are defined by Equation [10] with xmin = 0 and xmax = ∞. These functions are plotted in Figure 6.2.22 for $\sigma = 23.41$.

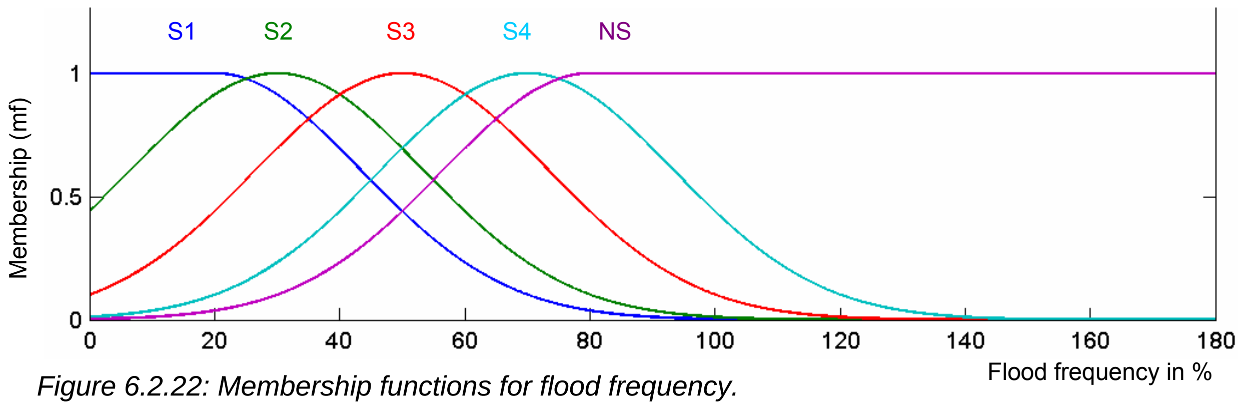


Figure 6.2.22: Membership functions for flood frequency.

Crop: summer wheat.

6.2.2.13 Fuzzy Evaluation

Once the input has been fuzzified, the membership grade of each suitability class is known. One, two or even more membership values from these fuzzified variables can be used as input to the fuzzy operator. In the present case only one value, i.e. the minimum of the maximum values in each factor was chosen. For the inputs and output operators the following logical and implication operators were employed:

AND Method = “Min”

OR Method = “Max”

Implication Method = “Min”

Defuzzification Method = “Smallest of Maximum” (SOM).

The weights of each evaluation factor in the implication process are taken as equal to 1, assuming that all considering factors are equally important for the crops (e.g. if the soil is considered: first, one needs to study its soil-chemical properties and to find out whether nutrient elements or other properties are insufficient or abundant). The minimum operator

(AND) was used in the aggregation procedure to combine the outputs of 11 factors into a single fuzzy set. These numbers are the inputs for the defuzzification process, which should be carry out to resolve a single output from the set. Thus, the smallest of maximum (SOM) operator was chosen for the defuzzification procedure to show the minimum suitability class for land units. In this way, farmers can calculate the expected minimum yield value for their land. The role of GIS in such numerous calculations and their cartographic presentation is signigicant. More details about how the Arc/Info Macro Languge (AML) was used to process the above fuzzy calculations will be discussed in the following sub-chapters.

6.2.2.14 Generation of Suitability Maps

6.2.2.14.1 Summer Wheat

In the present study all input data were integrated into a GIS using Arc/Info. AML helps to carry out the fuzzy evaluations described in the previous sub-chapter. Below is an example of the calculations (for more details see Appendix B5):

```
&sv currmin = %:edit.HU1_W%
&if %:edit.AAB1_w% le %currmin% &then &sv currmin = %:edit.AAB1_w%
&if %:edit.PH1_w% le %currmin% &then &sv currmin = %:edit.PH1_w%
&if %:edit.NO31_w% le %currmin% &then &sv currmin = %:edit.NO31_w%
&if %:edit.P2O51_w% le %currmin% &then &sv currmin = %:edit.P2O51_w%
&if %:edit.K2O1_w% le %currmin% &then &sv currmin = %:edit.K2O1_w%
&if %:edit.CEC1_w% le %currmin% &then &sv currmin = %:edit.CEC1_w%
&if %:edit.HTC1A_w% le %currmin% &then &sv currmin = %:edit.HTC1A_w%
&if %:edit.HTC2A_w% le %currmin% &then &sv currmin = %:edit.HTC2A_w%
&if %:edit.FFL1_w% le %currmin% &then &sv currmin = %:edit.FFL1_w%
…
```

The obtained results are presented in Table 6.2.1 and Figure 6.2.3.

Table 6.2.1: SI for summer wheat based on the Fuzzy Logic – SOM Approach.

Soil type (St*)	Suitability class (SI**) for summer wheat based on Fuzzy Logic - SOM Approach	Limitation class (LC***)
St1	S4 (0.21)	LC4
St2	NS (0.18)	LC5
St3	S4 (0.39)	LC4
St4	S2 (0.60)	LC2
St5*4	S4 (0.39)	LC4
St6	S2 (0.62)	LC2
St7	S3 (0.42)	LC3
St8	NS (0.12)	LC5
St9	S4 (0.45)	LC4
St10	NS (0.14)	LC5
St11*5	NS (0.12)	LC5

**- the location of the various soil type can be determined in the Map B5 using the enclosed transparency (cf. Appendix C),*
*** - for details refer to Table 1.3,*
**** - for details refer to Table 6.2.2,*
**4 – joined with St3,*
**5 – joined with St8.*

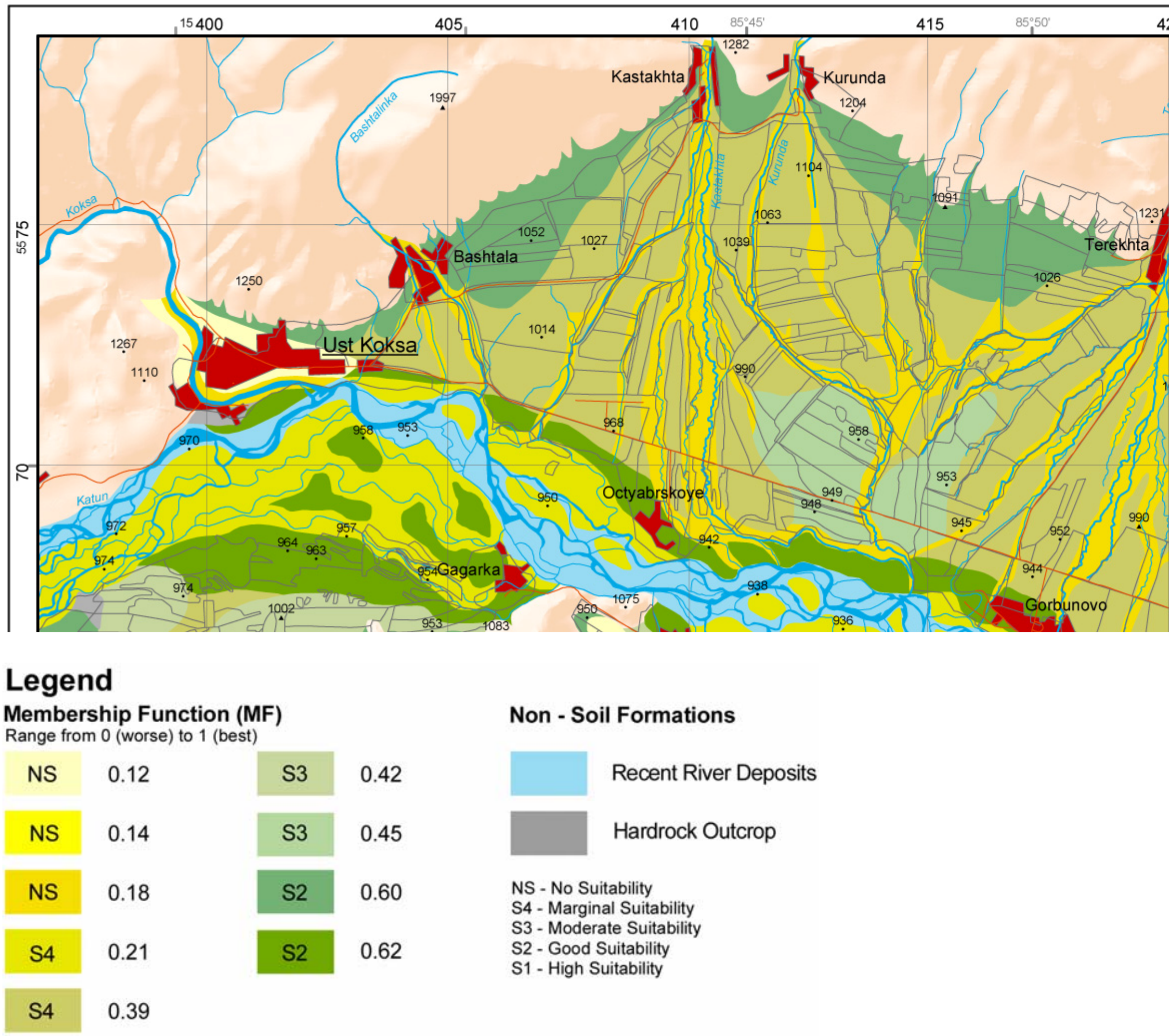


Figure 6.2.23: Portion of land suitability map for summer wheat (for more details see Map B5).

Table 6.2.2: Limiting factors.

Limitation class	Limiting factors
LC1	No significant limitations. All factors are in favour of a high suitability.
LC2	Slight limitations through soil nutrient elements like P_2O_5, NO_3, K_2O and humus.
LC3	Moderate limitations of soil factors in rooting zone: $H_{(A+AB)}$, CEC and a moderate degree of the LC2 factors.
LC4	Severe limitations in HTC1, HTC_2, pH and a high degree of the LC3 factors.
LC5	Very severe limitations due to flooding risk, erodability and salinisation- the latter one was excluded for the present study area. Very severe limitations of the LC4.

Table 6.2.4: Total area of each suitability level for summer wheat based on the Fuzzy Logic - SOM Approach.

SI for summer wheat (Model II)	MF values	Area in km^2	% of total area
NS	0.12	7.81	26.1
	0.14	23.40	
	0.18	83.13	
S4	0.21	37.16	39.7
	0.39	132.74	
S3	0.42	22.81	9.6
	0.45	18.62	
S2	0.60	3.82	16.6
	0.62	31.41	
Recent river deposits	31.08	31.08	7.2
Hardrock outcrops	3.65	3.65	0.8
Total		429.89	100

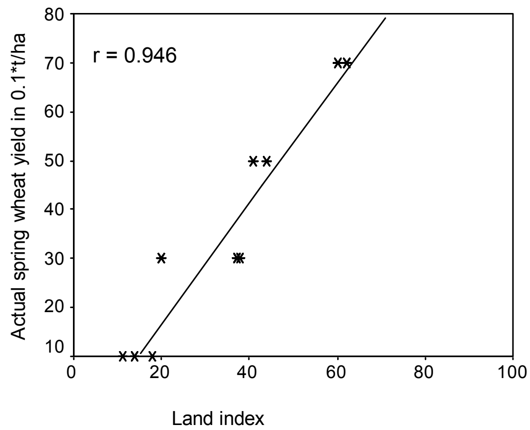


Figure 6.2.24: Linear regression of the land indices and the actual summer wheat yield. Note: some asterisks are super-imposed due to same values.

The results show that 16.6% of the area have a good suitability for growing and developing summer wheat. This area belongs to the medium humused standard chernozem, which is located in the fluvial-periglacial zone, however the slope is higher (2.8° - 5.6°) here than in the plains of the Uimon Basin. Only 9.6% of the total area show a moderate suitability in which chestnut soils prevail. The highest percentages of the area, i.e. 39.7% and 26.1% of the area, show marginal and no suitability, respectively (cf. Map B5). Similar to Model I, here the reason for being marginal and not suitable is due to their location on the flood lands of the river basins (Katun, Kastachta, Terekhta, Chendyk, Multa, Tikhonkaya and Verkhni Uimon) which are located in the fluvial-humid and fluvial-semiarid zone. However, the weakly humused chernozem in the northern part of the Uimon Basin also shows marginal suitability. Another big reason of the highest percentage of the marginal suitability here is the type of the applied method. It was found that the Fuzzy Logic - SOM Approach takes into account only

the factors of the low suitability classes of a factor set as the result for the whole area. Meanwhile, the disadvantage is that it ignores other more suitable factors. As stated at the beginning of this chapter, the purpose of using this method is only to show the minimum potential of the land, so farmers can calculate their minimum yield.
In order to judge the efficiency of the classification methods the land indices (see Table 1.3) were compared with the actual yield data of standard chernozem (due to their majority in the Uimon Basin). The correlation coefficient shows a high agreement (r = 0.946) of yields and land indices. The statistical calculations were carried out for 182 polygon units. Due to the coincidene of suitability classes Figure 6.2.24 shows no density distribution of the asterisks.

6.2.2.14.2 Sunflowers

The same GIS approach was used to integrate all data and make possible fuzzy evaluations using AML. Below an example of AML calculations for sunflowers is given (for more details see Appendix B6):

```
&sv currmin = %:edit.HU1_s%
&if %:edit.AAB1_s% le %currmin% &then &sv currmin = %:edit.AAB1_s%
&if %:edit.PH1_s% le %currmin% &then &sv currmin = %:edit.PH1_s%
&if %:edit.NO31_s% le %currmin% &then &sv currmin = %:edit.NO31_s%
&if %:edit.P2O51_s% le %currmin% &then &sv currmin = %:edit.P2O51_s%
&if %:edit.K2O1_s% le %currmin% &then &sv currmin = %:edit.K2O1_s%
&if %:edit.CEC1_s% le %currmin% &then &sv currmin = %:edit.CEC1_s%
&if %:edit.HTC1A_s% le %currmin% &then &sv currmin = %:edit.HTC1A_s%
&if %:edit.HTC2A_s% le %currmin% &then &sv currmin = %:edit.HTC2A_s%
&if %:edit.FFL1_s% le %currmin% &then &sv currmin = %:edit.FFL1_s%
…
```

The obtained results are presented in Table 6.2.5 and Figure 6.2.25.

Table 6.2.5: SI for sunflowers based on the Fuzzy Logic – SOM Approach.

Soil types (St*)	Suitability class (SI**) for sunflowers based on the Fuzzy Logic - SOM Approach	Limitation class (LC***)
St1	NS (0.05)	LC5
St2	NS (0.04)	LC5
St3	S3 (0.58)	LC3
St4	S3 (0.57)	LC3
St5	S4 (0.26)	LC4
St6	S4 (0.38)	LC4
St7	NS (0.08)	LC5
St8*6	NS (0.05)	LC5
St9	S4 (0.22)	LC4
St10*4	NS (0.05)	LC5
St11*5	NS (0.04)	LC5

** - the location of the various soil types can be determined in the Map B6 using the enclosed transparency (cf. Appendix C),*
*** - for details refer to Table 1.3,*
**** - for details refer to Table 6.2.6,*
**4 – joined with St1,*
**5 – joined with St2.*

Table 6.2.6: Limiting factors

Limitation class	Limiting factors
LC1	No significant limitations. All factors are in favour of high suitability.
LC2	Slight limitations through soil nutrient elements like P_2O_5, NO_3, K_2O and humus.
LC3	Moderate limitations of soil factors in rooting zone: $H_{(A+AB)}$, CEC and a moderate degree of LC2 factors.
LC4	Severe limitations in HTC_1, HTC_2, pH and a high degree of LC3 factors.
LC5	A very severe limitation due to flooding risk, erodability and salinisation- the latter one was excluded for the present study area. Very severe limitations of LC4.

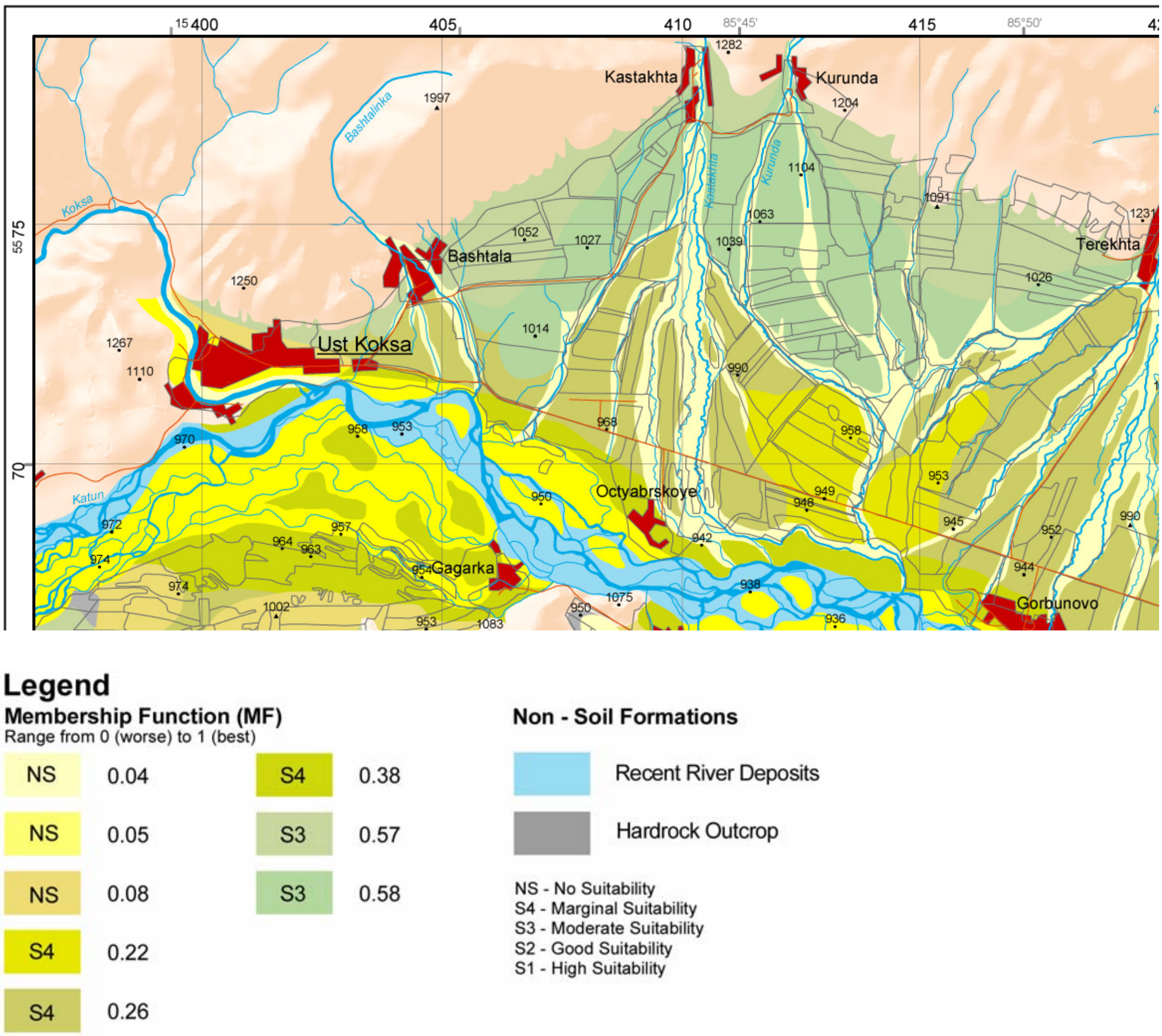


Figure 6.2.25: Portion of land suitability map for sunflowers (for more details see Map B6).

Table 6.2.7: Total area of each suitability level for sunflowers based on the Fuzzy Logic - SOM Approach.

SI for sunflowers (Model II)	MF values	Area in km^2	% of total area
NS	0.04	65.42	40.6
	0.05	85.20	
	0.08	24.28	
S4	0.22	18.62	30.7
	0.26	82.32	
	038	31.41	
S3	0.57	38.05	20.5
	0.58	50.42	
Recent river deposits	31.08	31.08	7.2
Hardrock outcrops	3.65	3.65	0.8
Total		429.89	100

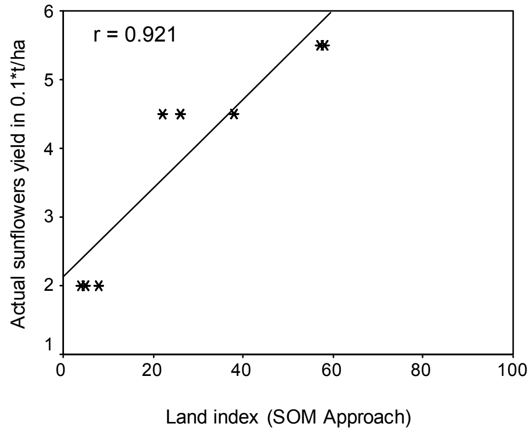


Figure 6.2.26: Linear regression of the land indices and the actual sunflowers yield. Note: some asterisks are superimposed due to same values.

The results do not show any areas of good suitability for the growing of sunflowers (cf. Map B6). About 20.5% of the area show a moderate suitability. These areas belong to medium humused standard chernozem. About 30.7% of the total area show a marginal suitability and belong to weakly humused chernozem located in fluvial-subhumid zones. The highest percentage of the area, i.e. 40.6%, shows the “not suitable” class. The reason for being not suitable is their location on the flood lands of the river basins (Katun, Kastachta, Terekhta, Chendyk, Multa, Tikhonkaya and Verkhni Uimon) which are located in the fluvial-humid zone of the Uimon Basin. As already stated in the previous sub-chapter, another major reason for this low suitability of the area for sunflowers may be the type of the applied approach. It was found that the Fuzzy Logic - SOM Approach takes into account only the factors of the low suitability classes of a factor set. The disadvantage of this method is that it ignores other more suitable factors and the advantage is that it shows the minimum potential of the suitability of the area.

In order to judge the efficiency of the classification methods the land indices (see Table 1.3) were compared with actual yields on standard chernozem (majority of soils in the Uimon Basin). The correlation coefficient has shown a high agreement (r = 0.921) of yields and land indices. Statistical calculations were carried out for 182 polygons. Due to the coincidene of suitability classes Figure 6.2.26 shows no density in the distribution of asterisks.

6.2.2.14.3 Potatoes

The same procedure as for summer wheat and sunflowers was carryied out for potatoes using Arc/Info. AML helps to carry out the fuzzy evaluations in GIS environment. Below an example of the AML calculations is given (for more details see Appendix B7):

```
&sv currmin = %:edit.HU1_p%
&if %:edit.AAB1_p% le %currmin% &then &sv currmin = %:edit.AAB1_p%
&if %:edit.PH1_p% le %currmin% &then &sv currmin = %:edit.PH1_p%
&if %:edit.NO31_p% le %currmin% &then &sv currmin = %:edit.NO31_p%
&if %:edit.P2O51_p% le %currmin% &then &sv currmin = %:edit.P2O51_p%
&if %:edit.K2O1_p% le %currmin% &then &sv currmin = %:edit.K2O1_p%
&if %:edit.CEC1_p% le %currmin% &then &sv currmin = %:edit.CEC1_p%
&if %:edit.HTC1A_p% le %currmin% &then &sv currmin = %:edit.HTC1A_p%
&if %:edit.HTC2A_p% le %currmin% &then &sv currmin = %:edit.HTC2A_p%
&if %:edit.FFL1_p% le %currmin% &then &sv currmin = %:edit.FFL1_p% , ….
```

The obtained results are presented in Table 6.2.8 and Figure 6.2.27.

Table 6.2.8: SI for potatoes based on the Fuzzy Logic - SOM Approach.

Soil types (St*)	Suitability class (SI**) for potatoes based on the Fuzzy Logic - SOM Approach	Limitation class (LC***)
St1	NS (0.04)	LC4
St2*4	NS (0.04)	LC5
St3	S4 (0.29)	LC4
St4	S2 (0.65)	LC2
St5	NS (0.15)	LC4
St6	S4 (0.28)	LC2
St7	NS (0.05)	LC3
St8	NS (0.16)	LC5
St9	NS (0.19)	LC4
St10*4	NS (0.04)	LC5
St11*4	NS (0.04)	LC5

**- the location of the various soil units can be determined in the Map B7 using the enclosed transparency (cf. Appendix C),*
*** - for details refer to Table 1.3,*
**** - for details refer to Table 6.2.9,*
**4 – joined with St1.*

Table 6.2.9: Limiting factors.

Limitation class	Limiting factors
LC1	No significant limitations. All factors are in favour of high suitability.
LC2	Slight limitations through soil nutrient elements like P_2O_5, NO_3, K_2O and humus.
LC3	Moderate limitations of soil factors in rooting zone: $H_{(A+AB)}$, CEC and a moderate degree of LC2 factors.
LC4	Severe limitations in HTC1, HTC_2, pH and a high degree of LC3 factors.
LC5	A very severe limitation due to flooding risk, erodability and salinisation- the latter one was excluded for the present study area. Very severe limitations of LC4.

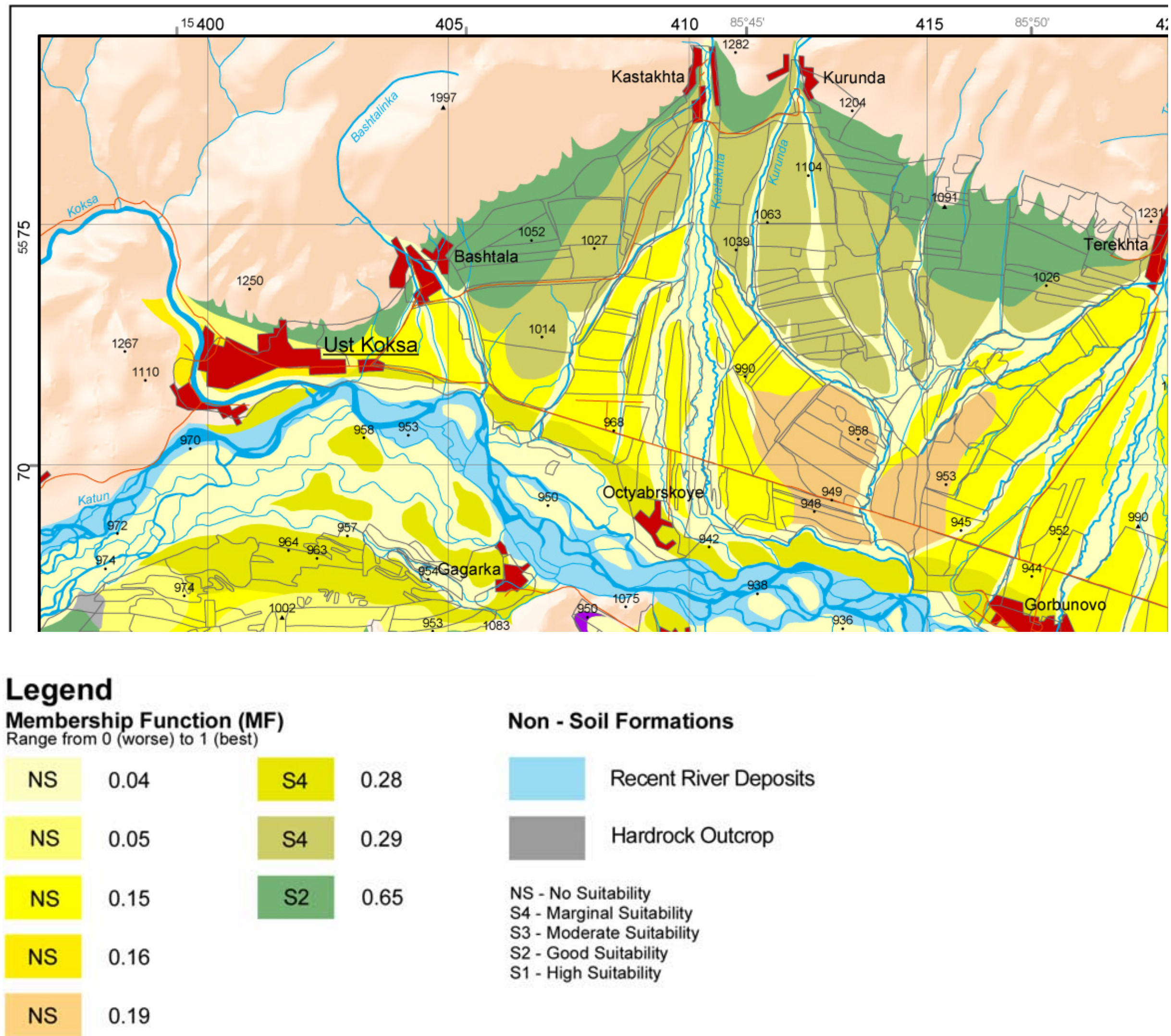


Figure 6.2.27: Portion of land suitability map for potatoes (for more details see Map B7).

The results show only 8.9% with good suitability for potatoes located in the medium humused chernozem (cf. Map B7). About 26.3% of the area show marginal suitability. The highest percentage of the area, i.e. 75.9% fall into the class “no suitability”. The reason for not being suitable is their distribution in less fertile soils like alluvial-humid meadow soil and alluvial meadow soil which are located in the flood lands of the river basins (Katun, Kastachta, Terekhta, Chendyk, Multa, Tikhonkaya and Verkhni Uimon) and belong to the fluvial-humid zone of the basin. The weakly humused chernozem located in the fluvial-semiarid zone show “no suitability” for potatoes due to the lack of sufficient humidity in the soil rooting zone and the low content of phosphorous and nitrogen. The southern part of the Uimon Basin has more fertile soils (leached chernozem), however, due to frequent rains and the proximity to the mountains, there the potatoes cannot be supplied with enough sunlight.

Table 6.2.10: Total area of each suitability level for potatoes based on the Fuzzy Logic - SOM Approach.

SI for potatoes (Model II)	MF values	Area in km^2	% of total area
NS	0.04	85.20	75.9
	0.05	24.28	
	0.15	86.71	
	0.16	113.34	
	0.19	18.63	
S4	0.28	31.41	26.3
	0.29	82.72	
S2	0.65	38.06	8.9
Recent river deposits	31.08	31.08	7.2
Hardrock outcrops	3.65	3.65	0.8
Total		429.89	100

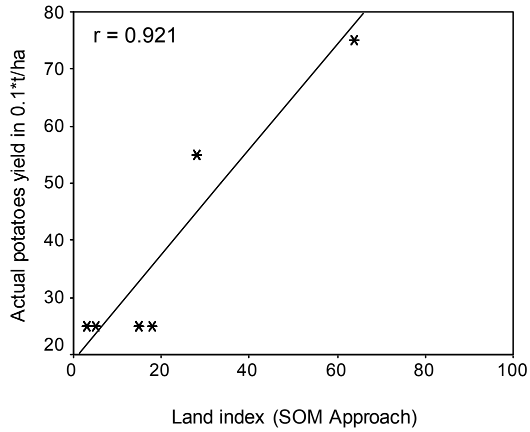


Figure 6.2.28: Linear regression of the land indices and the actual potatoes yield. Note: some asterisks are superimposed due to same values.

As already stated in the previous sub-chapter, another major reason for this low suitability of the area can be the type of method applied. It was found that the Fuzzy Logic - SOM Approach takes into account only the factors of the low suitability classes of a factor set. To sum up, the method presents the minimum potential of the land, but on other side it ignores other more suitable factors for the calculation of the suitability class.

In order to judge the efficiency of the classification methods the land indices (see Table 1.3) were compared with actual yields on standard chernozem (majority of soils in the Uimon Basin). The correlation coefficient shows a high agreement (r = 0.921) of yields and land indices. The statistical calculations were carried out for 182 polygon units. Due to the coincidence of the suitability classes Figure 6.2.28 shows no density in the distribution of the asterisks.

6.2.2.14.4 Combination: One Map with Most Suitable Crops

The GIS was used to combine the three maps (for summer wheat, sunflowers and potatoes) into one, using the maximum operator (cf. Figure 6.2.29). Thus, farmers can see which crop is where preferable for growing. Below, an example of the AML calculations for this combination is given (for more details see Map B8):

```
/* Checking the maximum
  &sv currmax = [value :ptcur.W_MINMF]
  &if [value :ptcur.S_MINMF] gt %currmax% &then &sv %currmax% = [value :ptcur.S_MINMF]
  &if [value :ptcur.P_MINMF] gt %currmax% &then &sv %currmax% = [value :ptcur.P_MINMF]
    &sv :ptcur.MAXMINMF = %currmax%

 /* Case if W=S=P
```

```
&if [value :ptcur.W_SI] eq [value :ptcur.P_SI] and [value :ptcur.P_SI] eq [value :ptcur.S_SI] &then
&do
 &sv :ptcur.WSP = WSP
 &sv :ptcur.WSPC = [value :ptcur.W_SI]
&end

/* Case if W
&if [value :ptcur.W_SI] lt [value :ptcur.S_SI] and [value :ptcur.W_SI] lt [value :ptcur.P_SI] &then
&do
 &sv :ptcur.WSP = W
 &sv :ptcur.WSPC = [value :ptcur.W_SI]
&end

/* Case if S
&if [value :ptcur.S_SI] lt [value :ptcur.W_SI] and [value :ptcur.S_SI] lt [value :ptcur.P_SI] &then
&do
 &sv :ptcur.WSP = S
 &sv :ptcur.WSPC = [value :ptcur.S_SI]
&end
```

The obtained results are presented in Table 6.2.11 and Figure 6.2.29.

Table 6.2.11: SI for WSP based on the Fuzzy Logic - SOM Approach.*

Soil types (St**)	Combined SI*** for WSP based on the Fuzzy Logic - SOM Approach	Limitation class (LC****)
St1	S4 (0.21)/W	LC4
St2	NS (0.18)/W/S/P	LC5
St3	S3 (0.58)/S	LC3
St4*5	S2 (0.65) W/P	LC2
St5	S4 (0.39)W/S	LC4
St6	S2 (0.62)/W	LC2
St7	S3 (0.42)/W	LC3
St8	NS (0.16)/W/S/P	LC5
St9	S4 (0.45)W/S	LC4
St10	NS(0.14)/W/S/P	LC5
St11	NS(0.12)/W/S/P	LC5

** - for details refer to Figure 6.2.29,*
***- the location of the various soil types can be determined in the Map B8 using the enclosed transparency (cf. Appendix C),*
**** - for details refer to Table 1.3.*
***** - for details refer to Table 6.2.12,*
**5 – joined with St6*

Table 6.2.12: Limiting factors.

Limitation class	Limiting factors
LC1	No significant limitations. All factors are in favour of high suitability.
LC2	Slight limitations through soil nutrient elements like P_2O_5, NO_3, K_2O and humus.
LC3	Moderate limitations of soil factors in rooting zone: $H_{(A+AB)}$, CEC and a moderate degree of LC2 factors.
LC4	Severe limitations in HTC1, HTC_2, pH and a high degree of LC3 factors.
LC5	Very severe limitations due to flooding risk, erodability and salinisation- the latter one was excluded for the present study area. Very severe limitations of LC4.

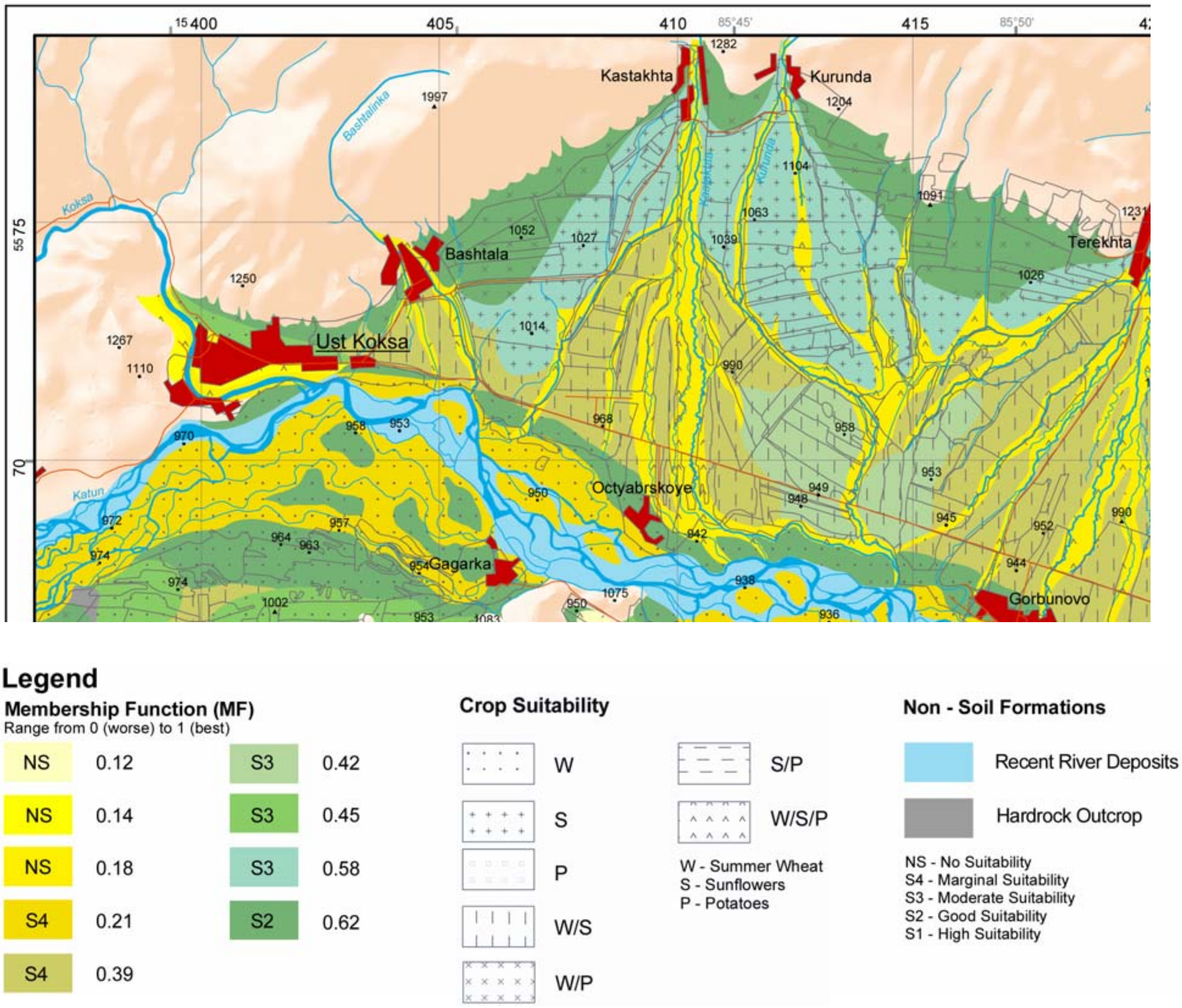


Figure 6.2.29: Portion of land suitability map for combined crops (for more details see Map B8).

Table 6.2.13: Total area of each suitability level for combined crops based on the Fuzzy Logic - SOM Approach.

SI for WSP (Model II)	MF values	Prevailed crop	Area in km^2	% of total area
NS	0.12	W/S/P*	23.39	25.6
	0.14	W/S/P	5.01	
	0.16	W/S/P	83.13	
S4	0.21	W	37.17	8.6
S3	0.39	W/S	82.32	40.9
	0.42	W	24.28	
	0.45	W/S	18.63	
	0.58	S	50.42	
S2	0.62	W	38.22	16.5
	0.65	W/P	32.58	
Recent river deposits	31.08		31.08	7.2
Hardrock outcrops	3.65		3.65	0.8
Total		429.89		100

The results show that summer wheat is most suitable among the other crops (cf. Table 6.2.13). About 16.5% of the total area show a good suitability for summer wheat and potatoes. The moderate suitability area shows 40.9% of the total area in which summer wheat and sunflowers prevail. Marginal suitability areas for summer wheat represent only 8.6% of the total area, and about 25.6% of the area do not show any suitability for the three crops. Summing up, the results show that the preferable crops in the Uimon Basin are summer wheat and sunflowers (Table 6.2.13).
In order to judge the efficiency of the classification method, the combined land suitability data were compared with the actual landuse.

6.2.2.15 Conclusions

It was found that the Fuzzy Logic - SOM Approach takes into account only the factors of the low suitability classes of a factor set. The advantage is that it is easy to calculate. The disadvantage is that it ignores other more suitable factors. As stated at the beginning of this chapter, the purpose of using this method is only to show the minimum potential of the land, so farmers can calculate their minimum yield.

6.3 Modelling of the ALSM Using the Fuzzy Logic GMF Approach

This version of the model shows the maximum advantages of the fuzzy classification and its best presentation of the heterogeneity of soil types (subtypes). In comparison to the previous Model II, where we show the minimum suitability of the area for specified crops, here its value for medium to maximum suitability is presented. This means that the farmers can calculate the expected medium and maximum crop yields. This is one of the advantages of fuzzy logic. The flowchart of this calculation process is presented in Figure 6.3.1.

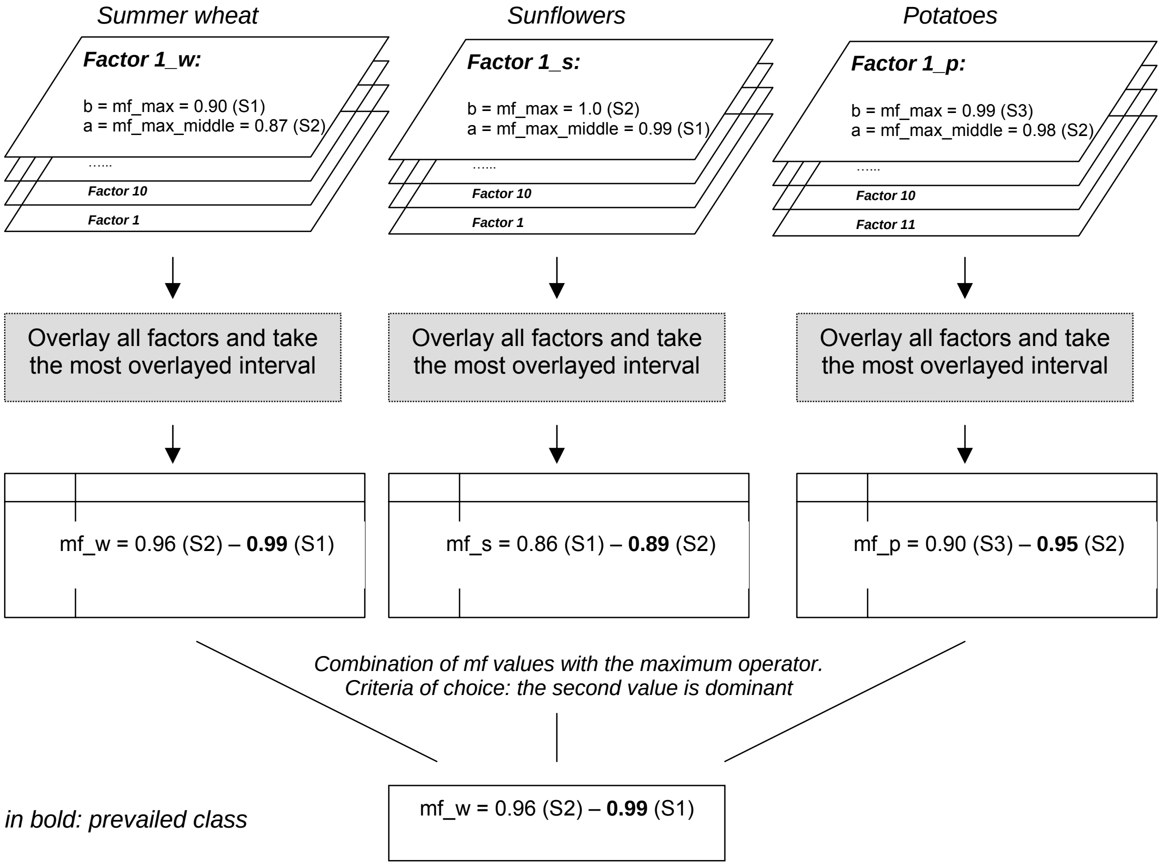


Figure 6.3.1: Flow chart for the modelling of ALSM using the Fuzzy Logic GMF Approach.

6.3.1 Fuzzy Evaluation

In this version of the model two membership values (maximum and middle (max_middle)) Gaussmf values were used. They were taken due to both their closeness to the highest value (e.g. maximum mf = 0.99 (Class S1) and the middle mf = 0.95 (Class S2)), which also says something about their belonging to different classes or only to one (then on range). For the input and output operators the following logical and implication operators were employed:

AND Method = “Min”;

OR Method = “Max”;

Implication Method = “Min”;

Defuzzification Method = “Overlaying Procedure”.

The weights of each evaluation factor in the implication process similar to Model II are taken as equal to 1, assuming also that all considering factors are equally important for the crops. The minimum operator (AND) was used to combine the outputs of 11 factors into a single fuzzy set in the aggregation procedure. The overlaying procedure (Figure 6.3.2) is applied for the defuzziification. Finally, the maximum of overlayed intervals (0 ≤ mf ≤ 1.0) among the 11 factors was taken as the result.

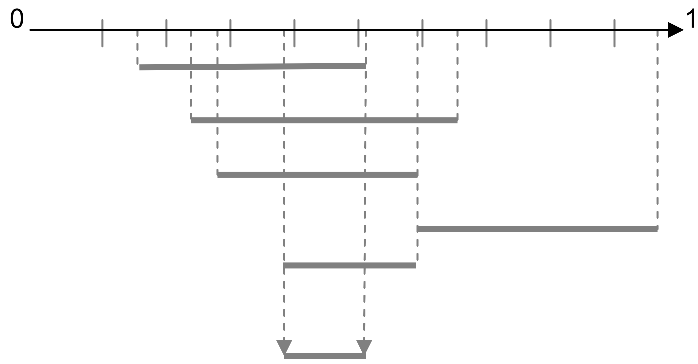


Figure 6.3.2: An example of the overlaying procedure in the Fuzzy Logic GMF Model.

The use of AML for these numerous calculations was signigicant. More details about these fuzzy calculations will be discussed in the next sub-chapters.

6.3.2 Generation of Suitability Maps

6.3.2.1 Summer Wheat

The GIS approach was used to integrate all data and calculate the fuzzy evaluation using AML. Below, an example of the AML calculations is presented (for more details see Appendix B9):

```
&sv factormin = 1.0
&sv factormax = %:edit.HU1_W%
&if %:edit.AAB1_W% ge %factormax% &then &sv factormax = %:edit.AAB1_W%
&if %:edit.PH1_W% ge %factormax% &then &sv factormax = %:edit.PH1_W%
&if %:edit.NO31_W% ge %factormax% &then &sv factormax = %:edit.NO31_W%
&if %:edit.P2O51_W% ge %factormax% &then &sv factormax = %:edit.P2O51_W%
&if %:edit.K2O1_W% ge %factormax% &then &sv factormax = %:edit.K2O1_W%
&if %:edit.CEC1_W% ge %factormax% &then &sv factormax = %:edit.CEC1_W%
&if %:edit.HTC1A_W% ge %factormax% &then &sv factormax = %:edit.HTC1A_W%
&if %:edit.HTC2A_W% ge %factormax% &then &sv factormax = %:edit.HTC2A_W%
&if %:edit.FFL1_W% ge %factormax% &then &sv factormax = %:edit.FFL1_W%
&if %:edit.St1_W% ge %factormax% &then &sv factormax = %:edit.St1_W%

calc amax = %factormax%

&if %:edit.HU2_W% gt %factormax% AND %:edit.HU2_W% lt %factormin% &then &svfactormin = %:edit.HU2_W%
&if %:edit.AAB2_W% gt %factormax% AND %:edit.AAB2_W% lt %factormin% &then &svfactormin = %:edit.AAB2_W%
&if %:edit.PH2_W% gt %factormax% AND %:edit.PH2_W% lt %factormin% &then &svfactormin = %:edit.PH2_W&
&if %:edit.NO32_W% gt %factormax% AND %:edit.NO32_W% lt %factormin% &then &sv factormin = %:edit.NO32_W%
&if %:edit.P2O52_W% gt %factormax% AND %:edit.P2O52_W% lt %factormin% &then &sv factormin = %:edit.P2O52_W%
&if %:edit.K2O2_W% gt %factormax% AND %:edit.K2O2_W% lt %factormin% &then &sv factormin = %:edit.K2O2_W%
```

```
&if %:edit.CEC2_W% gt %factormax% AND %:edit.CEC2_W% lt %factormin% &then &sv factormin = %:edit.CEC2_W%
&if %:edit.HTC1B_W% gt %factormax% AND %:edit.HTC1B_W% lt %factormin% &then &sv factormin = %:edit.HTC1B_W%
&if %:edit.HTC2B_W% gt %factormax% AND %:edit.HTC2B_W% lt %factormin% &then &sv factormin = %:edit.HTC2B_W%
&if %:edit.FFL2_W% gt %factormax% AND %:edit.FFL2_W% lt %factormin% &then &sv factormin = %:edit.FFL2_W%
&if %:edit.St2_W% gt %factormax% AND %:edit.St2_W% lt %factormin% &then &sv factormin = %:edit.St2_W%
….
```

The obtained results are presented in Table 6.3.1 and Figure 6.3.3.

Table 6.3.1: SI for summer wheat based on the Fuzzy Logic GMF Approach.

Soil types (St*)	Suitability class (SI**) for summer wheat based on Fuzzy Logic GMF Approach	Limitation classes (LC***)
St1	S4 – NS (0.96 – 1.0)	LC5
St2	S4 – NS (0.99 – 1.0)	LC5
St3	S2 – S1 (0.99 – 1.0)	LC2
St4	S1 – S2 (0.95 – 0.98)	LC2
St5	NS – S4 (0.94 – 0.98)	LC5
St6	S2 – S1 (0.98 – 0.99)	LC2
St7	S3 – S4 (0.96 – 1.0)	LC4
St8[*5]	S4 – NS (0.99 – 1.0)	LC5
St9	S1 – S2 (0.98 – 1.0)	LC2
St10[*5]	S4 – NS (0.99 – 1.0)	LC5
St11[*4]	S4 – NS (0.96 – 1.0)	LC5

**- the location of the various soil types can be determined in the Map B9 using the enclosed transparency (cf. Appendix C),*
*** - for details refer to Table 1.3,*
**** - for details refer to Table 6.3.2,*
*[*4,5] – joined with St2 (cf. Figure 6.3.3).*

Table 6.3.2: Limiting factors.

Limitation class	Limiting factors.
LC1	No significant limitations. All factors are in favour of high suitability.
LC2	Slight limitations through soil nutrient elements like P_2O_5, NO_3, K_2O and humus.
LC3	Moderate limitations of soil factors in rooting zone: $H_{(A+AB)}$, CEC and a moderate degree of LC2 factors.
LC4	Severe limitations in HTC_1, HTC_2, pH and a high degree of LC3 factors.
LC5	Very severe limitations due to flooding risk, erodability and salinization-the latter one was excluded for the present study area. Very severe limitations of LC4.

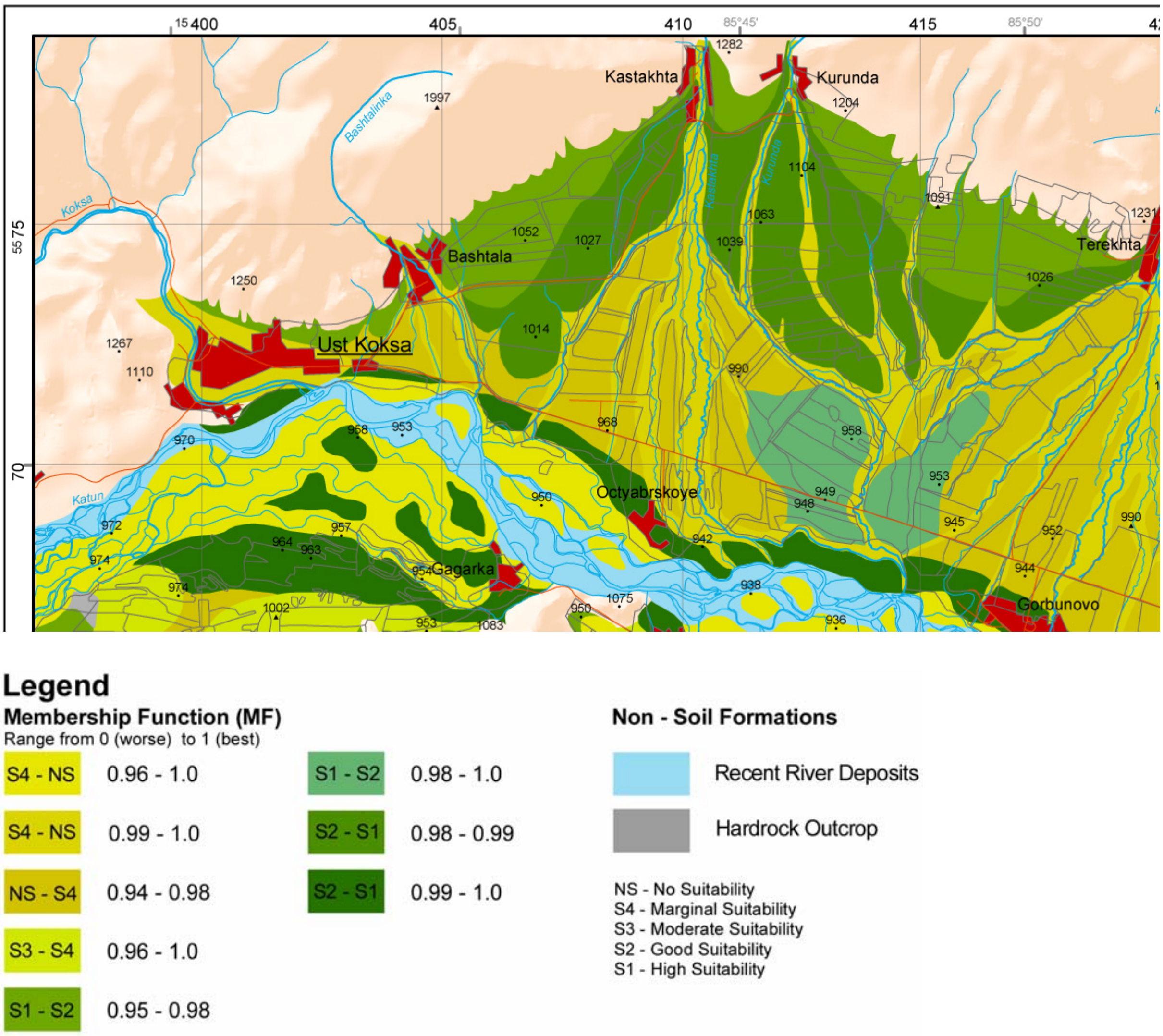


Figure 6.3.3: Portion of land suitability map for summer wheat (for more details see Map B9).

Table 6.3.3: SI for summer wheat based on the Fuzzy Logic GMF Approach.

SI and mf values for summer wheat (Model III)	Area in km^2	% of total area
S4 – NS (0.99 – 1.0)	151.34	35.2
S4 – NS (0.96 – 1.0)		
NS - S4 (0.94 - 0.98)	82.32	19.1
S3 - S4 (0.96 – 1.0)	22.81	5.3
S1 - S2 (0.98 – 1.0)	18.63	4.3
S1 - S2 (0.95 – 0.98)		
S2 - S1 (0.99 – 1.0)	50.42	11.7
S2 - S1 (0.98 – 0.99)		
Recent river deposits	31.08	7.2
Hardrock outcrops	3.65	0.8
Total	429.89	100

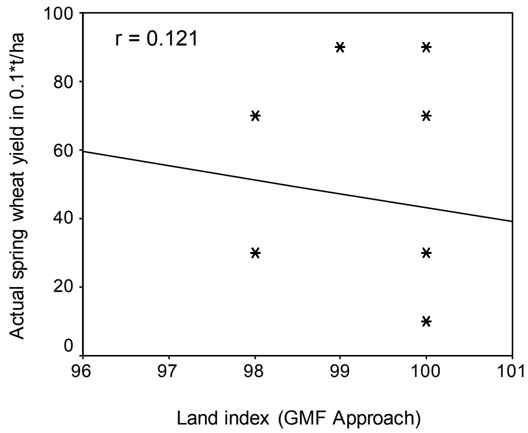


Figure 6.3.4: Linear regression of the land indices and the actual summer wheat yield. *Note: some asterisks are superimposed due to same values.*

The results show that 11.7% of the total area show a good to high suitability (class S2 - S1) for growing summer wheat (see Map B9). About 4.3% of the total area show a high to good suitability (class S1 – S2). Both of these areas consist of standard and leached chernozem. The area, with a moderate to marginal suitability (class S3 - S4) makes up for only 5.3%. The condition of no to marginal suitability (NS - S4) class makes up 19.1% of the total area. The area marginal to no suitability (class S4 - NS) makes up for 35.2% of the area. However, the reasons for marginal and no suitability for the areas are due to their location in the flood lands of the river basins (Katun, Kastachta, Terekhta, Chendyk, Multa, Tikhonkaya and Verkhni Uimon), where proluvium and alluvium deposits prevail. The location of these areas in the fluvial-humid zone and fluvial-semiarid zone has an effect on the plant rooting zone as well as on soil fertility.

In order to judge the efficiency of the classification methods, the land indices data (see Table 1.3) were compared with the actual yield data of standard chernozem (majority in the Uimon Basin). The correlation coefficient shows a low agreement (r = 0.121) of yields and land indices, which can be explained by using maximum Gaussmf values. However, as stated at the beginning of this chapter, the aim of this model was to show the maximum land potential achievable under ideal conditions.

6.3.2.2 Sunflowers

The same procedure as in Chapter 6.3.2.1 was used here. Below an example of AML calculations is given (for more details see Appendix B10):

```
&sv factormin = 1.0
&sv factormax = %:edit.HU1_s%
&if %:edit.AAB1_s% ge %factormax% &then &sv factormax = %:edit.AAB1_s%
&if %:edit.PH1_s% ge %factormax% &then &sv factormax = %:edit.PH1_s%
&if %:edit.NO31_s% ge %factormax% &then &sv factormax = %:edit.NO31_s%
&if %:edit.P2O51_s% ge %factormax% &then &sv factormax = %:edit.P2O51_s%
&if %:edit.K2O1_s% ge %factormax% &then &sv factormax = %:edit.K2O1_s%
&if %:edit.CEC1_s% ge %factormax% &then &sv factormax = %:edit.CEC1_s%
&if %:edit.HTC1A_s% ge %factormax% &then &sv factormax = %:edit.HTC1A_s%
&if %:edit.HTC2A_s% ge %factormax% &then &sv factormax = %:edit.HTC2A_s%
&if %:edit.FFL1_s% ge %factormax% &then &sv factormax = %:edit.FFL1_s%
&if %:edit.St1_s% ge %factormax% &then &sv factormax = %:edit.St1_s%

calc amax = %factormax%

&if %:edit.HU2_s% gt %factormax% AND %:edit.HU2_s% lt %factormin% &then &svfactormin = %:edit.HU2_s%
&if %:edit.AAB2_s% gt %factormax% AND %:edit.AAB2_s% lt %factormin% &then &svfactormin = %:edit.AAB2_s%
&if %:edit.PH2_s% gt %factormax% AND %:edit.PH2_s% lt %factormin% &then &svfactormin = %:edit.PH2_s&
&if %:edit.NO32_s% gt %factormax% AND %:edit.NO32_s% lt %factormin% &then &sv factormin = %:edit.NO32_s%
&if %:edit.P2O52_s% gt %factormax% AND %:edit.P2O52_s% lt %factormin% &then &sv factormin = %:edit.P2O52_s%
&if %:edit.K2O2_s% gt %factormax% AND %:edit.K2O2_s% lt %factormin% &then &sv factormin = %:edit.K2O2_s%
&if %:edit.CEC2_s% gt %factormax% AND %:edit.CEC2_s% lt %factormin% &then &sv factormin = %:edit.CEC2_s%
&if %:edit.HTC1B_s% gt %factormax% AND %:edit.HTC1B_s% lt %factormin% &then &sv factormin = %:edit.HTC1B_s%
&if %:edit.HTC2B_s% gt %factormax% AND %:edit.HTC2B_s% lt %factormin% &then &sv factormin = %:edit.HTC2B_s%
&if %:edit.FFL2_s% gt %factormax% AND %:edit.FFL2_s% lt %factormin% &then &sv factormin = %:edit.FFL2_s%
&if %:edit.St2_s% gt %factormax% AND %:edit.St2_s% lt %factormin% &then &sv factormin = %:edit.St2_s%
```

The obtained results are presented in Table 6.3.5 and Figure 6.3.5.

Table 6.3.5: SI for sunflowers based on the Fuzzy Logic GMF Approach.

Soil types (St*)	Suitability class (SI**) for sunflowers based on the FL GMF Approach	Limitation classes (LC***)
St1	S4 – NS (0.95 – 0.98)	LC5
St2	S4 (0.95 – 0.98)	LC4
St3	S3 – S2 (0.94 – 0.98)	LC3
St4	S2 – S1 (0.98 – 1.0)	LC2
St5	S4 – S3 (0.97 – 0.98)	LC4
St6	S2 – S3 (0.98 – 0.99)	LC3
St7	S3 – S2 (0.93 – 0.99)	LC3
St8	S4 – NS (0.96 – 1.0)	LC5
St9	S3 – S2 (0.93 – 0.95)	LC3
St10[*4]	S4 – NS (0.96 – 1.0)	LC5
St11	S4 – NS (0.99 – 1.0)	LC5

**- the location of the various soil types can be determined in the Map B10 using the enclosed transparency (cf. Appendix C),*
*** - for details refer to Table 1.3,*
**** - for details refer to Table 6.3.6,*
*[*4] – joined with St8 (cf. Figure 6.3.5).*

Table 6.3.6: Limiting factors.

Limitation class	Limiting factors
LC1	No significant limitations. All factors are in favour of high suitability.
LC2	Slight limitations through soil nutrient elements like P_2O_5, NO_3, K_2O and humus.
LC3	Moderate limitations of soil factors in rooting zone: $H_{(A+AB)}$, CEC and a moderate degree of LC2 factors.
LC4	Severe limitations in HTC_1, HTC_2, pH and a high degree of LC3 factors.
LC5	Very severe limitations due to flooding risk, erodability and salinisation- the latter one was excluded for the present study area. Very severe limitations of LC4.

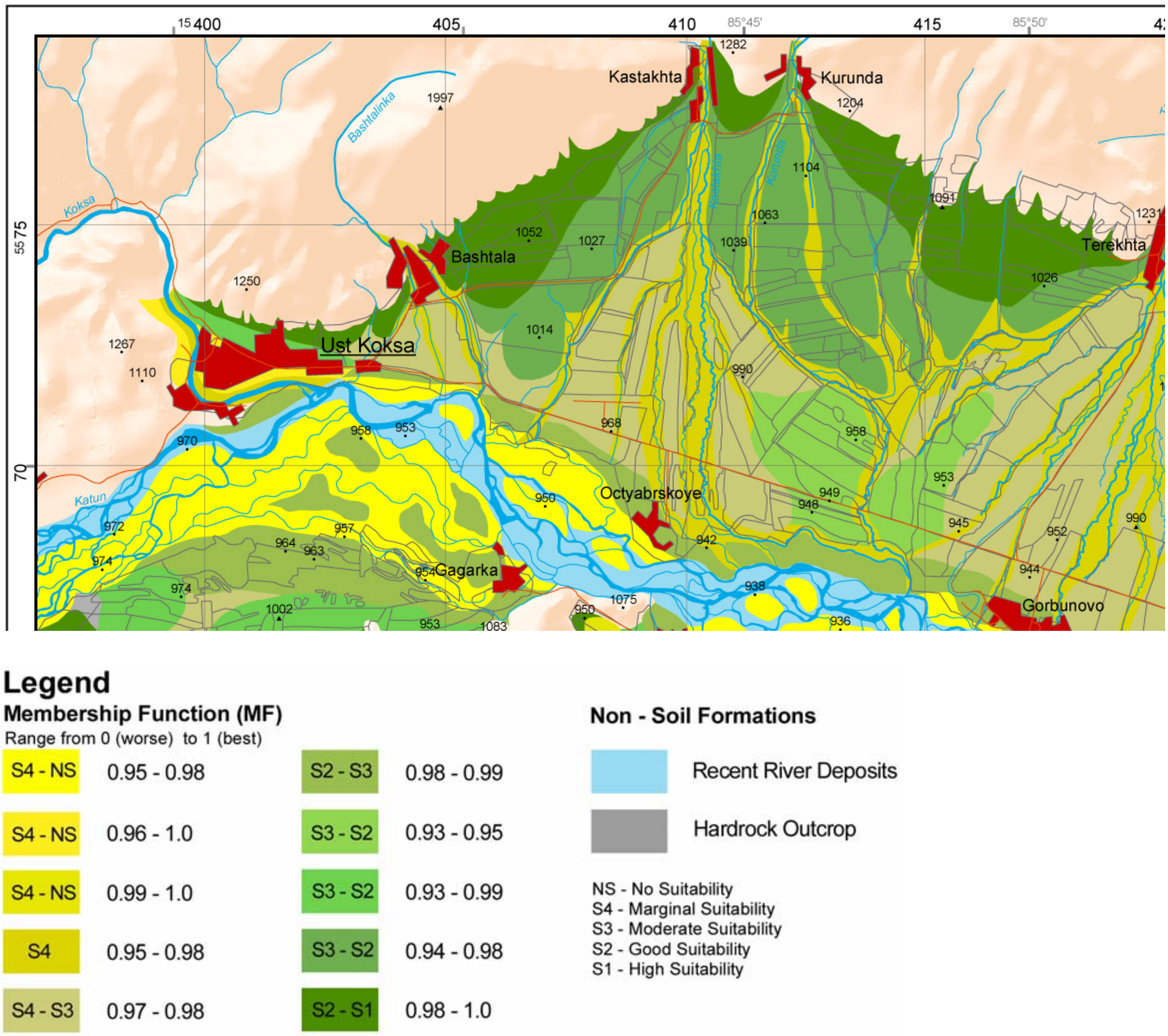


Figure 6.3.5: Portion of land suitability map for sunflowers (for more details see Map B10).

Table 6.3.7: SI for sunflowers based on the Fuzzy Logic GMF Approach.

SI and mf values for sunflowers (Model III)	Area in km^2	% of total area
S4 – NS (0.95 – 0.98)	66.41	15.4
S4 – NS (0.99 – 1.0)		
S4 – NS (0.96 – 1.0)		
S4 (0.95 – 0.98)	83.13	19.0
S4 – S3 (0.97 – 0.98)	82.32	19.0
S2 – S3 (0.98 – 0.99)	31,41	7.3
S3 - S2 (0.93 – 0.95)	93.60	22.0
S3 – S2 (0.93 – 0.99)		
S3 – S2 (0.94 – 0.98)		
S2 – S1 (0.98 – 1.0)	38.22	9.0
Recent river deposits	31.08	7.2
Hardrock outcrops	3.65	0.8
Total	429.89	100

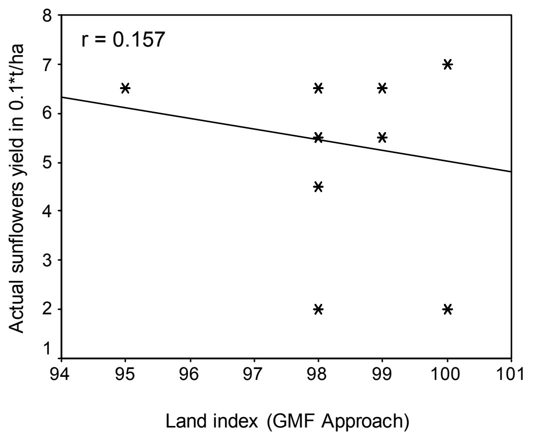


Figure 6.3.6: Linear regression of the land indices and the actual sunflower yield. *Note: some asterisks are superimposed due to same values.*

The results show that 9% of the total area are in a condition of good to high suitability (S2 – S1 class) for growing sunflowers (cf. Map B10). About 22% of the total area show a moderate to good suitability (S3 – S2 class).
About 7.3% of the total area show a good to moderate suitability (S2 – S3 class). Based on the soil map, all of these areas come under standard and leached chernozem. The area with marginal to moderate suitability (S4 – S3 class), makes up 19% of the area. The area consists of weakly humused standard chernozem which located in the fluvial-semiarid zone of the Uimon Basin. The Holocene proluvium deposits are characterized by their quaternary sediments. About 19% of the total area show only marginal suitability. The area with marginal to no suitability (S4 – NS class), makes up 15.4% of the total area. The reason for being marginal and not suitable is their location in the flood lands of the Katun River. The locations of these areas in the fluvial-humid zone have an effect on the soil rooting zone as well as on soil fertility.
In order to judge the efficiency of the classification methods, the land indices data (see Table 1.3) were compared with the actual yield data of standard chernozem (due to their predominance in the Uimon Basin). The correlation coefficient shows a low agreement (r = 0.157) of yields and land index data which can be explained by the use of maximum Gaussmf values. However, as stated at the beginning of this Chapter, the aim of this model was to show the maximum land potential achievable under ideal conditions.

6.3.2.3 Potatoes

The same procedure as in Chapter 6.3.2.1 was used here. Below an example of AML calculations is given (for more details see Appendix B11):

```
&sv factormin = 1.0
&sv factormax = %:edit.HU1_p%
&if %:edit.AAB1_p% ge %factormax% &then &sv factormax = %:edit.AAB1_p%
&if %:edit.PH1_p% ge %factormax% &then &sv factormax = %:edit.PH1_p%
&if %:edit.NO31_p% ge %factormax% &then &sv factormax = %:edit.NO31_p%
&if %:edit.P2O51_p% ge %factormax% &then &sv factormax = %:edit.P2O51_p%
&if %:edit.K2O1_p% ge %factormax% &then &sv factormax = %:edit.K2O1_p%
&if %:edit.CEC1_p% ge %factormax% &then &sv factormax = %:edit.CEC1_p%
&if %:edit.HTC1A_p% ge %factormax% &then &sv factormax = %:edit.HTC1A_p%
&if %:edit.HTC2A_p% ge %factormax% &then &sv factormax = %:edit.HTC2A_p%
&if %:edit.FFL1_p% ge %factormax% &then &sv factormax = %:edit.FFL1_p%
&if %:edit.St1_p% ge %factormax% &then &sv factormax = %:edit.St1_p%

calc amax = %factormax%

&if %:edit.HU2_p% gt %factormax% AND %:edit.HU2_p% lt %factormin% &then &svfactormin = %:edit.HU2_p%
&if %:edit.AAB2_p% gt %factormax% AND %:edit.AAB2_p% lt %factormin% &then &svfactormin = %:edit.AAB2_p%
&if %:edit.PH2_p% gt %factormax% AND %:edit.PH2_p% lt %factormin% &then &svfactormin = %:edit.PH2_p&
&if %:edit.NO32_p% gt %factormax% AND %:edit.NO32_p% lt %factormin% &then &sv factormin = %:edit.NO32_p%
&if %:edit.P2O52_p% gt %factormax% AND %:edit.P2O52_p% lt %factormin% &then &sv factormin = %:edit.P2O52_p%
&if %:edit.K2O2_p% gt %factormax% AND %:edit.K2O2_p% lt %factormin% &then &sv factormin = %:edit.K2O2_p%
&if %:edit.CEC2_p% gt %factormax% AND %:edit.CEC2_p% lt %factormin% &then &sv factormin = %:edit.CEC2_p%
…
```

The obtained results are presented in Table 6.3.8 and Figure 6.3.7.

Table 6.3.8: SI for potatoes based on the Fuzzy Logic GMF Approach.

Soil types (St*)	Suitability class (SI**) for potatoes based on the Fuzzy Logic GMF Approach	Limitation classes (LC***)
St1	S4 – NS (0.97 – 0.98)	LC5
St2	S4 – NS (0.95 – 0.98)	LC5
St3	S2 (0.93 – 0.95)	LC2
St4	S2 – S1 (0.98 – 1.0)	LC2
St5	S4 (0.94 – 0.97)	LC4
St6	S2 – S1 (0.98 – 0.99)	LC2
St7	S4 – S3 (0.96 – 0.97)	LC4
St8	NS – S4 (0.92 – 0.99)	LC5
St9	S3 (0.95 – 0.97)	LC3
St10	S4 – NS (0.91 – 1.0)	LC5
St11*4	S4 – NS (0.97 – 0.98)	LC5

**- the location of the various soil units can be determined in the Map B11 using the enclosed transparency (cf. Appendix C),*
*** - for details refer to Table 1.3,*
**** - for details refer to Table 6.3.9,*
**4 – joined with St1 (cf. Figure 6.3.7).*

Table 6.3.9: Limiting factors.

Limitation class	Limiting factors
LC1	No significant limitations. All factors are in favour of a high suitability.
LC2	Slight limitations through soil nutrient elements like P_2O_5, NO_3, K_2O and humus.
LC3	Moderate limitations of soil factors in rooting zone: $H_{(A+AB)}$, CEC and a moderate degree of the LC2 factors.
LC4	Severe limitations in HTC_1, HTC_2, pH and a high degree of the LC3 factors.
LC5	Very severe limitations due to flooding risk, erodability and salinisation-latter one was excluded for the present study area. Very severe limitations of the LC4.

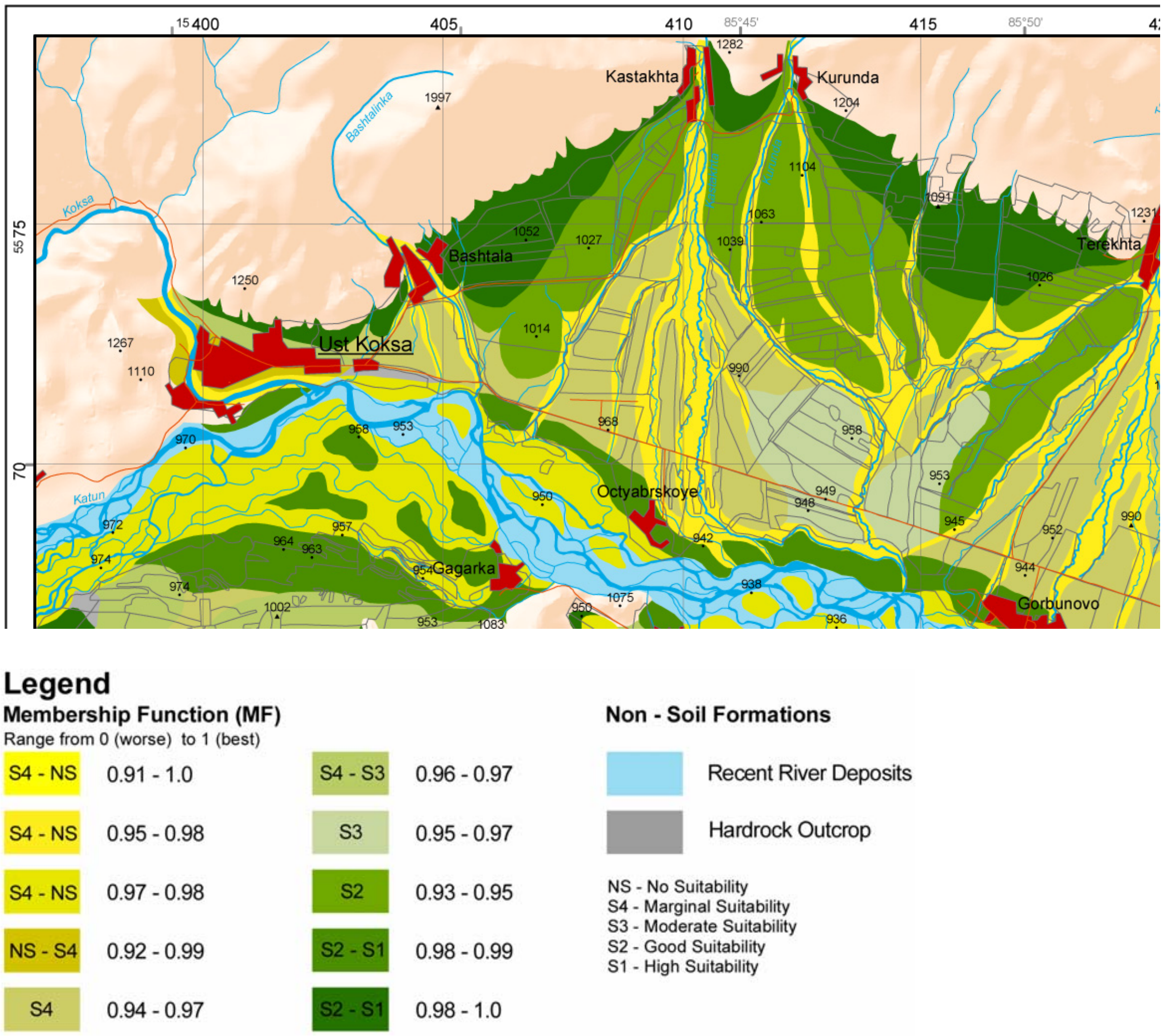


Figure 6.3.7: Portion of land suitability map for potatoes (for more details see Map B11).

Table 6.3.10: SI for potatoes based on Fuzzy Logic GMF Approach.

SI and mf values for potatoes (Model III)	Area in km^2	% of total area
S4 – NS (0.95 – 0.98)	144.86	33.3
S4 – NS (0.91 – 1.0)		
S4 – NS (0.97 – 0.98)		
NS – S4 (0.92 – 099)	5.01	1.2
S4 (0.94 – 0.97)	76.39	18.0
S4 – S3 (0.96 – 0.97)	24.28	5.6
S3 (0.95 – 0.97)	18.63	4.3
S2 (0.93 – 0.95)	56.36	13.1
S2 – S1 (0.98 – 0.99)	69.63	16.2
S2 – S1 (0.98 – 1.0)		
Recent river deposits	31.08	7.2
Hardrock outcrops	3.65	0.8
Total	429.89	100

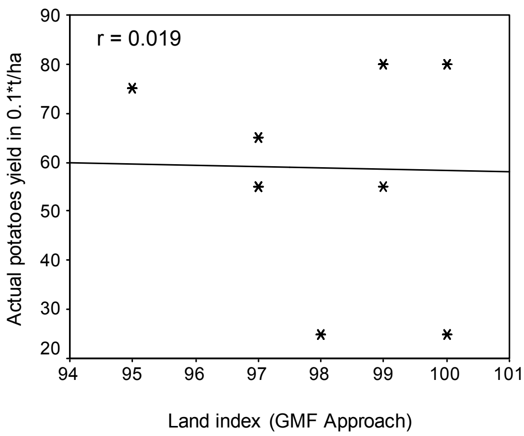


Figure 6.3.8: Linear regression of the land indices and the potatoes yield. Note: some asterisks are superimposed due to same values.

The results show that 16.2% of the total area has a good to high suitability for (class S2 – S1) for growing potatoes (see Map B11). About 13.1% of the total area show only good suitability (class S2). Based on the soil map, both of these areas consist of standard and leached chernozem. About 4.3% of the total area show only moderate suitability (class S3). Chestnut soil is distributed here. The area with marginal to moderate suitability (class S4 - S3), makes up 5.6% of the total area. About 18% of the total area have only a marginal suitability (class S4). The area belongs to less fertile soil such as meadow-forest soil which is located close to the foothill zones of Katun Range. The area with no suitability to marginal suitability (NS – S4 class), makes up 1.2% of the area. The reason for their being no to marginal suitability is their location in the flood lands of the river basins (Katun, Kastachta, Terekhta, Chendyk, Multa, Tikhonkaya and Verkhni Uimon), where recent proluvium and alluvium deposits are characterized by their quaternary sediments.

In order to judge the efficiency of the classification methods, the land indices data (see Table 1.3) were compared with the actual yield data of standard chernozem (due to their predominance in the Uimon Basin). The correlation coefficient shows a low agreement (r = 0.019) of yields and land index data, which can be explained by the use of the maximum Gaussmf values. However, as stated at the beginning of this Chapter, the aim of this model was to show the maximum land potential achievable under ideal conditions.

6.3.2.4 Combination: one Map with Most Suitable Crops

The same procedure as in Chapter 6.3.2.1 was used here. Below an example of the AML calculations is given (for more details see Appendix B12):

```
/* Checking the maximum of BMIN
&sv currmax = [value :ptcur.W_BMIN]
&if [value :ptcur.S_BMIN] gt %currmax% &then &sv %currmax% = [value :ptcur.S_BMIN]
&if [value :ptcur.P_BMIN] gt %currmax% &then &sv %currmax% = [value :ptcur.P_BMIN]

&sv :ptcur.MAX_BMIN = %currmax%

/* Checking the maximum of AMAX
&sv currmax = [value :ptcur.W_AMAX]
&if [value :ptcur.S_AMAX] gt %currmax% &then &sv %currmax% = [value :ptcur.S_AMAX]
&if [value :ptcur.P_AMAX] gt %currmax% &then &sv %currmax% = [value :ptcur.P_AMAX]

&sv :ptcur.MAX_AMAX = %currmax%

/* Checking the maximum of SI_MIN
&sv currmax = [value :ptcur.W_SI_MIN]
&if [value :ptcur.S_SI_MIN] gt %currmax% &then &sv %currmax% = [value :ptcur.S_SI_MIN]
&if [value :ptcur.P_SI_MIN] gt %currmax% &then &sv %currmax% = [value :ptcur.P_SI_MIN]
…
```

The obtained results are presented in Table 6.3.11 and Figure 6.3.9.

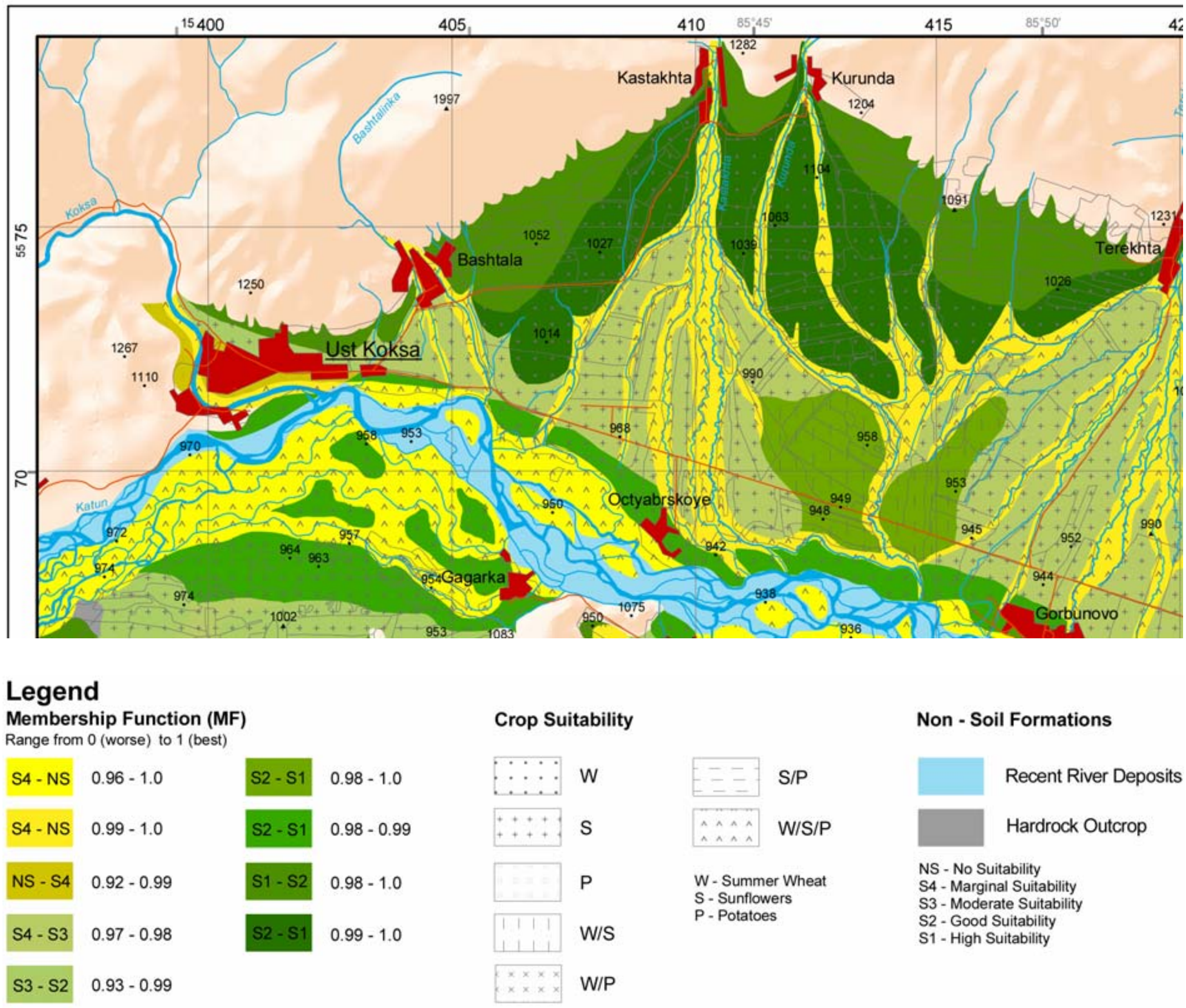


Figure 6.3.9: Portion of land suitability map for combined crops (for more details see Map B12).

Table 6.3.11: SI for WSP based on the Fuzzy Logic GMF Approach.*

Soil types (St**)	Combined SI*** for WSP based on Fuzzy Logic GMF Approach	Limitation classes (LC****)
St1	S4 – NS (0.96 – 1.0), W/S/P	LC5
St2	S4 – NS (0.99 – 1.0), W/S/P	LC5
St3	S2 – S1 (0.99 – 1.0), W	LC2
St4	S2 – S1 (0.98 – 1.0), S/P	LC2
St5	S4 – S3 (0.97 – 0.98), S	LC4
St6	S2 – S1 (0.98 – 0.99), W/P	LC2
St7	S3 – S2 (0.93 – 0.99), S	LC3
St8	NS – S4 (0.92 – 0.99), P	LC5
St9	S1 – S2 (0.98 – 1.0), W	LC2
St10*5	S4 – NS (0.99 – 1.0), W/S/P	LC5
St11*6	S4 – NS (0.99 – 1.0), W/S/P	LC5

** - for details refer to Figure 6.3.9,*
***- the location of the various soil types can be determined in the Map B12 using the enclosed transparency (cf. Appendix C),*
**** - for details refer to Table 1.3,*
***** - for details refer to Table 6.3.12,*
**5,6 – joined with St2 (cf. Figure 6.3.9).*

Table 6.3.12: Limiting factors.

Limitation class	Limiting factors
LC1	No significant limitations. All factors are in favour of a high suitability.
LC2	Slight limitations through soil nutrient elements like P_2O_5, NO_3, K_2O and humus.
LC3	Moderate limitations of soil factors in rooting zone: $H_{(A+AB)}$, CEC and a moderate degree of the LC2 factors.
LC4	Severe limitations in HTC_1, HTC_2, pH and a high degree of the LC3 factors.
LC5	A very severe limitation due to flooding risk, erodability and salinization-the latter one was excluded for the present study area. Very severe limitations of the LC4.

Table 6.3.13: SI for WSP based on the Fuzzy Logic GMF Approach.

SI and mf values for potatoes (Model III)	The most suitable crops	Area in km^2	% of total area
S4 – NS (0.96 – 1.0)	W/S/P	145.49	33.6
S4 – NS (0.99 – 1.0)	W/S/P		
NS – S4 (0.92 –099)	P	5.01	1.2
S4 – S3 (0.97 – 0.98)	S/P	81.69	19.0
S3 – S2 (0.93 – 0.99)	S	24.28	5.6
S2 – S1 (0.98 – 1.0)	S/P	138.68	32.5
S2 – S1 (0.98 – 0.99)	W/P		
S2 – S1 (0.99 – 1.0)	W		
S2 – S1 (0.98 – 1.0)	W		
Recent river deposits		31.08	7.2
Hardrock outcrops		3.65	0.8
Total		429.89	100

The results show that 32.5% of the area have a high suitability (class S1) for summer wheat, followed by sunflowers and, finally, potatoes (Table 6.3.13). Out of the total area 5.6% show good suitability (class S2) for sunflowers. About 19% of the total area show moderate to marginal suitability (class S3 – S4) for sunflowers and potatoes. Only 1.2% of the total area recognized marginally suitable (class S4) for potatoes. The area with conditions from no to marginal suitability amounts to 33.6% for all three crops. As already stated in the previous subchapter, the reason for their being marginal and not suitable for the area is their location in the flood lands of the river basins (Katun, Kastachta, Terekhta, Chendyk, Multa, Tikhonkaya and Verkhni Uimon), where recent proluvium and alluvium deposits are characterized by their quaternary sediments. The locations of these areas in the fluvial-humid and fluvial-semiarid zone have an effect on the soil rooting zone as well as on soil fertility, too.

6.3.3 Conclusions

The Fuzzy Logic GMF method shows a low agreement of the classification results for summer wheat, sunflowers and potatoes with values of 0.121, 0.157 and 0.019 respectively (cf. Figure 6.3.4, 6.3.6 and 6.3.8). Nevertheless, the applied method shows the heterogeneity of nature, i.e. the Gaussmf presents its belonging to different classes and the wide range of maximum, middle and minimum values of probability. This is the advantage of this method. The disadvantage is that it takes a large number of mathematical calculations and is, thus, very time-consuming. The low correlation coefficients can be explained by the use of maximum Gaussmf values which perhaps do not match the present land potential. However, as stated at the beginning of this Chapter, the aim of the application of this model was to show the maximum land potential achievable under ideal conditions.

6.4 Modelling of the ALSM Using the Fuzzy Set Theory JMF Approach (Model IV)

For the fourth approach, the Joint Membership Function (JMF) was used which belongs to the Fuzzy Set Theory. Here, the overall suitability assessment of land units is based on a weighting factor of the relevant land characteristics. The JMF provides a weighted sum of the different land characteristics (*A, B, … Z*).

$$JMF_x = \lambda_1 MF_1 + \lambda_2 MF_2 + \ldots + \lambda_n MF_n \quad [11]$$

and $$\lambda_1 + \lambda_2 + \ldots + \lambda_n = 1 \quad [12]$$

The choice of weights ($\lambda_1, \lambda_2, \ldots \lambda_n$) is of critical importance. They can be obtained on the basis of expert knowledge and local advice, experimental data, previous land evaluation methods, etc. Here, the guidance comes from Burlakova's model (see Model I). Below the flowchart of the modelling of the Fuzzy Set Theory - JMF is presented.

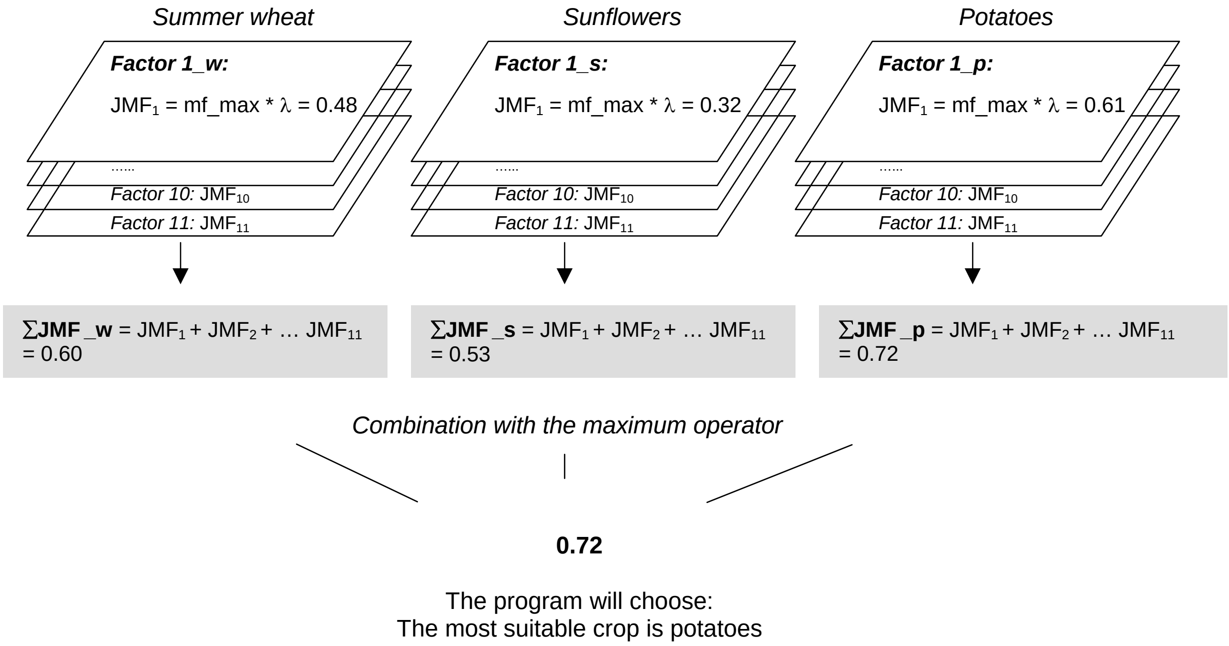


Figure 6.4.1: Flow chart for modelling of ALSM using Fuzzy Set Theory - JMF Approach.

6.4.1 Fuzzy Evaluation

In this version of the model for the evaluation of land suitability only maximum Gaussmf values were used. This input data is rather similar to Model III, the difference is that it applies another type of fuzzy approach. The following logical and implication operators were used:
AND Method = “Min”;

It uses an additive procedure instead of the implication method and defuzzification.

The weights of all evaluation factors in the implication method was taken as equal to 1, assuming also that all considered factors are equally important for the crops. The sum of the factor's weights for the calculation of equation 3 was also taken equal to 1. The minimum operator (AND) was used to combine the outputs of 11 factors (i.e. 11 JMFs) into a single fuzzy set in the aggregation procedure. Then, the summing procedure was employed in the defuzziification for every land unit. Finally, the sum of JMF was taken as a result, which was classified based on the FAO classification adapted to Altai conditions.

The help of GIS sofware using the AML program was significant for the many calculations. More details about these fuzzy calculations in the GIS environment will be discussed in the next sub-chapters.

6.4.2 Generation of Suitability Maps

6.4.2.1 Summer wheat

Arc/Info was used to integrate all data and to materialize the calculation of the Fuzzy Set Theory - JMF Approach in the AML. Below an example of the AML calculations (for more details see Appendix B13) is given:

```
CURSOR open
&do &while %:edit.aml$next%
/* multiply
&sv temp1 =  [ calc %:edit.HU2_w_l% * %:edit.HU2_w% ]
&sv temp2 =  [ calc %:edit.AAB2_w_l% * %:edit.AAB2_w% ]
&sv temp3 =  [ calc %:edit.PH2_w_l% * %:edit.PH2_w% ]
&sv temp4 =  [ calc %:edit.NO32_w_l% * %:edit.NO32_w% ]
&sv temp5 =  [ calc %:edit.P2052_w_l% * %:edit.P2052_w% ]
&sv temp6 =  [ calc %:edit.K202_w_l% * %:edit.K202_w% ]
&sv temp7 =  [ calc %:edit.CEC2_w_l% * %:edit.CEC2_w% ]
&sv temp8 =  [ calc %:edit.HTC1B_w_l% * %:edit.HTC1B_w% ]
&sv temp9 =  [ calc %:edit.HTC2B_w_l% * %:edit.HTC2B_w% ]
&sv temp10 = [ calc %:edit.FFL2_w_l% * %:edit.FFL2_w% ]
&sv temp11 = [ calc %:edit.St2_w_l% * %:edit.St2_w% ]

/* summarize

calc JMF = [calc %temp1% + %temp2% + %temp3% + %temp4% + %temp5% + %temp6% + %temp7% + %temp8% +
%temp9% + %temp10% + %temp11% ]
```

The obtained results are presented in Table 6.4.1 and Figure 6.4.2.

Table 6.4.1: SI for summer wheat based on the Fuzzy Set Theory - JMF Approach.

Soil types (St*)	Suitability class (SI**) for summer wheat based on Fuzzy Set Theory - JMF Approach	Limitation classes (LC***)
St1	S2 (0.65)	LC2
St2	S3 (0.53)	LC2
St3	S1 (0.81)	LC1
St4	S2 (0.78)	LC2
St5	S2 (0.72)	LC2
St6	S1 (0.87)	LC1
St7	S2 (0.76)	LC2
St8	S2 (0.60)	LC2
St9[*4]	S2 (0.73)	LC2
St10[*5]	S3 (0.53)	LC3
St11	NS (0.08)	LC5

**- the location of the various soil type can be determined in the Map B13 using the enclosed transparency (cf. Appendix C),*
*** - for details refer to Table 1.3,*
**** - for details refer to Table 6.4.2,*
**4 – joined with St5 and*
**5 – joined with St2 (cf. Figure 6.4.2).*

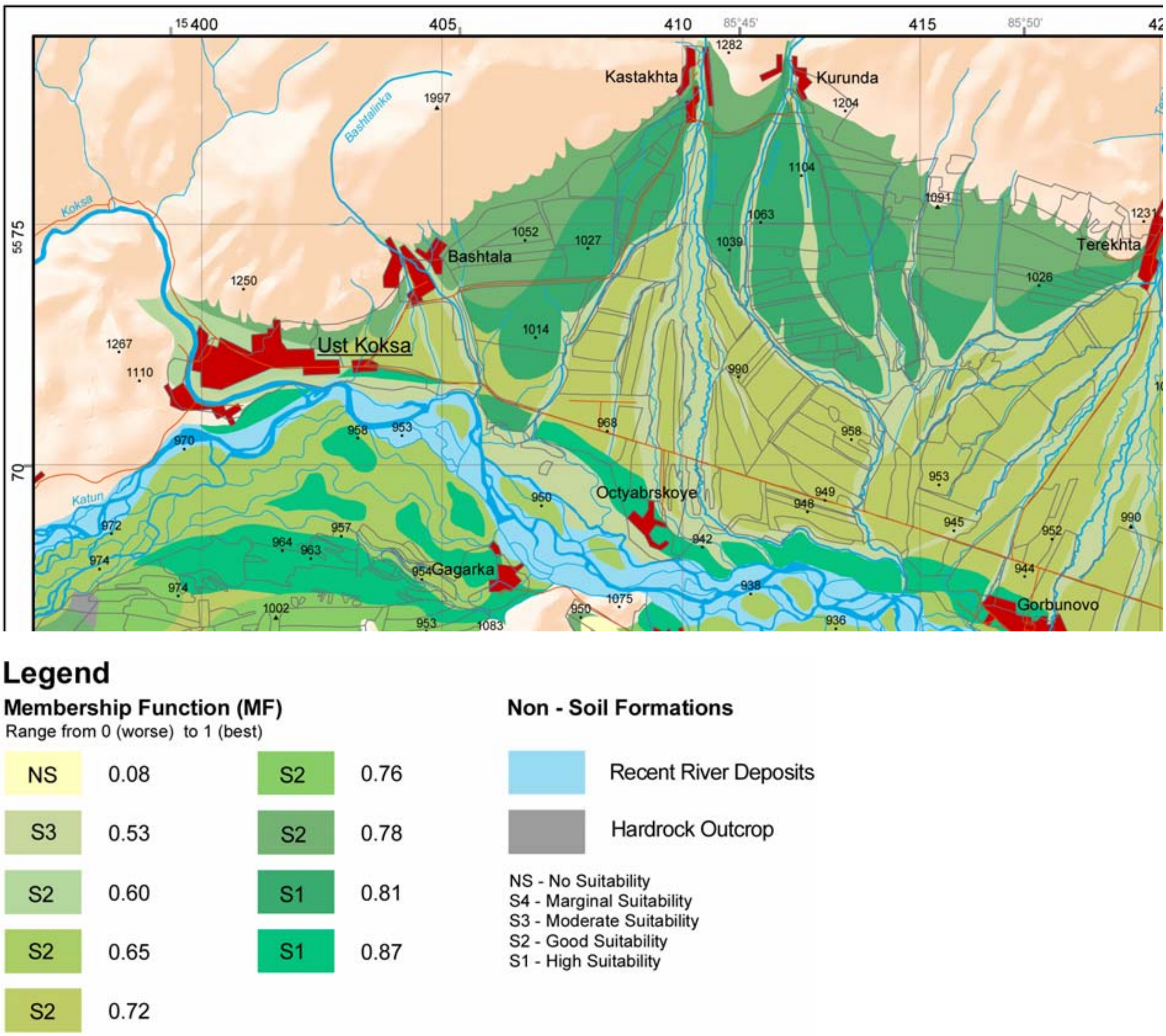


Figure 6.4.2: Portion of land suitability map for summer wheat (for more details see Map B13).

Table 6.4.2: Limiting factors.

Limitation class	Limiting factors
LC1	No significant limitations. All factors are in favour of high suitability.
LC2	Slight limitations through soil nutrient elements like P_2O_5, NO_3, K_2O and humus.
LC3	Moderate limitations of soil factors in rooting zone: $H_{(A+AB)}$, CEC and a moderate degree of LC2 factors.
LC4	Severe limitations in HTC_1, HTC_2, pH and a high degree of LC3 factors.
LC5	Very severe limitations due to flooding risk, erodability and salinisation- the latter one was excluded for the present study area. Very severe limitations of LC4.

Table 6.4.3: SI for summer wheat based on the Fuzzy Set Theory - JMF Approach.

SI for summer wheat (Model IV)	JMF value	Area in km^2	% of total area
NS	0.08	0.90	0.2
S3	0.53	110.71	26
S2	0.60	6.49	46.2
	0.65	32.98	
	0.72	82.32	
	0.73	18.63	
	0.76	22.81	
	0.78	38.21	
S1	0.81	53.86	19.6
	0.87	28.23	
Recent river deposits		31.08	7.2
Hardrock outcrops		3.65	0.8
Total		429.89	100

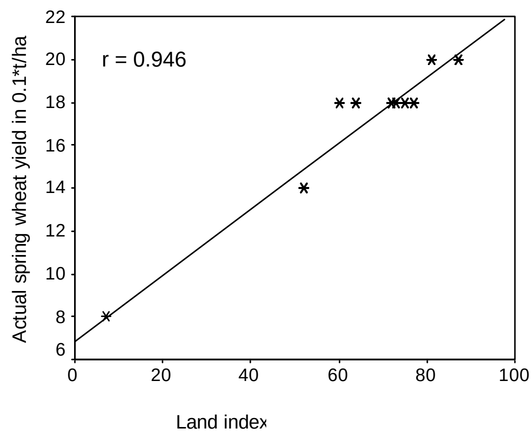


Figure 6.4.3: Linear regression of the land indices and the actual summer wheat yield.

Note: some asterisks are superimposed due to same values.

The results show that 19.6% of the area have high suitability for summer wheat. About 46.2% of the total area show good suitability. The soils, located on the flood lands are (also) contained in this class. This means, factors such as flood frequency were “ignored” by the soil properties and/or climate factors. The reason for the high percentage of good and high suitability is due to the use of the maximum Gaussmf. However, the main reason is the method as such, where the summarising procedure of all JMFs increases the suitability class by evening out all less suitable factors, which is a disadvantage of this approach. The advantage is that it is easy to calculate, offering favourable results. The moderate suitability makes up for 26% of the area and no suitability only 0.2% of the total area.

In order to judge the efficiency of the classification methods the land indices data were compared with the actual yield data. The results show a very high agreement (correlation coefficient r = 0.946).

6.4.2.2 Sunflowers

The GIS procedure as in subchapter 6.4.2.1 was used here. Below an example of the AML calculations (for more details see Appendix B14) is given:

```
CURSOR open
&do &while %:edit.aml$next%
/* multiply

&sv temp1 =  [ calc %:edit.HU2_s_l% * %:edit.HU2_s% ]
&sv temp2 =  [ calc %:edit.AAB2_s_l% * %:edit.AAB2_s% ]
&sv temp3 =  [ calc %:edit.PH2_s_l% * %:edit.PH2_s% ]
&sv temp4 =  [ calc %:edit.NO32_s_l% * %:edit.NO32_s% ]
&sv temp5 =  [ calc %:edit.P2052_s_l% * %:edit.P2052_s% ]
&sv temp6 =  [ calc %:edit.K202_s_l% * %:edit.K202_s% ]
&sv temp7 =  [ calc %:edit.CEC2_s_l% * %:edit.CEC2_s% ]
&sv temp8 =  [ calc %:edit.HTC1B_s_l% * %:edit.HTC1B_s% ]
&sv temp9 =  [ calc %:edit.HTC2B_s_l% * %:edit.HTC2B_s% ]
&sv temp10 = [ calc %:edit.FFL2_s_l% * %:edit.FFL2_s% ]
&sv temp11 = [ calc %:edit.St2_s_l% * %:edit.St2_s% ]

/* summarize

calc JMF = [calc %temp1% + %temp2% + %temp3% + %temp4% + %temp5% + %temp6% + %temp7% + %temp8% +
%temp9% + %temp10% + %temp11% ]
```

The obtained results are presented in Table 6.4.4 and Figure 6.4.4.

Table 6.4.4: SI for sunflowers based on the Fuzzy Set Theory - JMF Approach.

Soil units (St*)	Suitability class (SI**) for sunflowers based on the Fuzzy Set Theory – JMF Approach	Limitation classes (LC***)
St1	S3 (0.53)	LC3
St2	S3 (0.46)	LC3
St3	S2 (0.79)	LC2
St4	S2 (0.74)	LC2
St5	S2 (0.65)	LC2
St6[*4]	S1 (0.65)	LC1
St7	S2 (0.69)	LC2
St8	S3 (0.55)	LC3
St9	S2 (0.49)	LC2
St10[*5]	S3 (0.49)	LC3
St11	NS (0.11)	LC5

**- the location of the various soil units can be determined in the B14 using the enclosed transparency (cf. Appendix C),*
*** - for details refer to Table 1.3,*
**** - for details refer to Table 6.4.5,*
*[*4] – joined with St5 (cf. Figure 6.4.4),*
*[*5] – joined with St2 (cf. Figure 6.4.4).*

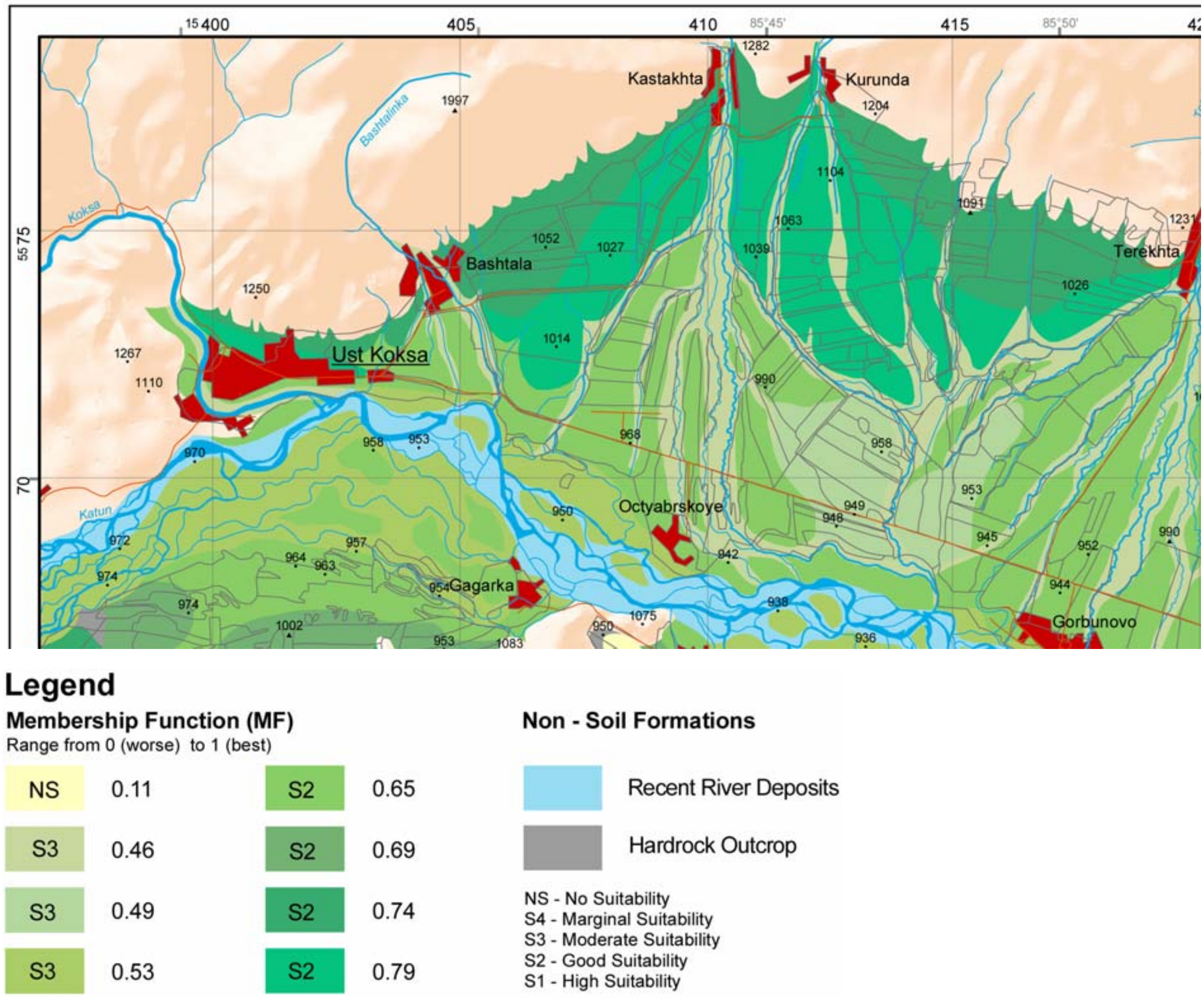


Figure 6.4.4: Portion of land suitability map for sunflowers (for more details see Map B14).

Table 6.4.5: Limiting factors.

Limitation class	Limiting factors
LC1	No significant limitations. All factors are in favour of high suitability.
LC2	Slight limitations through soil nutrient elements like P_2O_5, NO_3, K_2O and humus.
LC3	Moderate limitations of soil factors in rooting zone: $H_{(A+AB)}$, CEC and a moderate degree of LC2 factors.
LC4	Severe limitations in HTC_1, HTC_2, pH and a high degree of LC3 factors.
LC5	Very severe limitations due to flooding risk, erodability and salinisation- the latter one was excluded for the present study area. Very severe limitations of LC4.

Table 6.4.6: SI for sunflowers based on the Fuzzy Set Theory - JMF Approach.

SI for sunflowers (Model IV)	JMF values	Area in km^2	% of total area
NS	0.11	0.90	0.2
S3	0.46	83.13	38.2
	0.49	44.49	
	0.53	37.17	
	0.55	2.55	
S2	0.65	113.73	53.6
	0.69	24.28	
	0.74	38.47	
	0.79	50.42	
Recent river deposits	31.08	31.08	7.2
Hardrock outcrops	3.65	3.65	0.8
Total		429.89	100

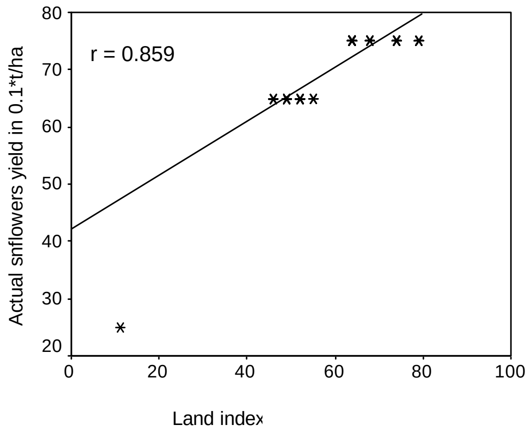


Figure 6.4.5: Linear regression of the land indices and the actual sunflowers yield. Note: some asterisks are superimposed due to same values.

The results show that 53.6% of the area have good suitability for growing sunflowers. The reason for this high percentage is due to the method, where the summarizing procedure of all JMFs increases the suitability classes by evening out less suitable factors. 38.2% of the total area show a moderate suitability. However, similar to the previous subchapter, the area on the floodlands also shows moderate suitability. No suitability only occurs in 0.2% of the area. In order to judge the efficiency of the classification methods, the land indices data were compared with the actual yield data. The results show a high agreement (correlation coefficient r = 0.859).

6.4.2.3 Potatoes

The GIS procedure as in sub-chapter 6.4.2.2 was used here. Below an example of AML calculations is given (for more details see Appendix B15):

```
CURSOR open
&do &while %:edit.aml$next%
/* multiply
&sv temp1 =  [ calc %:edit.HU2_p_l% * %:edit.HU2_p% ]
&sv temp2 =  [ calc %:edit.AAB2_p_l% * %:edit.AAB2_p% ]
&sv temp3 =  [ calc %:edit.PH2_p_l% * %:edit.PH2_p% ]
&sv temp4 =  [ calc %:edit.NO32_p_l% * %:edit.NO32_p% ]
&sv temp5 =  [ calc %:edit.P2052_p_l% * %:edit.P2052_p% ]
&sv temp6 =  [ calc %:edit.K202_p_l% * %:edit.K202_p% ]
&sv temp7 =  [ calc %:edit.CEC2_p_l% * %:edit.CEC2_p% ]
&sv temp8 =  [ calc %:edit.HTC1B_p_l% * %:edit.HTC1B_p% ]
&sv temp9 =  [ calc %:edit.HTC2B_p_l% * %:edit.HTC2B_p% ]
&sv temp10 = [ calc %:edit.FFL2_p_l% * %:edit.FFL2_p% ]
&sv temp11 = [ calc %:edit.St2_p_l% * %:edit.St2_p% ]

/* summarize

calc JMF = [calc %temp1% + %temp2% + %temp3% + %temp4% + %temp5% + %temp6% + %temp7% + %temp8% +
%temp9% + %temp10% + %temp11% ]
```

The obtained results are presented in Table 6.4.6, 6.4.8 and Figure 6.4.6.

Table 6.4.6: SI for potatoes based on the Fuzzy Set Theory - JMF Approach.

Soil types (St*)	Suitability class (SI**) for potatoes based on the Fuzzy Set Theory – JMF Approach	Limitation classes (LC***)
St1	S3 (0.52)	LC3
St2	S3 (0.42)	LC3
St3*4	S2 (0.72)	LC2
St4	S2 (0.76)	LC2
St5	S2 (0.66)	LC2
St6	S1 (0.80)	LC1
St7	S2 (0.62)	LC2
St8	S3 (0.50)	LC3
St9	S2 (0.74)	LC2
St10	S3 (0.43)	LC3
St11	NS (0.05)	LC5

*- the location of the various soil types can be determined in Map B15 using the enclosed transparency (cf. Appendix C),
** - for details refer to Table 1.3
*** - for details refer to Table 6.4.7,
*4 – joined with St9 (cf. Figure 6.4.6).

Table 6.4.7: Limiting factors.

Limitation class	Limiting factors
LC1	No significant limitations. All factors are in favour of a high suitability.
LC2	Slight limitations through soil nutrient elements like P_2O_5, NO_3, K_2O and humus.
LC3	Moderate limitations of soil factors in rooting zone: $H_{(A+AB)}$, CEC and a moderate degree of LC2 factors.
LC4	Severe limitations in HTC_1, HTC_2, pH and a high degree of LC3 factors.
LC5	Very severe limitations due to flooding risk, erodability and salinisation- the latter one was excluded for the present study area. Very severe limitations of LC4.

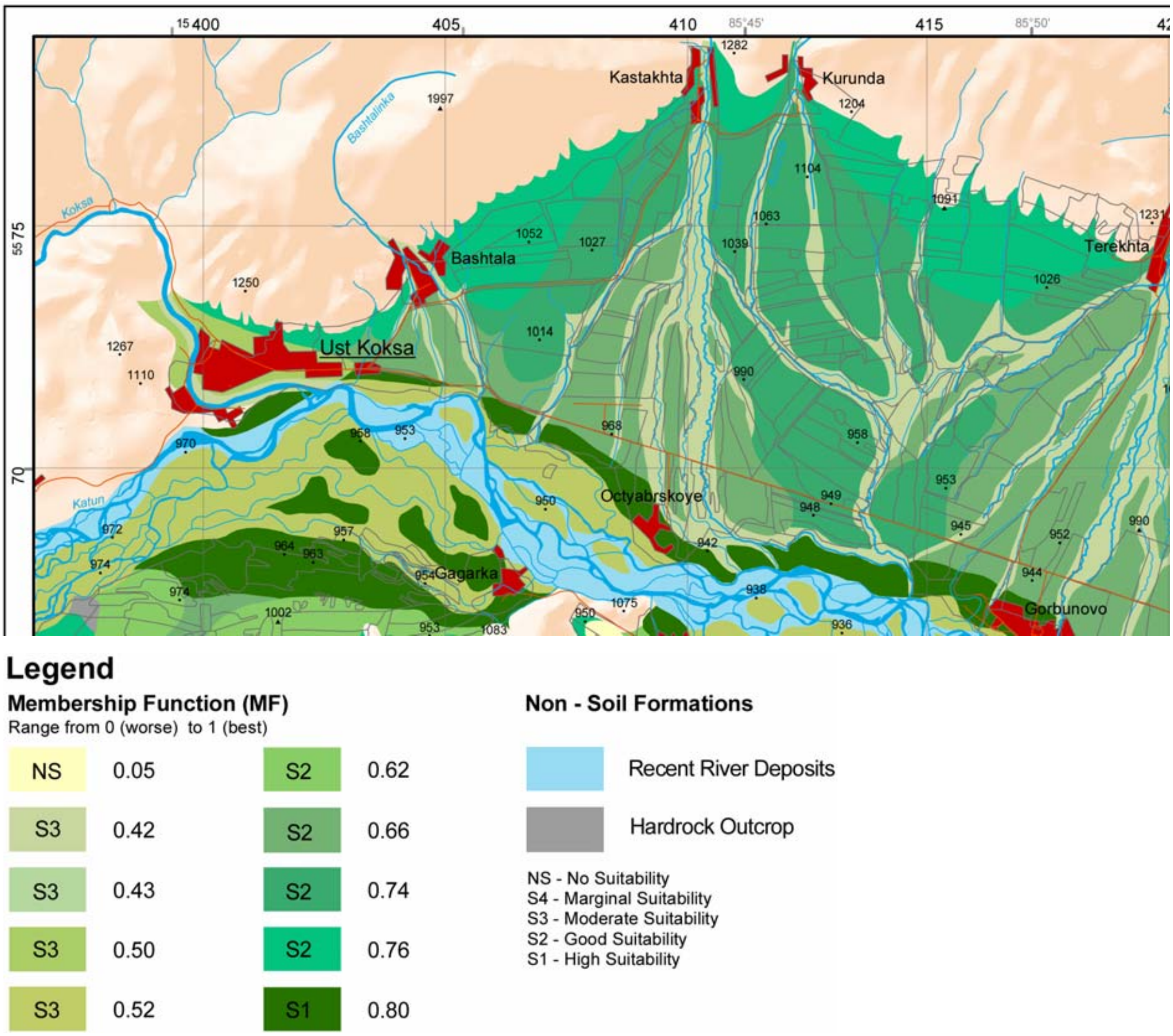


Figure 6.4.6: Portion of land suitability map for potatoes (for more details see Map B15)

Table 6.4.8: SI for potatoes based on the Fuzzy Set Theory - JMF Approach.

SI for potatoes (Model IV)	JMF values	Area in km^2	% of total area
NS	0.05	0.9	0.2
S3	0.42	83.13	35
	0.43	23.4	
	0.50	6.49	
	0.52	37.17	
S2	0.62	22.81	50
	0.66	80.23	
	0.72	52.51	
	0.74	18.63	
	0.76	38.29	
S1	0.80	31.59	7.4
Recent river deposits	31.08	31.08	7.2
Hardrock outcrops	3.65	3.65	0.8

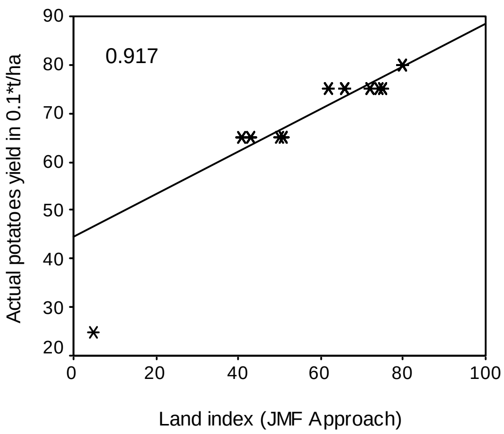


Figure 6.4.7: Linear regression of the land indices and the actual summer wheat yield. Note: some asterisks are superimposed due to same values.

The results show that 7.4% of the area have high suitability for growing potatoes on leached chernozem. A high percentage of the total area, i.e. 50%, shows good suitability. The areas consist of standard chernozem. About 35% of the area shows a moderate suitability. This area belongs to the alluvial-humid meadow soils in the fluvial-humid zone of the Uimon Basin. Here, similar to the previous sub-chapters, the main reason for the high perecentage is type of the applied method, where the summarizing procedure of all JMFs increases the low suitability of the factors. Flood frequency was evened out by the other factors. No suitability makes up only 0.2% of the area. In order to judge the efficiency of the classification methods the land indices data were compared with the actual yield data. The results show a very high agreement (correlation coefficient r = 0.917).

6.4.2.4 Combination: one Map with Most Suitable Crops

The same procedure as in sub-chapter 6.4.2.3 was used here. Below an example of AML calculations is presented (for more details see Appendix B16):

```
   /* Checking the maximum
&sv currmax = [value :ptcur.W_JMF]
&if [value :ptcur.S_JMF] gt %currmax% &then &sv %currmax% = [value :ptcur.S_JMF]
&if [value :ptcur.P_JMF] gt %currmax% &then &sv %currmax% = [value :ptcur.P_JMF]

&sv :ptcur.MAX_JMF = %currmax%

/* Case if W=S=P
&if [value :ptcur.W_SI] eq [value :ptcur.P_SI] and [value :ptcur.P_SI] eq [value :ptcur.S_SI] &then
&do
 &sv :ptcur.WSP = WSP
 &sv :ptcur.WSPC = [value :ptcur.W_SI]
&end

/* Case if W
&if [value :ptcur.W_SI] lt [value :ptcur.S_SI] and [value :ptcur.W_SI] lt [value :ptcur.P_SI] &then
&do
 &sv :ptcur.WSP = W
 &sv :ptcur.WSPC = [value :ptcur.W_SI]
&end

/* Case if S
&if [value :ptcur.S_SI] lt [value :ptcur.W_SI] and [value :ptcur.S_SI] lt [value :ptcur.P_SI] &then
&do
 &sv :ptcur.WSP = S
 &sv :ptcur.WSPC = [value :ptcur.S_SI]
&end
```

Table 6.4.9: SI for WSP based on the Fuzzy Set Theory - JMF Approach.*

Soil types (St**)	Combined SI*** of the WSP based on Fuzzy Set Theory - JMF Approach	Limitation Classes (LC****)
St1	S2 (0.65), W	LC2
St2	S3 (0.53), W/S/P	LC3
St3	S1 (0.81), W	LC1
St4[*5]	S2 (0.78), W/S/P	LC2
St5[*6]	S2 (0.72), W/S/P	LC2
St6[*7]	S1 (0.87), W/S/P	LC1
St7	S2 (0.76), W/S/P	LC2
St8	S2 (0.60), W	LC2
St9	S2 (0.74), W/P	LC2
St10	S3 (0.49)/W/S/P	LC3
St11	NS (0.11)/W/S/P	LC5

** - for details refer to Figure 6.4.7,*
***- the location of the various soil types can be determined in the Map B16 using the enclosed transparency (cf. Appendix C),*
**** - for details refer to Table 1.3,*
***** - for details refer to Table 6.4.10,*
*[*5] – joined with St7,*
*[*6] – joined with St9 and*
*[*7] – joined with St3 (cf. Figure 6.4.8).*

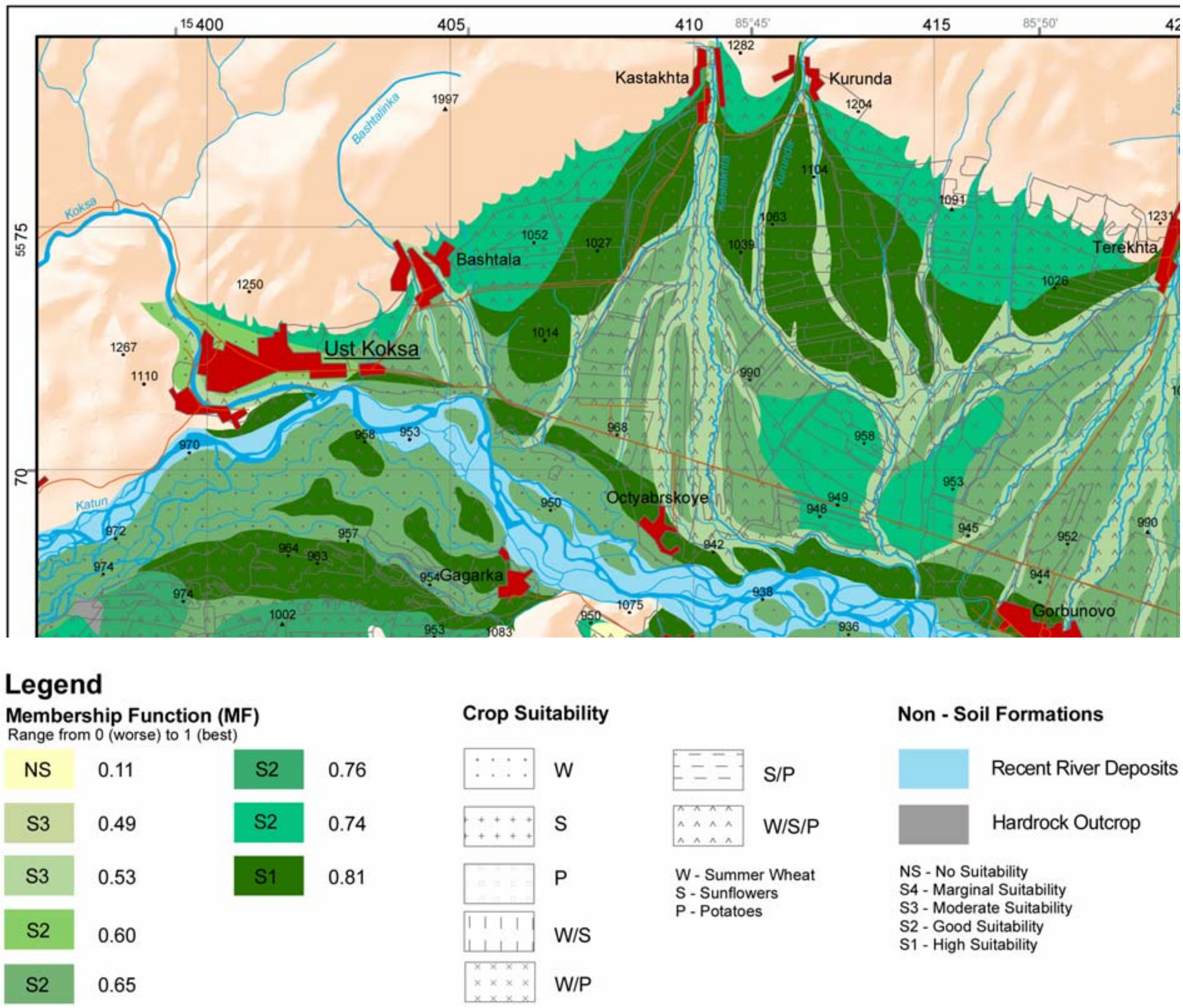


Figure 6.4.7: Portion of land suitability map for summer wheat, sunflowers and potatoes (for more details see Map B15)

Table 6.4.10: Limiting factors.

Limitation class	Limiting factors
LC1	No significant limitations. All factors are in favour of a high suitability.
LC2	Slight limitations through soil nutrient elements like P_2O_5, NO_3, K_2O and humus.
LC3	Moderate limitations of soil factors in rooting zone: $H_{(A+AB)}$, CEC and a moderate degree of LC2 factors.
LC4	Severe limitations in HTC_1, HTC_2, pH and a high degree of LC3 factors.
LC5	Very severe limitations due to flooding risk, erodability and salinisation- the latter one was excluded for the present study area. Very severe limitations of LC4.

Table 6.4.11: SI for WSP based on the Fuzzy Set Theory - JMF Approach.

SI for WSP (Model IV)	MF values	Area in km^2	Most suitable crops	% of total area
NS	0.11	0.90	W	0.2
S3	0.53	23.40	W/S/P	24.4
S2	0.60	6.49	W	47.8
	0.65	11.94		
	0.72/0.74	56.84	W/S/P, W/P	
	0.76/0.78	22.81	W/S/P	
S1	0.81/0.87	82.09	W, W/S/P	19.0
Recent river deposit		31.08		7.2
Hardrock outcrops		3.65		0.8
Total		429.89		100

The results show that 19% of the area have high suitability for all three crops (Table 6.4.11). Most of the total area, i.e. 47.8%, also shows good suitability for all three crops. Moderate suitability areas makes up 24.4%. Out of the total area 0.2% show no suitability for summer wheat. Summing up, the results show that, in decreasing order, the most suitable crops in the Uimon Basin are summer wheat, sunflowers and potatoes.

6.4.3 Conclusions

The Fuzzy Set Theory - JMF approach shows a high agreement of its classification results for summer wheat, sunflowers and potatoes with values of 0.946, 0.859 and 0.917 respectively (cf. Figure 6.4.3, 6.4.5 and 6.4.7). The advantage of this method is that it is easy to calculate, offering favourable results as compared to Model II. The disadvantage is that the summarising procedure of all JMFs increases the low suitability of other factors. For instance, flood frequency was evened out by the other factors.

7. Results and Discussions

Based on the methodological approaches treated in the Chapters 6.1, 6.2, 6.3 and 6.4 the results described below have been achieved. In the summarising form of tables the three major crops of the Uimon Basin, summer wheat, sunflowers and potatoes, are shown and the derived Sis discussed. Due to the fact that the slope gradient in the agriculturally used parts of the Uimon Basin is very low and that apart from very local erosive events along the rivers and creeks draining the Terekhta Range and the Katun Range there are nearly no erosion occurring. Based on the above, the Global Assessment of Soil Degradation (GLASOD) Approach (cf. Middleton and Thomas 1997, Feddema and Freire 2001) was not applied. The potential erodability (based on unpublished mappings of Butvilovsky (2007b)), however, is shown in Figure 2.6 and Map A5.

The land suitabilities for summer wheat were classified according to the 1) Weighted Means Approach, 2) Fuzzy Logic – SOM Approach, 3) Fuzzy Logic GMF Approach and 4) Fuzzy Set Theory – JMF Approach. 11 evaluation criteria were used in the present study.

Based on the obtained results, the data in Table 7.1 to 7.3 indicate agreements and differences among the four applied classification approaches for all three crops. Good agreement between the 1st, 2nd and 3rd approaches is observed, so the differences only show where land units have a differing degree of suitability near class limits.

Table 7.1: Suitability classification results for summer wheat using different approaches.

Soil type (St*)	Suitability evaluation (SI**)			
	WM Approach (Model I)	Fuzzy Logic – SOM Approach (Model II)	Fuzzy Logic GMF Approach (Model III)	Fuzzy Set Theory – JMF Approach (Model IV)
St1	S4***	S4 (0.21)	S4 – S5 (0.96 -1.0)	S2 (0.65)
St2	S4	S4 (0.18)	S4 – S5 (0.99 -1.0)	S3 (0.53)
St3	S1	S4 (0.39)	S2 – S1 (0.99 -1.0)	S1 (0.81)
St4	S2	S2 (0.60)	S1 – S2 (0.95 – 0.98)	S2 (0.78)
St5	S3	S3 (0.39)	S5 – S4 (0.94 – 0.98)	S2 (0.72)
St6	S2	S2 (0.62)	S2 – S1 (0.98 – 0.99)	S1 (0.87)
St7	S3	S3 (0.42)	S3 – S4 (0.96 -1.0)	S2 (0.76)
St8	S3	S5 (0.12)	S4 – S5 (0.99 -1.0)	S2 (0.60)
St9	S2	S4 (0.45)	S1 – S2 (0.98 -1.0)	S2 (0.73)
St10	S4	S5 (0.14)	S4 – S5 (0.99 -1.0)	S3 (0.53)
St11	S5	S5 (0.12)	S4 – S5 (0.99 -1.0)	S5 (0.08)

**- the location of the various soil types and subtypes can be determined in Map B1, B5, B9 and B13 using the enclosed transparency (cf. Appendix C),*
*** - for details refer to Table 1.3,*
**** - SI in green colour show the similarity of the class in different approaches.*

Table 7.2: Suitability classification results for sunflowers using different approaches.

Soil type (St*)	Suitability evaluation (SI**) of sunflowers by different approaches			
	WM Approach (Model I)	Fuzzy Logic – SOM Approach (Model II)	Fuzzy Logic GMF Approach (Model III)	Fuzzy Set Theory – JMF Approach (Model IV)
St1	NS***	NS (0.05)	S4 – NS (0.95 – 0.98)	S3 (0.53)
St2	NS	NS (0.04)	S4 (0.95 – 0.98)	S3 (0.46)
St3	S2	S3 (0.58)	S3 – S2 (0.94 – 0.98)	S2 (0.79)
St4	S3	S3 (0.57)	S2 – S1 (0.98 – 1.0)	S2 (0.74)
St5	S4	S4 (0.26)	S4 – S3 (0.97 – 0.98)	S2 (0.65)
St6	S3	S4 (0.38)	S2 – S3 (0.98 – 0.99)	S1 (0.65)
St7	S4	NS (0.08)	S3 – S2 (0.93 – 0.99)	S2 (0.69)
St8	S4	NS (0.05)	S4 – NS (0.96 – 1.0)	S3 (0.55)
St9	S3	S4 (0.22)	S3 – S2 (0.93 – 0.95)	S2 (0.49)
St10	NS	NS (0.05)	S4 – NS (0.96 – 1.0)	S3 (0.49)
St11	S4	NS (0.04)	S4 – NS (0.99 – 1.0)	NS (0.11)

**- the location of the various soil types and subtypes can be determined in Map B2, B6, B10 and B14 using the enclosed transparency (cf. Appendix C),*
*** - for details refer to Table 1.3,*
**** - SI in green colour show the similarity of the class in different approaches.*

Table 7.3: Suitability classification results for potatoes using different approaches.

Soil types (St*)	Suitability evaluation (SI**) of potatoes by different approaches			
	WM Approach (Model I)	Fuzzy Logic – SOM Approach (Model II)	Fuzzy Logic GMF Approach (Model III)	Fuzzy Set Theory – JMF Approach (Model IV)
St1	NS***	NS (0.04)	S4 – NS (0.97 – 0.98)	S3 (0.52)
St2	S4	NS (0.04)	S4 – NS (0.95 – 0.98)	S3 (0.42)
St3	S2	S4 (0.29)	S2 (0.93 – 0.95)	S2 (0.72)
St4	S2	S2 (0.65)	S2 – S1 (0.98 – 1.0)	S2 (0.76)
St5	S4	NS (0.15)	S4 (0.94 – 0.97)	S2 (0.66)
St6	S3	S4 (0.28)	S2 – S1 (0.98 – 0.99)	S1 (0.80)
St7	S4	NS (0.05)	S4 – S3 (0.96 – 0.97)	S2 (0.62)
St8	S4	NS (0.16)	NS – S4 (0.92 – 0.99)	S3 (0.50)
St9	S3	NS (0.19)	S3 (0.95 – 0.97)	S2 (0.74)
St10	NS	NS (0.04)	S4 – NS (0.91 – 1.0)	S3 (0.43)
St11	S4	NS (0.04)	S4 – NS (0.97 – 0.98)	NS (0.05)

**- the location of the various soil types and subtypes can be determined in maps Map B3, B7, B11 and B15 using the enclosed transparency (cf. Appendix C),*
*** - for details refer to Table 1.3,*
**** - SI in green colour show the similarity of the class in different approaches.*

The Figure 7.1 and 7.2 show a comparison of the actual landuse Map (2002) with the combined land suitability maps of Model I, Model II, Model III and Model IV for summer wheat.

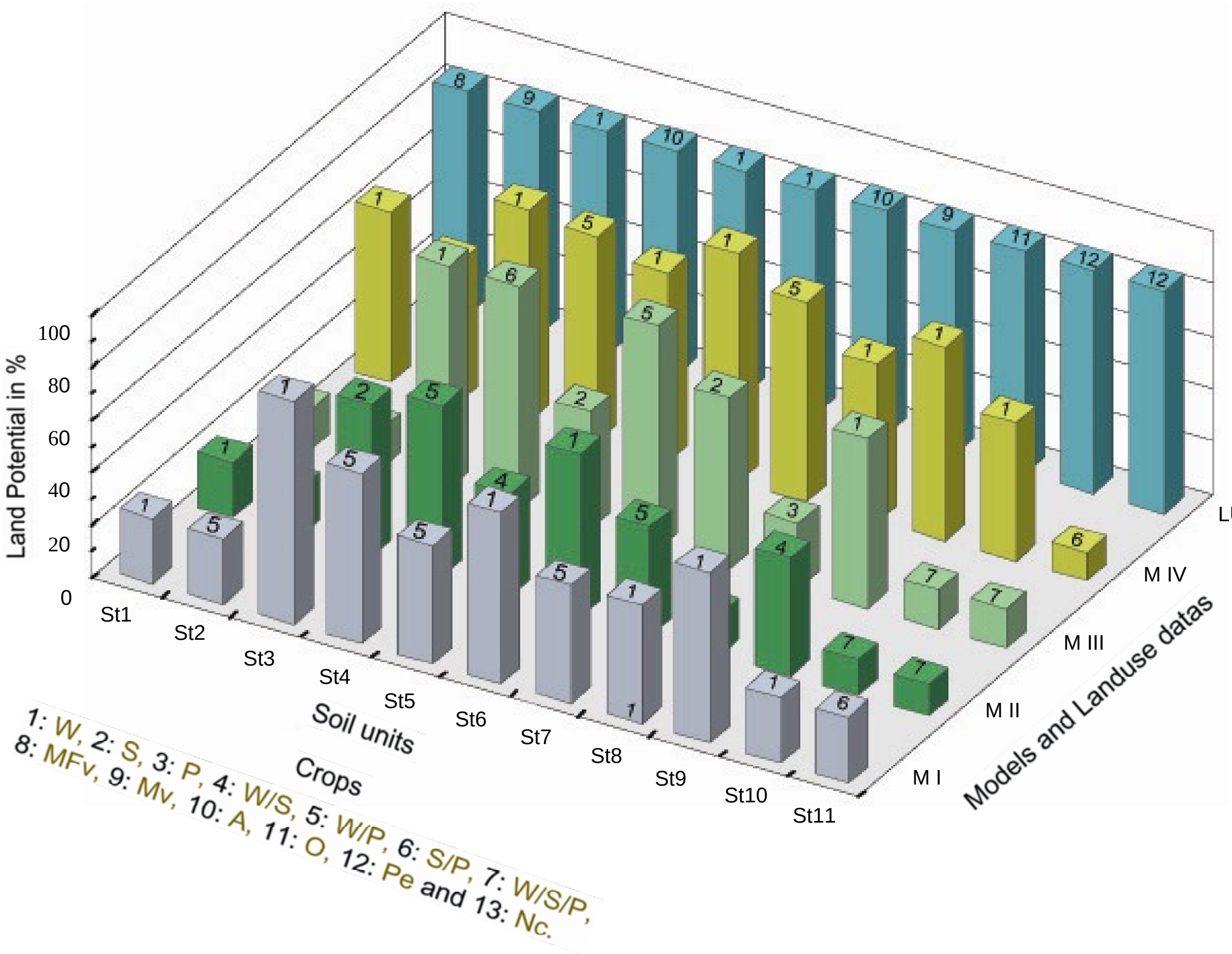


Figure 7.1: Comparison of the datasets of the Actual Landuse Map (2002) with those of the Combined Land Suitability Maps of Model I (M I), Model II (M II), Model III (M III) and Model IV (M IV) for summer wheat. For the abbreviations see Figure 6.1.10. For the conversion of SI classes into Land Potential see Table 1.4.

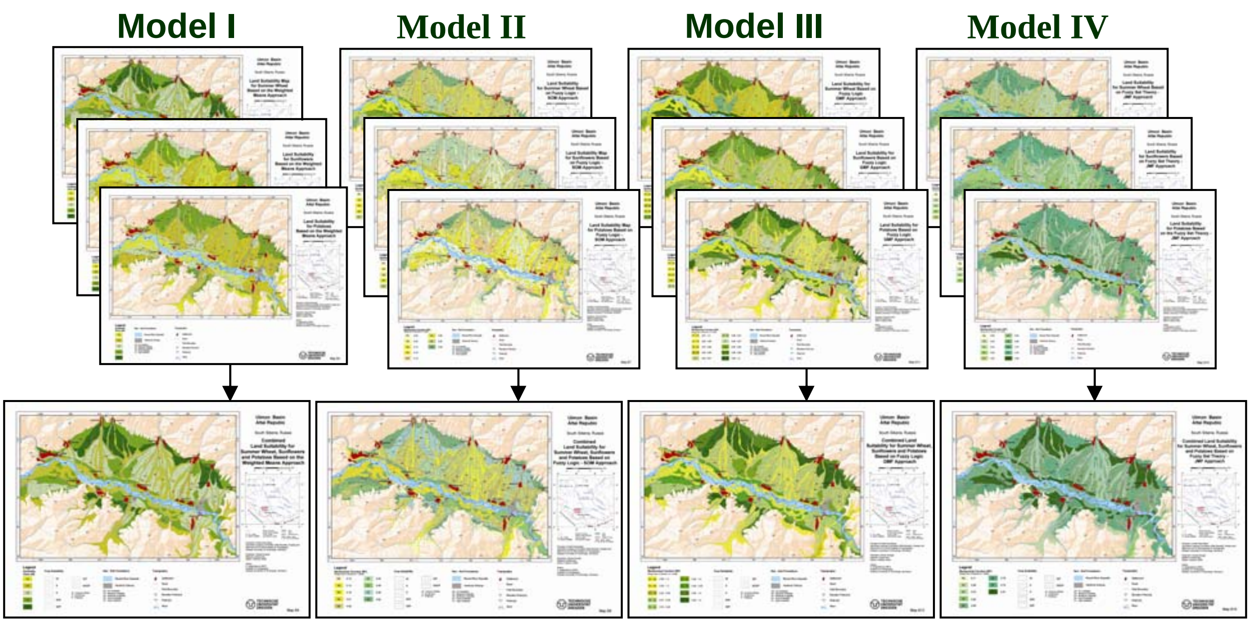


Fig. 7.2: Visualisation of the Land Suitability Map for summer wheat (top), sunflowers (second row), and potatoes (third row), in the four models used and the Combined Suitability Map (lowest row).

Summing up, the WM Approach shows a high agreement of classification results for summer wheat, sunflowers and potatoes with values of 0.989, 0.956 and 0.933 (cf. Chapter 6.1), respectively, which means that a high correlation between both datasets. The WM Approach allows for the determination of suitability classes without further specifications but does not allow to take into the account the effect of crop properties which are near the class boundaries. The WM and the Fuzzy Set Theory - JMF Approach equalize the key land-properties which depress and/or increase the overall suitability class.

The Fuzzy Logic - SOM Approach shows a high agreement of classification results for summer wheat, sunflowers and potatoes with values of 0.989, 0.956 and 0.933 (cf. Chapter 6.2), which means that a high correlation between both datasets. The approach takes into account only the factors of the low suitability classes of a factor set as the result for the whole area. The advantage is that it is easy to calculate and shows the minimum potential of the land. The disadvantage is that it ignores other more suitable factors.

The Fuzzy Logic GMF Approach shows a low agreement of classification results for summer wheat, sunflowers and potatoes with values of 0.121, 0.157 and 0.019 (cf. Chapter 6.3), respectively, which means that a low correlation between both datasets. Nevertheless, the applied approach shows the heterogeneity of nature, i.e. the Gaussmf presents a wide range of maximum, middle and minimum values of probability. This is the advantage of the method. The disadvantage is that it requires a large number of mathematical calculations and is, thus, very time consuming. The low correlation coefficients can be explained by using maximum Gaussmf values. However, the aim of this approach was to show the maximum land potential achievable under ideal conditions.

The Fuzzy Set Theory - JMF Approach shows a high agreement of classification results for summer wheat, sunflowers and potatoes with values of 0.946, 0.859 and 0.917 (cf. Chapter 6.4), respectively, which means a high correlation between both datasets. The advantage of this method is that it is easy to calculate, offering more favourable land suitability results as compared to Model II. The disadvantage is that the summarizing procedure of all JMFs increases the low suitability of factors. Flood frequency was, for instance, evened out by the other factors.

Summing up, all approaches show a high agreement of their classification results for the chosen three crops except the Fuzzy Logic GMF. Compared to the WM Approach, the Fuzzy Logic Approach is able to describe the degree of belonging of each land unit to a certain suitability class independent of class limits. A disadvantage of the Fuzzy Logic Approach is its high calculation intensity.

8. Conclusions and Outlook

As stated in the introduction of this thesis, one objective of this study was to improve current land-resource survey-technology by means of GIS. RS and GIS have shown powerful tools to analyse and evaluate spatial data (e.g. soil, relief and hydrothermal coefficients).

The ***limitations*** of the present study are:

- A less than recent satellite image.
- Unavailability of high-resolution satellite imagery for soil and/or agricultural mapping.
- Recent land suitability evaluation map not available.
- Only limited secondary data like ground water, landuse history, annual yield statistics and other socio-economic data of study area.

The agricultural land evaluation of the Uimon Basin based on soil, climate and relief factors using RS and GIS technologies leads to the following ***findings:***

- For the environmentally compatible development of land, selecting the basal varia-bles according to local conditions to evaluate land suitability is highly significant.
- Erodability and flood frequency are important factors for land evaluation.
- The soils on which most agricultural cereals of the Uimon Basin are grown are standard and leached chernozem showing rich nitrogen and phosphorus contents.
- Due to soil properties, erodability, climate, flood frequency and slope factors, the Uimon Basin has good suitability for growing spring wheat, sunflowers and potatoes. However, sunshine duration is one of the greatest limiting factors for the sunflower yield of seeds and potatoes due to the Altai’s (South Siberian) climatic conditions. Summer wheat is not biased by any climatic limitations here.
- To develop a time- and cost-efficient land evaluation procedure, sufficient soil, climatic, geomor-phological, RS and GIS knowledge is necessary. Thus, time-consuming misclassi-fications can be avoided. The more ancillary data and geofactors can be included, the better the result. High-quality soil maps and high-resolution RS data clearly improve the results.
- Integration of data of different origins (soil, climate) can help solve mapping problems. Most of the required steps can be realised within a GIS.
- RS and GIS allow for consideration of the spatial variability of the terrain. They are found to be advantageous for delineating areas of various suitability ratings for a given land use type.
- A fully satisfying empirical data base allowing for statistical testing of the essential factors and their weights is hardly ever available.

- The main disadvantages of the WM Approach are: the inability to take into account the effect of crop properties which happen to have values near class boundaries; the masking of key and positive land properties by less important ones, which may decrease the overal suitability class.
- The determination of weights for each variable is also vital because they effect the evaluation result in any approach. Long-term expert knowledge, literature and an analytical hierarchy process are suitable assets.
- In land evaluation the need for rating is fundamental. Intuitively the Fuzzy Logic Approach seems better since it takes into account the spatial variability and differences in factor weights. The Fuzzy Logic Approach is to be preferred to one using weighted means due to presenting land suitability classes as neat crisp sets, the results of which, when given as membership values after field validation, give a more realistic and graded pattern.
- The fuzzy operators used in the first or further steps of analyses also affect the possibilities obtained for the final map. The choosen weights effect the results obtained for the final land suitability map.
- Because of the ease with which the fuzzy sets can be edited via a GIS system, it is easy to try various scenarios to minimize the effects of overestimated membership values.
- The results obtained by all fourth models (Model I, Model II, Model III and Model IV) were mostly dependent on data quality. The application of the Gaussmf values has an effect on the results of the employed fuzzy models (Model II, Model III and Model IV).
- In Model IV, multiplying a weighting factor to the factor maps considers the degree of the effect of each input map on landuse suitability.
- Based both on a classical" rigid approach and on Fuzzy Theory crop suitability maps of a high degree of reliability can produced.
- Fuzzy systems provide a rich and powerful addition to standard logic. The mathematics generated by these theories is consistent, and Fuzzy Logic can be a generalization of classic logic. The applications which generated from or adapted to Fuzzy Logic are wide-ranging and provide the opportunity for modelling of conditions which are inherently imprecisely defined, despite the concerns of „classical logicians".
- Ravine erosion and flood risk which might be dangerous to the agricultural areas and the ecological development of the Uimon Basin should be considered.

Based on the findings and the aforementioned limitations the study leads to the following ***suggestions/recommendations:***

- Use of high resolution and more advanced remote sensing data such as Landsat imagery for detection and mapping of soil, agriculture or landuse parameters.
- Training and capacity building of local farmers association in the application of remote sensing in natural resource studies.
- Establishment of a more extensive regional monitoring network to collect baseline data relevant to all aspects of landuse.
- In-depth and detailed assessment of causes and consequences of land degradation and loss of soil fertility by means of remote sensing data.
- Establishment of shelterbelts and windbreaks by cultivating suitable species to avoid wind erosion and to protect the study area from desert encroachment.
- Development, restoration and re-vegetation of degraded areas.
- Integration of local people in management and establishment of sustainable projects at the village level for the prevention and rehabilitation of the tree cover especially in the areas which are subjected to loss of soil fertility.
- Improvement and management of the grazing activities in mountain areas.
- The development and enhancement of the rural water supply by increasing the number of water pumps for even distribution of activities within the study area.
- Establishment and improvement of water harvesting techniques in the study area.
- Enhancement of local and regional programs by forest and agriculture sector in the study area to protect the natural forest with more emphasis on the community participation in management and conservation programs.
- Strengthen afforestation and agroforestry activities to reduce soil erosion in the steep and foothill parts of the Uimon Basin, and and conserve agricultural land and construct irrigational channels in the northern part of the Uimon Basin to maximize water supply for agricultural crops. For the southern part of the Uimon Basin taking measures against soil-wash-off during strong rains in the summer period are suggested.
- Prevention of land degradation processes through decrease of anthropogenic impact, deforestation and soil fertility control.
- Areas near Katun and other rivers (Multa, Koksa, etc.) should be taken into account due to possible extreme situations of flood risks.
- Increase of animal husbandry for economical improvement of the region is sugges-ted. Maral-breeding is one of the solutions.
- A modern visualisation of the envisaged landuse by means of state-of-the-art planning maps for rural areas (cf. Chudy 2007) has to be considered.

Further research is needed to identify and use accurate, practical and inexpensive methods for the monitoring of the processes of soil fertility loss. High-resolution remote sensing data like *Ikonos* or *QuickBird* can widely support this objective and increase the monitoring accuracy. Proposed further studies have to integrate GIS in mapping the dynamics of landuse. This can be facilitated by the establishment of a network for regional monitoring, mapping and consequently detection of long-term trends in soil degradation.

REFERENCES

ABKAR (1999): *Likelihood-based Segmentation and Classification of Remotely Sensed Images. A Baysesian Optimization Approach for Combining RS and GIS.* PhD Thesis. University of Twente. Enschede/ITC. The Netherlands.

ALBERTZ, J. (1991): *Grundlagen der Interpretation von Luft- und Satellitenbildern. Eine Einführung in die Fernerkundung*. Darmstadt.

BÄHR D. (2006): *Modellierung, Typisierung und kartographische Darstellung der Vegetationsdynamik der Republik Altai (Südsibirien) auf Grundlage einer AVHRR-Zeitreihe.* Diplomarbeit, Institut für Kartographie, TU Dresden.

BARSCH D. & LIEDKE H. (1980): *Geomorphologische Detailkartierung in der Bundesrepublik Deutschland. Erste Ergebnisse des GMK - Schwerpunktprogrammes der DFG.* Berliner Geogr. Abh., 31: 1 - 33.

BASTIAN O. & SCHREIBER K. (1994): *Analyse und Ökologische Bewertung der Landschaft.* Bearb. von 16 Fachwissenschaftern. Jena - Stuttgart: G. Fischer.

BATJES N., BOUWMAN A. & SINCLAIR K. (1987): *Jamaica Physical Land Evaluation System.* Proceedings of the International Workshop on Quantified Land Evaluation Proce-dures. Washington, 27 April - 2 May 1986, ITC Publication, 6: 39 - 43.

BEEK, K. (1987): *Land Evaluation and Perspective.* Proceedings of the International Workshop on Quantified Land Evaluation Procedures. Washington, 27 April - 2 May 1986, ITC Publication, 6: 2 - 6.

BEEK K. & BENNEMA J. (1972): *Land Evaluation for Agricultural Land Use Planning.* An ecological methodology. Dept. Soil and Geol., Agric. University, Wageningen. Spanish ed.: Boletin Latinoamericano sobre fomento de tierras y aguas 3. Proyecto Regional FAO/PNUD RLA 70/457. Santiago, Chile.

BERTIN J. (1983): *Semiology of Graphics.* Translated by W.J. Berg. University of Wisconsin Press, Madison.

BLAKEMORE M. (1988): *Cartography and Geographic Information Systems.* Progress in Human Geography, 12/4: 525 - 537.

BOOSEL, H. (1992): *Modellbuildung und Simulation. Konzepte, Verfahren und Modelle zum Verhalten dynamischer Systeme;* ein Lehr- und Arbeitsbuch mit Simulations-Software. Braunschweig, Wiesbaden, Vieweg.

BOUMA J. (1997). *The Role of Quantitative Approaches in Soil Science when Interacting with Stakeholders.* Geoderma, 78: 1 - 12.

BOUMA J., WAGENET R., HOOSBEEK M. & HUTSON J. (1993): *Using Expert Sys-tems and Simulation Modeling for Land Evaluation at Farm Level: A Case Study from New York State.* Soil Use and Management, 9: 131 - 139.

BRINKMAN R., SMYTH A. (1973.): *Land Evaluation for Rural Purposes.* Publ.17. Wageningen: Intern. Inst. Land Reclm. and Improvement (ILRI): 34 - 45.

BUCHROITHNER M. (1985): *Zur Geologie des Altai.* Österreichische Alpenzeitung. Folge 1460, März/April.

BUCHROITHNER M. (1989): *Fernerkundungskartographie mit Satellitenaufnahmen - Digitale Methoden, Reliefaspekte, geowissenschaftlishe Applikationsbeispile.* In: Enzyklopädie der Kartographie. Teilband IV/I, Franz Deuticke Verl., Wien.

BUCHROITHNER M. (1993): *Fernerkundungskartographie und GIS. Kartographische Schriften,* Bd.1, Kirschbaum Verlag, Bonn: 88 - 98.

BUCHROITHNER M. (1995a): *Der Katun-Nationalpark im Altai.* Österreichische Alpenzeitung. Folge 1521.

BUCHROITHNER M. (1995b): *Problems of Mountain Hazard Mapping Using Spaceborne Remote Sensing Techniques.* Advances in Space Research, 15/11: 57 - 66.

BUCHROITHNER M. (1996): *High-Mountain Remote Sensing Cartography (HMRSC)*. Proceedings of International Symposium on HMRSC, Schladming, Austria, 26 - 28 September, 1990. Institut für Kartographie, TU Dresden, Germany.

BUCHROITHNER M., KRAETZSCHMAR E. & HELLMANN M. (1999): *Advanced Polarimetric*

SAR Data Classification for Cartographic Information Extraction. Proceedings of the 19th EARSeL Symposium on Remote Sensing in the 21st Century: Economic and Environmental Applications. Valladolid (Spain), 31 May - 2 June 1999.

BUCHTUEVA L. (2003): *Osobennosti Prirodopolzovania Etnosov na Territorii Uimonskoi Kotloviny (The Peculiarities of Nature Management of Ethnoses in the Uimon Basin).* Magister Thesis. Altai State University, Barnaul (in Russian).

BUCK A. (1996): *Bestimmung des Bodenerosionpotentials mit Hilfe der Fernerkundung und digitaler Zusatzdaten in Landschaftschutzgebiet der „Sächsischen Schweiz".* Diplomarbeit, Uni Tübungen.

BULLOCK P., JONES R. & MONTANARELLA L. (1999): *Soil Resources of Europe.* Luxembourg: Office for Official Publications of the EU.

BURLAKOVA L. (1974): *Elementy Plodorodiya Chernozemov Altaiskogo Priobjya i ich Ozenka v Systeme Gospodstvujushego Agrozenoza (Fertility Features of Chernozem Soils and their Evaluation for Agropedological Purposes.* Case Study for Altaian Ob'). PhD Thesis. Altai Agricultural Institute, Barnaul, Russia (in Russian).

BURLAKOVA L. (1988): *Pochvenno-Klimaticheskie Usloviya Altaiskogo Kraya. Osnovnye Zakonomernosti Formirovaniya Urojaya i Kachestva Polevyx Kultur. (Soil - Climatic Conditions of Altai Region. Altaian Field Crops and Methods on Forecasing of their Yields*). Yield by Programming. Barnaul, Altai Region, Russia: 16 - 31 (in Russian).

BURROUGH P. (1987): *Natural Resources Databases: Conceptual Units, Data Structures and Natural Variation.* Proceedings of the International Workshop on Quantified Land Evaluation Procedures. Washington, 27 April - 2 May 1986, ITC Publication, 6: 60 - 65.

BURROUGH P. (1989): *Fuzzy Mathematical Methods for Soil Survey and Land Evaluation.* Journal of Soil Science, 40/8: 477 - 492.

BURROUGH P. (1991): *Fuzzy and Fractal Objects for Intelligent Spatial Analysis in Geographical Information Systems.* MANDL P. (Ed.): Modelling and New Methods in Image Processing and in Geographical Information Systems. Schriftenreihe der OCG, 61: 37 - 38.

BURROUGH P. & MCDONNELL R. (1998): *Principles of Geographical Information Sys-tems.* Oxford University Press.

BURROUGH P., MacMILLAN R. & DEURSEN W. van (1992): *Fuzzy Classification Methods for Determining Land Suitability from Soil Profile Observations and Topography*. Journal of Soil Science, 43/2: 193 - 210.

BUTVILOVSKY V. (1993): *Paleogeographia Poslednego Oledenenia I Golozena Altaya: Sobytiyno-katastrophicheskaya Model (Paleogeography of the Last Glaciation and the Holocene of the Altai Mountains: Model of Natural-catastrophical Events).* Tomsk University, Russia (in Russian).

BUTVILOVSKY V. (2007a): *Einführung in die theoretische Geomorphologie - eine Alternativdarstellung*. Institut für Kartographie, TU Dresden. Kartographische Bausteine, 32.

BUTVILOVSKY V. (2007b): *Map of Erodability, Geology and Quaternary Sediments of the Uimon Basin* (unpublished).

BUTVILOVSKY V. & PRECHTEL N. (2000): *Osobennosti Proyavlenia Poslednei Lednikovoi Epochi v Basseine Koksy I Verchov'e Katuni (The Peculiar Properties of Glacial Epoch in the Basin of the Koksa River and in the Upper course of the Katoon River).* Altai State University, Barnaul, Sovremennye Problemy Geographii i Prirodopolzovania, 2: 31 - 47.

BUOL C., HOUL F. & MacCREKEN R. (1977): *Genesis and Soil Classification.* Translated from English by I. P. Gerasimova. Moscow, Progress Press, Russia (in Russian).

CARDOSO J. (1970). *A Soil Classification System for Irrigation Areas.* Serv. Rec. Ord. Agr. Pub. Lisboa.

C.E.B.A.C (1976): *Soil Survey and Evaluation of Viar and Valle Inferior Irrigation Areas*, Sevilla. CEBAC Res. Rep., Sevilla.

CHIEVRIE F. & GUELY F (1998): *Fuzzy Logic.* Cahier Technique, 191.

CHIRKOV Yu. (1988): *Osnovy Agrometeorologii (Basic Principles of Agricultural Meteorology).* Hydrometeo Press, Leningrad (in Russian).

CHISTYAKOV K. (1988): *Sezonnaya Dinamika Sostoyanii Prirodnyx Territorialnyx Komplexsov na primere Kotlovinnyx Lugostepei Zentralnogo Altaya (Seasonal Dynamics of Natural Complexes on the example of Basin Meadow Steppes of Central Altai).* All-Union Geographic Association Press, 120/6: 531 - 539 (in Russian).

CLEVERS J., MÜCHER C., POPOV V., VANDYSHEVA N. AND VASSILENKO G. (1999): *Agricultural Land Cover Monitoring in Russia Using Remote Sensing. Operational Remote Sensing for Sustainable Development*, Nieuwenhuis, Vaughan & Molenaar, Balkema, Rotterdam: 34 - 45.

COMERMA J. & GUENNI L. de (1987): *The IBSNAT Simulation Models as a Means of QLE in Developing Countries.* Proceedings of the International Workshop on Quantified Land Evaluation Procedures. Washington, 27 April - 2 May 1986, ITC Publication, 6: 44 - 47.

COWEN D.J. (1988): *GIS versus CAD versus DMBS: What are the differences?* Photogrammetric Engineering & Remote Sensing, 54/11: 1551 - 1555.

DALLEMAND J. & VOSSEN P. (1994): Agrometeological Models: Theory and Applications in the MARS Project". Proceedings of the Workshop for Central and Eastern Europe, Joint Research Centre of Ispra, Luxembourg.

DAVIDSON D., THEOCHAROPOULOS S. & BLOKSMA R.(1994): *A Land Evaluation Project in Greece Using GIS and Based on Boolean and Fuzzy Set Methodologies.* International Journal of Geographical Information Systems, 8/4: 369 - 384.

DE LA ROSA D., GARCIA L. & ALMORZA J. (1992): *MicroLEIS: A Microcomputer-based Mediterranean Land Evaluation Information System.* Soil Use and Management, 8: 89 - 96.

DIEPEN C. van, KEULEN H. van, WOLF J. & BERKHOUT J. (1991): *Land Evaluation: from Intuition to Quantification.* In: Stewart B.A. (Ed.). Advances in Soil Science, 15: 139 - 204.

DENGIZ O., BAYRAMIN I. & YÜKSEL M. (2003): *Geographic Information System and Remote Sensing Based Land Evaluation of Beypazari Area Soils by Ilsen Model. T*urkish Journal of Agriculture and Forestry, 27/3: 145 - 153.

DENT D.L. & COOK H. (1987): *Soil Water Sufficiency: Data Needs and Error bars of a Soil Water Potential Model.* Proceedings of the International Workshop on Quantified Land Evaluation Procedures. Washington, 27 April - 2 May 1986, ITC Publication, 6: 111 - 118.

DRIESSEN P. & DIEPEN C. van (1987): *WOFOST: a Procedure for Estimating the Production Possibilities of Land Use Systems.* Proceedings of the International Workshop on Quantified Land Evaluation Procedures. Washington, 27 April - 2 May 1986, ITC Publication, 6: 100 - 105.

DENT, D. & YOUNG, A. (1981): *Soil Survey & Land Evaluation.* London: George Allen & Unwin.

DRIESSEN P. & KONIJN N. (1992): *Landuse Systems Analysis.* Wageningen: Wageningen Agricultural University.

DUMANSKI J., MacDONALD B. & HUFFMAN E. (1987): *Advances in Research in Quantitative Land Evaluation in Canada.* Proceedings of the International workshop on quantified land evaluation procedures. Washington, 27 April - 2 May 1986, ITC Publication, 6: 24 - 27.

EARSeL (2006): *New Developments and Challenges in Remote Sensing.* CD Proceedings of the 26th EARSeL Symposium. Warsaw, Poland, 29 May - 2 June 2006.

EARSeL (2007): *Geoinformation in Europe.* Abstracts Book of the 27th EARSeL Symposium. Bolzano/Bozen, Italy, 4 - 7 June 2007.

ELMER B. (1966): *Elements of Probability and Statistics.* Prentice-Hall Inc., Englewood Cliffs, N.J.: 127 - 160.

ERMOKHIN Yu. & NEKLUDOV A. (2002): *Programmirovanie Urojaya v Zapadnoi Sibiri (Forecasting of Yield in Western Siberia).* Omsk State Agrarian University Press. Omsk (in Russian).

ERNST E. (1991): *Bodenhorizonte und bodensystematische Einheiten Mitteleuropas im internationalen Vergleich (Dem XIII. Kongreß der INQUA in Peking)*. Petermanns Geographische Mitteilungen, 135.

FAO (1976): *A Framework for Land Evaluation.* FAO Soil Bulletin, 32. Rome.

FAO (1981): *Report on the Agroecological Zones Project.* Vol. 3. Tethodology and results for

South and Central America. World Soil Resour., 48/5. Rome.

FEDDEMA J. & FREIRE S. (2001): *Soil Degradation, Global Warming and Climate Impacts*. Climate Research, 17: 209 - 216.

FERRARI G. & MAGALDI D. (1989): *Land Suitability Evaluation for Mediterranean Regions.* Instituto Agronomico per L'Oltremere, Firenze.

FISHER G., VELTHUIZEN H., SHAH M. & NACHTERGAELE F. (2002): *Global Agro-ecological Assessment for Agriculture in the 21st Century: Methodology and Results.* Joint Research Report RR-02-02 of the International Institute for Applied Systems Analysis. Laxenburg, Austria and FAO, Rome, Italy.

FISHER P. & LINDENBERG R. (1989): *On Distinctions among Cartography, Remote Sensing and Geographical Information Systems.* Photogrammetric Engineering & Remote Sensing, 55/10: 1431 - 1434.

FUSSELL J., RUNDQUIST D. & HARRINGTON J. (1986): *On Defining Remote Sensing. Photogrammetric Engineering & Remote Sensing,* 52/9: 1507 - 1511.

GIORDANO A., TORINO, BONFILS P., MONTPELLIER, BRIGGS D., HUDDERSFIELD, MENEZES DE SEQUEIRA, OEIRAS C., ROQUERO DE LABURU & YASSOGLOU N. (1991): *The Methodological Approach to Soil Erosion and Important Land Resources Evaluation of the European Community*. Cremlingen. Soil Technology, 4: 65 - 77.

GONZALEZ R. & WOODS R. (1992): *Digital Image Processing.* Addison-Wesley, Reading, MA.

GORSHENIN K. (1934): *Klassifikaziya pochv Zapadnoi Sibiri (Classification of Soil for the Western Siberia).* Soil Science, 6: 765 - 791 (in Russian).

GORSHENIN K. (1955): *Soil of the Southern Siberia (Ural to Baikal). Moscow, Academy of Science of the USSR* (in Russian).

GRIGORYEVA E. (2001a): *Theoretischeskie Osnovy Rastenievodstva (Teoretical Basics of Plant Science).* Altai State Agrarian University. Publ. by Altai Institute of Land Monitoring and Ecosystem. Barnaul: 24 – 50 (in Russian).

GRIGORYEVA E. (2001b): *Chto Doljen Znat Spezialist ob Osobennostyax Biologii Polevyx Kultur i Technologii ich Vozdelyvania? (What Should Know the Agronomist about Biology and Growing up Technology of Agricultural Crops?).* Part I. Altai Institute of Land Monitoring and Ecosystem. Barnaul, 67 – 89 (in Russian).

HABERMANN K. (2000): *Aufbau komplexer Vektor- und Bilddatenansätze des Rayon Ust-Koksa (Gebirgsaltai, Sibirien) für geowissenschaftliche Anwendungen,* Diplomarbeit, Institut für Kartographie, TU Dresden.

HALL G., WANG F. & SUBARYONO (1992). *Comparison of Boolean and Fuzzy Classification Methods in Land Suitability Analysis by Using Geographical Information Systems.* Environment and Planning, 24: 497 - 516.

HARALD J. (1999): *Bilddatenorientierte atmosphärische Korrektur und Auswertung von Satellitenbildern zur Kartierung vegetationsdominierter Gebiete,* Dissertationarbeit, TU Dresden.

HÄNEL C. (2002): *Integration und Topographiedaten in ein Hochgebirgs-GIS des Zentral-Altai*, Diplomarbeit, Institut für Kartographie, TU Dresden.

HÖPPNER E. (2001): *Untersuchungen zur jahreszeitlichen Kartierung der saisonalen Schnee-bedeckung im russischen Altai (Südsibirien) mittels meteorologischer Fernerkundungs-daten (AVHRR).* Diplomarbeit, Institut für Kartographie, TU Dresden.

HÖPPNER E. & PRECHTEL N. (2002): *Snow Cover Mapping with NOAA-AVHRR Images in the Scope of an Environmental GIS Project for the Russian Altai (South Siberia).* Proceedings of the Commission on Mountain Cartography of the International Cartographic Association (ICA); Mt. Hood, Oregon, May, 15 - 19, 2002.

HOOTSMANS R. (1996): *Fuzzy Sets and Series Analysis for Visual Decision Support in Spatial Data Exploration.* PhD Thesis. Universiteit Utrecht, Utrecht.

HUAJUN T., DEBAVEYE J., RUAN D. & RAINST E. van (1991): *Land Suitability Classification based on Fuzzy Set Theory.* Pedologie, XLI/3: 277 - 290.

HUAJUN T. & RANST E. van (1992): *Testing Fuzzy Set Theory in Land Suitability Assessment for Rainfed Grain Maize Production.* Pedologie, XLII/2: 129 - 147.

HUDDLESTON J.H. (1984): *Development and Use of Soil Productivity Ratings in the United States. Geoderma*, 32: 297 - 317.

ICA (1989): *Teaching the Interface between Cartography, Remote Sensing and GIS.* CD Proceedings of the ICA. Budapest, August 15 - 16, International Cartographic Association, Utrecht.

ISACHENKO A. (1985): Landschafty SSSR (Landscapes of USSR). Leningrad University Press (in Russian).

JANG J. & Gulley N. (1998): *Fuzzy Logic Toolbox. For use with MATLAB*. User's Guide Version 2. Natick: The Math Works Inc.

JONES R. & THOMASSON A. (1987): *Land Suitability Classification for Temperate Arable Crops.* Proceedings of the International Workshop on Quantified Land Evaluation Procedures. Washington, 6: 29 - 35.

KALIMA C. & VELDKAMP W. (1987): *Quantified Land Evaluation in Zambia. Land Evaluation and Perspective.* Proceedings of the International Workshop on Quantified Land Evaluation Procedures. Washington, 27 April-2 May 1986, ITC Publication, 6: 48 - 52.

KARNCHANASUTHAM S. (2002): *Rice Planted Area Suitability in Thailand.* GIS and Development, 6/9: 19 - 23.

KING L. (1967): *Morphologiya Zemli (The Morphology of the Earth).* Moscow. Progress Press. Russia (in Russian).

KELGENBAEVA K. (2002): *Adaptation of a Mediterranean Land Suitability Models for Inner-Alpine Basins of the Siberian Altai.* Seventh International Symposium on High-Mountain Remote Sensing Cartography (HMRSC VII), 15 - 26 July, 2002, Bishkek, Kyrgyzstan: 109 - 114.

KELGENBAEVA K., PRECHTEL N. & BUCHROITHNER M: (2003): *Modelling Soil and Climatic Conditions for Agricultural Suitability Assessment in the Siberian Altai*. CD-Publication, 21st International Cartographic Conference & 12th General Assembly of the International Cartographic Association. August 10 - 16, 2003, Durban, South Africa.

KERN M. (2000): *Future of Agriculture, Global Dialogue EXPO 2000. The Role of the Village in the 21st Century: Crops, Jobs and Livelihood,* Hannover, Germany: 5 - 23.

KHANTULEV A., BALASHOV A., KATINYAN I. & BOGDANOV I. (1972): *Pochvy Zemlepolzovaniya Sovchoza Ust-Koksinski (The arable soils of the Ust-Koksa state-farm).* The Report of Soil Expert Expedition, Leningrad State University (in Russian).

KLINGEBIEL A. & MONTGOMERY P. (1961): *Land Capability Classification.* Agricultural Handbook 210. USDA, Soil Conservation Service, Waschington.

KOLACNY A. (1969): *Cartographic information - a fundamental concept and term in modern cartography.* The Cartographical Journal, 6: 47 - 49.

KOVALEV R. (1973): *Pochvy Gorno-Altaiskoi Avtonomnoi Oblasti (Soils of Gorno-Altaisk Region).* Novosibirsk, Russia (in Russian).

KOVDA V. & ROSANOV B. (1988): *Soil Science*. Tom 1 & 2. Moscow, Russia (in Russian).

KUGLER H. (1965): *Aufgabe, Grundsätze und methodische Wege für großmaßstabiges geomorphologisches Kartieren.* Petermanns Mitteilungen, 109: 241 - 257.

KUMINOVA A. & VANDAKUROV E. (1949): *Stepi Sibiri (Siberian Steeps).* Novosibirsk, Russia (in Russian).

KUMINOVA A. (1960): *Rastitelnyi Pokrov Altaya (Vegetation of Altai Region).* Novosibirsk, Russia (in Russian).

KUNERT A. (2003): *Kartierung der Natürlichen Bodenbedeckung des Altai-Untersuchungsgbietes außerhalb des Waldes mit hochauflösenden Bilddaten mehrerer optischer Weltraumsensoren und wissenbasierter Klassifikationansätzen.* Diplomarbeit. Institut für Kartographie, TU Dresden.

KUZYAKOV Ya. (2001): *World Soils. More than 2000 Images of Soil Profiles and Horizon Characteristics, Soil Classifications, Maps, Biomes, Plants etc.* CD Version (1st edition). University of Honenheim. Germany.

KÜHBAUCH W., KUPFER G., BOOCHS F., BÜKER C., DOCKTER K., SCHELLBERG J., RÜSTEN CH. & TEMPELMANN U. (1991): *Ertragsshätzung an Landwirtschaftlichen Kul-*

turpflanzenbeständen mit Hilfe der Fernerkundungstechnik, Abschlußbericht, Rheinischen F.-W.- Universität, Bonn.
LAK M., HAMRAH M. & MAJDABADI G., (2006): *Using Landsat TM Images in Iran. Fuzzy Classification: a Case Study.* Journal of GIM International, July 2006: 42 - 43.
LANDON J. (Ed.) (1984): *Booker Tropical Soil Manual: a Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics.* Longman, New York.
LANEN H. van (1991): *Qualitative and Quantitative Physical Land Evaluation: An Operational Approach.* Wageningen: PhD Thesis. Wageningen Agricultural University.
LANEN H. van, DIEPEN C. van, REINDS G. & KONING G. de (1992a): *A Comparison of Qualitative and Quantitative Physical Land Evaluations, Using an Assessment of the Potential for Sugar-Beet Growth in the European Community.* Soil Use and Management, 8/2: 80 - 88.
LANEN H. van & WOPEREIS H. (1992b): *Computer-captured Expert Knowledge to Evaluate Possibilities for Injection of Slurry from Animal Manure in the Netherlands. Geoderma*, 54: 107 - 124.
LARSON W. (1986): *An Index for Assessing the Long-Term Productivity of Soil.* Proceedings of the International Workshop on Quantified Land Evaluation Procedures. Washington, 27 April - 2 May 1986, ITC Publication, 6: 72 - 76.
LASTOCHKIN A. (1991): *Morfodinamicheskaya Konzeptiya Obshei Oeomorphologii (Morphodinamic Conception of General Geomorphology).* Leningrad State University Press (in Russian).
LASTOCHKIN A. (1995): *O novom Prednaznachenii Geomorphologii v Sistemax Nauk o Zemle (A New Role of Geomorphology in Geosciences).* Leningrad State University Press (in Russian).
LILLESAND T. & KIEFER R. (1994): *Remote Sensing and Photo Interpretation,* 3rd. ed. John Wiley & Sons: New York.
LONDERSHAUSEN K. (2003): *Erstellung einer animierten kartographischen Präsentation von und aus Inhalten eines komplexen Geoinformationssystems im Kontext der Dresdener Altai-Forschung.* Diplomarbeit. Institut für Kartographie, TU Dresden.
LOK S. & PHIPPS M. (1981): *Calculating Indices of Land Suitability for Agricultural Crops: An interactive numerical technique.* Journal of Soil and Water Conservation, IX-XII: 351 - 353.
LOWERY B. & LARSON W. (1995): *Erosion Impact on Soil Productivity - reamble.* Soil Sci.Soc.Am.J., 59: 647 - 648.
LOWERY B., HART G., BRADFORD J., KUNG K-J. & HUANG C (1999): *Erosion Impact on Soil Quality and Properties and Model Estimates of Leaching Potential.* In: Soil Quality and Soil Erosion. Rattan Lal, CRC Press, Florida: 75 - 91.
MACEACHREN (1985): *How maps work. Representation, Visualization and Design.* The Guilford Press, New York.
MAGUIRE D. (1991): *An Overview and Definition of GIS*. In Maguire D. J., Goodchild M. F. & Rhind D. W. (eds.). Geographical Information Systems. Principles and Applications, 1: 923 - 958.
MANNHEIM S. (2001): *Kartierung der Aktuellen Waldbedeckung im Zentralen Altai (Südsibirien) mittels Fernerkundung und Feldaufnahmen.* Diplomarbeit. Institut für Kartographie, TU Dresden.
MATHER P. (1987): *Computer Processing of Remotely Sensed Images. An Introduction.* Willey and Sons, Chichester.
MATINYAN & KERZUM (1972): *Soil Map of the Ust-Koksa Basin.* Scale 1: 25,000. Barnaul Land Cadastre (Giprozem) Research Institute. Barnaul, Russia (in Russian).
MAUSBACH M. & REYBOLD W. (1987): *In support of GIS in the SCS: SIS.* Proceedings of the International workshop on quantified land evaluation procedures. Washington, 27 April - 2 May 1986. ITC Publication, 6: 77 - 80.
MAIER M. (2006). *Gene Expression Analysis with Fuzzy Logic.* M.Tech. Thesis. University of Portsmouth, UK.

McCORMACK D. (1987): *Soil Potential Ratings - A Special Case of Land Evaluation.* . Proceedings of the International Workshop on Quantified Land Evaluation Procedures, Washington, 27 April - 2 May 1986. ITC Publication, 6: 81 - 84.

MCRAE S. & BURNHAM S. (1981): *Land Evaluation.* Clarendon Press, Oxford: 11 - 26.

MIDDLETON N. & THOMAS D. *(1997) World Atlas of Desertification,* 2nd edn. UNEP, Geneva.

MOURIK D. van (1987): *Marketing and Environmentally Oriented Socio-Economic Quantitative Land Evaluation in Sejenane, Tunisia.* Proceedings of the International Workshop on Quantified Land Evaluation Procedures. Washington, 27 April - 2 May 1986, ITC Publication, 6: 140 - 143.

NARTZISSOV V. (1982): *Nauchnye Osnovy System Zemledelia (Landuse Laws).* Moscow. Kolos (in Russian).

NYERGES, T. (1993). *Understanding the Scope of GIS - Its Relationship to Environmental* Modelling. Oxford University Press, New York: 75 - 93.

OLLIYER K. (1987): *Vyvetrivanie (Weathering).* Translated from English. Moscow, Nedra Press, Russia (in Russian).

ONERN L. (1982): *Clasificación de las tierras del Peru.* Pub. Ofic. Nac. Ev. Rec. Nat. Lima.

ODEH I., McBRATNEY A. & CHITTLEBOROUGH D. (1992): *Soil Pattern Recognition with Fuzzy-C-Means: Application to Classification and Soil-landform Interrelationships*. Soil Sci. Soc. Am. J., 56: 505 - 516.

ORLOVSKI N. (1959): *Materialy po agroproizvodstvennoi xarakteristike pochv Altaiskogo Kraya(Reports on Agroproductional Charachteristics of Altaian soils).* Soils of the Altai Region. Moscow. USSR Academy of Science Press: 321 - 379 (in Russian).

ORMELING F. (1995): *Atlas Information Systems*. Proceedings of the 17th International Cartographic Conference (Barcelona), 2: 2127 - 2133.

OSTROM V. (1986): *Guidance, Control and Evaluation in the Public Sector.* In F.X. Kaufmann G. Majone & V. Ostrom (Eds.). Berlin.

PANFILOV V. (1956): *Brief Description of Soils of Gorno-Altaisk' Region (Kratkaya Xarakteristika Pochvennogo Pokrova Gorno-Altaiskoi Avtonomnoi Oblasti).* Fodder supply in Gorno-Altaisk' Autonom Region. Biological Institut Press, 2. Novosibirsk: 126 - 135 (in Russian).

PIERI C. (1997): *Planning Sustainable Land Management: the Hierarchy of User Needs.* ITC Journal, 3/4: 223 - 228.

PIERCE F., LARSON W., DOWDY R. & GRAHAM W. (1983): *Productivity of Soils: Assessing Long-term Changes due to Erosion.* Journal of Soil and Water Conservation, January-February: 39 - 44 p.

PIOTROWSKI J., BARTELS F., SALSKI A. & SCHMIDT G. (1996). *Geostatistical Regionalization of Glacial Aquitard Thickness in Northwestern Germany, based on Fuzzy Kriging*. Mathematical Geology, 28/4: 437 - 452.

POHJAKAS K. (1987); *Land Irrigability Classification in Alberta*. Proceedings of the International Workshop on Quantified Land Evaluation Procedures. Washington, 27 April - 2 May 1986, ITC Publication, 6: 122 - 126.

POLLACK M. (2002): Methodischer Beitrag zur GIS-basierten mittelmaßstäbigen geomorphologischen Klassifizierung und Kartierung des Zentral-Altai auf Grundlage von DGM und Geländeerhebungen. Diplomarbeit. Institut für Kartographie, TU Dresden.

PRECHTEL N. (2000): *Operational Analytical Hill Shading Within an Advanced Image Processing System.* Proceedings of the ICA-Commission on Mountain Cartography, Symposium 29.3. - 2.4.2000, Rudolfshütte (Austria) = Kartographischer Baustein 18.

PRECHTEL N. (2003): *GIS-Aufbau für den Naturschutz im Russischen Altai* (Establishing a GIS for Environmental Protection in the Russian Altai). Geoinformationssysteme - Theorie, Anwendungen, Problemlösungen. Institut für Kartographie, TU Dresden. Kartographische Bausteine, 21: 82 - 100.

PRECHTEL N. & BUCHROITHNER M. (2001): *The Contribution of Remote Sensing to Alpine Tourism in Protected Landscapes. The Example of the Altai Mountains.* Proceedings of Sixth International Symposium on High-Mountain Remote Sensing Cartography, Addis

Abeba, September, 3 - 18, 2000. Grazer Schriften der Geographie und Raumforschung, Bd. 37: 15 - 34.

PRECHTEL N. & BUCHROITHNER M. (2003): *Establishing an Environmental GIS for Mountain Regions: the Altai Example.* - CD Proceedings of the Workshop "GIS Ostrava 2003", January, 26 - 29, 2003, Ostrava University of Technology. http://gis.vsb.cz/GIS2002/Konference/GIS_Ova/GIS_Ova_2003 /abstrakty.htm

PUENTES R. (1987): *Risk of Land Degradation as Main Criterion for Land Evaluation.* Proceedings of the International Workshop on Quantified Land Evaluation Procedures. Washington, 27 April - 2 May 1986, ITC Publication, 6: 53 - 59.

PURNELL M. (1987): *Quantitative Land Evaluation in some FAO Programmes.* Proceedings of the International Workshop on Quantified Land Evaluation Procedures. Washington, 27 April - 2 May 1986, ITC Publication, 6: 7 - 15.

PEISKER T. (2006): *Klassifizierung von Biotypen mit wissenbasierten Fuzzy-Logik-Modellen basierend auf hyperspektralen Flugzeugscannerdaten.* Diplomarbeit. Institut für Kartographie, TU Dresden.

RAICHERT E. (2004): *Pochvy Paxotnyx Ugodii Uimonskoi Kotloviny Respubliki Altai i Sovremennoe Sostoyanie ich Plodorodia (Soils of Arable Lands of the Uimon Basin and Present State of Fertility).* PhD Thesis, Altai Agricultural University, Barnaul (in Russian).

RATAJSKI L. (1973): *The Research Structure of Theoretical Cartography.* L. Guelke (ed.): Monograph, 19. Cartographica: 46 - 57.

REES W. (1990): *Physical principles of remote sensing. Topics in remote sensing.*Cambridge University Press, Cambridge.

RICHARDS J. (1999): *Remote Sensing Digital Image Analysis. An Introduction*. Third revised and enlarged edition. Springer Verlag, Heidelberg.

ROSSITER D. (1990). *ALES: A Framework for Land Evaluation Using a Microcomputer.* Soil Use and Management*,* 6: 7 - 20.

ROSSITER D. (1996). *A Theoretical Framework for Land Evaluation.* Geoderma, 72: 165 - 190.

ROY R., FINCK A. BLAIR G. & TANDON H. (2006): *Plant Nutrition for Food Security. A Guide for Integrated Nutrient Management.* FAO Fertilizer and Plant Nutrition Bulletin, 16. Rome, Italy.

SALSKI A. (1999): *Fuzzy Logic Approach to Data Analysis and Ecological Modeling.* IDigital Proceedings of European Symposium on Intelligent Techniques (ESIT). Orthodox Academy of Crete, Greece, June 3 - 4, 1999.

SALSKI A. (2006): *Ecological Applications of Fuzzy Logic.* Ecological Informatics. Scope, Techniques and Applications. 2nd Edition. Verlag: Springer Berlin Heidelberg, 3 - 14

SAMAEVA G. (1992): *Respublika Altai (Altai Republic),* Brochure, Gorno-Altaisk (in Russian).

SANCHEZ P., PALM C., BUOL S. (2003): Fertility Capability Soil Classification: A Tool to Help Assess Soil Quality in the Tropics. Geoderma 114: 157 - 185.

SASIKALA K., PETROU M. & KITTLER J. (1996): *Fuzzy Classification with a GIS as an AID to Decision Making.* EARSeL, Advances in Remote Sensing, 4/ 4: 97 - 105.

SHANNON C. (1948): *The Mathematical Theory of Communication*. Bell Systems Technical Journal, 27: 379 - 423.

SHARMA A. (1987). *Qualitative and Quantitative Land Evaluation for Rainfed Maize in Subhumid Tropical and Subtropical Climates. Land Evaluation and Perspective.* Proceedings of the International Workshop on Quantified Land Evaluation Procedures. Washington, 27 April - 2 May 1986, ITC Publication, 6: 147 - 156.

SIMS T. (2000): *Soil Fertility Evaluation.* In: Handbook of Soil Science, Editor in-Chief: Malcolm E. Sumner, Univ. of Delaware, USA: D-113 - 153.

SMIRNOV V. (1910): O pochvax Zapadnoi Chasti Gornogo Altaya mejdu Basseinami Rek Katuni i Charysha (Soils of the Western Gorno-Altaisk between the both Katun and Tcharysh Rivers). Part I: 145 – 153 (in Russian).

STEEG J. van (2003). *Land Evaluation for Agrarian Reform. A Case Study for Brasil.* Landbauforschung Völkenrode - FAL Agricultural Research. Bundesforschungsanstalt für Landwirtschaft (FAL)/246.

STOLBOVOI V. (2000): *Soils of Russia: Correlated with the Revised Legend of the FAO Soil Map of the World and World Reference Base for Soil Resources.* Research Report RR-00-13, International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria: 15 - 47.

STOLZ R. (1998): *Die Verwendung der Fuzzy Logic Theorie zur wissenbasierten Klassifikation von Fernerkundungsdaten.* Dissertationarbeit. Institut für Geographie der Universität München.

STORIE R. (1933): *An Index for Rating the Agricultural Value of Soils.* California Agricultural Experimental Station Bulletin.

SYRBE R.-U. (1993): *Landschaftsbewertung im Oberspreewald auf geoökologischer Grundlage - eine methodische Studie.* Dissertation. Universität Potsdam.

SYRBE R.-U. (1998a): *Landschaftsbewertung unter Verwendung analytischer Verfahren und Fuzzy–Logic*, UFZ-Bericht, 6: 145 - 168.

SYRBE R.-U. (1998b): *Landscape Evaluation of Heterogeneous Areas Using Fuzzy Sets.* Cybergeo, 40. In: http://193.55.107.3/ revgeo/rostok/textes/syrbe.htm, dated 1998.

SYS C. (1985): *Land Evaluation: Part I, II and III.* In: ITC lecture notes, University of Ghent, Belgium.

TANG H., DEBAVEYE J., RUAN D. & RANST E. van (1991): *Land Suitability Classification* based on Fuzzy Set Theory. Pedologie XLI/3: 277 - 290.

TANG H. & RANST E. van (1992): *Testing of Fuzzy Set Theory in Land Suitability Assessment for Rainfed Grain Maize Production.* Pedologie XLII/2: 129 - 147.

TEACH D. & BURT M., (1974): *Land Evaluation & Classification in East-European Countries.* FAO Soils Bulletin, 22: 35 - 46.

TERANO T., ASAI K. & SUGENO M. (1992): *Fuzzy Systems Theory and its Applications.* Academic Press, INC. Harcourt Brace Jovanovich, Publishers (Boston, San Diego, New York, London, Sydney, Tokyo and Toronto): 26 - 29.

TROEH F., HOBBS J. & DONOHUE R. (1980): *Soil and Water Conservation for Productivity and Environmental Protection*. Prentice-Hall, Englewood Cliffs, NJ.

USDA (1961): *Land Capability Classification.* Agriculture Handbook 210. Washington. U.S. Government Printing Office.

VILMYAMS V. (1951): *Pochvovedenie, 6. (Soil Science, 6. Agricultural Press. Moscow, Russia)* (in Russian).

WAMBEKE A. (1987): *Quantified Land Evaluation as a Basis for Alternative Land Use Planing. Proceedings of the International Workshop on Quantified Land Evaluation Procedures,* Washington, ITC Publication, 6: 29 - 35.

WANG F., HALL G. & SUBARYONO (1990): *Fuzzy Information Representation and Processing in Conventional GIS Software: Database Design and Application.* International Journal of Geographical Information Systems, 4/3: 261 - 283.

WEBSTER R & OLIVER M. (1990): *Statistical Methods in Soil and Land Resource Survey.* Oxford University Press published in the Unites States, New York: 9 - 22.

WEL F. (2000): *Assessment and Visualisation of Uncertainty in Remote Sensing Land Cover Classifications.* PhD Thesis. Universiteit Utrecht, Utrecht.

WERNER D. (2003): *Gestaltung und Herstellung von Klimakarten des Russischen Altai 1: 1500000 unter Berücksichtigung von Datenhomogenizierung und GIS-Integration.* Diplomarbeit. Institut für Kartographie, TU Dresden.

WOOD S. & DENT F. (1983): *LECS: a Land Evaluation Computer System.* AGOF/INS/78/006. Vols. 5 (Methodology) & (User’s Manual), Ministry of Agriculture, Government of Indonesia, Bogor.

YASHUTIN N. B., BIVALKEICH V. & YOIST N. (1996). *Sistemnoe Zemledelie (Landuse System).* Barnaul. Altai State Agarian University, Barnaul, Russia (in Russian).

YASHUTIN N., DROBYSHEV A. & IOST N. (2001): *Zemledelie na Altae (Landuse in the Altai),* Altai State Agrarian University, Barnaul, Russia: 107 – 152 (in Russian).

ZIMMERMANN H.-J. (1999): *Practical Applications of Fuzzy Technologies.* Published in the USA.

ZINCK J. (1990): *Soil survey: epistemology of a vital discipline.* ITC Journal, 4: 335 - 350.

ZVONKOVA T. (1959): *Izuchenie rel'yefa v prakticheskix zelyax (Relief in Practice)*. Moscow. Geographic Literature Press, Russia (in Russian).
ZVONKOVA T. (1962): *Prikladnaya Geomorphologia (Applied Geomorphology).* Moscow. Nedra Press, Russia (in Russian).

WEB SOURCES

(accessed 2005 - 2007)

[INT-01] *Rossiter D. Lecture Notes: "Land Evaluation".* Department of Earth Systems Analysis. International Institute for Geo-information Science & Earth Observation (ITC). Enschede, the Netherlands http://www.itc.nl/~rossiter/teach/lecnotes.html#l5, dated 2005

[INT-02] *Agriculture and Global Environmental Change* http://www.ciesin.columbia.edu/TG/AG/AG-home.html, dated 2007

[INT-03] *Website of Altai Republic* http://www.altai-republic.ru/modules.php?op=modload&name=Sections &file=index&req= viewarticle&artid=17&page=1, dated 2006

[INT-04] *Soil in Land Evaluation* http://edafologia.ugr.es/comun/congres/cartart.htm, dated 2006

[INT-05] *Altai Project at Dresden University of Technology, Institute for Cartograp*hy http://www.tu-dresden.de/fghgik/board/altai/UK/SONST/einfuehr.htm, dated 2007

[INT-06] *De La Rosa D.: MicroLEIS 1998: Conceptual Framework Agroecological land evaluation* http://leu.irnase.csic.es/microlei/manual2/pdfs/framework-eng.pdf, dated 2005

[INT-07] *Land Evaluation* http://www.cfm.ohio-state.edu/~raul/Documents/Chapter_6.pdf, dated 2005

[INT-08] *Digital Geo-Spatial Data Analysis* http://www.cfm.ohio-state.edu/~raul/Documents/Chapter_1.pdf, dated 2006

[INT-09] *International Cartographic Association* http://www.icaci.org/en/ICA_Strategic_Plan_2003-08-16.pdf, 2006

[INT-10] *Agronomic Factors: Humus* http://en.wikipedia.org/wiki/Humus, dated 2005

[INT-11] *Agronomic Factors: Nitrogen* (http://www.fao.org/docrep/X5648E/x5648e0e.htm), dated 2005

[INT-12] *Agronomic Factors: CEC,* http://www.soils.umn.edu/academics/classes/soil2125/doc/labunts.htm, dated 2007

[INT-13] *Agronomic Factors: Soil pH* http://ltpwww.gsfc.nasa.gov/globe/soil_pH/plant_pH.htm, dated 2005

[INT-14] *Flood Frequency* http://www.fao.org/docrep/X5648E/x5648e0e.htm, dated 2007

[INT-15] *Wheat* http://www.extension.umn.edu/distribution/cropsystems/DC2547.html

[INT-16] *Siler W.: Building Fuzzy Expert Systems. Lecture notes:* http://members.aol.com/wsiler/, dated 2007

[INT-17] *Fuzzy Logic Toolbox Tutorial* http://www.mathworks.com/access/helpdesk_r13/ help/toolbox/fuzzy/fuzzytu3.html, dated 2007

[INT-18] *Brule J.* (1985): *Fuzzy Systems − A Tutorial [Electronic Version].* http://www.austinlinks.com/Fuzzy/tutorial.html, dated 2007

[INT-19] *Stolbovoi V. (2000): Soils of Russia: Correlated with the Revised Legend of the FAO Soil Map of the World and World Reference Base for Soil Resources,* dated 2005 http://ideas.repec.org/p/wop/iasawp/rr00013.html.

[INT-20] *Stolbovoi* V.: *Land Resource of Russia, part: Soil: Fertility capability,* dated 2005 http://www.iiasa.ac.at/Research/FOR/russia_cd/soil_des.htm

Appendices

Appendix A: Values of Gaussmf for summer wheat, sunflowers and potatoes

Appendix B: GIS AML programmings for WM Approach

Appendix C: Transparency for the determination of the location of the 11 soil units

Appendix D: Maps

Map A: General Base Maps

Map B: Maps of the Four Approaches

Appendix A:
Values of Gaussmf for summer wheat, sunflowers and potatoes

Values of Gaussmf for 11 factors. Crop: Summer Wheat

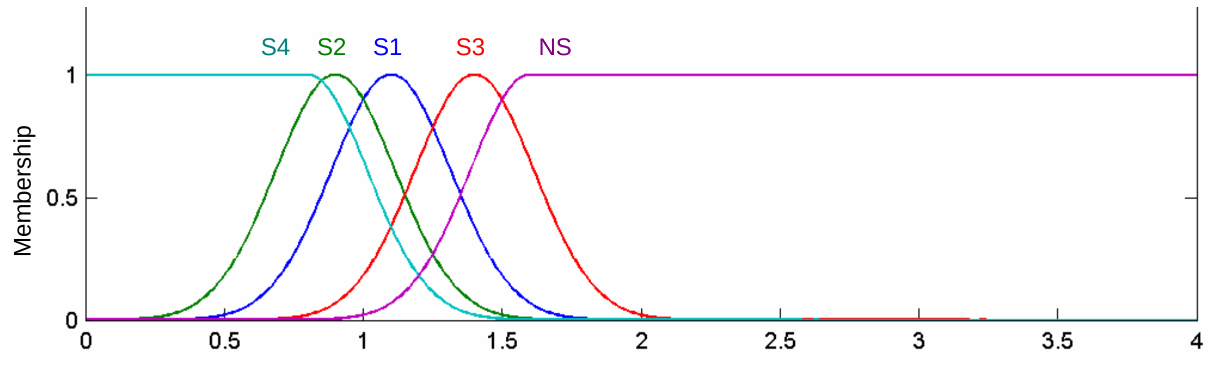


Fig. 6.2.12: Membership functions for HTK_1

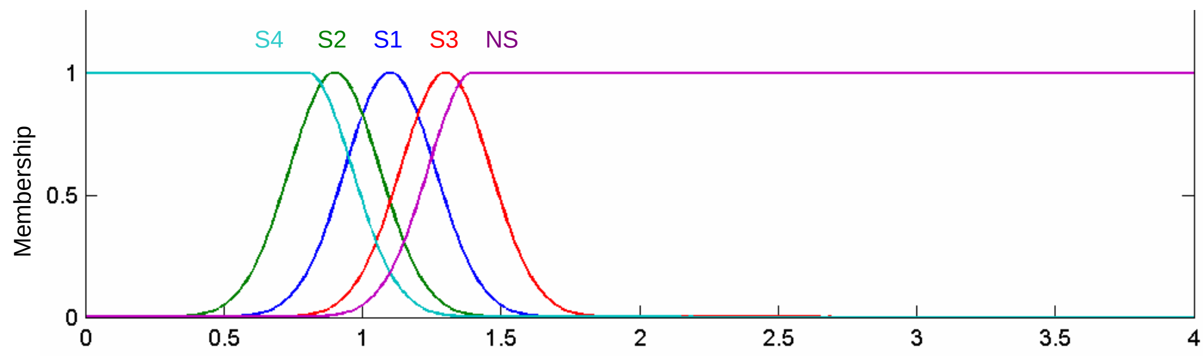


Fig. 6.2.13: Membership functions for HTK_2

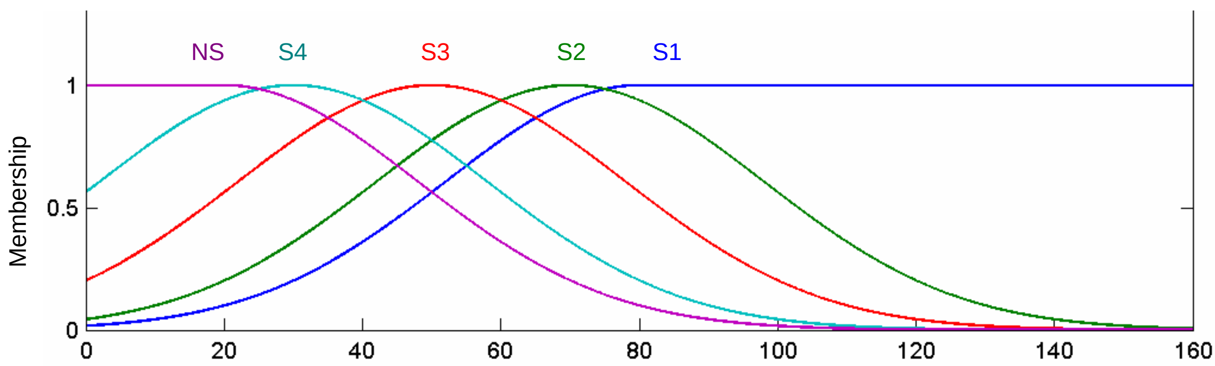


Fig. 6.2.14: Membership functions for soil type

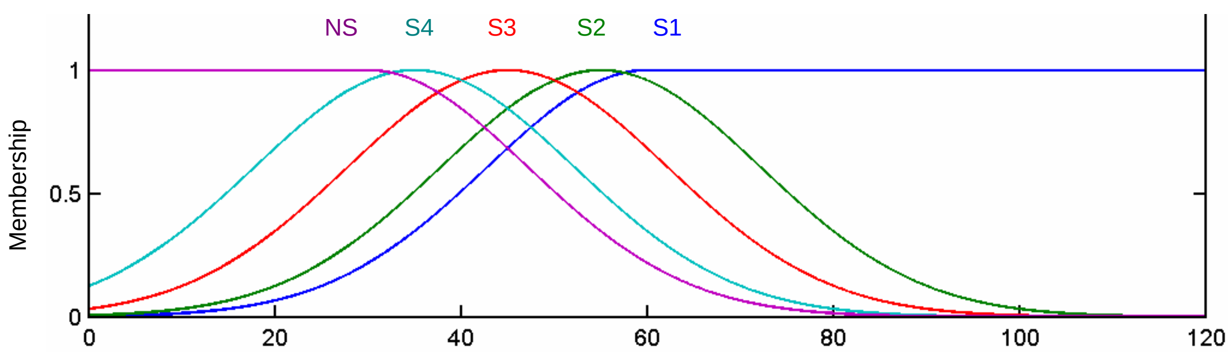


Fig. 6.2.15: Membership functions for depth of humus horizon

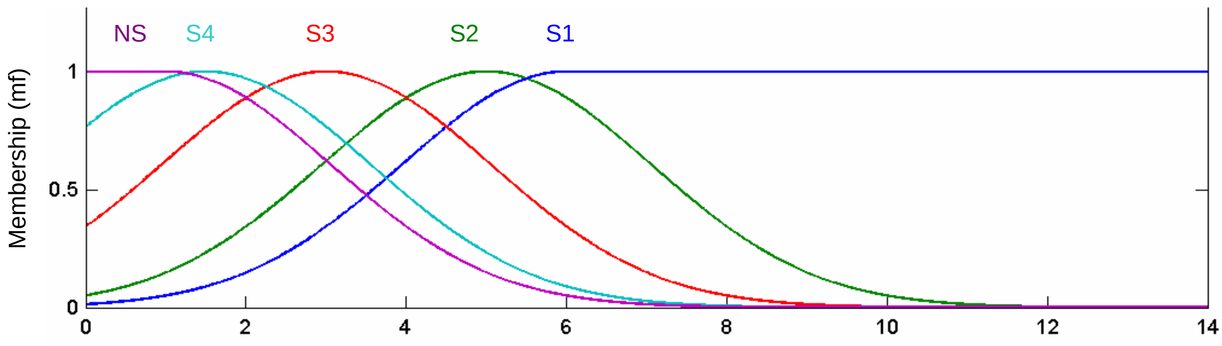


Figure 6.2.16: Membership functions for humus.

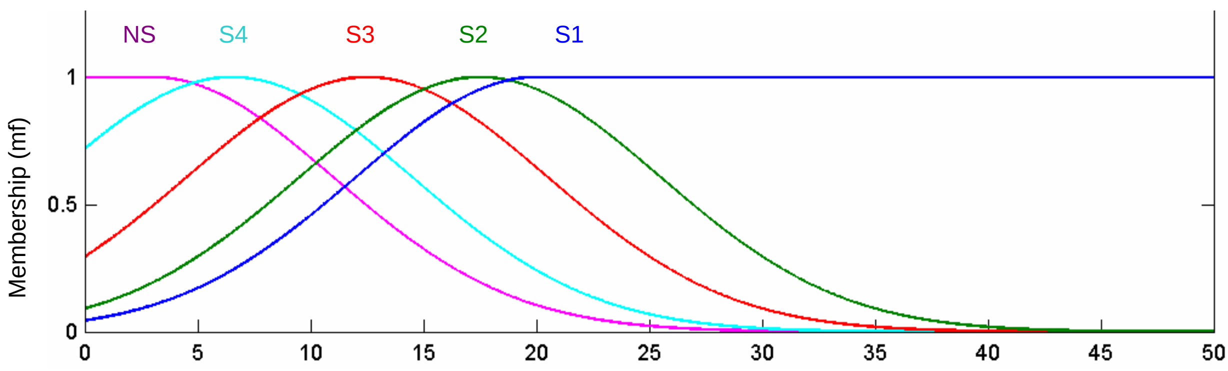


Figure 6.2.17: Membership functions for NO_3

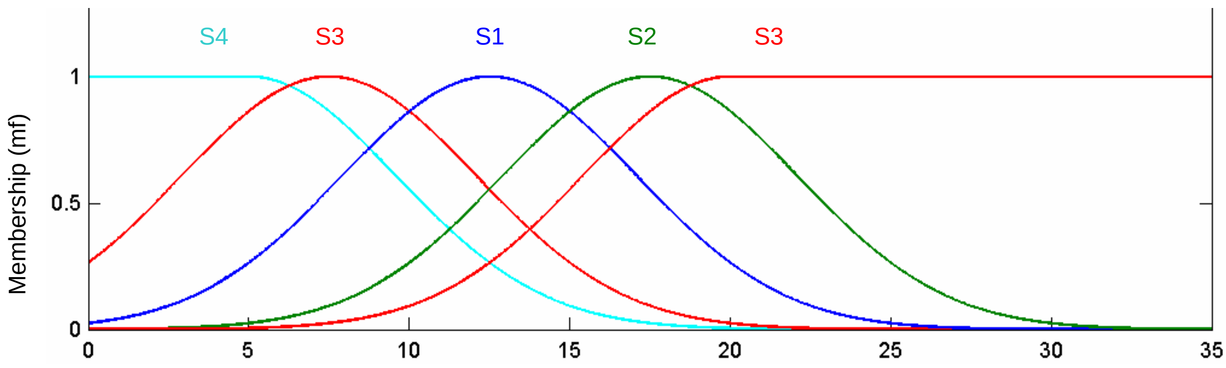


Figure 6.2.18: Membership functions for P_2O_5

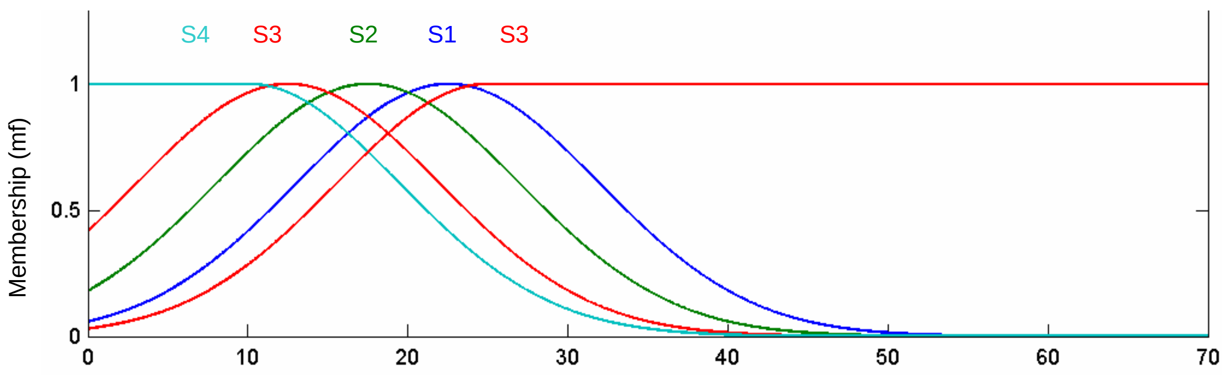


Fig. 6.2.19: Membership functions for K_2O

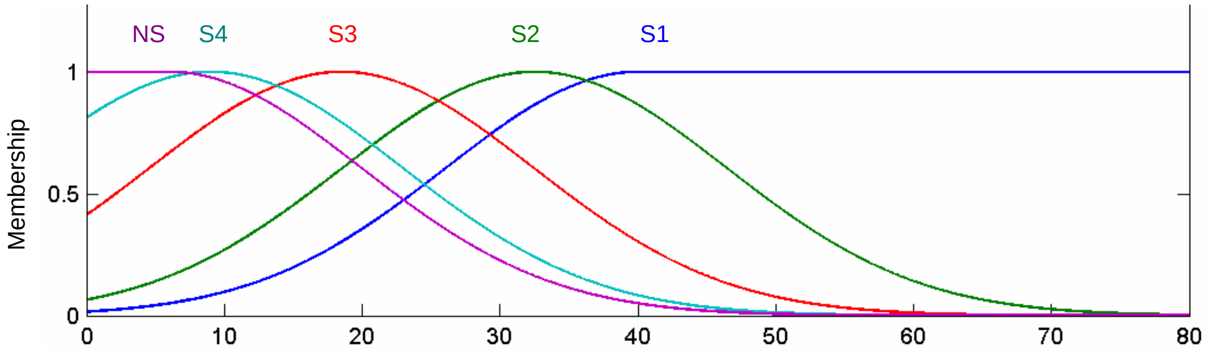


Fig. 6.2.20: Membership functions for CEC

CEC in meq/100g

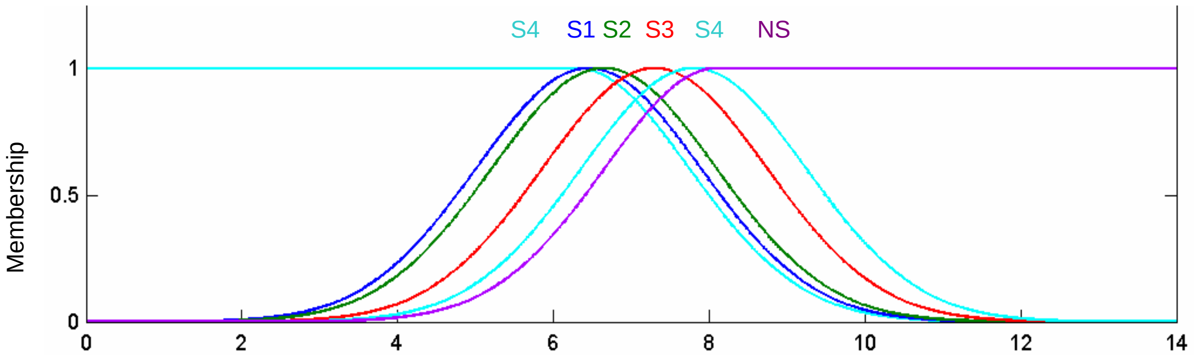


Fig. 6.2.21: Membership functions for pH

pH

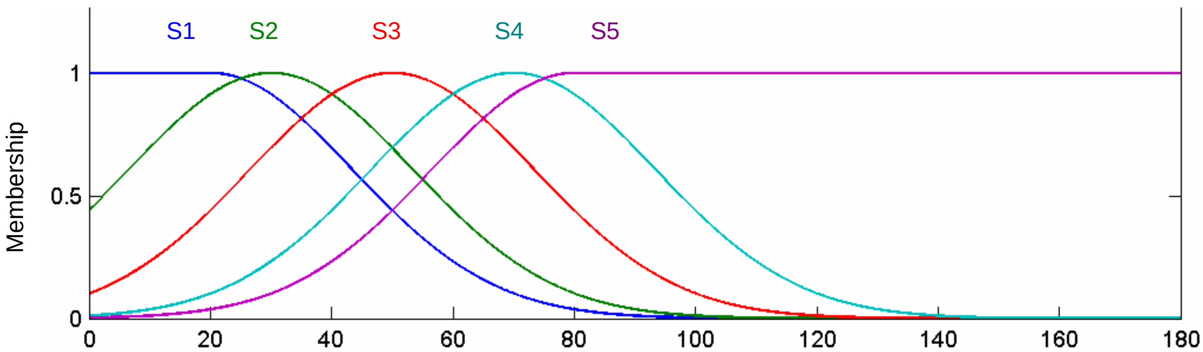


Fig. 6.2.22: Membership functions for flood frequency

Flood frequency in %

Values of Gaussmf for 11 factors. **Crop: Sunflowers**

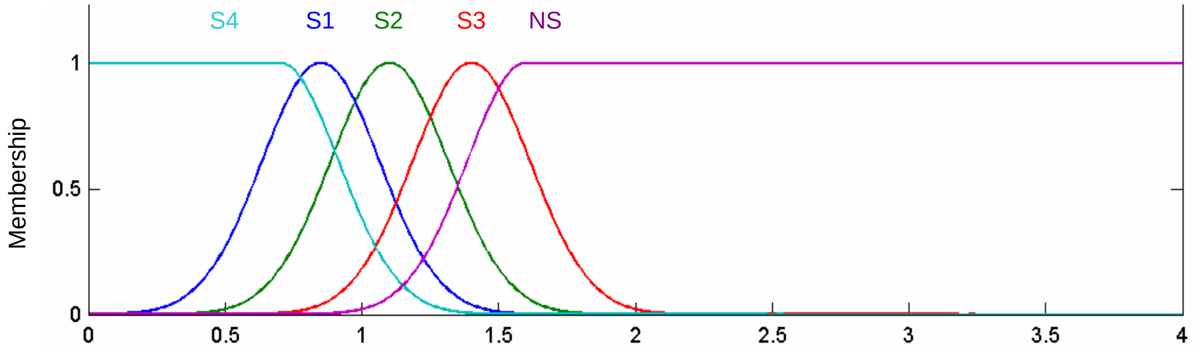


Fig. 6.50: Membership functions for HTK_1

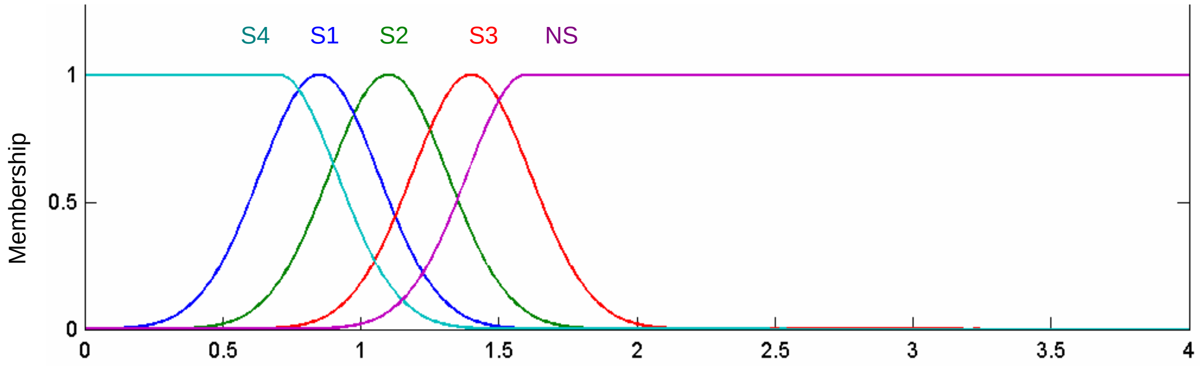


Fig. 6.51: Membership functions for HTK_2

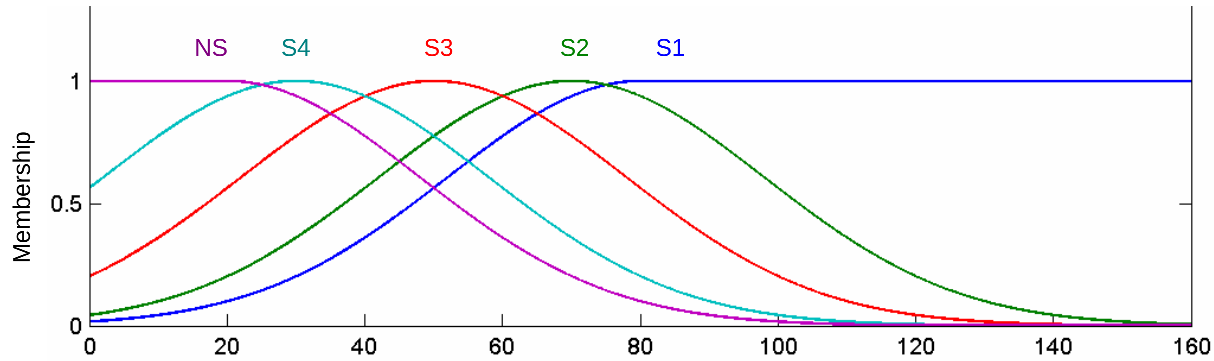


Fig. 6.52: Membership functions for soil type

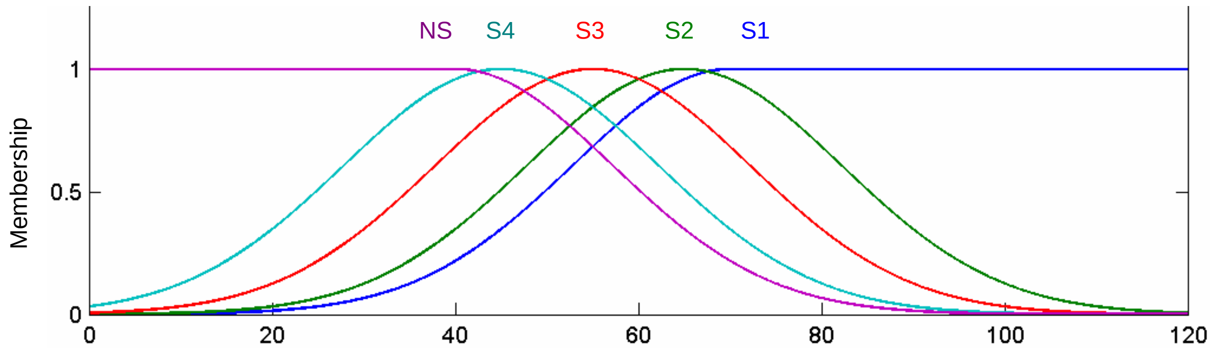


Fig. 6.53: Membership functions for depth of humus horizon

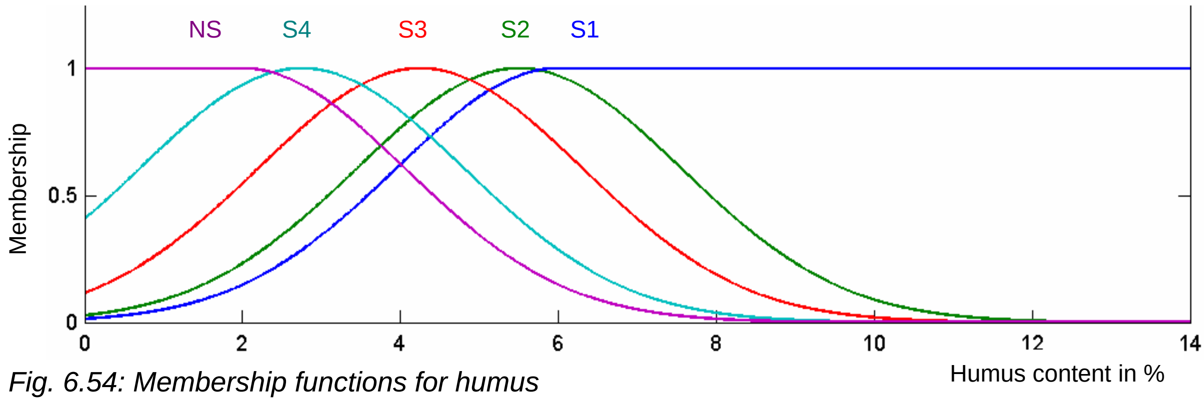


Fig. 6.54: Membership functions for humus

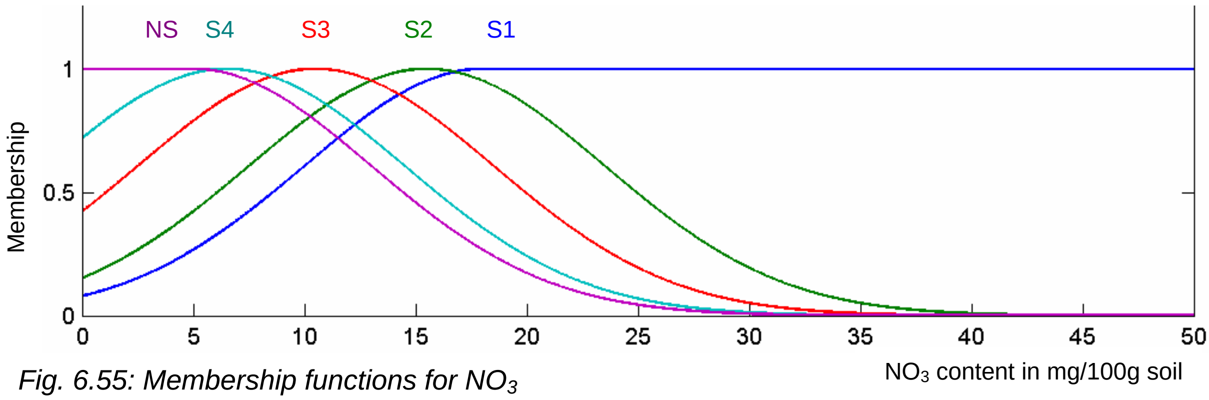


Fig. 6.55: Membership functions for NO_3

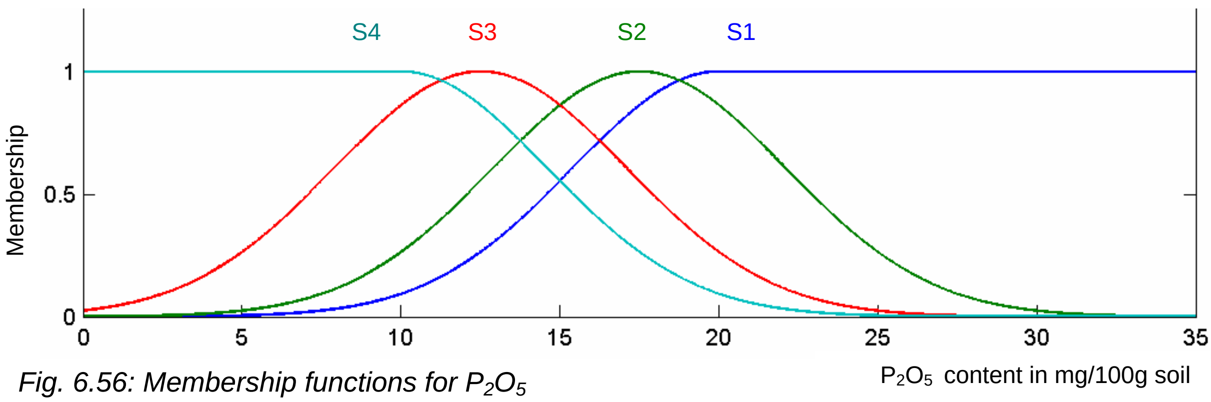


Fig. 6.56: Membership functions for P_2O_5

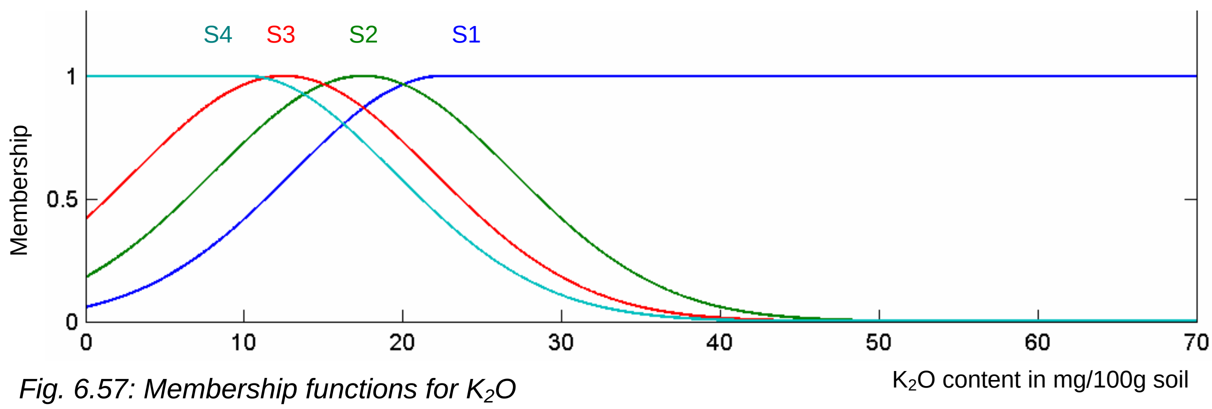


Fig. 6.57: Membership functions for K_2O

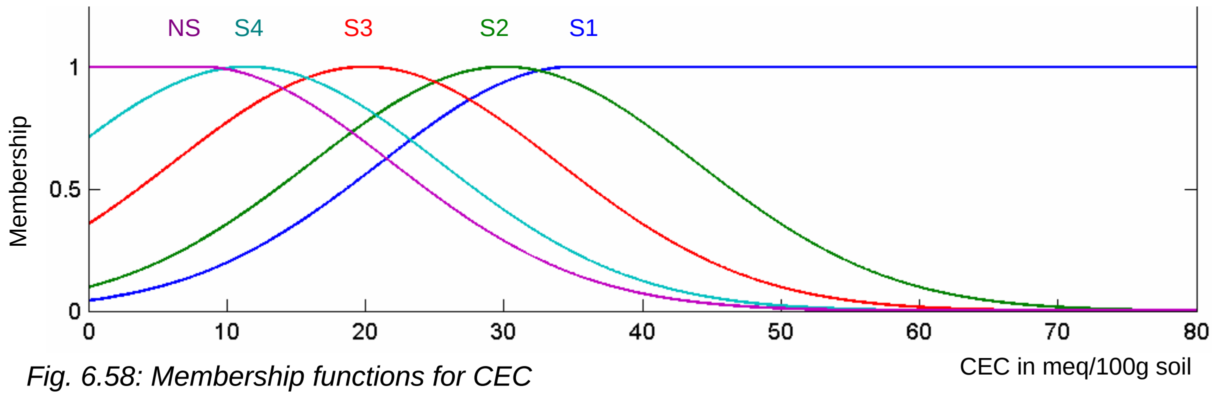


Fig. 6.58: Membership functions for CEC

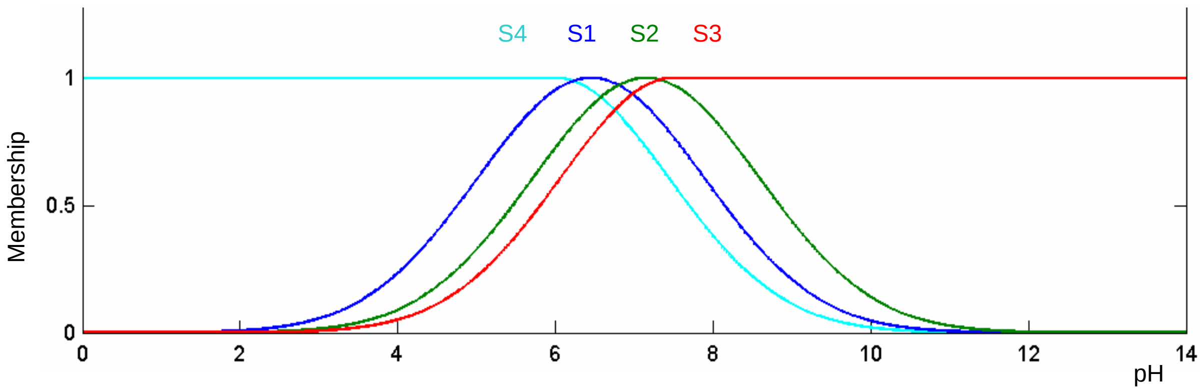


Fig. 6.59: Membership functions for pH

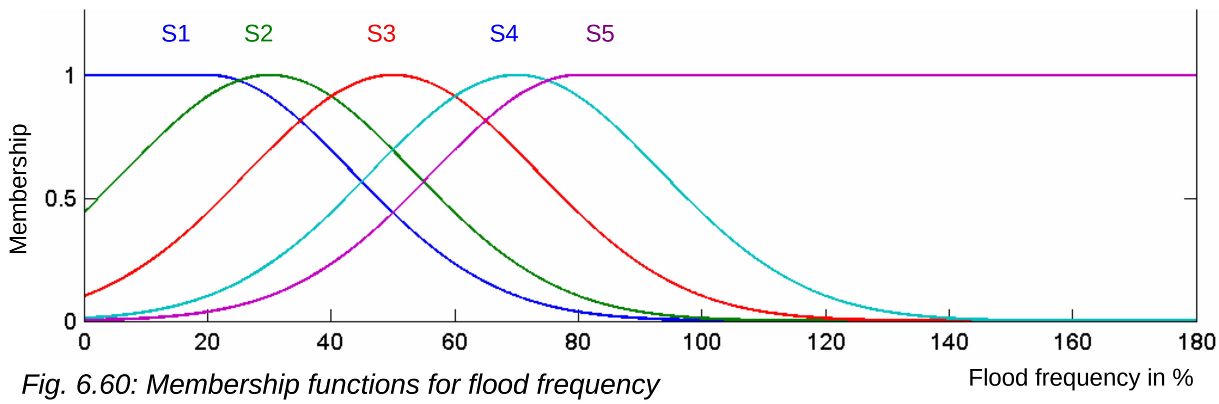


Fig. 6.60: Membership functions for flood frequency

Values of Gaussmf for 11 factors. ***Crop: Potatoes***

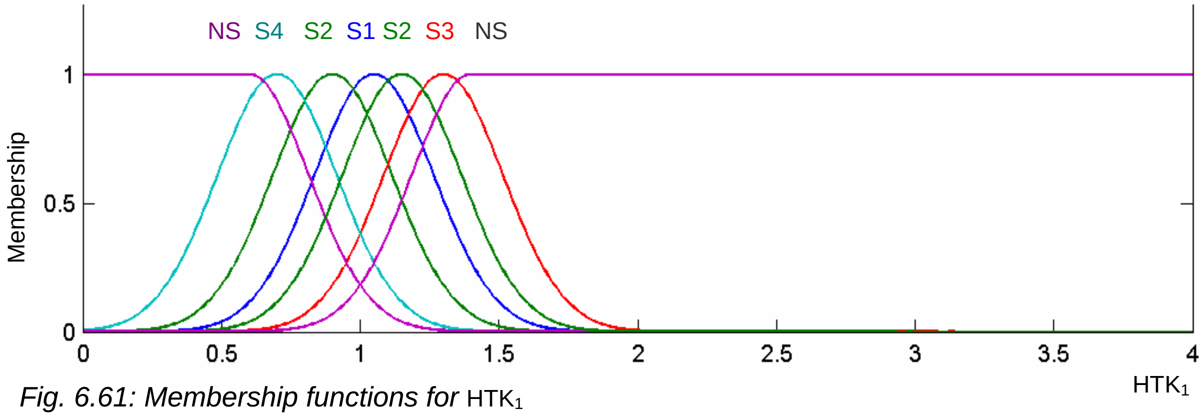


Fig. 6.61: Membership functions for HTK_1

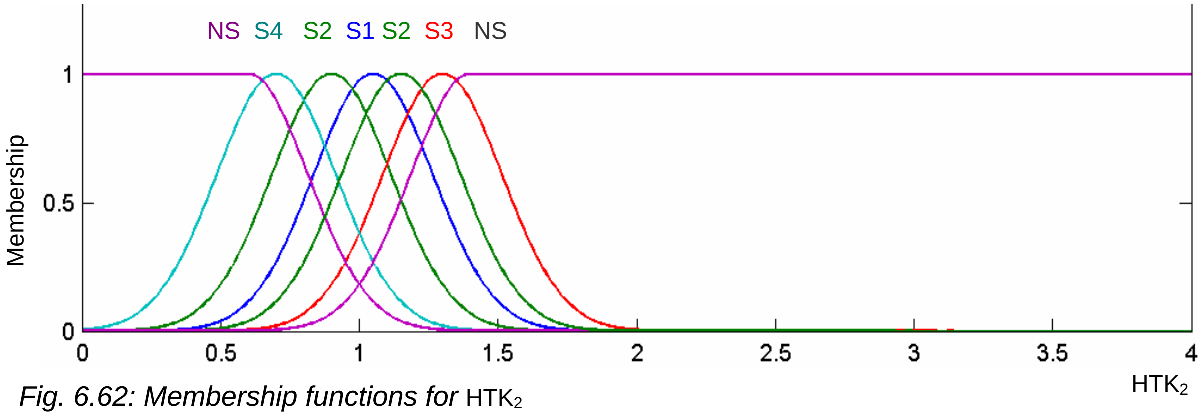


Fig. 6.62: Membership functions for HTK_2

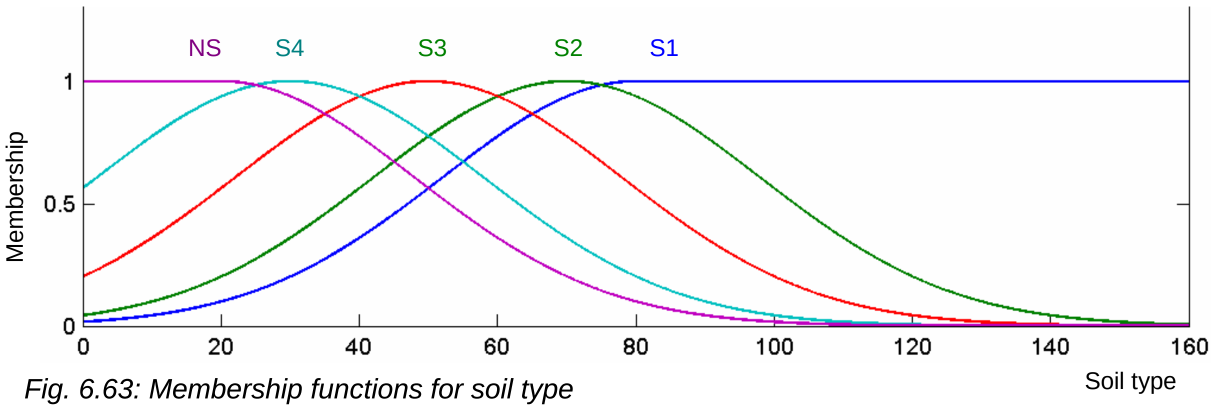


Fig. 6.63: Membership functions for soil type

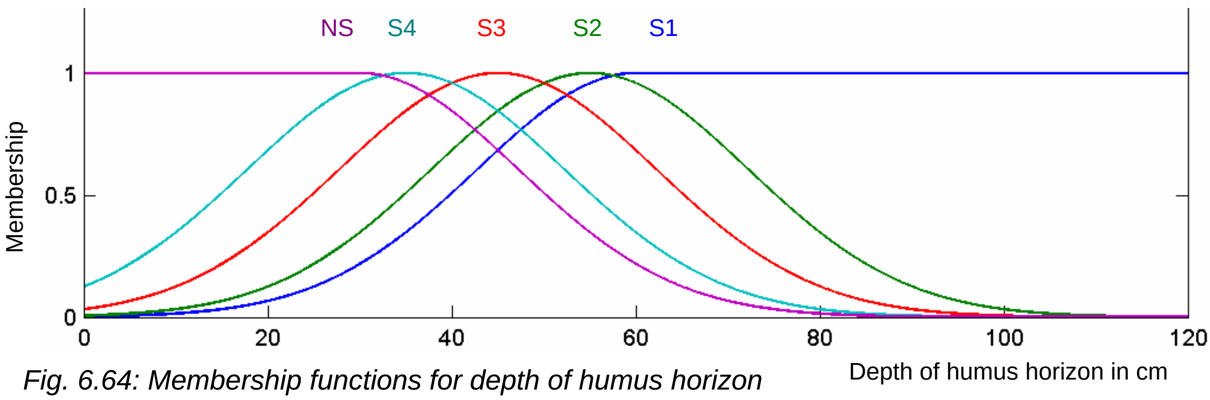


Fig. 6.64: Membership functions for depth of humus horizon

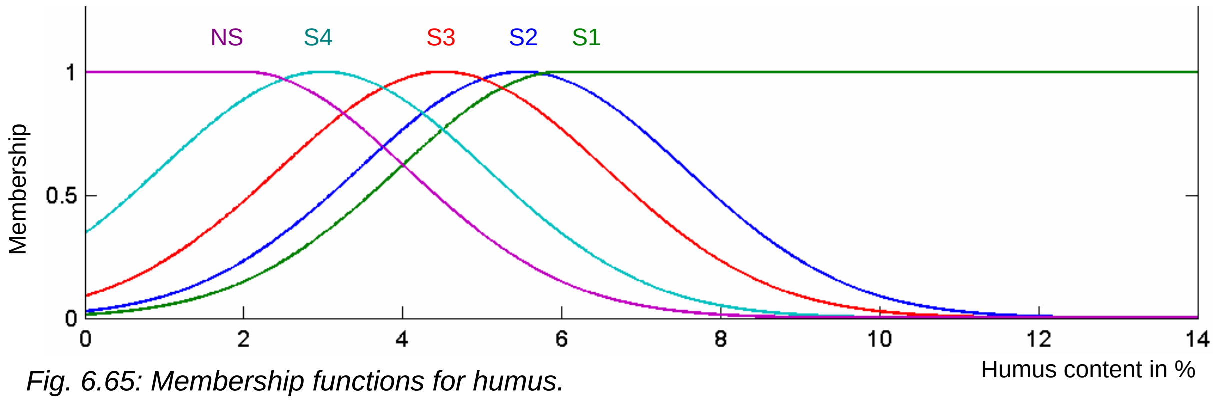


Fig. 6.65: Membership functions for humus.

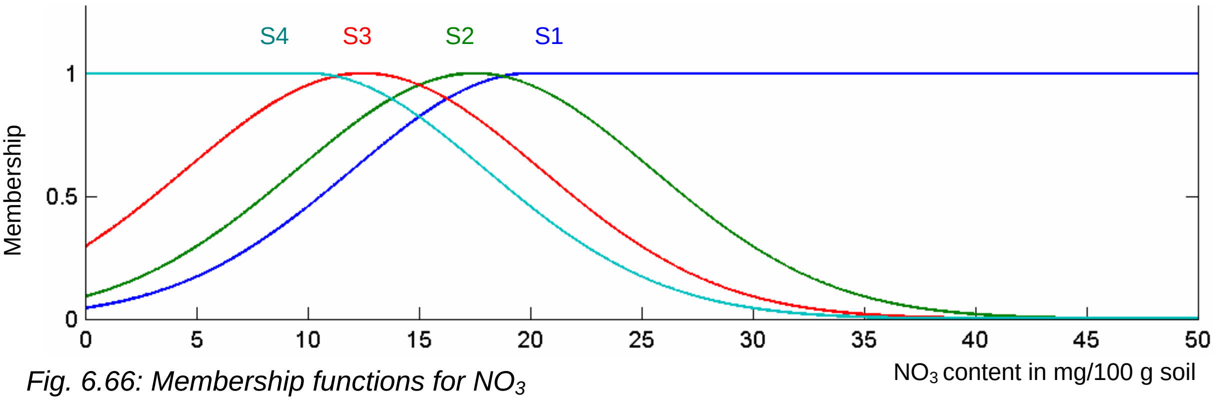


Fig. 6.66: Membership functions for NO_3

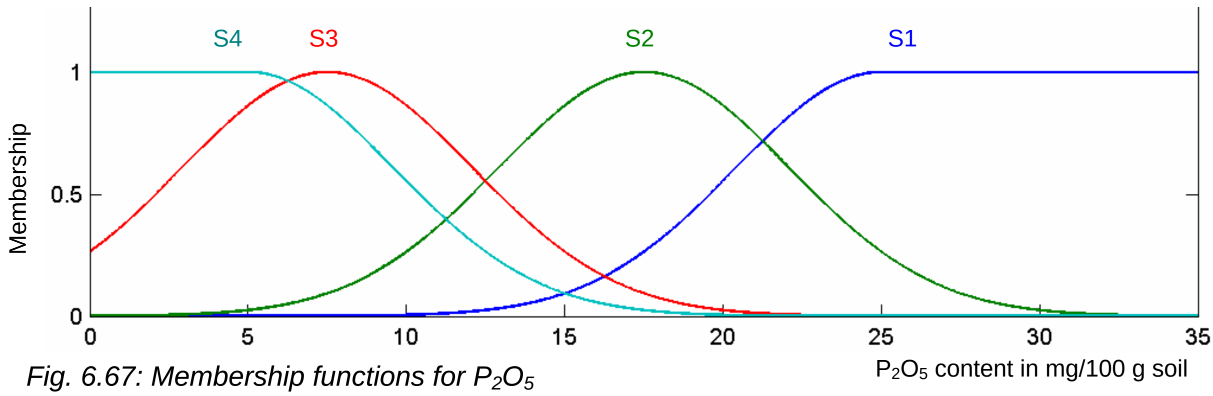


Fig. 6.67: Membership functions for P_2O_5

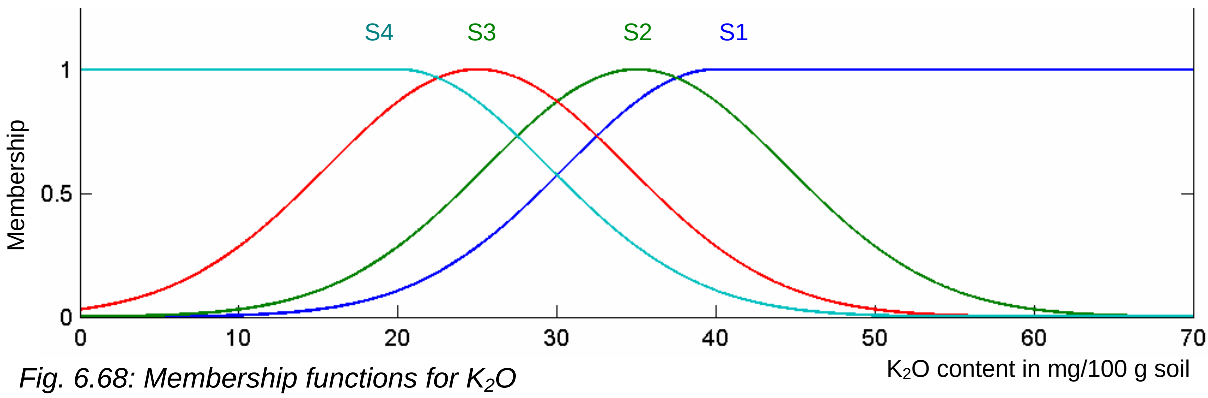


Fig. 6.68: Membership functions for K_2O

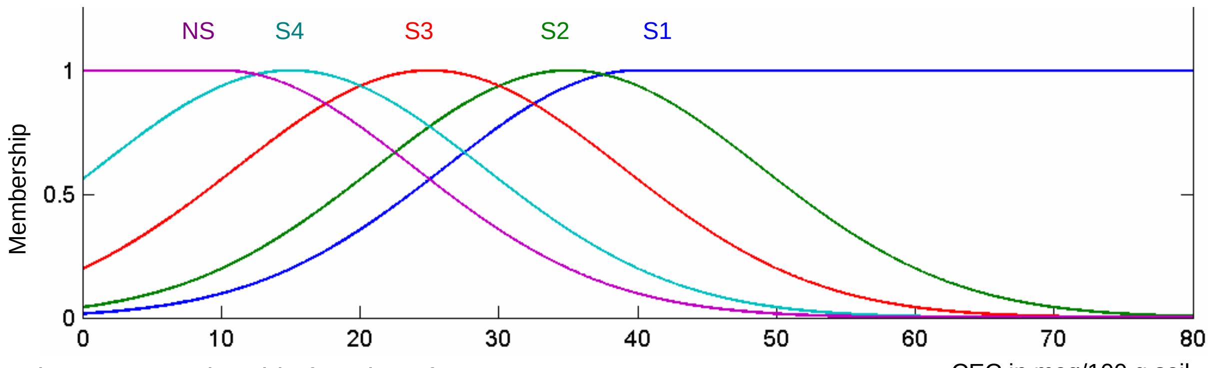


Fig. 6.69: Membership functions for CEC

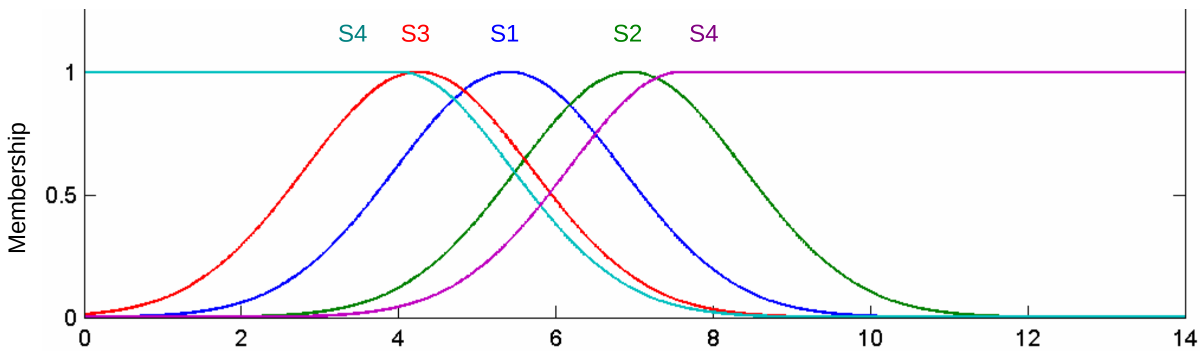


Fig. 6.70: Membership functions for pH

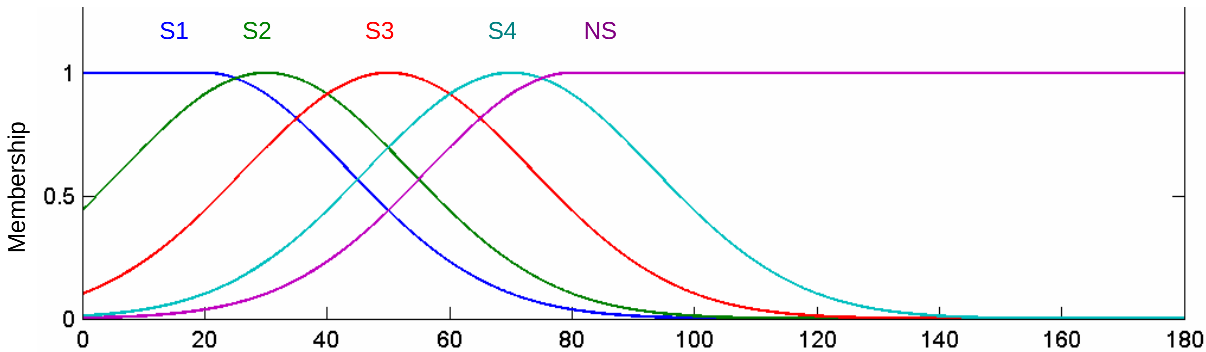


Fig. 6.71: Membership functions for flood frequency

Appendix B:
GIS AML programmings for WM Approach

B1: AML programming for summer wheat

```
&ty *** AML to Calculate the SI for summer wheat

/*Name of the Coverage
&sv incov = data_1m
&sv outcov = out_weam1

&ty *** Kill old datasets

&if [EXISTS %outcov% -COVER] &then kill %outcov% all

&ty *** Create working coverage %outcov%
copy %incov% %outcov%

/*Name of the Types
&sv item1 = HUMUS
&sv item2 = H_A_AB_
&sv item3 = PH
&sv item4 = N
&sv item5 = P2O5
&sv item6 = K2O
&sv item7 = CEC
&sv item8 = HTK1
&sv item9 = HTK2
&sv item10 = FFL
&sv item11 = St

ae
edit %outcov% POLY

&ty *** Adding the Items to cover %outcov%
additem C%item1% 2 4 b
additem C%item2% 2 4 b
additem C%item3% 2 4 b
additem C%item4% 2 4 b
additem C%item5% 2 4 b
additem C%item6% 2 4 b
additem C%item7% 2 4 b
additem C%item8% 2 4 b
additem C%item9% 2 4 b
additem C%item10% 2 4 b
additem C%item11% 2 4 b
additem SI 2 4 b

select all
&sv numb = [show number select]
&sv x = 0
&ty *** Starting the Calculation of HUMUS,H_A_AB_,PH,P2O5,K2O,N,CEC,HTK1,HTK2,FFL,St
CURSOR OPEN

&do &while %:edit.aml$next%

&sv x = %x% + 1

&sv temp1 = 0
&sv temp2 = 0
&sv temp3 = 0
&sv temp4 = 0
&sv temp5 = 0
&sv temp6 = 0
&sv temp7 = 0
&sv temp8 = 0
&sv temp9 = 0
&sv temp10 = 0
```

```
&sv temp11 = 0

/*________________________ITEM1-Classification


&sv temp1 = %:edit.HUMUS%
&if %temp1% <  1                  &then &sv class1 = 5
&if %temp1% >= 1 AND %temp1% < 2   &then &sv class1 = 4
&if %temp1% >= 2 AND %temp1% < 4   &then &sv class1 = 4
&if %temp1% >= 4 AND %temp1% < 6   &then &sv class1 = 2
&if %temp1% >= 6                  &then &sv class1 = 1
calc C%item1% = %class1%

/*________________________ITEM2-Classification

&sv temp2 = %:edit.H_A_AB_%
&if %temp2% <  30                 &then &sv class2 = 5
&if %temp2% >= 30 AND %temp2% < 40 &then &sv class2 = 4
&if %temp2% >= 40 AND %temp2% < 50 &then &sv class2 = 3
&if %temp2% >= 50 AND %temp2% < 60 &then &sv class2 = 1
&if %temp2% >= 60                 &then &sv class2 = 2
calc C%item2% = %class2%

/*________________________ITEM3-Classification

&sv temp3 = %:edit.PH%
&if %temp3% <  6.3                  &then &sv class3 = 4
&if %temp3% >= 6.4 AND %temp3% < 6.5  &then &sv class3 = 1
&if %temp3% >= 6.6 AND %temp3% < 7.0  &then &sv class3 = 2
&if %temp3% >= 7.1 AND %temp3% < 7.5  &then &sv class3 = 3
&if %temp3% >= 7.6 AND %temp3% < 8.0  &then &sv class3 = 4
&if %temp3% >= 8.1                  &then &sv class3 = 5
calc C%item3% = %class3%

/*________________________ITEM4-Classification

&sv temp4 = %:edit.N%
&if %temp4% <  3 &then &sv class4 = 5
&if %temp4% >= 3 AND %temp4% < 10  &then &sv class4 = 4
&if %temp4% >= 10 AND %temp4% < 15 &then &sv class4 = 3
&if %temp4% >= 15 AND %temp4% < 20 &then &sv class4 = 2
&if %temp4% >= 20 &then &sv class4 = 1
calc C%item4% = %class4%

/*________________________ITEM5-Classification

&sv temp5 = %:edit.P2O5%
&if %temp5% <  5 &then &sv class5 = 4
&if %temp5% >= 5 AND %temp5% < 10 &then &sv class5 = 3
&if %temp5% >= 10 AND %temp5% < 15 &then &sv class5 = 1
&if %temp5% >= 15 AND %temp5% < 20 &then &sv class5 = 2
&if %temp5% >= 20 &then &sv class5 = 3
calc C%item5% = %class5%

/*________________________ITEM6-Classification

&sv temp6 = %:edit.K2O%
&if %temp6% <  10 &then &sv class6 = 4
&if %temp6% >= 10 AND %temp6% < 15 &then &sv class6 = 3
&if %temp6% >= 15 AND %temp6% < 20 &then &sv class6 = 2
&if %temp6% >= 20 AND %temp6% < 25 &then &sv class6 = 1
&if %temp6% >= 25 &then &sv class6 = 3
calc C%item6% = %class6%

/*________________________ITEM7-Classification

&sv temp7 = %:edit.CEC%
&if %temp7% <  6                  &then &sv class7 = 5
&if %temp7% >= 6  AND %temp7% < 12 &then &sv class7 = 4
&if %temp7% >= 12 AND %temp7% < 25 &then &sv class7 = 3
```

```
&if %temp7% >= 25 AND %temp7% < 40 &then &sv class7 = 2
&if %temp7% >= 40                &then &sv class7 = 1
calc C%item7% = %class7%

/*________________________ITEM8-Classification

&sv temp8 = %:edit.HTK1%
&if %temp8% <  0.8               &then &sv class8 = 5
&if %temp8% >= 0.8 AND %temp8% < 1.0 &then &sv class8 = 4
&if %temp8% >= 1.0 AND %temp8% < 1.2 &then &sv class8 = 1
&if %temp8% >= 1.2 AND %temp8% < 1.6 &then &sv class8 = 2
&if %temp8% >= 1.6               &then &sv class8 = 3
calc C%item8% = %class8%

/*________________________ITEM9-Classification

&sv temp9 = %:edit.HTK2%
&if %temp9% <  0.8               &then &sv class9 = 5
&if %temp9% >= 0.8 AND %temp9% < 1.0 &then &sv class9 = 4
&if %temp9% >= 1.0 AND %temp9% < 1.2 &then &sv class9 = 1
&if %temp9% >= 1.2 AND %temp9% < 1.4 &then &sv class9 = 2
&if %temp9% >= 1.4               &then &sv class9 = 3
calc C%item9% = %class9%

/*________________________ITEM10-Classification

&sv temp10 = %:edit.FFL%
&if %temp10% >= 80               &then &sv class10 = 5
&if %temp10% >= 60 AND %temp10% < 80 &then &sv class10 = 4
&if %temp10% >= 40 AND %temp10% < 60 &then &sv class10 = 3
&if %temp10% >= 20 AND %temp10% < 40 &then &sv class10 = 2
&if %temp10% <  20               &then &sv class10 = 1
calc C%item10% = %class10%

/*________________________ITEM11-Classification

&sv temp11 = %:edit.St%
&if [quote %temp11%] eq 'Ah' OR [quote %temp11%] eq 'Mar' OR [quote %temp11%] eq 'S'
&then &sv class11 = 5

&if [quote %temp11%] eq 'A' OR [quote %temp11%] eq 'Mofch' OR [quote %temp11%] eq 'Gf'
&then &sv class11 = 4

&if [quote %temp11%] eq 'Mef' OR [quote %temp11%] eq 'K'
&then &sv class11 = 3

&if [quote %temp11%] eq 'Chk' OR [quote %temp11%] eq 'Chml' OR [quote %temp11%] eq 'Melch'
&then &sv class11 = 2

&if [quote %temp11%] eq 'Chl' OR [quote %temp11%] eq  'Chp' OR [quote %temp11%] eq  'MoCh' OR [quote
%temp11%] eq  'Me'
&then &sv class11 = 1

calc C%item11% = %class11%


&sv a = %class8%
&sv b = %class9%
&sv c = %class2%
&sv d = %class3%
&sv e = %class1%
&sv f = %class6%
&sv g = %class4%
&sv h = %class5%
&sv i = %class7%
&sv j = %class10%
&sv k = %class11%

&sv si1 = [calc [calc %i% + %j%] / 2]
&sv si2 = [calc [calc %g% + %h% + %si1%] / 3]
```

```
&sv si3 = [calc [calc %e% + %f% + %si2%] / 3]
&sv si4 = [calc [calc %c% + %d% + %si3%] / 3]
&sv si5 = [calc [calc %a% + %b% + %si4%] / 3]
&sv si = [calc [calc %k% + %si5%] / 2]

&if %si% eq 0                &then &sv si = 0
&if %si% <= 1.5              &then &sv si = 1
&if %si% >  1.5 AND %si% <= 2.5 &then &sv si = 2
&if %si% >  2.5 AND %si% <= 3.5 &then &sv si = 3
&if %si% >  3.5 AND %si% <= 4.5 &then &sv si = 4
&if %si% >  4.5 AND %si% <= 5.5 &then &sv si = 5

calc si = %si%

&ty SI = %si% of Polygonnumber %x% (%numb%)

CURSOR NEXT

&END

CURSOR CLOSE

&ty *** Calculation finished. The result is written in the coverage %outcov%
q
y
y

&ret
```

B2: AML programming for sunflowers (WM Approach)

```
&ty *** AML to Calculate the SI for sunflowers


/*Name of the Coverage
&sv incov = data_1m
&sv outcov = out_sunm1

&ty *** Kill old datasets

&if [EXISTS %outcov% -COVER] &then kill %outcov% all
/*kill %outcov% all

&ty *** Create working coverage %outcov%
copy %incov% %outcov%

/*Name of the Types
&sv item1 = HUMUS
&sv item2 = H_A_AB_
&sv item3 = PH
&sv item4 = N
&sv item5 = P2O5
&sv item6 = K2O
&sv item7 = CEC
&sv item8 = HTK1
&sv item9 = HTK2
&sv item10 = FFL
&sv item11 = ST

ae
edit %outcov% POLY

&ty *** Adding the Items to cover %outcov%
additem C%item1% 2 4 b
additem C%item2% 2 4 b
additem C%item3% 2 4 b
```

```
additem C%item4% 2 4 b
additem C%item5% 2 4 b
additem C%item6% 2 4 b
additem C%item7% 2 4 b
additem C%item8% 2 4 b
additem C%item9% 2 4 b
additem C%item10% 2 4 b
additem C%item11% 2 4 b
additem SI 2 4 b

select all
&sv numb = [show number select]
&sv x = 0
&ty *** Starting the Calculation of St, HUMUS, H_A_AB_,PH,P2O5, K2O,N,CEC,HTK1,HTK2,FFL
CURSOR OPEN

&do &while %:edit.aml$next%

&sv x = %x% + 1

&sv temp1 = 0
&sv temp2 = 0
&sv temp3 = 0
&sv temp4 = 0
&sv temp5 = 0
&sv temp6 = 0
&sv temp7 = 0
&sv temp8 = 0
&sv temp9 = 0
&sv temp10 = 0
&sv temp11 = 0

/*______________________ITEM1-Classification


&sv temp1 = %:edit.HUMUS%
&if %temp1% < 2.0                   &then &sv class1 = 5
&if %temp1% >= 2.0 AND %temp1% < 3.5 &then &sv class1 = 4
&if %temp1% >= 3.5 AND %temp1% < 5.0 &then &sv class1 = 3
&if %temp1% >= 5.0 AND %temp1% < 6.0 &then &sv class1 = 2
&if %temp1% >= 6                    &then &sv class1 = 1
calc C%item1% = %class1%

/*______________________ITEM2-Classification

&sv temp2 = %:edit.H_A_AB_%
&if %temp2% <  40                 &then &sv class2 = 5
&if %temp2% >= 40 AND %temp2% < 50 &then &sv class2 = 4
&if %temp2% >= 50 AND %temp2% < 60 &then &sv class2 = 3
&if %temp2% >= 60 AND %temp2% < 70 &then &sv class2 = 2
&if %temp2% >= 70                  &then &sv class2 = 1
calc C%item2% = %class2%

/*______________________ITEM3-Classification

&sv temp3 = %:edit.PH%
&if %temp3% <  6.0                  &then &sv class3 = 4
&if %temp3% >= 6.1 AND %temp3% < 6.8 &then &sv class3 = 1
&if %temp3% >= 6.8 AND %temp3% < 7.5 &then &sv class3 = 2
&if %temp3% >= 7.5                   &then &sv class3 = 3
calc C%item3% = %class3%

/*______________________ITEM4-Classification

&sv temp4 = %:edit.N%
&if %temp4% <  5                 &then &sv class4 = 5
&if %temp4% >= 5 AND %temp4% < 8 &then &sv class4 = 4
&if %temp4% >= 8 AND %temp4% < 13 &then &sv class4 = 3
&if %temp4% >= 13 AND %temp4% < 18 &then &sv class4 = 2
&if %temp4% >= 18                  &then &sv class4 = 1
```

```
calc C%item4% = %class4%

/*________________________ITEM5-Classification

&sv temp5 = %:edit.P2O5%
&if %temp5% <  10                 &then &sv class5 = 4
&if %temp5% >= 10 AND %temp5% < 15 &then &sv class5 = 3
&if %temp5% >= 15 AND %temp5% < 20 &then &sv class5 = 2
&if %temp5% >= 20                 &then &sv class5 = 1
calc C%item5% = %class5%

/*________________________ITEM6-Classification

&sv temp6 = %:edit.K2O%
&if %temp6% <  10                &then &sv class6 = 4
&if %temp6% >= 10 AND %temp6% < 20 &then &sv class6 = 3
&if %temp6% >= 20 AND %temp6% < 30 &then &sv class6 = 2
&if %temp6% >= 30                &then &sv class6 = 1
calc C%item6% = %class6%

/*________________________ITEM7-Classification

&sv temp7 = %:edit.CEC%
&if %temp7% <  8               &then &sv class7 = 5
&if %temp7% >= 8  AND %temp7% < 15 &then &sv class7 = 4
&if %temp7% >= 15 AND %temp7% < 25 &then &sv class7 = 3
&if %temp7% >= 25 AND %temp7% < 35 &then &sv class7 = 2
&if %temp7% >= 35               &then &sv class7 = 1
calc C%item7% = %class7%

/*________________________ITEM8-Classification

&sv temp8 = %:edit.HTK1%
&if %temp8% <  0.7               &then &sv class8 = 3
&if %temp8% >= 0.7 AND %temp8% < 1.0 &then &sv class8 = 1
&if %temp8% >= 1.0 AND %temp8% < 1.2 &then &sv class8 = 2
&if %temp8% >= 1.2 AND %temp8% < 1.6 &then &sv class8 = 4
&if %temp8% >= 1.6               &then &sv class8 = 5
calc C%item8% = %class8%

/*________________________ITEM9-Classification

&sv temp9 = %:edit.HTK2%
&if %temp9% <  0.7               &then &sv class9 = 3
&if %temp9% >= 0.7 AND %temp9% < 1.0 &then &sv class9 = 1
&if %temp9% >= 1.0 AND %temp9% < 1.2 &then &sv class9 = 2
&if %temp9% >= 1.2 AND %temp9% < 1.6 &then &sv class9 = 4
&if %temp9% >= 1.6               &then &sv class9 = 5
calc C%item9% = %class9%

/*________________________ITEM10-Classification

&sv temp10 = %:edit.FFL%
&if %temp10% >= 80               &then &sv class10 = 5
&if %temp10% >= 60 AND %temp10% < 80 &then &sv class10 = 4
&if %temp10% >= 40 AND %temp10% < 60 &then &sv class10 = 3
&if %temp10% >= 20 AND %temp10% < 40 &then &sv class10 = 2
&if %temp10% <  20               &then &sv class10 = 1
calc C%item10% = %class10%

/*________________________ITEM11-Classification

&sv temp11 = %:edit.St%
&if [quote %temp11%] eq 'Ah' OR [quote %temp11%] eq 'Mar' OR [quote %temp11%] eq 'S' &then &sv class11 = 5

&if [quote %temp11%] eq 'Mofch' OR [quote %temp11%] eq 'Gf'
&then &sv class11 = 4

&if [quote %temp11%] eq 'A' OR [quote %temp11%] eq 'Mef' OR [quote %temp11%] eq 'MoCh' &then &sv class11 = 3
&if [quote %temp11%] eq 'Chk' OR [quote %temp11%] eq 'Chml' OR [quote %temp11%] eq 'K'
```

```
&then &sv class11 = 2
&if [quote %temp11%] eq 'Chl' OR [quote %temp11%] eq 'Chp' OR [quote %temp11%] eq  'MeCh' OR [quote
%temp11%] eq  'Me'
&then &sv class11 = 1

calc C%item11% = %class11%


&sv a = %class8%
&sv b = %class2%
&sv c = %class3%
&sv d = %class5%
&sv e = %class1%
&sv f = %class4%
&sv g = %class6%
&sv h = %class7%
&sv i = %class9%
&sv j = %class10%
&sv k = %class11%


&sv si1 = [calc [calc %i% + %a%] / 2]
&sv si2 = [calc [calc %e% + %k% + %si1%] / 3]
&sv si3 = [calc [calc %d% + %c% + %si2%] / 3]
&sv si4 = [calc [calc %g% + %f% + %si3%] / 3]
&sv si5 = [calc [calc %j% + %b% + %si4%] / 3]
&sv si = [calc [calc %h% + %si5%] / 2]

&if %si% eq 0                  &then &sv si = 0
&if %si% <= 1.5                &then &sv si = 1
&if %si% >  1.5 AND %si% <= 2.5 &then &sv si = 2
&if %si% >  2.5 AND %si% <= 3.5 &then &sv si = 3
&if %si% >  3.5 AND %si% <= 4.5 &then &sv si = 4
&if %si% >  4.5 AND %si% <= 5.5 &then &sv si = 5

calc si = %si%

&ty SI = %si% of Polygonnumber %x% (%numb%)

CURSOR NEXT

&END

CURSOR CLOSE

&ty *** Calculation finished. The result is written in the coverage %outcov%.
q
y
y

&ret
```

B3: AML programming for potatoes (WM Approach)

```
&ty *** AML to Calculate the SI for potatoes


/*Name of the Coverage
&sv incov = data_1m
&sv outcov = out_potm1

&ty *** Kill old datasets

&if [EXISTS %outcov% -COVER] &then kill %outcov% all
/*kill %outcov% all
```

```
&ty *** Create working coverage %outcov%
copy %incov% %outcov%

/*Name of the Types
&sv item1 = HUMUS
&sv item2 = H_A_AB_
&sv item3 = PH
&sv item4 = N
&sv item5 = P2O5
&sv item6 = K2O
&sv item7 = CEC
&sv item8 = HTK1
&sv item9 = HTK2
&sv item10 = FFL
&sv item11 = St

ae
edit %outcov% POLY

&ty *** Adding the Items to cover %outcov%
additem C%item1% 2 4 b
additem C%item2% 2 4 b
additem C%item3% 2 4 b
additem C%item4% 2 4 b
additem C%item5% 2 4 b
additem C%item6% 2 4 b
additem C%item7% 2 4 b
additem C%item8% 2 4 b
additem C%item9% 2 4 b
additem C%item10% 2 4 b
additem C%item11% 2 4 b
additem SI 2 4 b

select all
&sv numb = [show number select]
&sv x = 0
&ty *** Starting the Calculation of St,HUMUS,H_A_AB_,PH,P2O5, K2O,N,CEC,HTK1,HTK2,FFL
CURSOR OPEN

&do &while %:edit.aml$next%

&sv x = %x% + 1

&sv temp1 = 0
&sv temp2 = 0
&sv temp3 = 0
&sv temp4 = 0
&sv temp5 = 0
&sv temp6 = 0
&sv temp7 = 0
&sv temp8 = 0
&sv temp9 = 0
&sv temp10 = 0
&sv temp11 = 0

/*_______________________ITEM1-Classification

&sv temp1 = %:edit.HUMUS%
&if %temp1% <  2.0                          &then &sv class1 = 5
&if %temp1% >= 2.0 AND %temp1% < 4.0 &then &sv class1 = 4
&if %temp1% >= 4.0 AND %temp1% < 5.0 &then &sv class1 = 3
&if %temp1% >= 5.0 AND %temp1% < 6.0 &then &sv class1 = 2
&if %temp1% >= 6.0                          &then &sv class1 = 1
calc C%item1% = %class1%

/*_______________________ITEM2-Classification

&sv temp2 = %:edit.H_A_AB_%
&if %temp2% <  30                          &then &sv class2 = 5
&if %temp2% >= 30 AND %temp2% < 40 &then &sv class2 = 4
```

```
&if %temp2% >= 40 AND %temp2% < 50 &then &sv class2 = 3
&if %temp2% >= 50 AND %temp2% < 60 &then &sv class2 = 2
&if %temp2% >= 60                  &then &sv class2 = 1
calc C%item2% = %class2%

/*________________________ITEM3-Classification

&sv temp3 = %:edit.PH%
&if %temp3% <  4.0                   &then &sv class3 = 4
&if %temp3% >= 4.0 AND %temp3% < 4.5 &then &sv class3 = 3
&if %temp3% >= 4.5 AND %temp3% < 6.3 &then &sv class3 = 1
&if %temp3% >= 6.3 AND %temp3% < 7.6 &then &sv class3 = 2
&if %temp3% >= 7.6                   &then &sv class3 = 4
calc C%item3% = %class3%

/*________________________ITEM4-Classification

&sv temp4 = %:edit.N%
&if %temp4% <  10                  &then &sv class4 = 4
&if %temp4% >= 10 AND %temp4% < 15 &then &sv class4 = 3
&if %temp4% >= 15 AND %temp4% < 20 &then &sv class4 = 2
&if %temp4% >= 20                  &then &sv class4 = 1
calc C%item4% = %class4%

/*________________________ITEM5-Classification

&sv temp5 = %:edit.P2O5%
&if %temp5% <  5                   &then &sv class5 = 4
&if %temp5% >= 5 AND %temp5% < 10  &then &sv class5 = 3
&if %temp5% >= 10 AND %temp5% < 25 &then &sv class5 = 2
&if %temp5% >= 25                  &then &sv class5 = 1
calc C%item5% = %class5%

/*________________________ITEM6-Classification

&sv temp6 = %:edit.K2O%
&if %temp6% <  20                  &then &sv class6 = 4
&if %temp6% >= 20 AND %temp6% < 30 &then &sv class6 = 3
&if %temp6% >= 30 AND %temp6% < 40 &then &sv class6 = 2
&if %temp6% >= 40                  &then &sv class6 = 1
calc C%item6% = %class6%

/*________________________ITEM7-Classification

&sv temp7 = %:edit.CEC%
&if %temp7% <  10                  &then &sv class7 = 5
&if %temp7% >= 10 AND %temp7% < 20 &then &sv class7 = 4
&if %temp7% >= 20 AND %temp7% < 30 &then &sv class7 = 3
&if %temp7% >= 30 AND %temp7% < 40 &then &sv class7 = 2
&if %temp7% >= 40                  &then &sv class7 = 1
calc C%item7% = %class7%

/*________________________ITEM8-Classification

&sv temp8 = %:edit.HTK1%
&if %temp8% <  0.6                   &then &sv class8 = 5
&if %temp8% >= 0.6 AND %temp8% < 0.8 &then &sv class8 = 4
&if %temp8% >= 0.8 AND %temp8% < 1.0 &then &sv class8 = 2
&if %temp8% >= 1.0 AND %temp8% < 1.1 &then &sv class8 = 1
&if %temp8% >= 1.1 AND %temp8% < 1.2 &then &sv class8 = 2
&if %temp8% >= 1.2 AND %temp8% < 1.4 &then &sv class8 = 3
&if %temp8% >= 1.4                   &then &sv class8 = 5
calc C%item8% = %class8%

&ty yessss
/*________________________ITEM9-Classification

&sv temp9 = %:edit.HTK2%
&if %temp9% <  0.6                   &then &sv class9 = 5
&if %temp9% >= 0.6 AND %temp9% < 0.8 &then &sv class9 = 4
```

```
&if %temp9% >= 0.8 AND %temp9% < 1.0 &then &sv class9 = 2
&if %temp9% >= 1.0 AND %temp9% < 1.1 &then &sv class9 = 1
&if %temp9% >= 1.1 AND %temp9% < 1.2 &then &sv class9 = 2
&if %temp9% >= 1.2 AND %temp9% < 1.4 &then &sv class9 = 3
&if %temp9% >= 1.4                  &then &sv class9 = 5
calc C%item9% = %class9%

/*________________________ITEM10-Classification

&sv temp10 = %:edit.FFL%
&if %temp10% >=  80                   &then &sv class10 = 5
&if %temp10% >= 60 AND %temp10% < 80 &then &sv class10 = 4
&if %temp10% >= 40 AND %temp10% < 60 &then &sv class10 = 3
&if %temp10% >= 20 AND %temp10% < 40 &then &sv class10 = 2
&if %temp10% <  20                    &then &sv class10 = 1
calc C%item10% = %class10%

/*________________________ITEM11-Classification

&sv temp11 = %:edit.St%
&if [quote %temp11%] eq 'Ah' OR [quote %temp11%] eq 'Mar' OR [quote %temp11%] eq 'S' &then &sv class11 = 5

&if [quote %temp11%] eq 'A' OR [quote %temp11%] eq 'Mofch' OR [quote %temp11%] eq 'Gf' &then &sv class11 = 4

&if [quote %temp11%] eq 'Mef' OR [quote %temp11%] eq 'Mech' OR [quote %temp11%] eq 'K' &then &sv class11 = 3

&if [quote %temp11%] eq 'Chk' OR [quote %temp11%] eq 'Chml' OR [quote %temp11%] eq 'Me' &then &sv class11 =
2

&if [quote %temp11%] eq 'Chl' OR [quote %temp11%] eq 'Chp' OR [quote %temp11%] eq  'MoCh'
&then &sv class11 = 1

calc C%item11% = %class11%

&sv a = %class4%
&sv b = %class5%
&sv c = %class1%
&sv d = %class6%
&sv e = %class9%
&sv f = %class2%
&sv g = %class3%
&sv h = %class7%
&sv i = %class8%
&sv j = %class10%
&sv k = %class11%

&sv si1 = [calc [calc %h% + %j%] / 2]
&sv si2 = [calc [calc %f% + %g% + %si1%] / 3]
&sv si3 = [calc [calc %i% + %e% + %si2%] / 3]
&sv si4 = [calc [calc %c% + %d% + %si3%] / 3]
&sv si5 = [calc [calc %a% + %b% + %si4%] / 3]
&sv si  = [calc [calc %k% + %si5%] / 2]

&if %si% eq 0                        &then &sv si = 0
&if %si% <= 1.5                      &then &sv si = 1
&if %si% >  1.5 AND %si% <= 2.5 &then &sv si = 2
&if %si% >  2.5 AND %si% <= 3.5 &then &sv si = 3
&if %si% >  3.5 AND %si% <= 4.5 &then &sv si = 4
&if %si% >  4.5 AND %si% <= 5.5 &then &sv si = 5

calc si = %si%
&ty SI = %si% of Polygonnumber %x% (%numb%)
CURSOR NEXT
&END
CURSOR CLOSE
&ty *** Calculation finished. The result is written in the coverage %outcov%.
q
y
y
&ret
```

B4: AML programming for combination of WSP (WM Approach)

```
/* AML to determine WSP


&if [exists wspcalc -cover] &then kill wspcalc all

&sv input1 = out_weam1
&sv input2 = out_potm1
&sv input3 = out_sunm1

copy %input1% wspcalc

additem wspcalc.pat wspcalc.pat W_SI 4 2 f 3
additem wspcalc.pat wspcalc.pat S_SI 4 2 f 3
additem wspcalc.pat wspcalc.pat P_SI 4 2 f 3
additem wspcalc.pat wspcalc.pat WSPC 4 2 f 3
additem wspcalc.pat wspcalc.pat WSP 7 7 C

relate add rel1 %input1%.pat info wspcalc# %input1%# linear rw
relate add rel2 %input2%.pat info wspcalc# %input2%# linear rw
relate add rel3 %input3%.pat info wspcalc# %input3%# linear rw

tables
sel wspcalc.pat
calc W_SI = rel1//SI
calc S_SI = rel2//SI
calc P_SI = rel3//SI
q

ap
cursor ptcur declare wspcalc.pat info rw
cursor ptcur open
&do &while %:ptcur.aml$next%

  /* Case if W=S=P
  &if [value :ptcur.W_SI] eq [value :ptcur.P_SI] and [value :ptcur.P_SI] eq [value :ptcur.S_SI] &then
  &do
   &sv :ptcur.WSP = WSP
   &sv :ptcur.WSPC = [value :ptcur.W_SI]
  &end

  /* Case if W
  &if [value :ptcur.W_SI] lt [value :ptcur.S_SI] and [value :ptcur.W_SI] lt [value :ptcur.P_SI] &then
  &do
   &sv :ptcur.WSP = W
   &sv :ptcur.WSPC = [value :ptcur.W_SI]
  &end

  /* Case if S
  &if [value :ptcur.S_SI] lt [value :ptcur.W_SI] and [value :ptcur.S_SI] lt [value :ptcur.P_SI] &then
  &do
   &sv :ptcur.WSP = S
   &sv :ptcur.WSPC = [value :ptcur.S_SI]
  &end

  /* Case if P
  &if [value :ptcur.P_SI] lt [value :ptcur.W_SI] and [value :ptcur.P_SI] lt [value :ptcur.S_SI] &then
  &do
   &sv :ptcur.WSP = P
   &sv :ptcur.WSPC = [value :ptcur.P_SI]
  &end

  /* Case if WS
  &if [value :ptcur.W_SI] eq [value :ptcur.S_SI] and [value :ptcur.W_SI] lt [value :ptcur.P_SI] &then
  &do
   &sv :ptcur.WSP = WS
   &sv :ptcur.WSPC = [value :ptcur.W_SI]
```

```
  &end

    /* Case if WP
  &if [value :ptcur.W_SI] eq [value :ptcur.P_SI] and [value :ptcur.W_SI] lt [value :ptcur.S_SI] &then
  &do
   &sv :ptcur.WSP = WP
   &sv :ptcur.WSPC = [value :ptcur.W_SI]
  &end

    /* Case if SP
  &if [value :ptcur.S_SI] eq [value :ptcur.P_SI] and [value :ptcur.S_SI] lt [value :ptcur.W_SI] &then
  &do
   &sv :ptcur.WSP = SP
   &sv :ptcur.WSPC = [value :ptcur.S_SI]
  &end

  cursor ptcur next
&end
cursor ptcur close
cursor ptcur remove
q

relate drop $all

&ret
```

Appendix B:
GIS AML programmings for Fuzzy Logic – SOM Approach

B5: AML programming for summer wheat

```
&ty *** AML to Calculate the SI for wheat  based on the 2M

/*Name of the Coverage
&sv incov = data_w2m
&sv outcov = out_w2M
&ty *** Kill old datasets

&if [EXISTS %outcov% -COVER] &then kill %outcov% all

&ty *** Create working coverage %outcov%
copy %incov% %outcov%

additem %outcov%.pat %outcov%.pat MINMF 4 4 f 2
additem %outcov%.pat %outcov%.pat SI 2 4 b

ae
edit %outcov% poly

/*additem MFr_w 4 8 f 2
sel all
CURSOR open

&do &while %:edit.aml$next%


&sv currmin = %:edit.HU1_W%
&if %:edit.AAB1_w% le %currmin% &then &sv currmin = %:edit.AAB1_w%
&if %:edit.PH1_w% le %currmin% &then &sv currmin = %:edit.PH1_w%
&if %:edit.NO31_w% le %currmin% &then &sv currmin = %:edit.NO31_w%
&if %:edit.P2O51_w% le %currmin% &then &sv currmin = %:edit.P2O51_w%
&if %:edit.K2O1_w% le %currmin% &then &sv currmin = %:edit.K2O1_w%
&if %:edit.CEC1_w% le %currmin% &then &sv currmin = %:edit.CEC1_w%
&if %:edit.HTK1A_w% le %currmin% &then &sv currmin = %:edit.HTK1A_w%
&if %:edit.HTK2A_w% le %currmin% &then &sv currmin = %:edit.HTK2A_w%
&if %:edit.FFL1_w% le %currmin% &then &sv currmin = %:edit.FFL1_w%
&if %:edit.St1_w% le %currmin% &then &sv currmin = %:edit.St1_ww%

calc MINMF = %currmin%


&if %:edit.MINMF% eq 0 &then calc SI = 0
&if %:edit.MINMF% lt 0.2 and %:edit.MINMF% gt 0.0 &then calc SI = 5
&if %:edit.MINMF% lt 0.4 and %:edit.MINMF% gt 0.2 &then calc SI = 4
&if %:edit.MINMF% lt 0.6 and %:edit.MINMF% gt 0.4 &then calc SI = 3
&if %:edit.MINMF% lt 0.8 and %:edit.MINMF% gt 0.6 &then calc SI = 2
&if %:edit.MINMF% ge 0.8 &then calc SI = 1


cursor next

&end
cursor close
q

y

y

&ret
```

B6: AML programming for sunflowers (Fuzzy Logic-SOM Approach)

```
&ty *** AML to Calculate the SI for sunflowers  based on the 2M

/*Name of the Coverage
&sv incov = data_s2m
&sv outcov = out_s2M
&ty *** Kill old datasets

&if [EXISTS %outcov% -COVER] &then kill %outcov% all

&ty *** Create working coverage %outcov%
copy %incov% %outcov%

additem %outcov%.pat %outcov%.pat MINMF 4 4 f 2
additem %outcov%.pat %outcov%.pat SI 2 4 b

ae
edit %outcov% poly

/*additem MFr_w 4 8 f 2
sel all
CURSOR open

&do &while %:edit.aml$next%


&sv currmin = %:edit.HU1_W%
&if %:edit.AAB1_w% le %currmin% &then &sv currmin = %:edit.AAB1_w%
&if %:edit.PH1_w% le %currmin% &then &sv currmin = %:edit.PH1_w%
&if %:edit.NO31_w% le %currmin% &then &sv currmin = %:edit.NO31_w%
&if %:edit.P2O51_w% le %currmin% &then &sv currmin = %:edit.P2O51_w%
&if %:edit.K2O1_w% le %currmin% &then &sv currmin = %:edit.K2O1_w%
&if %:edit.CEC1_w% le %currmin% &then &sv currmin = %:edit.CEC1_w%
&if %:edit.HTK1A_w% le %currmin% &then &sv currmin = %:edit.HTK1A_w%
&if %:edit.HTK2A_w% le %currmin% &then &sv currmin = %:edit.HTK2A_w%
&if %:edit.FFL1_w% le %currmin% &then &sv currmin = %:edit.FFL1_w%
&if %:edit.St1_w% le %currmin% &then &sv currmin = %:edit.St1_ww%

calc MINMF = %currmin%


&if %:edit.MINMF% eq 0 &then calc SI = 0
&if %:edit.MINMF% lt 0.2 and %:edit.MINMF% gt 0.0 &then calc SI = 5
&if %:edit.MINMF% lt 0.4 and %:edit.MINMF% gt 0.2 &then calc SI = 4
&if %:edit.MINMF% lt 0.6 and %:edit.MINMF% gt 0.4 &then calc SI = 3
&if %:edit.MINMF% lt 0.8 and %:edit.MINMF% gt 0.6 &then calc SI = 2
&if %:edit.MINMF% ge 0.8 &then calc SI = 1


cursor next

&end
cursor close
q

y

y

&ret
```

B7: AML programming for potatoes (Fuzzy Logic-SOM Approach)

```
&ty *** AML to Calculate the SI for potatoes based on the 2M

/*Name of the Coverage
&sv incov = data_p2m
&sv outcov = out_p2M
&ty *** Kill old datasets

&if [EXISTS %outcov% -COVER] &then kill %outcov% all

&ty *** Create working coverage %outcov%
copy %incov% %outcov%

additem %outcov%.pat %outcov%.pat MINMF 4 4 f 2
additem %outcov%.pat %outcov%.pat SI 2 4 b

ae
edit %outcov% poly

/*additem MFr_p 4 8 f 2
sel all
CURSOR open

&do &while %:edit.aml$next%


&sv currmin = %:edit.HU1_p%
&if %:edit.AAB1_p% le %currmin% &then &sv currmin = %:edit.AAB1_p%
&if %:edit.PH1_p% le %currmin% &then &sv currmin = %:edit.PH1_p%
&if %:edit.NO31_p% le %currmin% &then &sv currmin = %:edit.NO31_p%
&if %:edit.P2O51_p% le %currmin% &then &sv currmin = %:edit.P2O51_p%
&if %:edit.K2O1_p% le %currmin% &then &sv currmin = %:edit.K2O1_p%
&if %:edit.CEC1_p% le %currmin% &then &sv currmin = %:edit.CEC1_p%
&if %:edit.HTK1A_p% le %currmin% &then &sv currmin = %:edit.HTK1A_p%
&if %:edit.HTK2A_p% le %currmin% &then &sv currmin = %:edit.HTK2A_p%
&if %:edit.FFL1_p% le %currmin% &then &sv currmin = %:edit.FFL1_p%
&if %:edit.St1_p% le %currmin% &then &sv currmin = %:edit.St1_p%

calc MINMF = %currmin%


&if %:edit.MINMF% eq 0                                  &then calc SI = 0
&if %:edit.MINMF% lt 0.2 and %:edit.MINMF% gt 0.0          &then calc SI = 5
&if %:edit.MINMF% lt 0.4 and %:edit.MINMF% gt 0.2          &then calc SI = 4
&if %:edit.MINMF% lt 0.6 and %:edit.MINMF% gt 0.4          &then calc SI = 3
&if %:edit.MINMF% lt 0.8 and %:edit.MINMF% gt 0.6          &then calc SI = 2
&if %:edit.MINMF% ge 0.8                                   &then calc SI = 1


cursor next

&end
cursor close
q

y

y

&ret
```

B8: AML programming for WSP (Fuzzy Logic-SOM Approach)

```
/* AML to determine WSP 2M

&if [exists wspcalc -cover] &then kill wspcalc all

&sv input1 = out_w2m
&sv input2 = out_p2m
&sv input3 = out_s2m

copy %input1% wspcalc

additem wspcalc.pat wspcalc.pat W_SI 4 2 f 3
additem wspcalc.pat wspcalc.pat S_SI 4 2 f 3
additem wspcalc.pat wspcalc.pat P_SI 4 2 f 3
additem wspcalc.pat wspcalc.pat W_MINMF 4 2 f 3
additem wspcalc.pat wspcalc.pat S_MINMF 4 2 f 3
additem wspcalc.pat wspcalc.pat P_MINMF 4 2 f 3
additem wspcalc.pat wspcalc.pat MAXMINMF 4 2 f 3
additem wspcalc.pat wspcalc.pat WSPC 4 2 f 3
additem wspcalc.pat wspcalc.pat WSP 7 7 C

relate add rel1 %input1%.pat info wspcalc# %input1%# linear rw
relate add rel2 %input2%.pat info wspcalc# %input2%# linear rw
relate add rel3 %input3%.pat info wspcalc# %input3%# linear rw

tables
sel wspcalc.pat
calc W_SI = rel1//SI
calc S_SI = rel2//SI
calc P_SI = rel3//SI
calc W_MINMF = rel1//MINMF
calc S_MINMF = rel2//MINMF
calc P_MINMF = rel3//MINMF
q

ap
cursor ptcur declare wspcalc.pat info rw
cursor ptcur open
&do &while %:ptcur.aml$next%

  /* Checking the maximum
  &sv currmax = [value :ptcur.W_MINMF]
  &if [value :ptcur.S_MINMF] gt %currmax% &then &sv %currmax% = [value :ptcur.S_MINMF]
  &if [value :ptcur.P_MINMF] gt %currmax% &then &sv %currmax% = [value :ptcur.P_MINMF]

  &sv :ptcur.MAXMINMF = %currmax%


  /* Case if W=S=P
  &if [value :ptcur.W_SI] eq [value :ptcur.P_SI] and [value :ptcur.P_SI] eq [value :ptcur.S_SI] &then
  &do
   &sv :ptcur.WSP = WSP
   &sv :ptcur.WSPC = [value :ptcur.W_SI]
  &end

  /* Case if W
  &if [value :ptcur.W_SI] lt [value :ptcur.S_SI] and [value :ptcur.W_SI] lt [value :ptcur.P_SI] &then
  &do
   &sv :ptcur.WSP = W
   &sv :ptcur.WSPC = [value :ptcur.W_SI]
  &end

  /* Case if S
  &if [value :ptcur.S_SI] lt [value :ptcur.W_SI] and [value :ptcur.S_SI] lt [value :ptcur.P_SI] &then
  &do
   &sv :ptcur.WSP = S
   &sv :ptcur.WSPC = [value :ptcur.S_SI]
```

```
  &end

  /* Case if P
  &if [value :ptcur.P_SI] lt [value :ptcur.W_SI] and [value :ptcur.P_SI] lt [value :ptcur.S_SI] &then
  &do
   &sv :ptcur.WSP = P
   &sv :ptcur.WSPC = [value :ptcur.P_SI]
  &end

  /* Case if WS
  &if [value :ptcur.W_SI] eq [value :ptcur.S_SI] and [value :ptcur.W_SI] lt [value :ptcur.P_SI] &then
  &do
   &sv :ptcur.WSP = WS
   &sv :ptcur.WSPC = [value :ptcur.W_SI]
  &end

    /* Case if WP
  &if [value :ptcur.W_SI] eq [value :ptcur.P_SI] and [value :ptcur.W_SI] lt [value :ptcur.S_SI] &then
  &do
   &sv :ptcur.WSP = WP
   &sv :ptcur.WSPC = [value :ptcur.W_SI]
  &end

    /* Case if SP
  &if [value :ptcur.S_SI] eq [value :ptcur.P_SI] and [value :ptcur.S_SI] lt [value :ptcur.W_SI] &then
  &do
   &sv :ptcur.WSP = SP
   &sv :ptcur.WSPC = [value :ptcur.S_SI]
  &end

  cursor ptcur next
&end
cursor ptcur close
cursor ptcur remove
q

relate drop $all

&ret
```

Appendix B:
GIS AML programmings for Fuzzy Logic GMF Approach

B9: AML programming for summer wheat (Fuzzy Logic-GMF Approach)

```
&ty *** AML to Calculate the MF for 3M wheat

/*Name of the Coverage

&sv incov = data_w3M
&sv outcov = out_w3m

&ty *** Kill old datasets
&if [EXISTS %outcov% -COVER] &then kill %outcov% all

&ty *** Create working coverage %outcov%

copy %incov% %outcov%
&ty AML for 3 MODEL

ae
edit %outcov% poly

additem bmin 4 5 f 2
additem amax 4 5 f 2
additem SI_MIN 4 5 f 2
additem SI_MAX 4 5 f 2
additem SI_CH 30 C
additem MF_CH 30 C

sel all
CURSOR open
&do &while %:edit.aml$next%

&sv factormin = 1.0
&sv factormax = %:edit.HU1_W%
&if %:edit.AAB1_W% ge %factormax% &then &sv factormax = %:edit.AAB1_W%
&if %:edit.PH1_W% ge %factormax% &then &sv factormax = %:edit.PH1_W%
&if %:edit.NO31_W% ge %factormax% &then &sv factormax = %:edit.NO31_W%
&if %:edit.P2O51_W% ge %factormax% &then &sv factormax = %:edit.P2O51_W%
&if %:edit.K2O1_W% ge %factormax% &then &sv factormax = %:edit.K2O1_W%
&if %:edit.CEC1_W% ge %factormax% &then &sv factormax = %:edit.CEC1_W%
&if %:edit.HTK1A_W% ge %factormax% &then &sv factormax = %:edit.HTK1A_W%
&if %:edit.HTK2A_W% ge %factormax% &then &sv factormax = %:edit.HTK2A_W%
&if %:edit.FFL1_W% ge %factormax% &then &sv factormax = %:edit.FFL1_W%
&if %:edit.St1_W% ge %factormax% &then &sv factormax = %:edit.St1_W%

calc amax = %factormax%

&if %:edit.HU2_W% gt %factormax% AND %:edit.HU2_W% lt %factormin% &then &svfactormin = %:edit.HU2_W%
&if %:edit.AAB2_W% gt %factormax% AND %:edit.AAB2_W% lt %factormin% &then &svfactormin =
%:edit.AAB2_W%
&if %:edit.PH2_W% gt %factormax% AND %:edit.PH2_W% lt %factormin% &then &svfactormin = %:edit.PH2_W&
&if %:edit.NO32_W% gt %factormax% AND %:edit.NO32_W% lt %factormin% &then &sv factormin =
%:edit.NO32_W%
&if %:edit.P2O52_W% gt %factormax% AND %:edit.P2O52_W% lt %factormin% &then &sv factormin =
%:edit.P2O52_W%
&if %:edit.K2O2_W% gt %factormax% AND %:edit.K2O2_W% lt %factormin% &then &sv factormin =
%:edit.K2O2_W%
&if %:edit.CEC2_W% gt %factormax% AND %:edit.CEC2_W% lt %factormin% &then &sv factormin =
%:edit.CEC2_W%
&if %:edit.HTK1B_W% gt %factormax% AND %:edit.HTK1B_W% lt %factormin% &then &sv factormin =
%:edit.HTK1B_W%
&if %:edit.HTK2B_W% gt %factormax% AND %:edit.HTK2B_W% lt %factormin% &then &sv factormin =
%:edit.HTK2B_W%
&if %:edit.FFL2_W% gt %factormax% AND %:edit.FFL2_W% lt %factormin% &then &sv factormin = %:edit.FFL2_W%
&if %:edit.St2_W% gt %factormax% AND %:edit.St2_W% lt %factormin% &then &sv factormin = %:edit.St2_W%
```

```
calc bmin = %factormin%

&if %factormin% eq 0                          &then calc SI_MIN = 0
&if %factormin% lt 0.2 and %factormin% gt 0.0        &then calc SI_MIN = 5
&if %factormin% lt 0.4 and %factormin% gt 0.2        &then calc SI_MIN = 4
&if %factormin% lt 0.6 and %factormin% gt 0.4        &then calc SI_MIN = 3
&if %factormin% lt 0.8 and %factormin% gt 0.6        &then calc SI_MIN = 2
&if %factormin% ge 0.8                        &then calc SI_MIN = 1

&if %factormax% eq 0                          &then calc SI_MAX = 0
&if %factormax% lt 0.2 and %factormin% gt 0.0        &then calc SI_MAX = 5
&if %factormax% lt 0.4 and %factormin% gt 0.2        &then calc SI_MAX = 4
&if %factormax% lt 0.6 and %factormin% gt 0.4        &then calc SI_MAX = 3
&if %factormax% lt 0.8 and %factormin% gt 0.6        &then calc SI_MAX = 2
&if %factormax% ge 0.8                        &then calc SI_MAX = 1

calc SI_CH = [quote [calc [ round [calc %:edit.SI_MIN% * 100 ] ] / 100 ] - [calc [ round [calc %:edit.SI_MAX% * 100 ] ] /
100 ] ]
calc MF_CH = [quote [calc [ round [calc %:edit.BMIN% * 100 ] ] / 100 ] - [calc [ round [calc %:edit.AMAX% * 100 ] ] /
100 ] ]

cursor next

&end
cursor close
q
y
y
&ret
```

B10: AML programming for sunflowers (Fuzzy Logic-GMF Approach)

```
&ty *** AML to Calculate the MF for 3M sunflowers

/*Name of the Coverage

&sv incov = data_s3M
&sv outcov = out_s3m

&ty *** Kill old datasets
&if [EXISTS %outcov% -COVER] &then kill %outcov% all

&ty *** Create working coverage %outcov%

copy %incov% %outcov%
&ty AML for 3 MODEL

ae
edit %outcov% poly

additem bmin 4 5 f 2
additem amax 4 5 f 2
additem SI_MIN 4 5 f 2
additem SI_MAX 4 5 f 2
additem SI_CH 30 C
additem MF_CH 30 C

sel all
CURSOR open
&do &while %:edit.aml$next%

&sv factormin = 1.0
&sv factormax = %:edit.HU1_s%
&if %:edit.AAB1_s% ge %factormax% &then &sv factormax = %:edit.AAB1_s%
&if %:edit.PH1_s% ge %factormax% &then &sv factormax = %:edit.PH1_s%
```

```
&if %:edit.NO31_s% ge %factormax% &then &sv factormax = %:edit.NO31_s%
&if %:edit.P2O51_s% ge %factormax% &then &sv factormax = %:edit.P2O51_s%
&if %:edit.K2O1_s% ge %factormax% &then &sv factormax = %:edit.K2O1_s%
&if %:edit.CEC1_s% ge %factormax% &then &sv factormax = %:edit.CEC1_s%
&if %:edit.HTK1A_s% ge %factormax% &then &sv factormax = %:edit.HTK1A_s%
&if %:edit.HTK2A_s% ge %factormax% &then &sv factormax = %:edit.HTK2A_s%
&if %:edit.FFL1_s% ge %factormax% &then &sv factormax = %:edit.FFL1_s%
&if %:edit.St1_s% ge %factormax% &then &sv factormax = %:edit.St1_s%

calc amax = %factormax%

&if %:edit.HU2_s% gt %factormax% AND %:edit.HU2_s% lt %factormin% &then &svfactormin = %:edit.HU2_s%
&if %:edit.AAB2_s% gt %factormax% AND %:edit.AAB2_s% lt %factormin% &then &svfactormin = %:edit.AAB2_s%
&if %:edit.PH2_s% gt %factormax% AND %:edit.PH2_s% lt %factormin% &then &svfactormin = %:edit.PH2_s&
&if %:edit.NO32_s% gt %factormax% AND %:edit.NO32_s% lt %factormin% &then &sv factormin = %:edit.NO32_s%
&if %:edit.P2O52_s% gt %factormax% AND %:edit.P2O52_s% lt %factormin% &then &sv factormin =
%:edit.P2O52_s%
&if %:edit.K2O2_s% gt %factormax% AND %:edit.K2O2_s% lt %factormin% &then &sv factormin = %:edit.K2O2_s%
&if %:edit.CEC2_s% gt %factormax% AND %:edit.CEC2_s% lt %factormin% &then &sv factormin = %:edit.CEC2_s%
&if %:edit.HTK1B_s% gt %factormax% AND %:edit.HTK1B_s% lt %factormin% &then &sv factormin =
%:edit.HTK1B_s%
&if %:edit.HTK2B_s% gt %factormax% AND %:edit.HTK2B_s% lt %factormin% &then &sv factormin =
%:edit.HTK2B_s%
&if %:edit.FFL2_s% gt %factormax% AND %:edit.FFL2_s% lt %factormin% &then &sv factormin = %:edit.FFL2_s%
&if %:edit.St2_s% gt %factormax% AND %:edit.St2_s% lt %factormin% &then &sv factormin = %:edit.St2_s%

calc bmin = %factormin%

&if %factormin% eq 0                               &then calc SI_MIN = 0
&if %factormin% lt 0.2 and %factormin% gt 0.0      &then calc SI_MIN = 5
&if %factormin% lt 0.4 and %factormin% gt 0.2      &then calc SI_MIN = 4
&if %factormin% lt 0.6 and %factormin% gt 0.4      &then calc SI_MIN = 3
&if %factormin% lt 0.8 and %factormin% gt 0.6      &then calc SI_MIN = 2
&if %factormin% ge 0.8                             &then calc SI_MIN = 1

&if %factormax% eq 0                               &then calc SI_MAX = 0
&if %factormax% lt 0.2 and %factormin% gt 0.0      &then calc SI_MAX = 5
&if %factormax% lt 0.4 and %factormin% gt 0.2      &then calc SI_MAX = 4
&if %factormax% lt 0.6 and %factormin% gt 0.4      &then calc SI_MAX = 3
&if %factormax% lt 0.8 and %factormin% gt 0.6      &then calc SI_MAX = 2
&if %factormax% ge 0.8                             &then calc SI_MAX = 1

calc SI_CH = [quote [calc [ round [calc %:edit.SI_MIN% * 100 ] ] / 100 ] - [calc [ round [calc %:edit.SI_MAX% * 100 ] ] /
100 ] ]
calc MF_CH = [quote [calc [ round [calc %:edit.BMIN% * 100 ] ] / 100 ] - [calc [ round [calc %:edit.AMAX% * 100 ] ] /
100 ] ]

cursor next

&end
cursor close
q
y
y
&ret
```

B11: AML programming for potatoes (Fuzzy Logic-GMF Approach)

```
&ty *** AML to Calculate the MF for 3M potato

/*Name of the Coverage

&sv incov = data_p3M
&sv outcov = out_p3m

&ty *** Kill old datasets
```

```
&if [EXISTS %outcov% -COVER] &then kill %outcov% all

&ty *** Create working coverage %outcov%

copy %incov% %outcov%
&ty AML for 3 MODEL

ae
edit %outcov% poly

additem bmin 4 5 f 2
additem amax 4 5 f 2
additem SI_MIN 4 5 f 2
additem SI_MAX 4 5 f 2
additem SI_CH 30 C
additem MF_CH 30 C

sel all
CURSOR open
&do &while %:edit.aml$next%

&sv factormin = 1.0
&sv factormax = %:edit.HU1_p%
&if %:edit.AAB1_p% ge %factormax% &then &sv factormax = %:edit.AAB1_p%
&if %:edit.PH1_p% ge %factormax% &then &sv factormax = %:edit.PH1_p%
&if %:edit.NO31_p% ge %factormax% &then &sv factormax = %:edit.NO31_p%
&if %:edit.P2O51_p% ge %factormax% &then &sv factormax = %:edit.P2O51_p%
&if %:edit.K2O1_p% ge %factormax% &then &sv factormax = %:edit.K2O1_p%
&if %:edit.CEC1_p% ge %factormax% &then &sv factormax = %:edit.CEC1_p%
&if %:edit.HTK1A_p% ge %factormax% &then &sv factormax = %:edit.HTK1A_p%
&if %:edit.HTK2A_p% ge %factormax% &then &sv factormax = %:edit.HTK2A_p%
&if %:edit.FFL1_p% ge %factormax% &then &sv factormax = %:edit.FFL1_p%
&if %:edit.St1_p% ge %factormax% &then &sv factormax = %:edit.St1_p%

calc amax = %factormax%

&if %:edit.HU2_p% gt %factormax% AND %:edit.HU2_p% lt %factormin% &then &svfactormin = %:edit.HU2_p%
&if %:edit.AAB2_p% gt %factormax% AND %:edit.AAB2_p% lt %factormin% &then &svfactormin = %:edit.AAB2_p%
&if %:edit.PH2_p% gt %factormax% AND %:edit.PH2_p% lt %factormin% &then &svfactormin = %:edit.PH2_p&
&if %:edit.NO32_p% gt %factormax% AND %:edit.NO32_p% lt %factormin% &then &sv factormin = %:edit.NO32_p%
&if %:edit.P2O52_p% gt %factormax% AND %:edit.P2O52_p% lt %factormin% &then &sv factormin =
%:edit.P2O52_p%
&if %:edit.K2O2_p% gt %factormax% AND %:edit.K2O2_p% lt %factormin% &then &sv factormin = %:edit.K2O2_p%
&if %:edit.CEC2_p% gt %factormax% AND %:edit.CEC2_p% lt %factormin% &then &sv factormin = %:edit.CEC2_p%
&if %:edit.HTK1B_p% gt %factormax% AND %:edit.HTK1B_p% lt %factormin% &then &sv factormin =
%:edit.HTK1B_p%
&if %:edit.HTK2B_p% gt %factormax% AND %:edit.HTK2B_p% lt %factormin% &then &sv factormin =
%:edit.HTK2B_p%
&if %:edit.FFL2_p% gt %factormax% AND %:edit.FFL2_p% lt %factormin% &then &sv factormin = %:edit.FFL2_p%
&if %:edit.St2_p% gt %factormax% AND %:edit.St2_p% lt %factormin% &then &sv factormin = %:edit.St2_p%

calc bmin = %factormin%

&if %factormin% eq 0                            &then calc SI_MIN = 0
&if %factormin% lt 0.2 and %factormin% gt 0.0        &then calc SI_MIN = 5
&if %factormin% lt 0.4 and %factormin% gt 0.2        &then calc SI_MIN = 4
&if %factormin% lt 0.6 and %factormin% gt 0.4        &then calc SI_MIN = 3
&if %factormin% lt 0.8 and %factormin% gt 0.6        &then calc SI_MIN = 2
&if %factormin% ge 0.8                          &then calc SI_MIN = 1

&if %factormax% eq 0                            &then calc SI_MAX = 0
&if %factormax% lt 0.2 and %factormin% gt 0.0        &then calc SI_MAX = 5
&if %factormax% lt 0.4 and %factormin% gt 0.2        &then calc SI_MAX = 4
&if %factormax% lt 0.6 and %factormin% gt 0.4        &then calc SI_MAX = 3
&if %factormax% lt 0.8 and %factormin% gt 0.6        &then calc SI_MAX = 2
&if %factormax% ge 0.8                          &then calc SI_MAX = 1

calc SI_CH = [quote [calc [ round [calc %:edit.SI_MIN% * 100 ] ] / 100 ] - [calc [ round [calc %:edit.SI_MAX% * 100 ] ] /
100 ] ]
```

```
calc MF_CH = [quote [calc [ round [calc %:edit.BMIN% * 100 ] ] / 100 ] - [calc [ round [calc %:edit.AMAX% * 100 ] ] /
100 ] ]

cursor next

&end
cursor close
q
y
y
&ret
```

B12: AML programming for WSP (Fuzzy Logic-GMF Approach)

```
/* AML to determine WSP

&if [exists wspcalc -cover] &then kill wspcalc all

&sv input1 = out_w3m
&sv input2 = out_p3m
&sv input3 = out_s3m

copy %input1% wspcalc

additem wspcalc.pat wspcalc.pat W_BMIN 4 2 f 3
additem wspcalc.pat wspcalc.pat S_BMIN 4 2 f 3
additem wspcalc.pat wspcalc.pat P_BMIN 4 2 f 3
additem wspcalc.pat wspcalc.pat W_AMAX 4 2 f 3
additem wspcalc.pat wspcalc.pat S_AMAX 4 2 f 3
additem wspcalc.pat wspcalc.pat P_AMAX 4 2 f 3
additem wspcalc.pat wspcalc.pat W_SI_MIN 4 2 f 3
additem wspcalc.pat wspcalc.pat S_SI_MIN 4 2 f 3
additem wspcalc.pat wspcalc.pat P_SI_MIN 4 2 f 3
additem wspcalc.pat wspcalc.pat W_SI_MAX 4 2 f 3
additem wspcalc.pat wspcalc.pat S_SI_MAX 4 2 f 3
additem wspcalc.pat wspcalc.pat P_SI_MAX 4 2 f 3
additem wspcalc.pat wspcalc.pat MAX_SI_MAX 4 2 f 3
additem wspcalc.pat wspcalc.pat MAX_SI_MIN 4 2 f 3
additem wspcalc.pat wspcalc.pat MAX_AMAX 4 2 f 3
additem wspcalc.pat wspcalc.pat MAX_BMIN 4 2 f 3
additem wspcalc.pat wspcalc.pat WSPC 4 2 f 3
additem wspcalc.pat wspcalc.pat WSP 7 7 C
additem wspcalc.pat wspcalc.pat SIR_CH 30 30 C
additem wspcalc.pat wspcalc.pat SPR_CH 30 30 C

relate add rel1 %input1%.pat info wspcalc# %input1%# linear rw
relate add rel2 %input2%.pat info wspcalc# %input2%# linear rw
relate add rel3 %input3%.pat info wspcalc# %input3%# linear rw

tables
sel wspcalc.pat

calc W_BMIN = rel1//BMIN
calc S_BMIN = rel2//BMIN
calc P_BMIN = rel3//BMIN
calc W_AMAX = rel1//AMAX
calc S_AMAX = rel2//AMAX
calc P_AMAX = rel3//AMAX
calc W_SI_MIN = rel1//SI_MIN
calc S_SI_MIN = rel2//SI_MIN
calc P_SI_MIN = rel3//SI_MIN
calc W_SI_MAX = rel1//SI_MAX
calc S_SI_MAX = rel2//SI_MAX
calc P_SI_MAX = rel3//SI_MAX

q
```

```
ap
cursor ptcur declare wspcalc.pat info rw
cursor ptcur open
&do &while %:ptcur.aml$next%

  /* Checking the maximum of BMIN
  &sv currmax = [value :ptcur.W_BMIN]
  &if [value :ptcur.S_BMIN] gt %currmax% &then &sv %currmax% = [value :ptcur.S_BMIN]
  &if [value :ptcur.P_BMIN] gt %currmax% &then &sv %currmax% = [value :ptcur.P_BMIN]

  &sv :ptcur.MAX_BMIN = %currmax%

  /* Checking the maximum of AMAX
  &sv currmax = [value :ptcur.W_AMAX]
  &if [value :ptcur.S_AMAX] gt %currmax% &then &sv %currmax% = [value :ptcur.S_AMAX]
  &if [value :ptcur.P_AMAX] gt %currmax% &then &sv %currmax% = [value :ptcur.P_AMAX]

  &sv :ptcur.MAX_AMAX = %currmax%

  /* Checking the maximum of SI_MIN
  &sv currmax = [value :ptcur.W_SI_MIN]
  &if [value :ptcur.S_SI_MIN] gt %currmax% &then &sv %currmax% = [value :ptcur.S_SI_MIN]
  &if [value :ptcur.P_SI_MIN] gt %currmax% &then &sv %currmax% = [value :ptcur.P_SI_MIN]

  &sv :ptcur.MAX_SI_MIN = %currmax%

  /* Checking the maximum of SI_MAX
  &sv currmax = [value :ptcur.W_SI_MAX]
  &if [value :ptcur.S_SI_MAX] gt %currmax% &then &sv %currmax% = [value :ptcur.S_SI_MAX]
  &if [value :ptcur.P_SI_MAX] gt %currmax% &then &sv %currmax% = [value :ptcur.P_SI_MAX]

  &sv :ptcur.MAX_SI_MAX = %currmax%

    /* checking prevailing crop
  /* Case if W=S=P
  &if [value :ptcur.W_SI_MAX] eq [value :ptcur.P_SI_MAX] and [value :ptcur.P_SI_MAX] eq [value :ptcur.S_SI_MAX]
&then
  &do
   &sv :ptcur.WSP = WSP
   &sv :ptcur.WSPC = [value :ptcur.W_SI_MAX]
  &end

  /* Case if W
  &if [value :ptcur.W_SI_MAX] lt [value :ptcur.S_SI_MAX] and [value :ptcur.W_SI_MAX] lt [value :ptcur.P_SI_MAX]
&then
  &do
   &sv :ptcur.WSP = W
   &sv :ptcur.WSPC = [value :ptcur.W_SI_MAX]
  &end

  /* Case if S
  &if [value :ptcur.S_SI_MAX] lt [value :ptcur.W_SI_MAX] and [value :ptcur.S_SI_MAX] lt [value :ptcur.P_SI_MAX]
&then
  &do
   &sv :ptcur.WSP = S
   &sv :ptcur.WSPC = [value :ptcur.S_SI_MAX]
  &end

  /* Case if P
  &if [value :ptcur.P_SI_MAX] lt [value :ptcur.W_SI_MAX] and [value :ptcur.P_SI_MAX] lt [value :ptcur.S_SI_MAX]
&then
  &do
   &sv :ptcur.WSP = P
   &sv :ptcur.WSPC = [value :ptcur.P_SI_MAX]
  &end

  /* Case if WS
  &if [value :ptcur.W_SI_MAX] eq [value :ptcur.S_SI_MAX] and [value :ptcur.W_SI_MAX] lt [value :ptcur.P_SI_MAX]
&then
```

```
  &do
   &sv :ptcur.WSP = WS
   &sv :ptcur.WSPC = [value :ptcur.W_SI_MAX]
  &end

    /* Case if WP
  &if [value :ptcur.W_SI_MAX] eq [value :ptcur.P_SI_MAX] and [value :ptcur.W_SI_MAX] lt [value :ptcur.S_SI_MAX]
&then
  &do
   &sv :ptcur.WSP = WP
   &sv :ptcur.WSPC = [value :ptcur.W_SI_MAX]
  &end

    /* Case if SP
  &if [value :ptcur.S_SI_MAX] eq [value :ptcur.P_SI_MAX] and [value :ptcur.S_SI_MAX] lt [value :ptcur.W_SI_MAX]
&then
  &do
   &sv :ptcur.WSP = SP
   &sv :ptcur.WSPC = [value :ptcur.S_SI_MAX]
  &end

 &sv :ptcur.SIR_CH = [quote [calc [ round [calc %:ptcur.MAX_BMIN% * 100 ] ] / 100 ] - [calc [ round [calc
%:ptcur.MAX_AMAX% * 100 ] ] / 100 ] ]
 &sv :ptcur.SPR_CH = [quote [calc [ round [calc %:ptcur.MAX_SI_MIN% * 100 ] ] / 100 ] - [calc [ round [calc
%:ptcur.MAX_SI_MAX% * 100 ] ] / 100 ] ]


  cursor ptcur next
&end
cursor ptcur close
cursor ptcur remove
q

relate drop $all

&ret
```

B13: AML programming for summer wheat (Fuzzy Set Theory - JMF Approach)

```
&ty *** AML to Calculate the SI wheat for 4M

/*name of coverage
&sv incov = data_4m_wh
&sv outcov = out_w4m
&ty *** Kill old datasets

&if [EXISTS %outcov% -COVER] &then kill %outcov% all

&ty *** Create working coverage %outcov%
copy %incov% %outcov%

ae
edit %outcov% poly

additem HU2_w_l 4 8 f 2
additem AAB2_w_l 4 8 f 2
additem PH2_w_l 4 8 f 2
additem NO32_w_l 4 8 f 2
additem P2052_w_l 4 8 f 2
additem K202_w_l 4 8 f 2
additem CEC2_w_l 4 8 f 2
additem HTK1B_w_l 4 8 f 2
additem HTK2B_w_l 4 8 f 2
additem FFL2_w_l 4 8 f 2
additem St2_w_l 4 8 f 2
additem JMF 4 8 f 2
additem SI 2 4 b

sel all

calc HU2_w_l = 0.09
calc AAB2_w_l = 0.12
calc PH2_w_l = 0.11
calc NO32_w_l = 0.06
calc P2052_w_l = 0.045
calc K202_w_l = 0.07
calc CEC2_w_l = 0.015
calc HTK1B_w_l = 0.15
calc HTK2B_w_l = 0.14
calc FFL2_w_l = 0.03
calc St2_w_l = 0.17

CURSOR open
&do &while %:edit.aml$next%

/* multiply

&sv temp1 =  [ calc %:edit.HU2_w_l% * %:edit.HU2_w% ]
&sv temp2 =  [ calc %:edit.AAB2_w_l% * %:edit.AAB2_w% ]
&sv temp3 =  [ calc %:edit.PH2_w_l% * %:edit.PH2_w% ]
&sv temp4 =  [ calc %:edit.NO32_w_l% * %:edit.NO32_w% ]
&sv temp5 =  [ calc %:edit.P2052_w_l% * %:edit.P2052_w% ]
&sv temp6 =  [ calc %:edit.K202_w_l% * %:edit.K202_w% ]
&sv temp7 =  [ calc %:edit.CEC2_w_l% * %:edit.CEC2_w% ]
&sv temp8 =  [ calc %:edit.HTK1B_w_l% * %:edit.HTK1B_w% ]
&sv temp9 =  [ calc %:edit.HTK2B_w_l% * %:edit.HTK2B_w% ]
&sv temp10 = [ calc %:edit.FFL2_w_l% * %:edit.FFL2_w% ]
&sv temp11 = [ calc %:edit.St2_w_l% * %:edit.St2_w% ]

/* summarize

calc JMF = [calc %temp1% + %temp2% + %temp3% + %temp4% + %temp5% + %temp6% + %temp7% + %temp8%
+ %

temp9% + %temp10% + %temp11% ]
```

```
&if %:edit.JMF% eq 0                          &then calc SI = 0
&if %:edit.JMF% lt 0.2 and %:edit.JMF% gt 0.0     &then calc SI = 5
&if %:edit.JMF% lt 0.4 and %:edit.JMF% gt 0.2     &then calc SI = 4
&if %:edit.JMF% lt 0.6 and %:edit.JMF% gt 0.4     &then calc SI = 3
&if %:edit.JMF% lt 0.8 and %:edit.JMF% gt 0.6     &then calc SI = 2
&if %:edit.JMF% ge 0.8                        &then calc SI = 1

cursor next

&end
cursor close
q
y
y
&ret
```

B14: AML programming for sunflowers (Fuzzy Set Theory - JMF Approach)

```
&ty *** AML to Calculate the SI sunflower for 4M

/*name of coverage
&sv incov = data_4m_s
&sv outcov = out_s4m
&ty *** Kill old datasets

&if [EXISTS %outcov% -COVER] &then kill %outcov% all

&ty *** Create working coverage %outcov%
copy %incov% %outcov%

ae
edit %outcov% poly

additem HU2_s_l 4 8 f 2
additem AAB2_s_l 4 8 f 2
additem PH2_s_l 4 8 f 2
additem NO32_s_l 4 8 f 2
additem P2052_s_l 4 8 f 2
additem K202_s_l 4 8 f 2
additem CEC2_s_l 4 8 f 2
additem HTK1B_s_l 4 8 f 2
additem HTK2B_s_l 4 8 f 2
additem FFL2_s_l 4 8 f 2
additem St2_s_l 4 8 f 2
additem JMF 4 8 f 2
additem SI 2 4 b

sel all

calc HU2_s_l = 0.09
calc AAB2_s_l = 0.12
calc PH2_s_l = 0.11
calc NO32_s_l = 0.06
calc P2052_s_l = 0.045
calc K202_s_l = 0.07
calc CEC2_s_l = 0.015
calc HTK1B_s_l = 0.15
calc HTK2B_s_l = 0.14
calc FFL2_s_l = 0.03
calc St2_s_l = 0.17

CURSOR open
&do &while %:edit.aml$next%

/* multiply
```

```
&sv temp1 =  [ calc %:edit.HU2_s_l% * %:edit.HU2_s% ]
&sv temp2 =  [ calc %:edit.AAB2_s_l% * %:edit.AAB2_s% ]
&sv temp3 =  [ calc %:edit.PH2_s_l% * %:edit.PH2_s% ]
&sv temp4 =  [ calc %:edit.NO32_s_l% * %:edit.NO32_s% ]
&sv temp5 =  [ calc %:edit.P2052_s_l% * %:edit.P2052_s% ]
&sv temp6 =  [ calc %:edit.K202_s_l% * %:edit.K202_s% ]
&sv temp7 =  [ calc %:edit.CEC2_s_l% * %:edit.CEC2_s% ]
&sv temp8 =  [ calc %:edit.HTK1B_s_l% * %:edit.HTK1B_s% ]
&sv temp9 =  [ calc %:edit.HTK2B_s_l% * %:edit.HTK2B_s% ]
&sv temp10 = [ calc %:edit.FFL2_s_l% * %:edit.FFL2_s% ]
&sv temp11 = [ calc %:edit.St2_s_l% * %:edit.St2_s% ]

/* summarize

calc JMF = [calc %temp1% + %temp2% + %temp3% + %temp4% + %temp5% + %temp6% + %temp7% + %temp8%
+ %

temp9% + %temp10% + %temp11% ]

&if %:edit.JMF% eq 0                              &then calc SI = 0
&if %:edit.JMF% lt 0.2 and %:edit.JMF% gt 0.0     &then calc SI = 5
&if %:edit.JMF% lt 0.4 and %:edit.JMF% gt 0.2     &then calc SI = 4
&if %:edit.JMF% lt 0.6 and %:edit.JMF% gt 0.4     &then calc SI = 3
&if %:edit.JMF% lt 0.8 and %:edit.JMF% gt 0.6     &then calc SI = 2
&if %:edit.JMF% ge 0.8                            &then calc SI = 1

cursor next

&end
cursor close
q
y
y
&ret
```

B15: AML programming for potatoes (Fuzzy Set Theory - JMF Approach)

```
&ty *** AML to Calculate the SI for potatoes for 4M

/*name of coverage
&sv incov = data_4m_p
&sv outcov = out_p4m
&ty *** Kill old datasets

&if [EXISTS %outcov% -COVER] &then kill %outcov% all

&ty *** Create working coverage %outcov%
copy %incov% %outcov%

ae
edit %outcov% poly

additem HU2_p_l 4 8 f 2
additem AAB2_p_l 4 8 f 2
additem PH2_p_l 4 8 f 2
additem NO32_p_l 4 8 f 2
additem P2052_p_l 4 8 f 2
additem K202_p_l 4 8 f 2
additem CEC2_p_l 4 8 f 2
additem HTK1B_p_l 4 8 f 2
additem HTK2B_p_l 4 8 f 2
additem FFL2_p_l 4 8 f 2
additem St2_p_l 4 8 f 2
additem JMF 4 8 f 2
additem SI 2 4 b
```

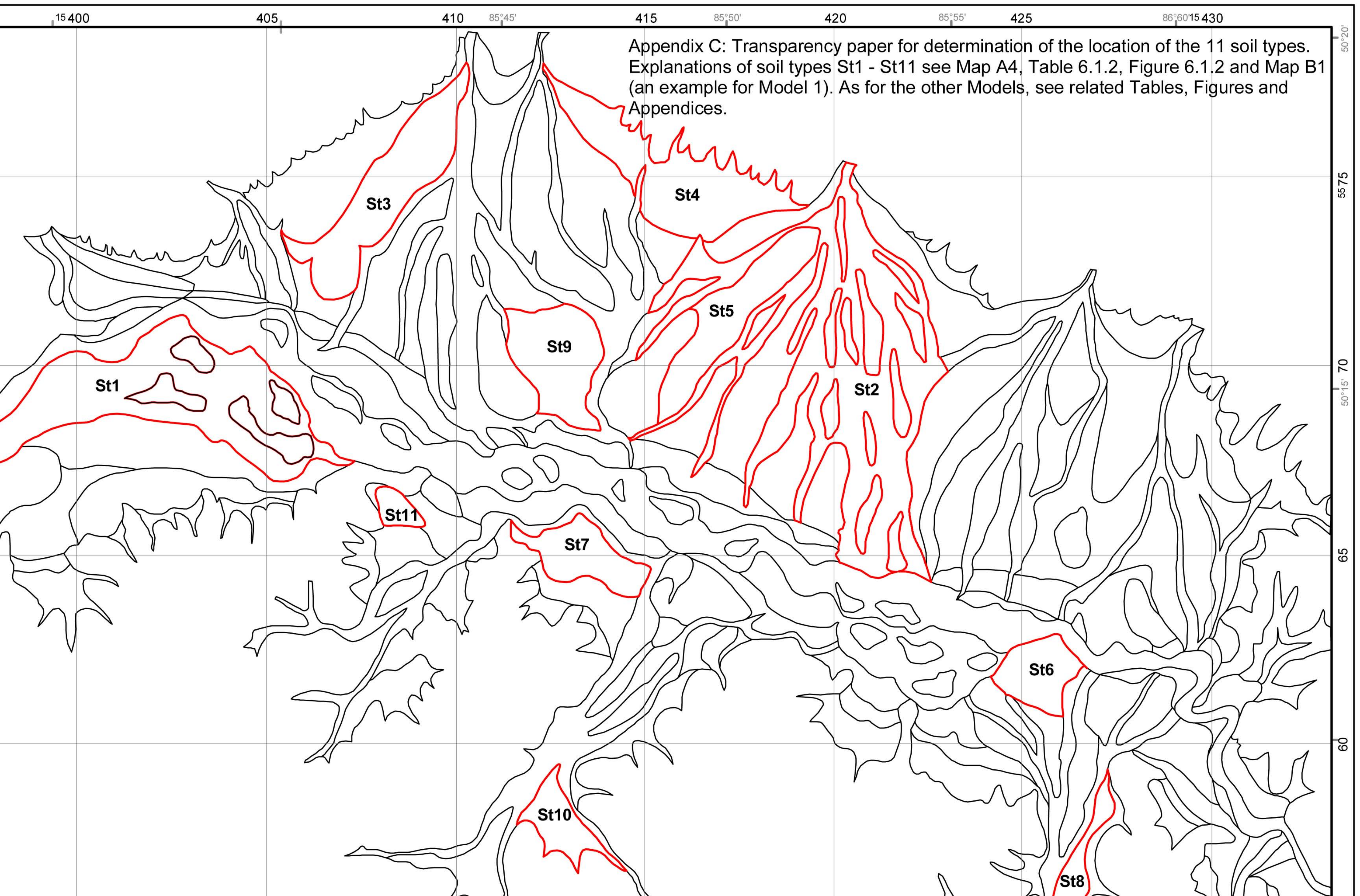
```
sel all

calc HU2_p_l = 0.09
calc AAB2_p_l = 0.12
calc PH2_p_l = 0.11
calc NO32_p_l = 0.06
calc P2052_p_l = 0.045
calc K202_p_l = 0.07
calc CEC2_p_l = 0.015
calc HTK1B_p_l = 0.15
calc HTK2B_p_l = 0.14
calc FFL2_p_l = 0.03
calc St2_p_l = 0.17

CURSOR open
&do &while %:edit.aml$next%

/* multiply

&sv temp1 =  [ calc %:edit.HU2_p_l% * %:edit.HU2_p% ]
&sv temp2 =  [ calc %:edit.AAB2_p_l% * %:edit.AAB2_p% ]
&sv temp3 =  [ calc %:edit.PH2_p_l% * %:edit.PH2_p% ]
&sv temp4 =  [ calc %:edit.NO32_p_l% * %:edit.NO32_p% ]
&sv temp5 =  [ calc %:edit.P2052_p_l% * %:edit.P2052_p% ]
&sv temp6 =  [ calc %:edit.K202_p_l% * %:edit.K202_p% ]
&sv temp7 =  [ calc %:edit.CEC2_p_l% * %:edit.CEC2_p% ]
&sv temp8 =  [ calc %:edit.HTK1B_p_l% * %:edit.HTK1B_p% ]
&sv temp9 =  [ calc %:edit.HTK2B_p_l% * %:edit.HTK2B_p% ]
&sv temp10 = [ calc %:edit.FFL2_p_l% * %:edit.FFL2_p% ]
&sv temp11 = [ calc %:edit.St2_p_l% * %:edit.St2_p% ]

/* summarize

calc JMF = [calc %temp1% + %temp2% + %temp3% + %temp4% + %temp5% + %temp6% + %temp7% + %temp8%
+ %

temp9% + %temp10% + %temp11% ]

&if %:edit.JMF% eq 0                              &then calc SI = 0
&if %:edit.JMF% lt 0.2 and %:edit.JMF% gt 0.0         &then calc SI = 5
&if %:edit.JMF% lt 0.4 and %:edit.JMF% gt 0.2         &then calc SI = 4
&if %:edit.JMF% lt 0.6 and %:edit.JMF% gt 0.4         &then calc SI = 3
&if %:edit.JMF% lt 0.8 and %:edit.JMF% gt 0.6         &then calc SI = 2
&if %:edit.JMF% ge 0.8                            &then calc SI = 1

cursor next

&end
cursor close
q
y
y
&ret
```

B16: AML programming for WSP (Fuzzy Set Theory - JMF Approach)

```
/* AML to determine WSP


&if [exists wspcalc -cover] &then kill wspcalc all

&sv input1 = out_w4m
&sv input2 = out_s4m
&sv input3 = out_p4m
```

```
copy %input1% wspcalc

additem wspcalc.pat wspcalc.pat W_JMF 4 2 f 3
additem wspcalc.pat wspcalc.pat S_JMF 4 2 f 3
additem wspcalc.pat wspcalc.pat P_JMF 4 2 f 3
additem wspcalc.pat wspcalc.pat W_SI 4 2 f 3
additem wspcalc.pat wspcalc.pat S_SI 4 2 f 3
additem wspcalc.pat wspcalc.pat P_SI 4 2 f 3
additem wspcalc.pat wspcalc.pat WSPC 4 2 f 3
additem wspcalc.pat wspcalc.pat WSP 7 7 C
additem wspcalc.pat wspcalc.pat MAX_JMF 4 2 f 3

relate add rel1 %input1%.pat info wspcalc# %input1%# linear rw
relate add rel2 %input2%.pat info wspcalc# %input2%# linear rw
relate add rel3 %input3%.pat info wspcalc# %input3%# linear rw

tables
sel wspcalc.pat
calc W_SI = rel1//SI
calc S_SI = rel2//SI
calc P_SI = rel3//SI
calc W_JMF = rel1//JMF
calc S_JMF = rel2//JMF
calc P_JMF = rel3//JMF
q

ap
cursor ptcur declare wspcalc.pat info rw
cursor ptcur open
&do &while %:ptcur.aml$next%

   /* Checking the maximum
  &sv currmax = [value :ptcur.W_JMF]
  &if [value :ptcur.S_JMF] gt %currmax% &then &sv %currmax% = [value :ptcur.S_JMF]
  &if [value :ptcur.P_JMF] gt %currmax% &then &sv %currmax% = [value :ptcur.P_JMF]

  &sv :ptcur.MAX_JMF = %currmax%


  /* Case if W=S=P
  &if [value :ptcur.W_SI] eq [value :ptcur.P_SI] and [value :ptcur.P_SI] eq [value :ptcur.S_SI] &then
  &do
   &sv :ptcur.WSP = WSP
   &sv :ptcur.WSPC = [value :ptcur.W_SI]
  &end


  /* Case if W
  &if [value :ptcur.W_SI] lt [value :ptcur.S_SI] and [value :ptcur.W_SI] lt [value :ptcur.P_SI] &then
  &do
   &sv :ptcur.WSP = W
   &sv :ptcur.WSPC = [value :ptcur.W_SI]
  &end

  /* Case if S
  &if [value :ptcur.S_SI] lt [value :ptcur.W_SI] and [value :ptcur.S_SI] lt [value :ptcur.P_SI] &then
  &do
   &sv :ptcur.WSP = S
   &sv :ptcur.WSPC = [value :ptcur.S_SI]
  &end

  /* Case if P
  &if [value :ptcur.P_SI] lt [value :ptcur.W_SI] and [value :ptcur.P_SI] lt [value :ptcur.S_SI] &then
  &do
   &sv :ptcur.WSP = P
   &sv :ptcur.WSPC = [value :ptcur.P_SI]
  &end

  /* Case if WS
  &if [value :ptcur.W_SI] eq [value :ptcur.S_SI] and [value :ptcur.W_SI] lt [value :ptcur.P_SI] &then
```

```
  &do
   &sv :ptcur.WSP = WS
   &sv :ptcur.WSPC = [value :ptcur.W_SI]
  &end

    /* Case if WP
  &if [value :ptcur.W_SI] eq [value :ptcur.P_SI] and [value :ptcur.W_SI] lt [value :ptcur.S_SI] &then
  &do
   &sv :ptcur.WSP = WP
   &sv :ptcur.WSPC = [value :ptcur.W_SI]
  &end

    /* Case if SP
  &if [value :ptcur.S_SI] eq [value :ptcur.P_SI] and [value :ptcur.S_SI] lt [value :ptcur.W_SI] &then
  &do
   &sv :ptcur.WSP = SP
   &sv :ptcur.WSPC = [value :ptcur.S_SI]
  &end

  cursor ptcur next
&end
cursor ptcur close
cursor ptcur remove
q

relate drop $all

&ret
```



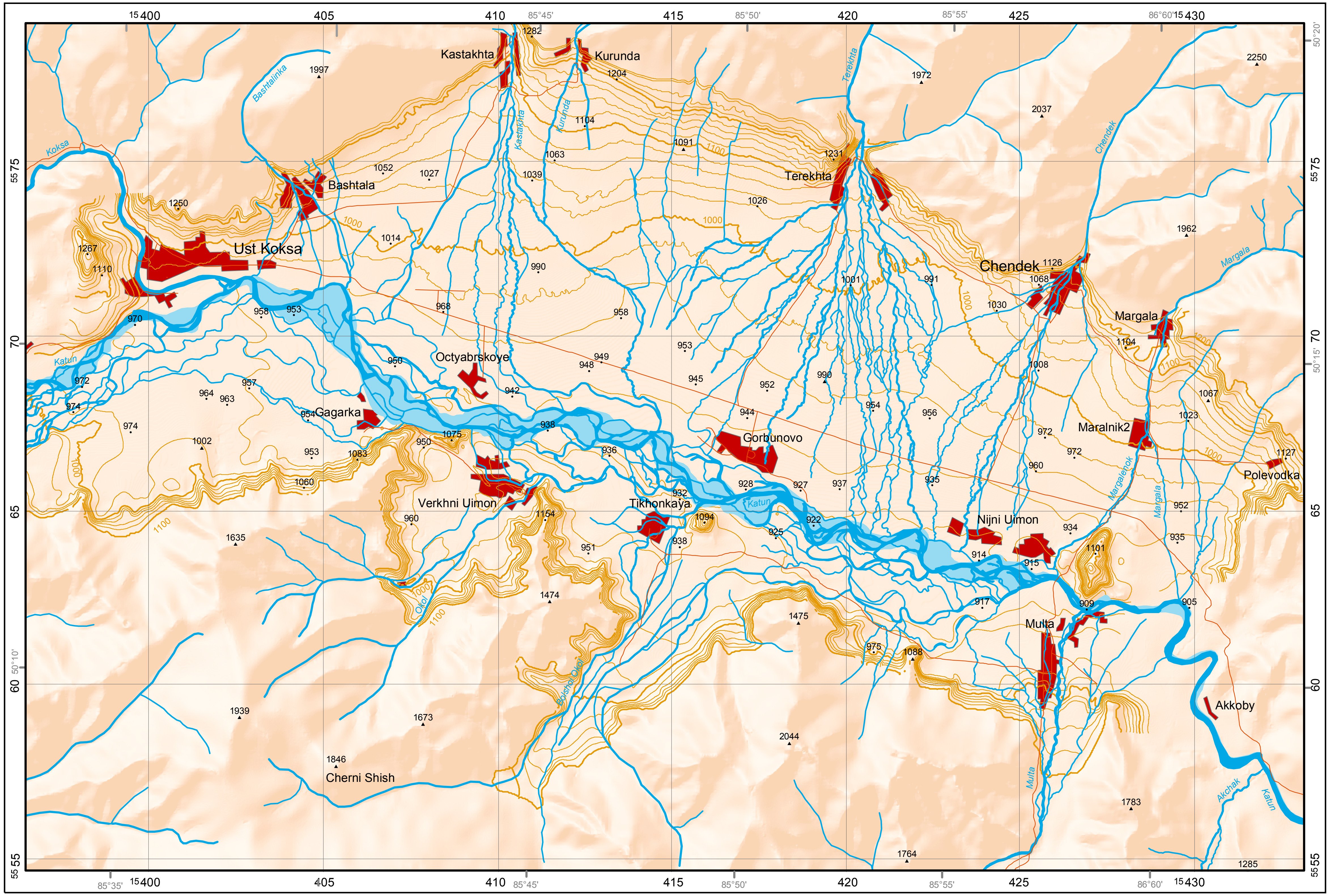
Appendix C: Transparency paper for determination of the location of the 11 soil types.
Explanations of soil types St1 - St11 see Map A4, Table 6.1.2, Figure 6.1.2 and Map B1
(an example for Model 1). As for the other Models, see related Tables, Figures and
Appendices.
15 400
405
410
85°45'
415
85°50'
420
85°55'
425
86°60'
15 430
50°20'
55 75
70
50°15'
65
60
St1
St2
St3
St4
St5
St6
St7
St8
St9
St10
St11

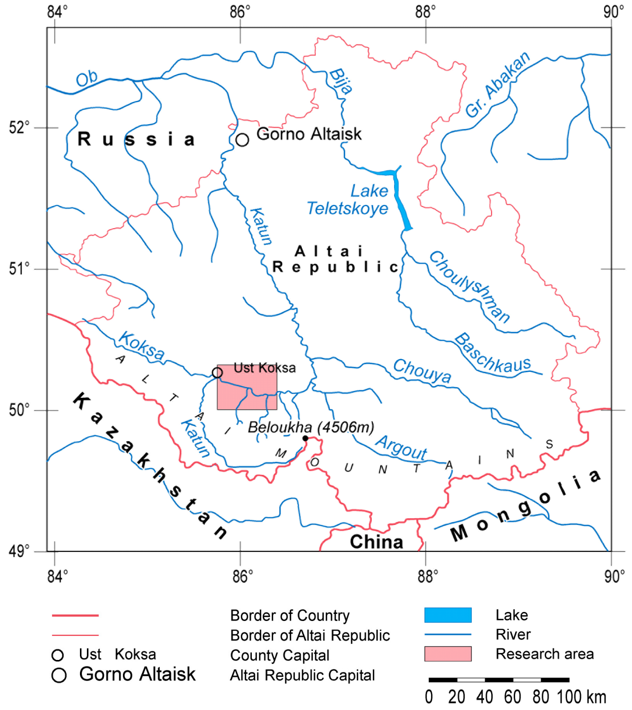
Uimon Basin
Altai Republic

South Siberia, Russia

Topography

km
0 2 4 6





Provision of relief information:
Ust Koksa Landuse Committee (Altai Republic, Russia) and
DEM from ALTAI 200 (Institute for Cartography,
Dresden University of Technology, Germany)

Projection: Gauss-Krueger
Ellipsoid: Krassovsky
Datum: Pulkowo 42/83

Author:
K. Kelgenbaeva (2007)
(Institute for Cartography,
Dresden University of Technology, Germany)

Legend

Topography

- Contour Line (20 m)
- Contour Line (100 m)
- Settlement
- Road
- Field Boundary
- 975 Elevation Point [m]
- 1613 Peak [m]
- River

Non - Soil Formations

- Recent River Deposits
- Hardrock Outcrop

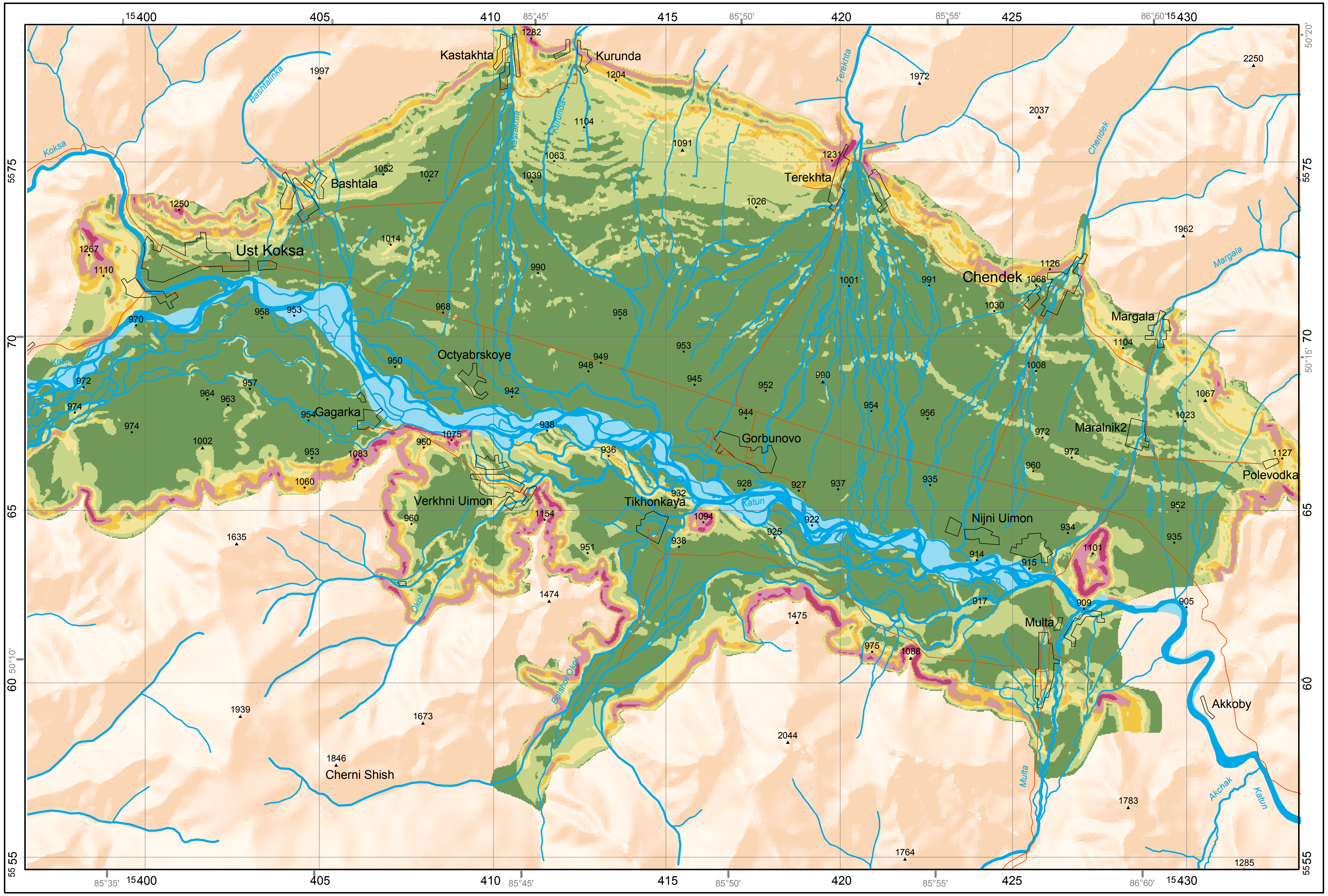
TECHNISCHE UNIVERSITÄT DRESDEN

Map A1

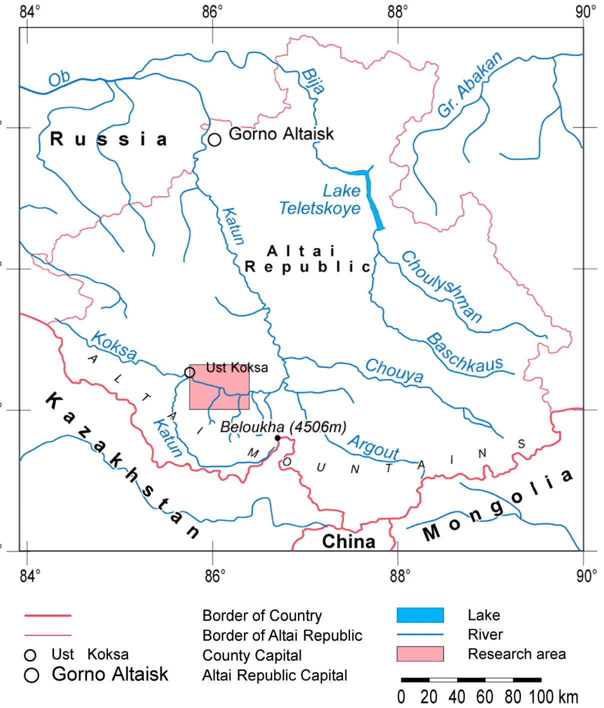
Uimon Basin
Altai Repubic

South Siberia, Russia

Slope Gradients



km
0 2 4 6



Provision of relief information:
Ust Koksa Landuse Committee (Altai Republic, Russia) and DEM from ALTAI 200 (Institute for Cartography, Dresden University of Technology, Germany)

Projection: Gauss-Krueger
Ellipsoid: Krassovsky
Datum: Pulkowo 42/83

Author:
K. Kelgenbaeva (2007)
(Institute for Cartography,
Dresden University of Technology, Germany)

Legend

Slope gradient

- < 1.4 °
- 1.4 - < 2.8 °
- 2.8 - < 5.6 °
- 5.6 - < 11.2 °
- 11.2 - < 22.5 °
- 22.5 - < 45 °
- > 45 °

Non - Soil Formations

- Recent River Deposits

Topography

- Settlement
- Road
- Field Boundary
- 975 Elevation Point [m]
- 1613 Peak [m]
- River

TECHNISCHE UNIVERSITÄT DRESDEN

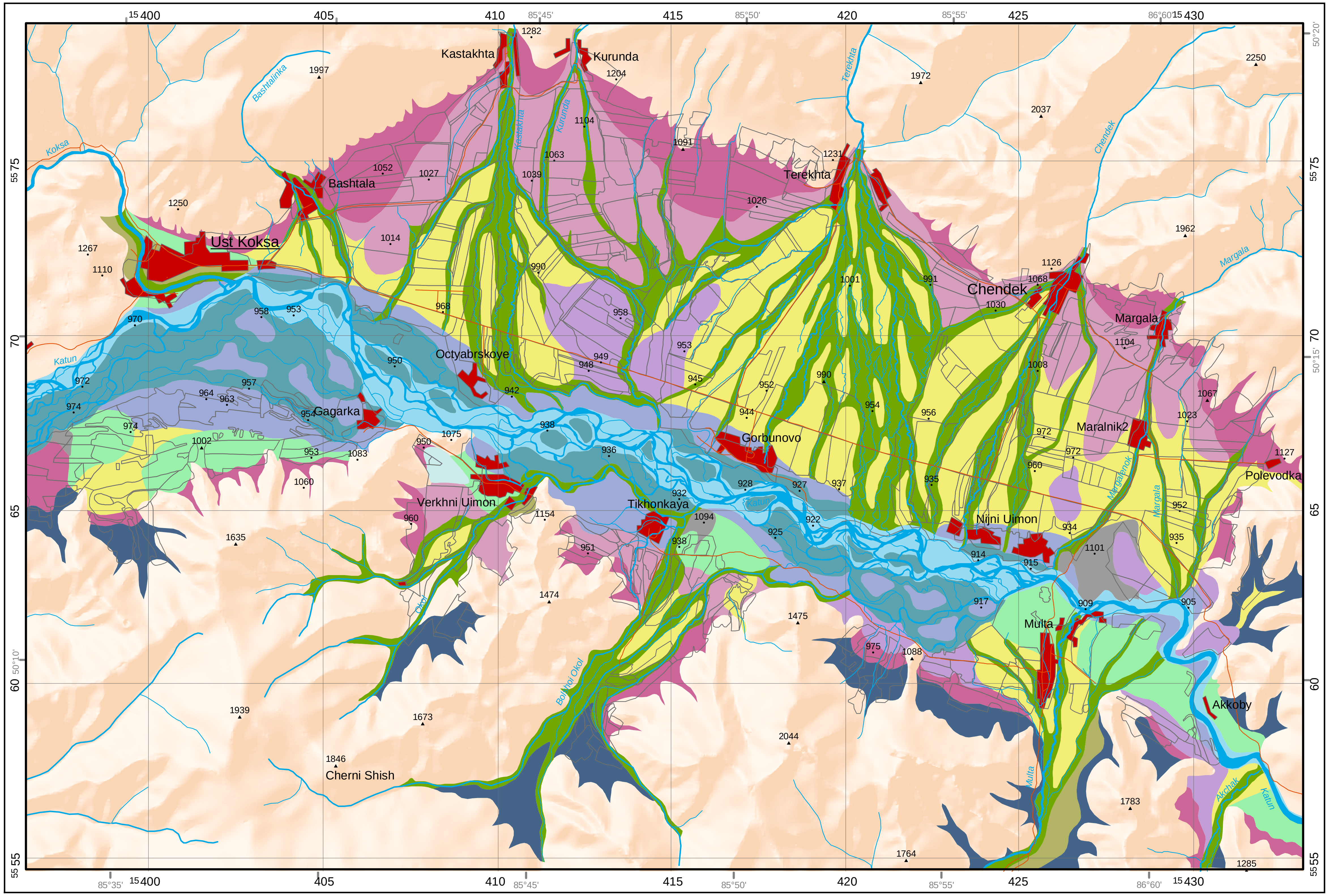
Map A2

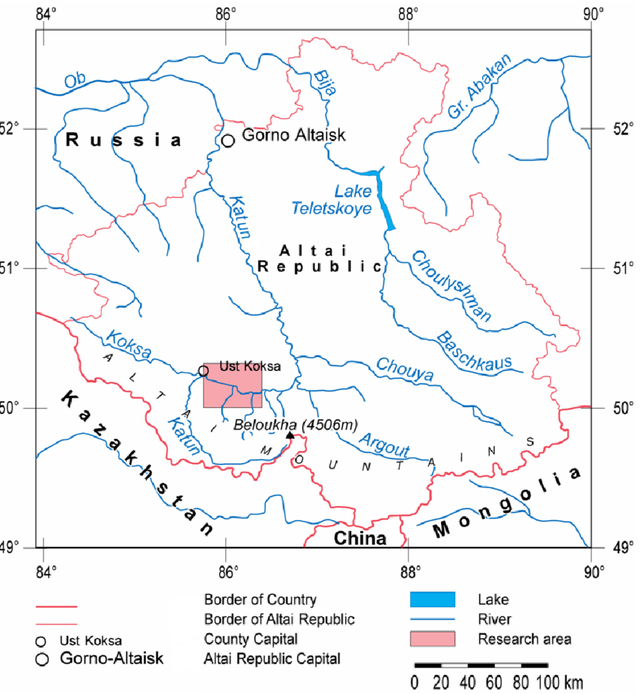
Uimon Basin
Altai Republic

South Siberia, Russia

Quaternary Sediments

0 2 4 6 km





Data source:
non-digital quaternary Map (Butvilovsky 2005; unpublished)

Provision of relief information:
Ust Koksa Landuse Committee (Altai Republic, Russia) and DEM from ALTAI 200 (Institute for Cartography, Dresden University of Technology, Germany)

Projection: Gauss-Krueger
Ellipsoid: Krassovsky
Datum: Pulkowo 42/83
Hill-Shading: DTM 5 x vertically exaggerated

GIS/Cartography:
K. Kelgenbaeva (2007)
(Institute for Cartography,
Dresden University of Technology, Germany)

Legend

Deposits:

Fluvio-periglacial zone:

- $fgQ_{IV}1$ - Holocene high floodland, fluvio-glacial terraces
- $kfQ_{III}3$ - upper Pleistocene katafluvial deposits of catastrophic flows
- $lfQ_{III}4$ - upper Pleistocene lake - fluvioglacial deposits of oses and lake plains
- $pfQ_{III}4$ - upper Pleistocene lake deltaic deposits
- cdQ - undivided Holocene-quarternary colluvial-delluvial deposits

Fluvial-humid zone:

- lQ_{IV} - Holocene lake marshy deposits
- $aQ_{IV}1$ - Holocene alluvium of high flood land terraces

Quaternary System:

Pleistocene:
Q_I1 - Early Quaternary
$Q_{II}2$ - Middle Quaternary
$Q_{III}3$ - Late Quaternary

Holocene:
$Q_{IV}1$ - Early Quaternary
$Q_{IV}2$ - Middle Quaternary

Fluvial-semiarid zone:

- $pfQ_{IV}2$ - upper Holocene modern proluvium and alluvium of flood lands and debris cones
- $pfQ_{IV}1$ - Holocene proluvial deposits of debris cones

Non - Soil Formations

- Recent River Deposits
- Hardrock Outcrop

Topography

- Settlement
- Road
- Field Boundary
- 975 Elevation Point [m]
- 1613 Peak [m]
- soil sample point
- River

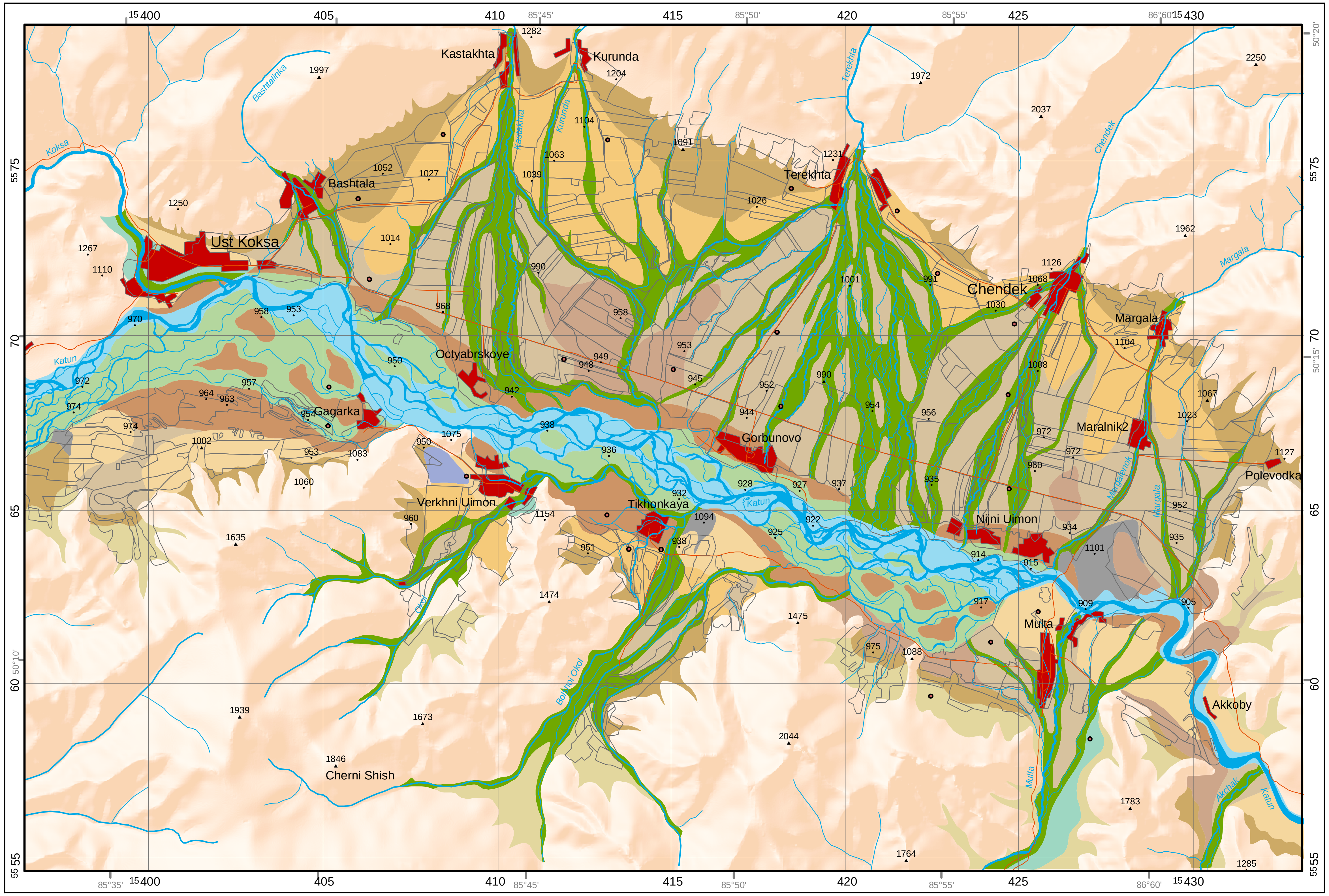
TECHNISCHE UNIVERSITÄT DRESDEN

Map A3

Uimon Basin
Altai Republic

South Siberia, Russia

Soil



km
0 2 4 6

Provision of relief information:
Ust Koksa Landuse Committee (Altai Republic, Russia) and
DEM from ALTAI 200 (Institute for Cartography,
Dresden University of Technology, Germany)

DTM from ALTAI 200
(Institute for Cartography,
Dresden University of Technology, Germany)

Projection: Gauss-Krueger
Ellipsoid: Krassovsky
Datum: Pulkowo 42/83
Hill-Shading: DTM 5 x vertically exaggerated

GIS/Cartography:
K. Kelgenbaeva (2007)
(Institute for Cartography,
Dresden University of Technology, Germany)

Legend

Soil Types and Subtypes

Soil Unit and Name in English

- Umbric Fluvisol (Fl-u): Alluvial-humid leached meadow soils
- Umbric Fluvisol (Fl-u): Alluvial meadow soil
- Haplic Chernozem (Ch-h): Carbonated, standard Chernozem medium thickness & weak humus content
- Haplic Chernozem (Ch-h): Carbonated, standard Chernozem medium thickness & medium humus content
- Haplic Chernozem (Ch-h): Carbonated, standard Chernozem weak thickness & weak humus content
- Luvic Chernozem (Ch-l): Leached Chernozem
- Gleyic Chernozem (Ch-g): Leached Meadow-chernozem-like soil
- Umbric Leptosol (LPum): Meadow-forest soil
- Haplic Kastanozem (KSh): Chestnut light soil
- Mollic Leptosol (Lp-m): Mountain-forest chermozem-like soil
- Gleysols (GL): Marshy soil

Non - Soil Formations

- Hardrock Outcrop
- Recent River Deposit

Topography

- Settlement
- Road
- Field Boundary
- 975 Elevation Point [m]
- 1613 Peak [m]
- soil sample point
- River

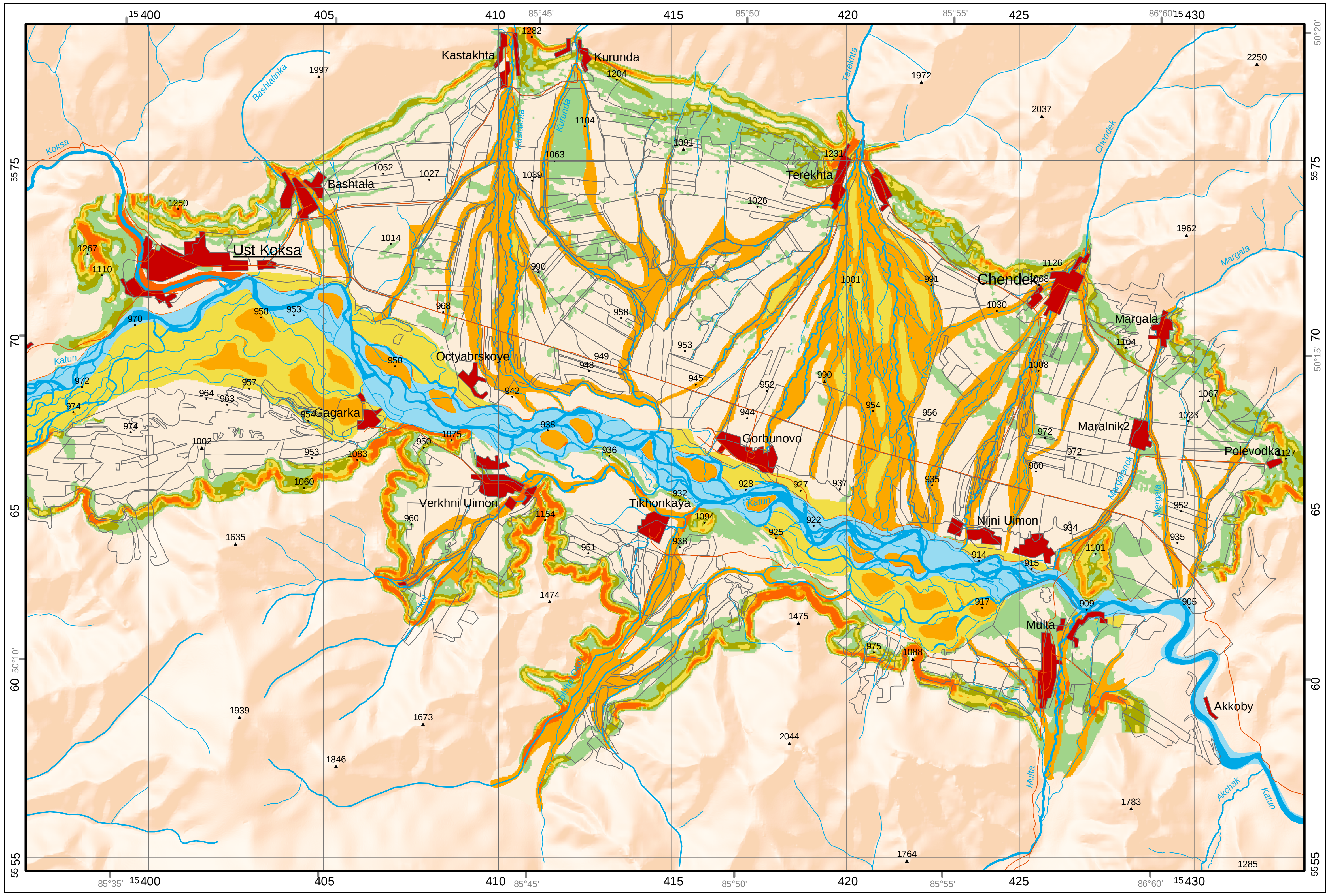
TECHNISCHE UNIVERSITÄT DRESDEN

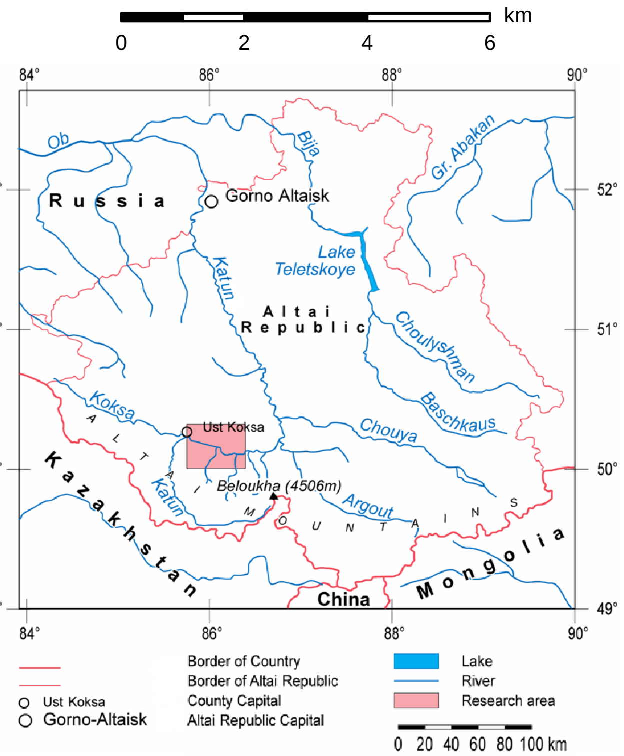
Map A4

Uimon Basin
Altai Repubic

South Siberia, Russia

Erodability





Provision of relief information:
Ust Koksa Landuse Committee (Altai Republic, Russia) and
DEM from ALTAI 200 (Institute for Cartography,
Dresden University of Technology, Germany)

Projection: Gauss-Krueger
Ellipsoid: Krassovsky
Datum: Pulkowo 42/83

Author:
K. Kelgenbaeva (2007)
(Institute for Cartography,
Dresden University of Technology, Germany)

Legend

Erodability

- No Erosion
- Very Low
- Low
- Moderate
- High
- Very High

Non - Soil Formations

- Recent River Deposits
- Hardrock Outcrop

Topography

- Settlement
- Road
- Field Boundary
- 975 Elevation Point [m]
- 1613 Peak [m]
- River

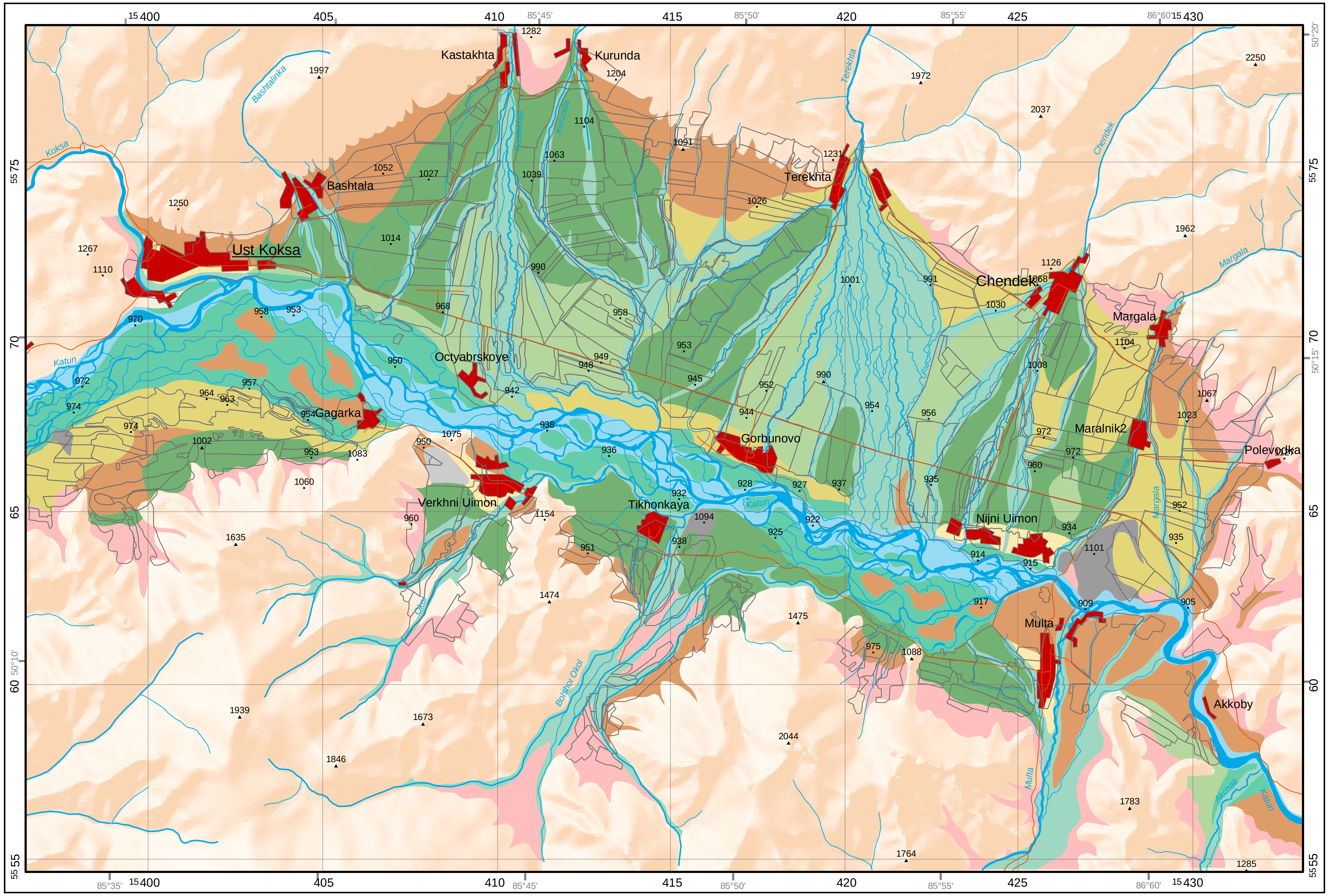
TECHNISCHE UNIVERSITÄT DRESDEN

Map A5

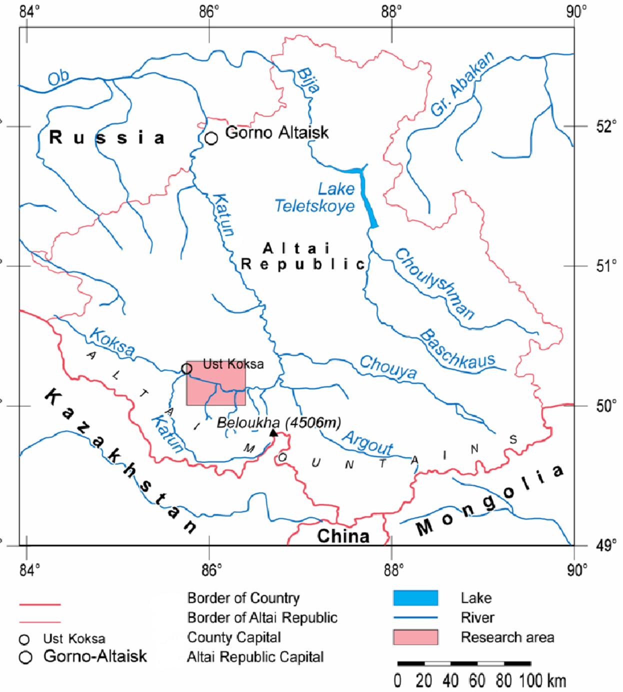
Uimon Basin
Altai Republic

South Siberia, Russia

Landuse
Based on Field Survey 2002 and Ust-Koksa Agronomy Report 2002



km
0 2 4 6



Data source:
Field Survey (2002) by K. Kelgenbaeva and
Ust Koksa Agronomy Report (1995 - 2002)
(Altai Republic, Russia)

Provision of relief information:
Ust Koksa Landuse Committee (Altai Republic, Russia) and
DEM from ALTAI 200 (Institute for Cartography,
Dresden University of Technology, Germany)

Projection: Gauss-Krueger
Ellipsoid: Krassovsky
Datum: Pulkowo 42/83

Author:
K. Kelgenbaeva (2007)
(Institute for Cartography,
Dresden University of Technology, Germany)

Legend

Cereals:
- Summer Wheat
- Oat
- Barley

Fodder Crops:
- Sunflowers with Peas, Barley with Sweet Clover, Buckwheat (Annual)
- Lucerne, Red Clover (Perennial)

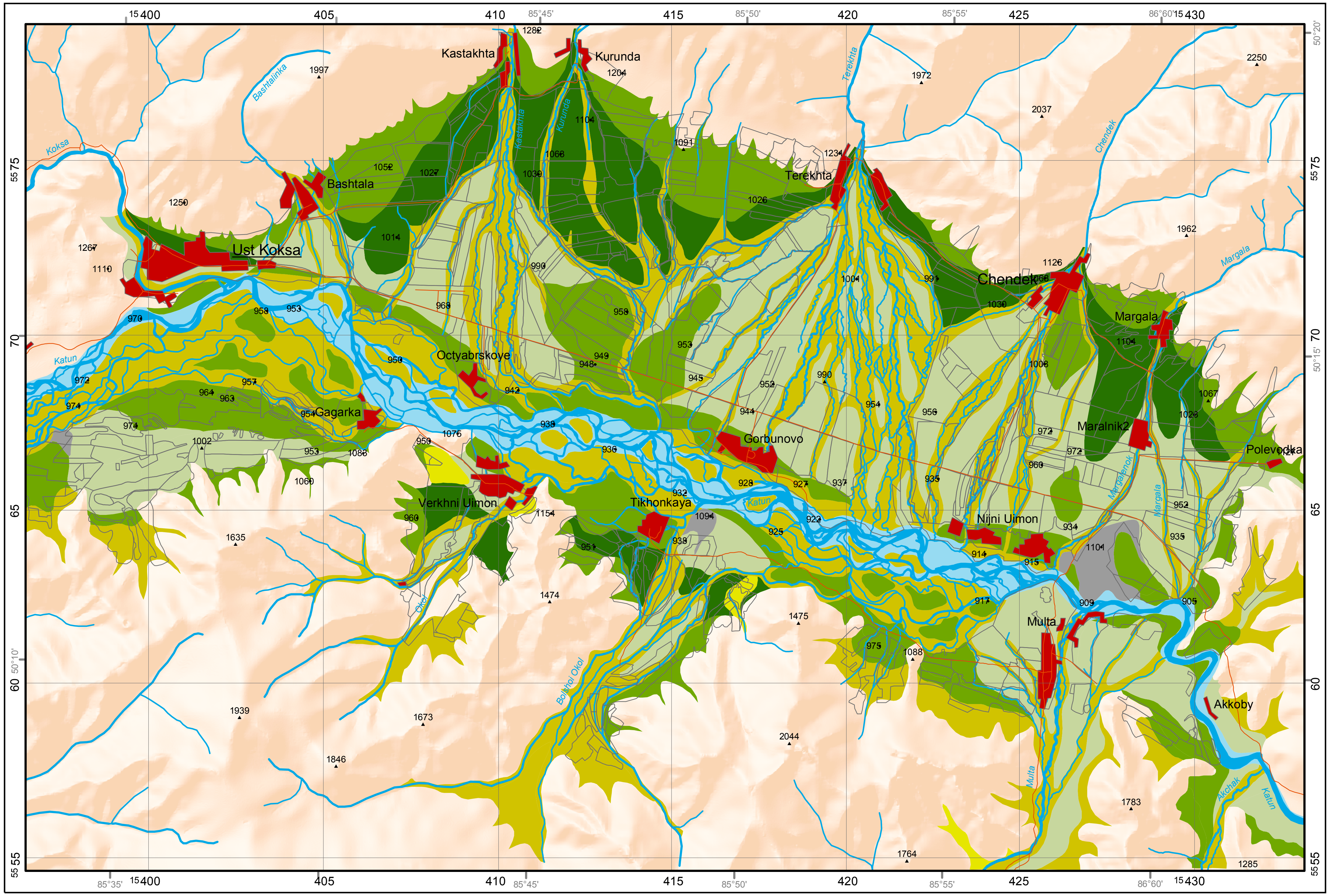
- Potatoes
- Meadow Vegetation
- Meadow and Forest Vegetation
- Not Cultivated Lands

Non - Soil Formations
- Recent River Deposits
- Hardrock Outcrop

Topography
- Settlement
- Road
- Field Boundary
- 975 Elevation Point [m]
- 1613 Peak [m]
- River

TECHNISCHE UNIVERSITÄT DRESDEN

Map A6

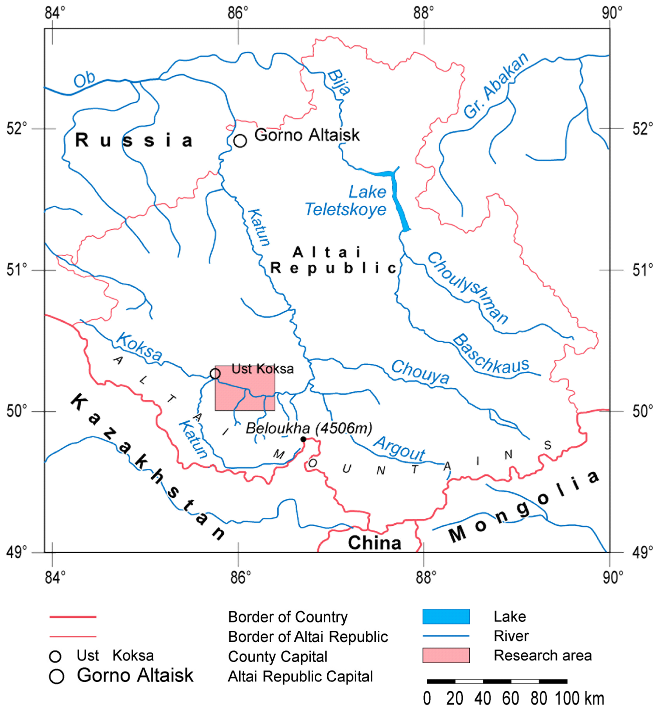


Uimon Basin
Altai Repubic

South Siberia, Russia

Land Suitability Map for Summer Wheat Based on the Weighted Means Approach

km
0 2 4 6



Provision of relief information:
Ust Koksa Landuse Committee (Altai Republic, Russia) and DEM from ALTAI 200 (Institute for Cartography, Dresden University of Technology, Germany)

Projection: Gauss-Krueger
Ellipsoid: Krassovsky
Datum: Pulkowo 42/83

Author:
K. Kelgenbaeva (2007)
(Institute for Cartography,
Dresden University of Technology, Germany)

Legend

Suitability Class (SI)

- NS
- S4
- S3
- S2
- S1

Non - Soil Formations

- Recent River Deposits
- Hardrock Outcrop

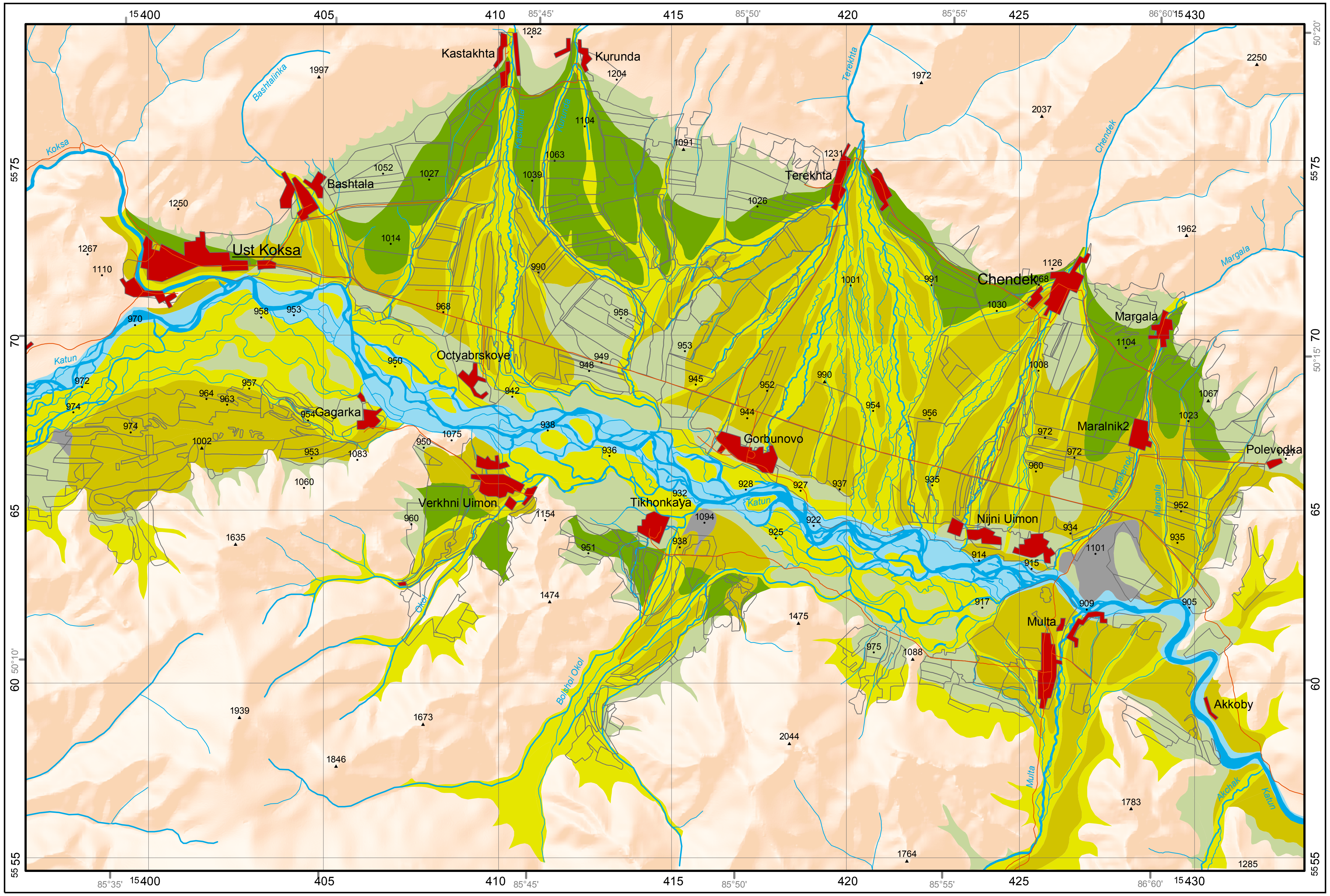
NS - No Suitability
S4 - Marginal Suitability
S3 - Moderate Suitability
S2 - Good Suitability
S1 - High Suitability

Topography

- Settlement
- Road
- Field Boundary
- 975 Elevation Point [m]
- 1613 Peak [m]
- River

TECHNISCHE UNIVERSITÄT DRESDEN

Map B1



Uimon Basin
Altai Repubic

South Siberia, Russia

Land Suitability for Sunflowers Based on the Weighted Means Approach

0 2 4 6 km

Provision of relief information:
Ust Koksa Landuse Committee (Altai Republic, Russia) and DEM from ALTAI 200 (Institute for Cartography, Dresden University of Technology, Germany)

Projection: Gauss-Krueger
Ellipsoid: Krassovsky
Datum: Pulkowo 42/83

Author:
K. Kelgenbaeva (2007)
(Institute for Cartography, Dresden University of Technology, Germany)

Legend

Suitability Class (SI)

- NS
- S4
- S3
- S2
- S1

Non - Soil Formations

- Recent River Deposits
- Hardrock Outcrop

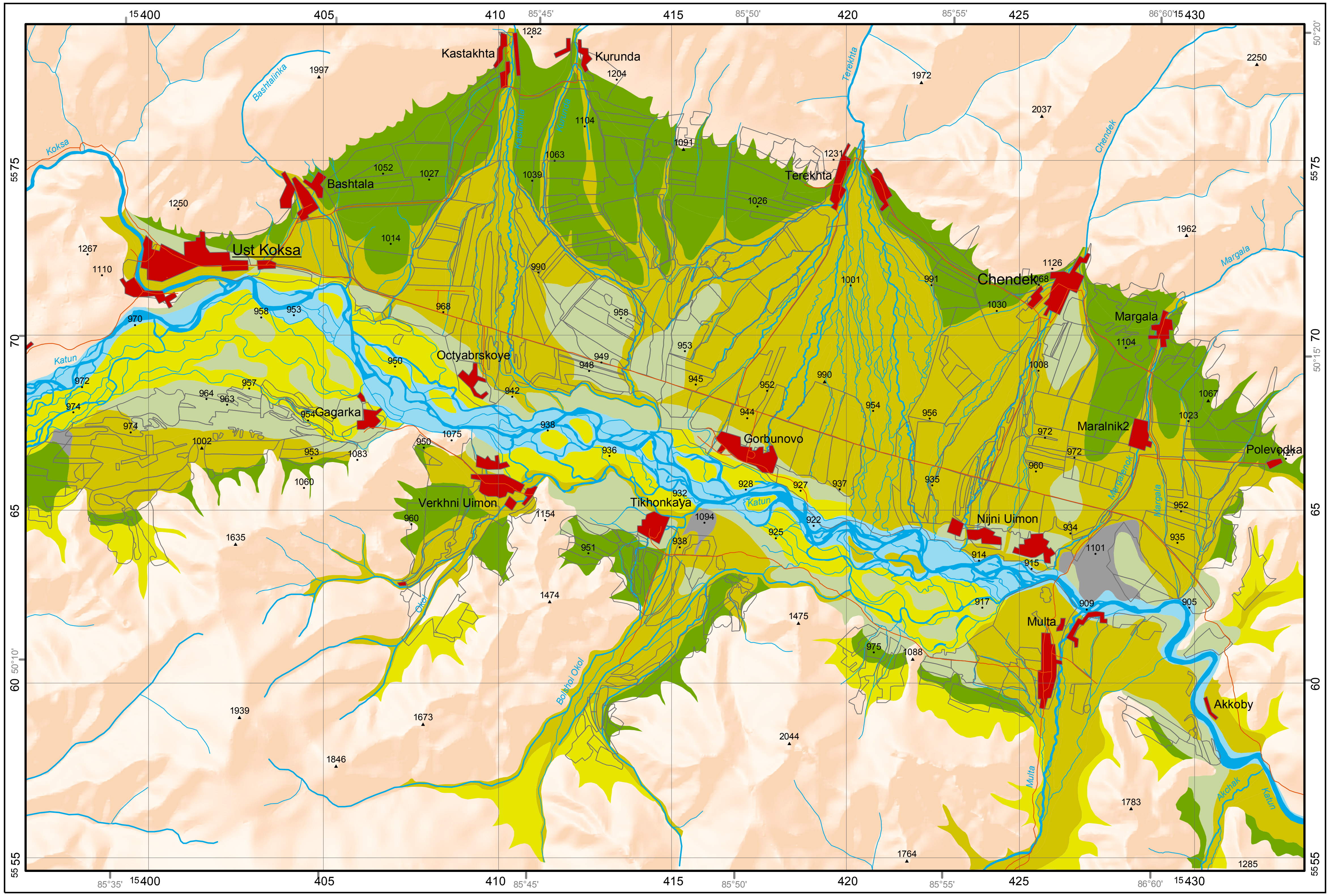
NS - No Suitability
S4 - Marginal Suitability
S3 - Moderate Suitability
S2 - Good Suitability
S1 - High Suitability

Topography

- Settlement
- Road
- Field Boundary
- 975 Elevation Point [m]
- 1613 Peak [m]
- River

TECHNISCHE UNIVERSITÄT DRESDEN

Map B2



Uimon Basin
Altai Repubic

South Siberia, Russia

Land Suitability for Potatoes Based on the Weighted Means Approach

Border of Country
Border of Altai Republic
Ust Koksa — County Capital
Gorno Altaisk — Altai Republic Capital
Lake
River
Research area
0 20 40 60 80 100 km

Provision of relief information:
Ust Koksa Landuse Committee (Altai Republic, Russia) and
DEM from ALTAI 200 (Institute for Cartography,
Dresden University of Technology, Germany)

Projection: Gauss-Krueger
Ellipsoid: Krassovsky
Datum: Pulkowo 42/83

Author:
K. Kelgenbaeva (2007)
(Institute for Cartography,
Dresden University of Technology, Germany)

Legend

Suitability Class (SI)

- NS
- S4
- S3
- S2
- S1

Non - Soil Formations

- Recent River Deposits
- Hardrock Outcrop

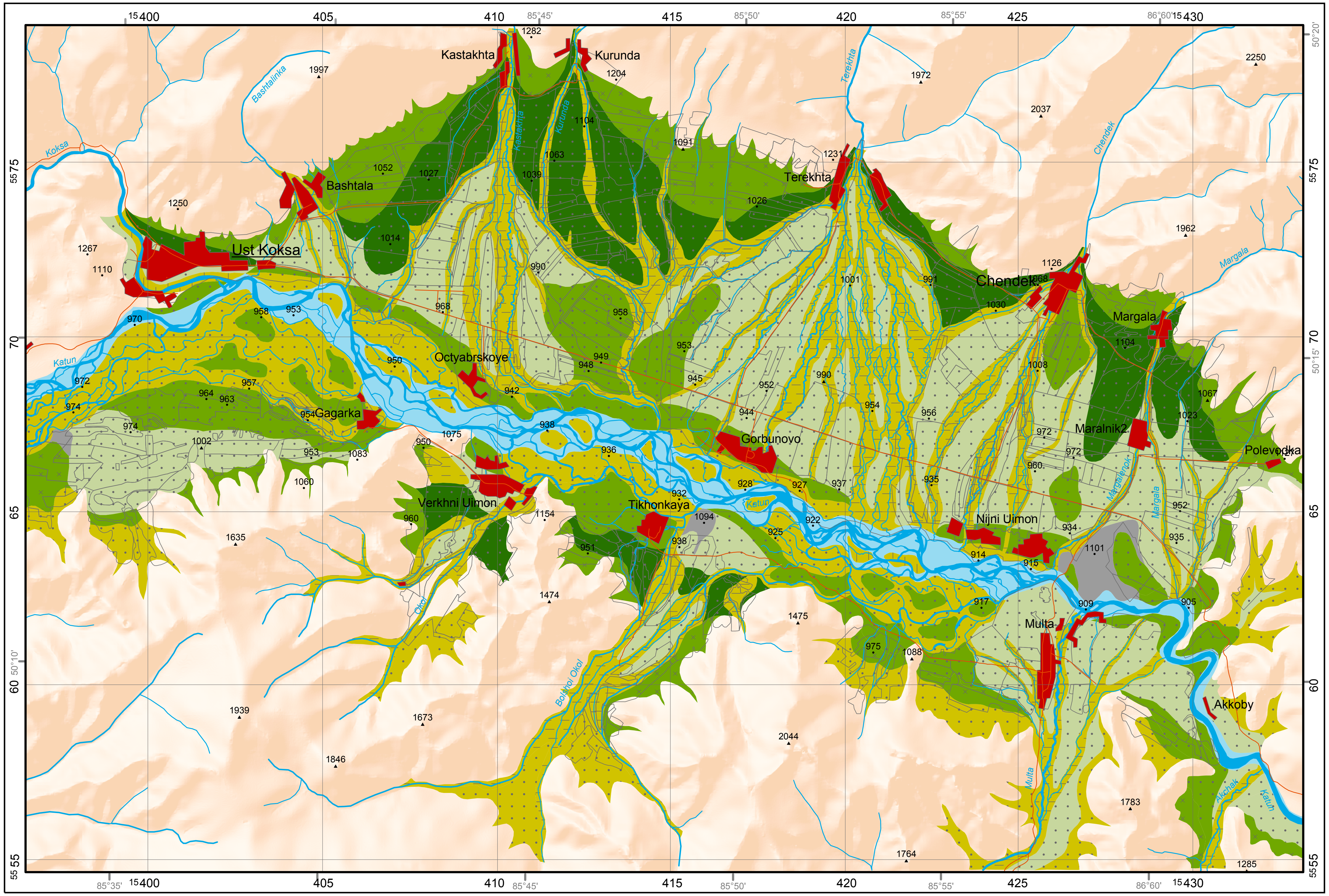
NS - No Suitability
S4 - Marginal Suitability
S3 - Moderate Suitability
S2 - Good Suitability
S1 - High Suitability

Topography

- Settlement
- Road
- Field Boundary
- 975 Elevation Point [m]
- 1613 Peak [m]
- River

TECHNISCHE UNIVERSITÄT DRESDEN

Map B3



Uimon Basin
Altai Republic

South Siberia, Russia

Combined Land Suitability for Summer Wheat, Sunflowers and Potatoes Based on the Weighted Means Approach

Provision of relief information:
Ust Koksa Landuse Committee (Altai Republic, Russia) and DEM from ALTAI 200 (Institute for Cartography, Dresden University of Technology, Germany)

Projection: Gauss-Krueger
Ellipsoid: Krassovsky
Datum: Pulkowo 42/83

Author:
K. Kelgenbaeva (2007)
(Institute for Cartography,
Dresden University of Technology, Germany)

Legend

Suitability Class (SI)

- NS
- S4
- S3
- S2
- S1

Crop Suitability

- W
- S
- P
- W/S
- W/P
- S/P
- W/S/P

W - Summer Wheat
S - Sunflowers
P - Potatoes

Non - Soil Formations

- Recent River Deposits
- Hardrock Outcrop

NS - No Suitability
S4 - Marginal Suitability
S3 - Moderate Suitability
S2 - Good Suitability
S1 - High Suitability

Topography

- Settlement
- Road
- Field Boundary
- 975 Elevation Point [m]
- 1613 Peak [m]
- River

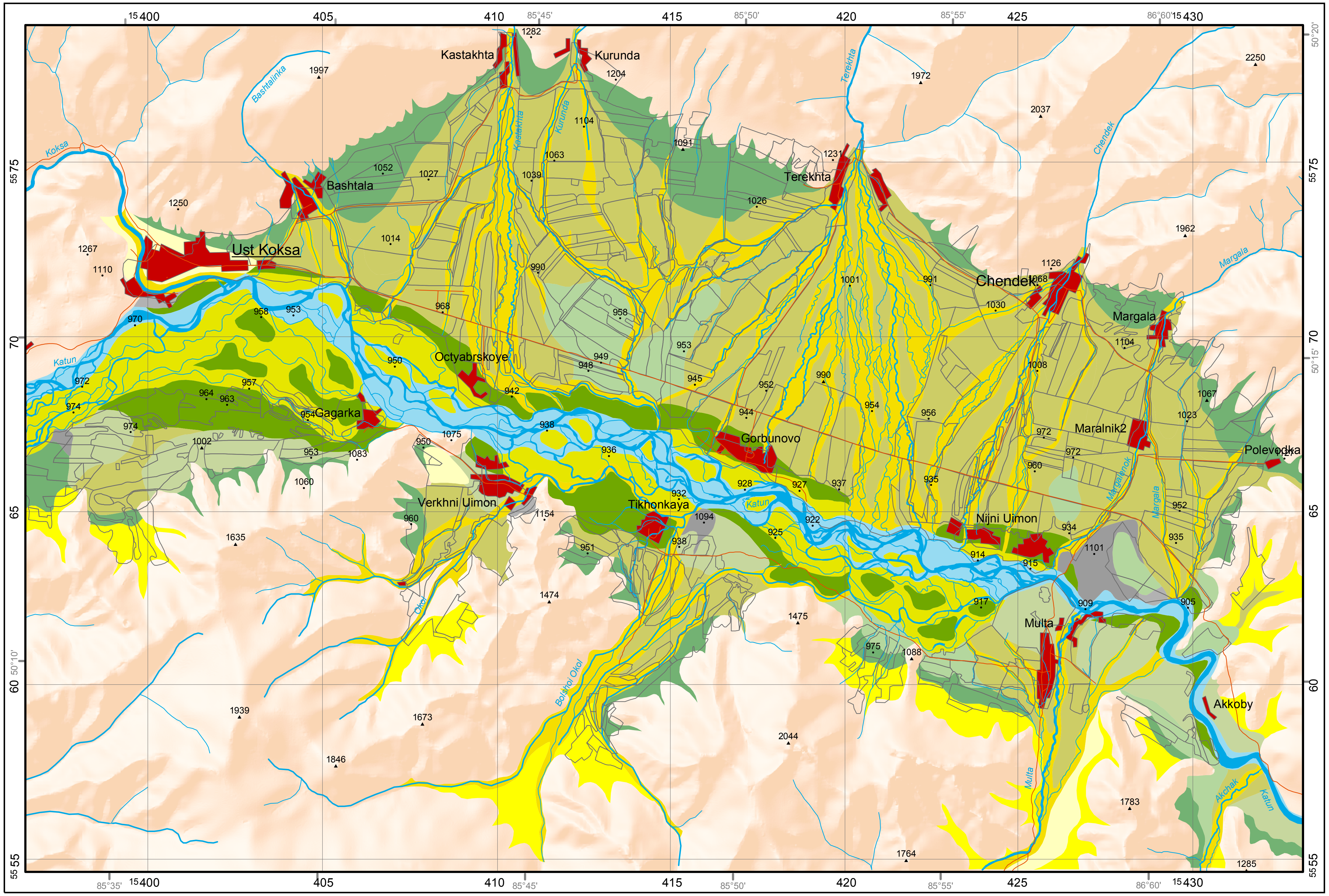
TECHNISCHE UNIVERSITÄT DRESDEN

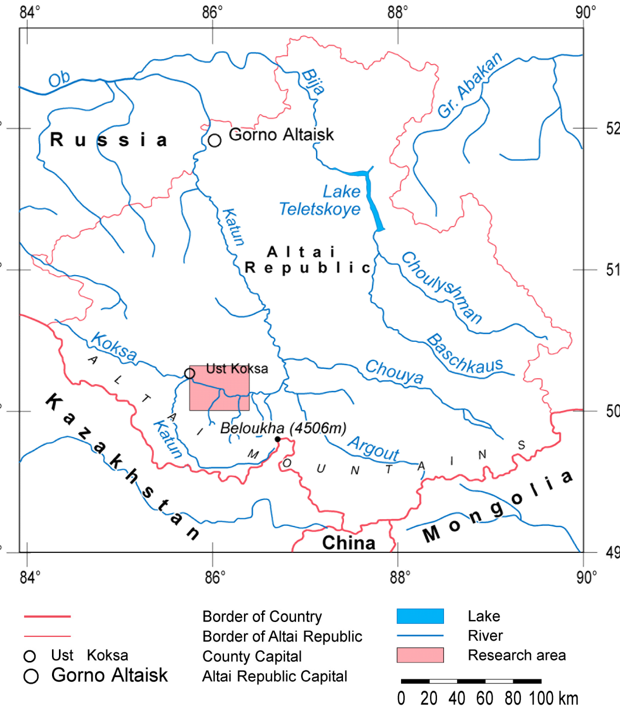
Map B4

Uimon Basin
Altai Republic

South Siberia, Russia

Land Suitability for Summer Wheat Based on Fuzzy Logic - SOM Approach





Provision of relief information:
Ust Koksa Landuse Committee (Altai Republic, Russia) and DEM from ALTAI 200 (Institute for Cartography, Dresden University of Technology, Germany)

Projection: Gauss-Krueger
Ellipsoid: Krassovsky
Datum: Pulkowo 42/83

Author:
K. Kelgenbaeva (2007)
(Institute for Cartography,
Dresden University of Technology, Germany)

Legend

Membership Function (MF)
Range from 0 (worse) to 1 (best)

NS	0.12
NS	0.14
NS	0.18
S4	0.21
S4	0.39
S3	0.42
S3	0.45
S2	0.60
S2	0.62

Non - Soil Formations

- Recent River Deposits
- Hardrock Outcrop

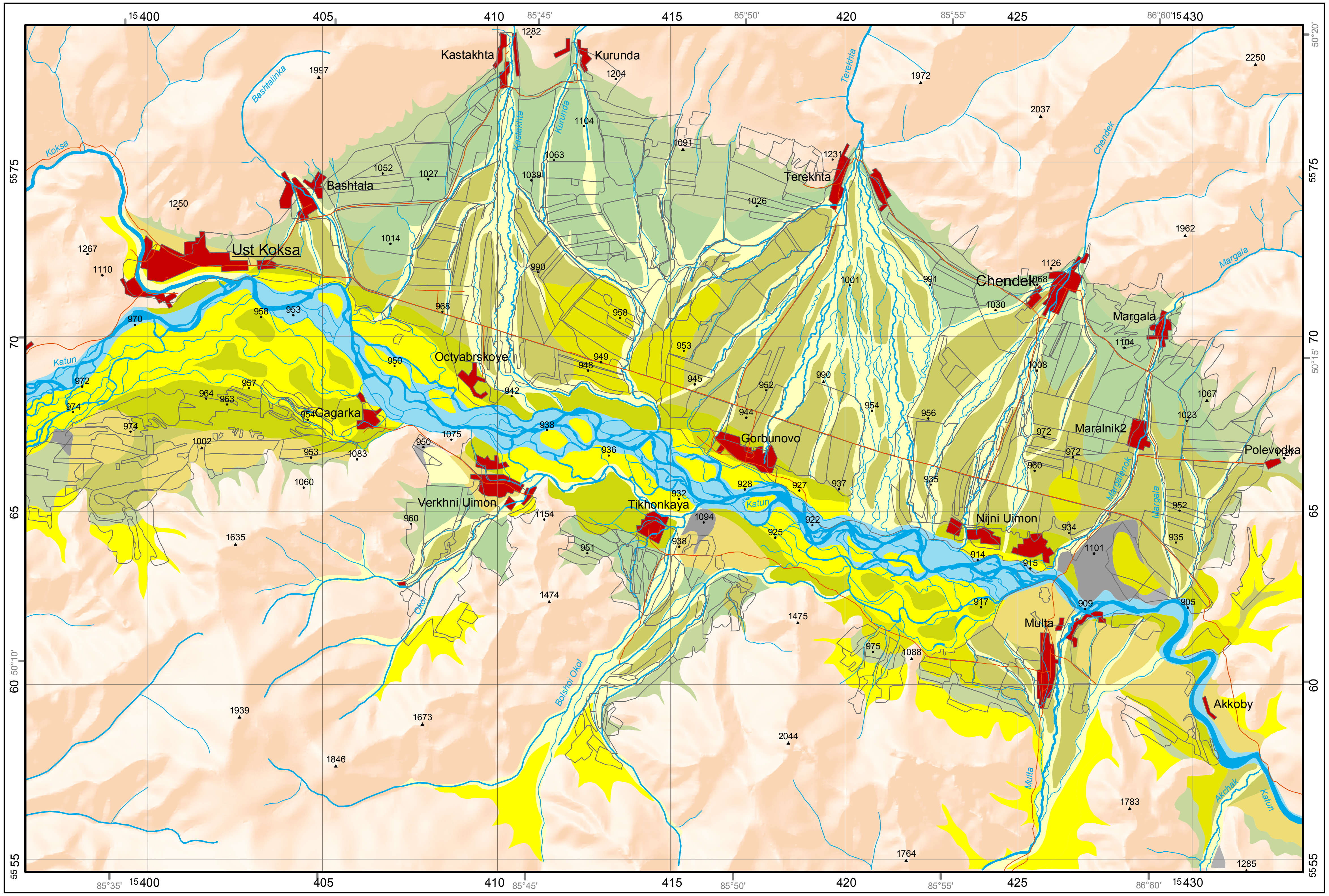
NS - No Suitability
S4 - Marginal Suitability
S3 - Moderate Suitability
S2 - Good Suitability
S1 - High Suitability

Topography

- Settlement
- Road
- Field Boundary
- 975 Elevation Point [m]
- 1613 Peak [m]
- River

TECHNISCHE UNIVERSITÄT DRESDEN

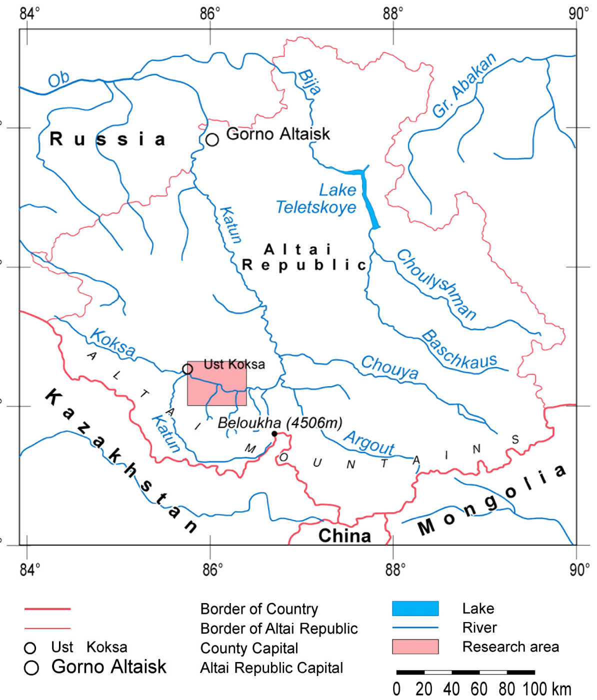
Map B5



Uimon Basin
Altai Repubic

South Siberia, Russia

Land Suitability Map for Sunflowers Based on Fuzzy Logic - SOM Approach



Provision of relief information:
Ust Koksa Landuse Committee (Altai Republic, Russia) and DEM from ALTAI 200 (Institute for Cartography, Dresden University of Technology, Germany)

Projection: Gauss-Krueger
Ellipsoid: Krassovsky
Datum: Pulkowo 42/83

Author:
K. Kelgenbaeva (2007)
(Institute for Cartography,
Dresden University of Technology, Germany)

Legend

Membership Function (MF)

Range from 0 (worse) to 1 (best)

NS	0.04
NS	0.05
NS	0.08
S4	0.22
S4	0.26
S4	0.38
S3	0.57
S3	0.58

Non - Soil Formations

- Recent River Deposits
- Hardrock Outcrop

NS - No Suitability
S4 - Marginal Suitability
S3 - Moderate Suitability
S2 - Good Suitability
S1 - High Suitability

Topography

- Settlement
- Road
- Field Boundary
- 975 Elevation Point [m]
- 1613 Peak [m]
- River

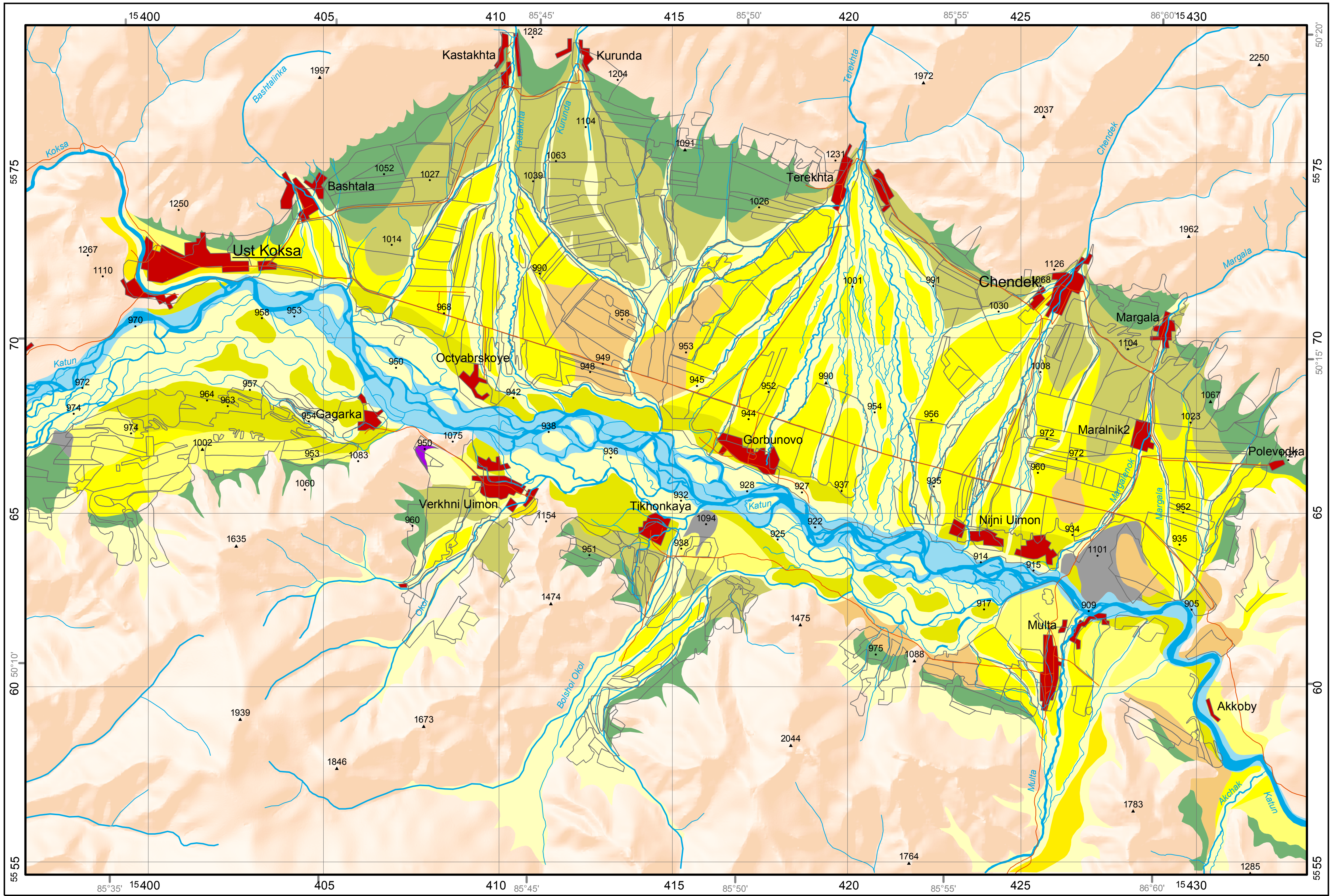
TECHNISCHE UNIVERSITÄT DRESDEN

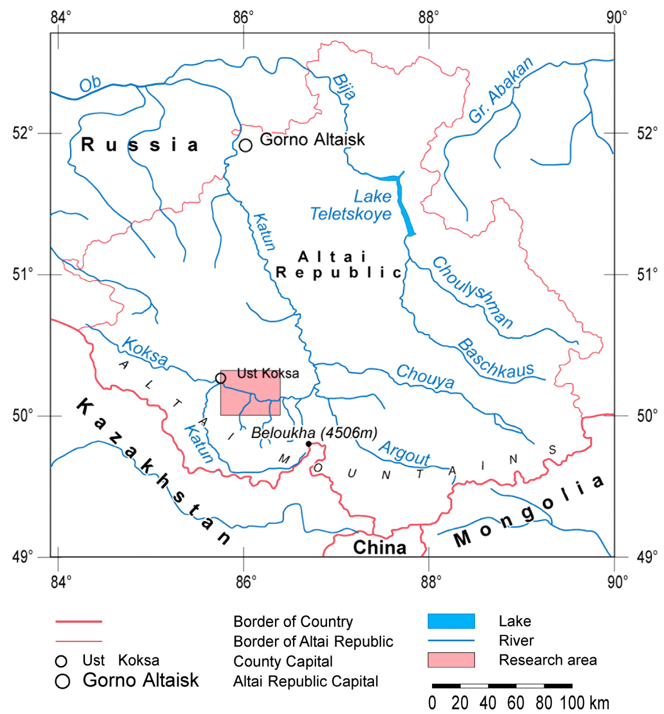
Map B6

Uimon Basin
Altai Republic

South Siberia, Russia

Land Suitability Map for Potatoes Based on Fuzzy Logic - SOM Approach





Legend

Membership Function (MF)
Range from 0 (worse) to 1 (best)

NS	0.04
NS	0.05
NS	0.15
NS	0.16
NS	0.19
S4	0.28
S4	0.29
S2	0.65

Non - Soil Formations

- Recent River Deposits
- Hardrock Outcrop

NS - No Suitability
S4 - Marginal Suitability
S3 - Moderate Suitability
S2 - Good Suitability
S1 - High Suitability

Topography

- Settlement
- Road
- Field Boundary
- 975 Elevation Point [m]
- 1613 Peak [m]
- River

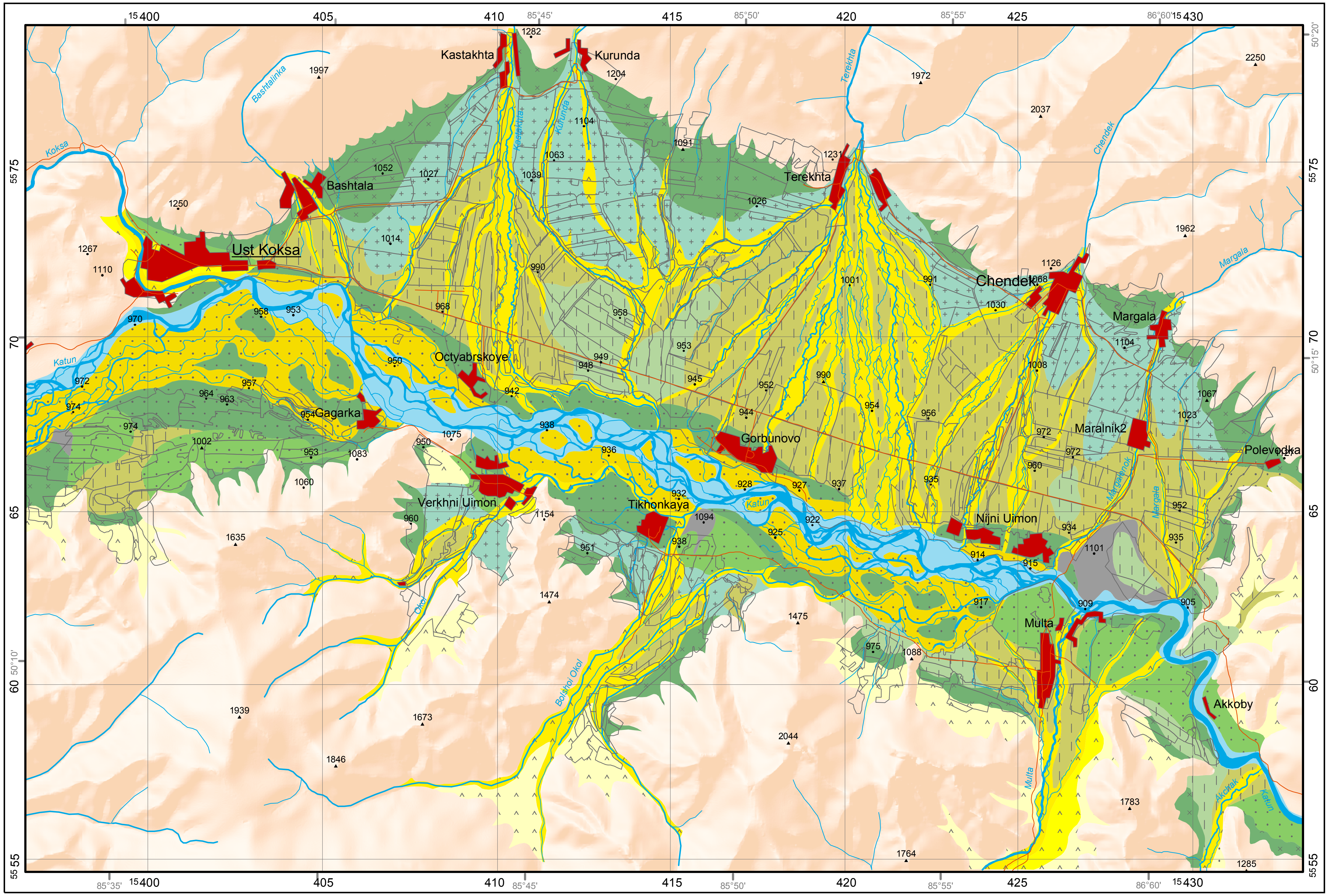
Provision of relief information:
Ust Koksa Landuse Committee (Altai Republic, Russia) and DEM from ALTAI 200 (Institute for Cartography, Dresden University of Technology, Germany)

Projection: Gauss-Krueger
Ellipsoid: Krassovsky
Datum: Pulkowo 42/83

Author:
K. Kelgenbaeva (2007)
(Institute for Cartography,
Dresden University of Technology, Germany)

TECHNISCHE UNIVERSITÄT DRESDEN

Map B7

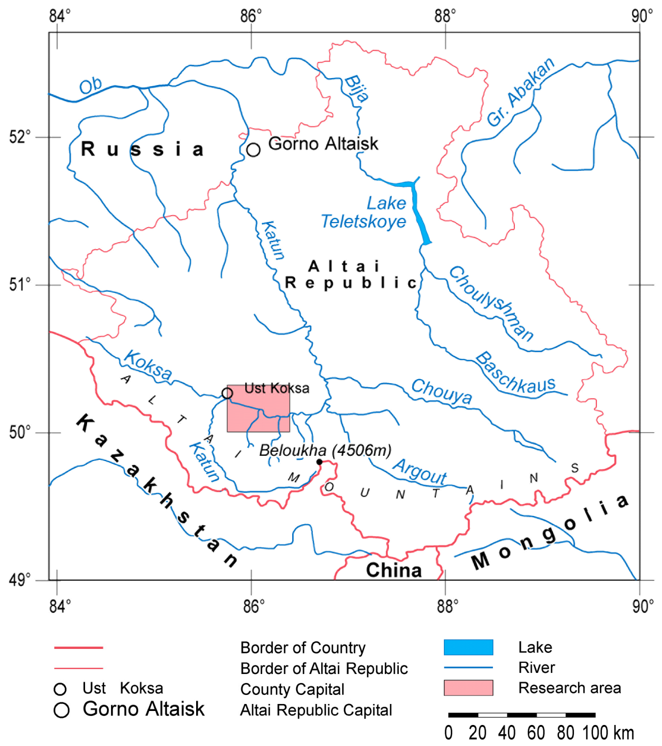


Uimon Basin
Altai Republic

South Siberia, Russia

Combined Land Suitability for Summer Wheat, Sunflowers and Potatoes Based on Fuzzy Logic - SOM Approach

0 2 4 6 km



Provision of relief information:
Ust Koksa Landuse Committee (Altai Republic, Russia) and DEM from ALTAI 200 (Institute for Cartography, Dresden University of Technology, Germany)

Projection: Gauss-Krueger
Ellipsoid: Krassovsky
Datum: Pulkowo 42/83

Author:
K. Kelgenbaeva (2007)
(Institute for Cartography,
Dresden University of Technology, Germany)

Legend

Membership Function (MF)
Range from 0 (worse) to 1 (best)

NS	0.12	S3	0.42
NS	0.14	S3	0.45
NS	0.18	S3	0.58
S4	0.21	S2	0.62
S4	0.39		

Crop Suitability

- W
- S
- P
- W/S
- W/P
- S/P
- W/S/P

W - Summer Wheat
S - Sunflowers
P - Potatoes

Non - Soil Formations

- Recent River Deposits
- Hardrock Outcrop

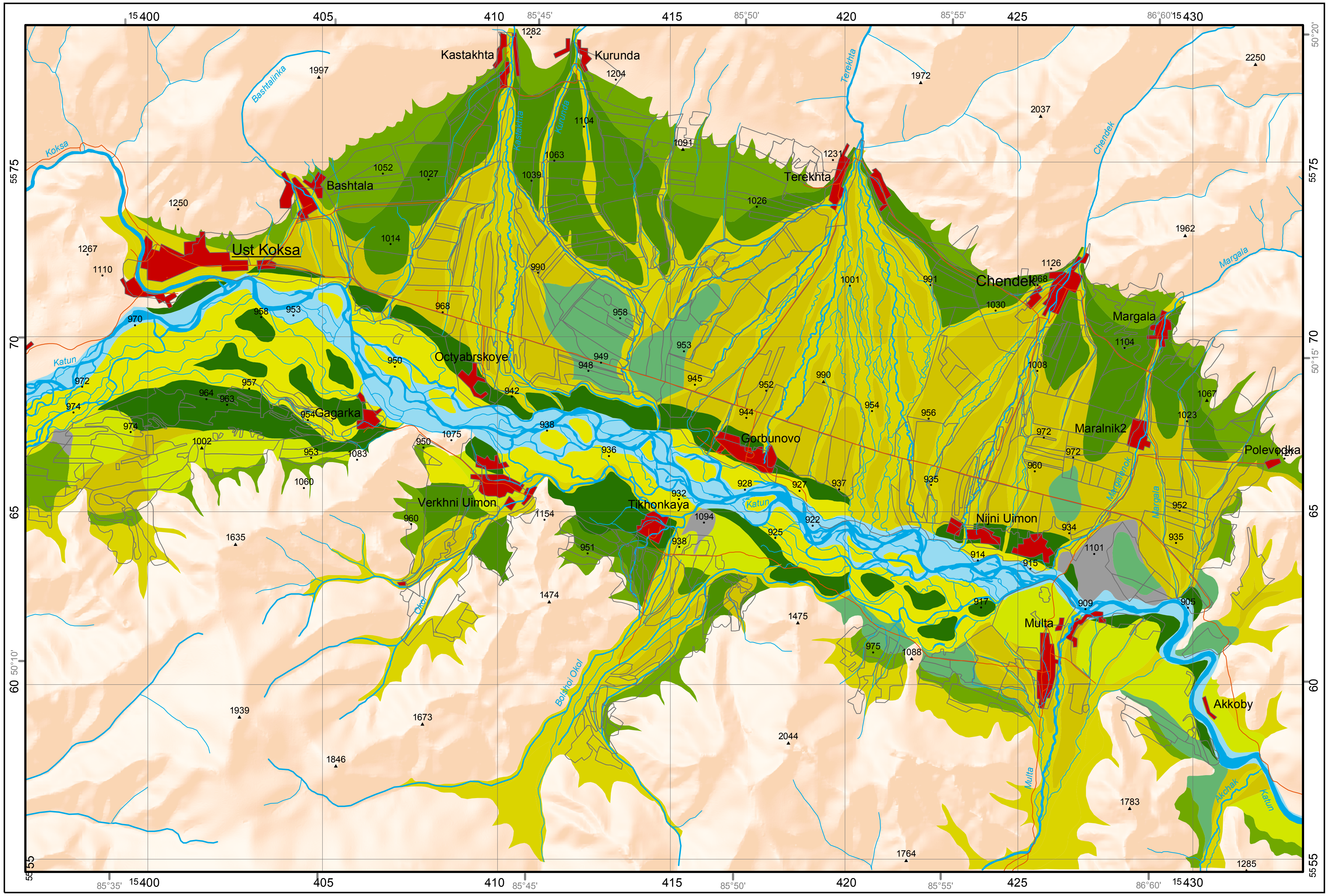
NS - No Suitability
S4 - Marginal Suitability
S3 - Moderate Suitability
S2 - Good Suitability
S1 - High Suitability

Topography

- Settlement
- Road
- Field Boundary
- 975 Elevation Point [m]
- 1613 Peak [m]
- River

TECHNISCHE UNIVERSITÄT DRESDEN

Map B8

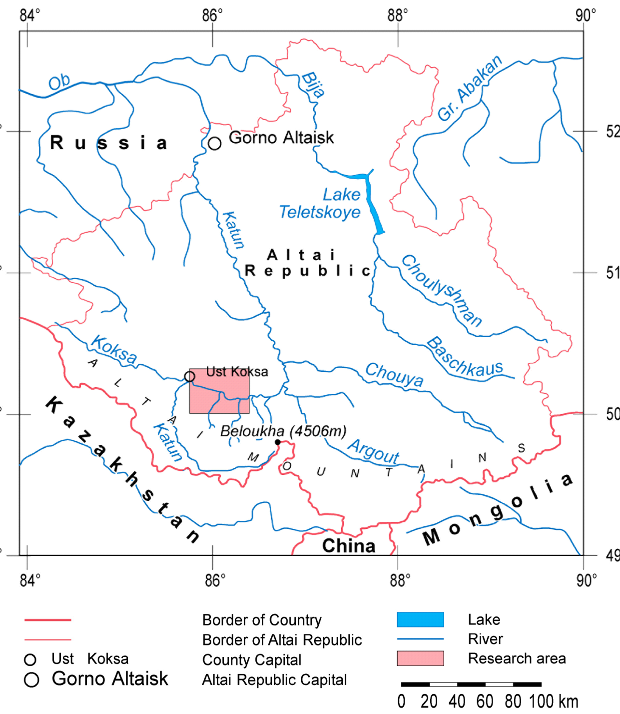


Uimon Basin
Altai Repubic

South Siberia, Russia

Land Suitability for Summer Wheat Based on Fuzzy Logic GMF Approach

0 2 4 6 km



Provision of relief information:
Ust Koksa Landuse Committee (Altai Republic, Russia) and DEM from ALTAI 200 (Institute for Cartography, Dresden University of Technology, Germany)

Projection: Gauss-Krueger
Ellipsoid: Krassovsky
Datum: Pulkowo 42/83

Author:
K. Kelgenbaeva (2007)
(Institute for Cartography,
Dresden University of Technology, Germany)

Legend

Membership Function (MF)
Range from 0 (worse) to 1 (best)

S4 - NS	0.96 - 1.0
S4 - NS	0.99 - 1.0
NS - S4	0.94 - 0.98
S3 - S4	0.96 - 1.0
S1 - S2	0.95 - 0.98
S1 - S2	0.98 - 1.0
S2 - S1	0.98 - 0.99
S2 - S1	0.99 - 1.0

Non - Soil Formations

- Recent River Deposits
- Hardrock Outcrop

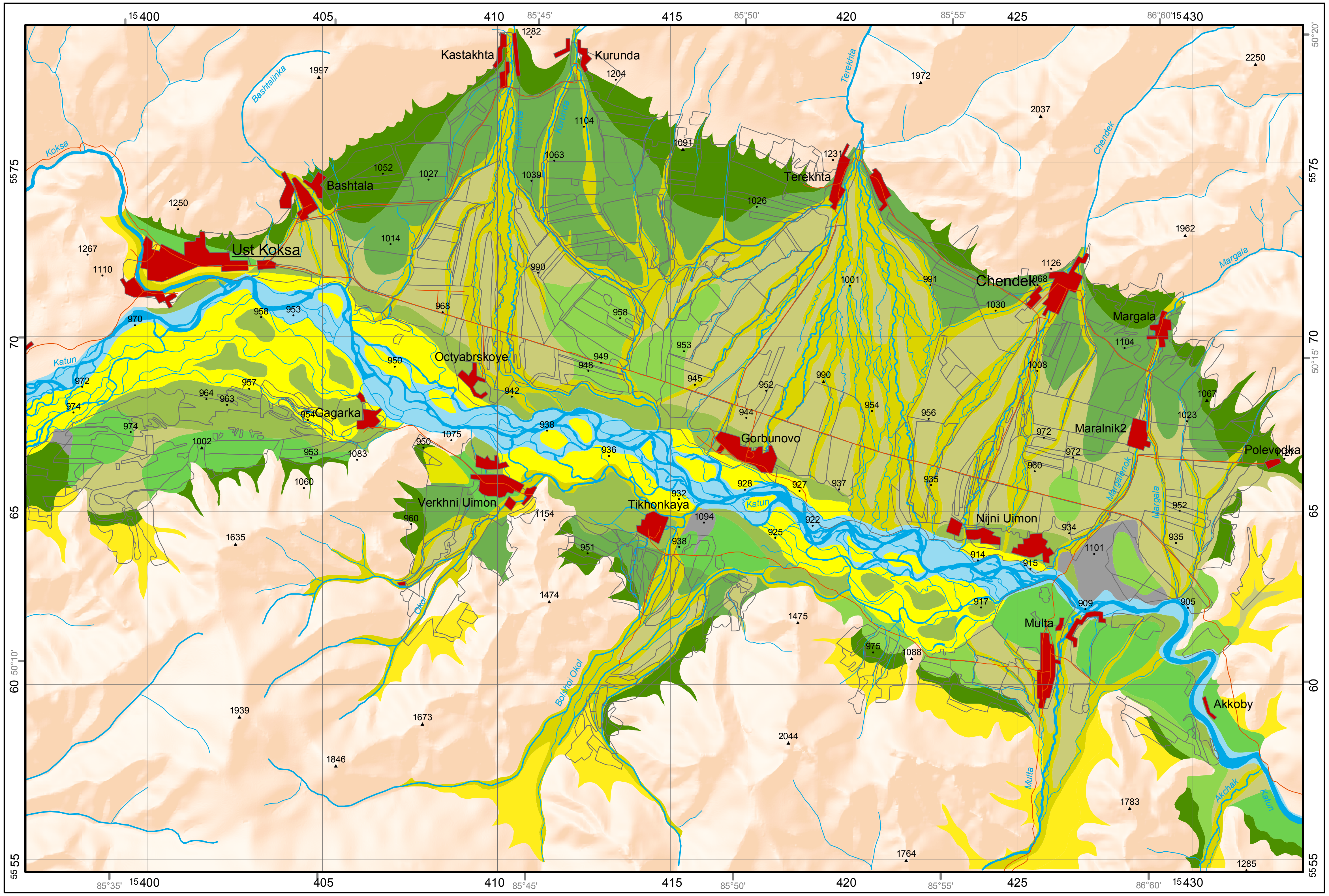
NS - No Suitability
S4 - Marginal Suitability
S3 - Moderate Suitability
S2 - Good Suitability
S1 - High Suitability

Topography

- Settlement
- Road
- Field Boundary
- 975 Elevation Point [m]
- 1613 Peak [m]
- River

TECHNISCHE UNIVERSITÄT DRESDEN

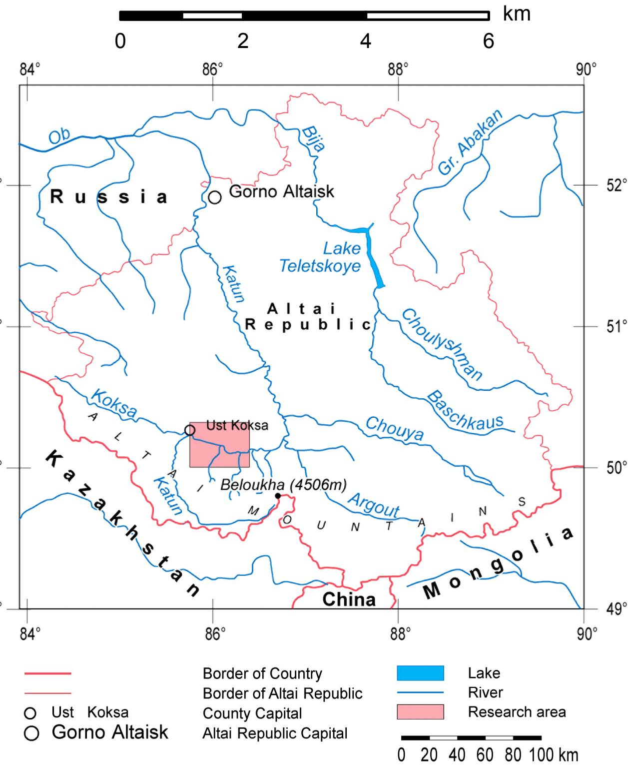
Map B9



Uimon Basin
Altai Republic

South Siberia, Russia

Land Suitability for Sunflowers Based on Fuzzy Logic GMF Approach



Provision of relief information:
Ust Koksa Landuse Committee (Altai Republic, Russia) and DEM from ALTAI 200 (Institute for Cartography, Dresden University of Technology, Germany)

Projection: Gauss-Krueger
Ellipsoid: Krassovsky
Datum: Pulkowo 42/83

Author:
K. Kelgenbaeva (2007)
(Institute for Cartography,
Dresden University of Technology, Germany)

Legend

Membership Function (MF)

Range from 0 (worse) to 1 (best)

S4 - NS	0.95 - 0.98	S2 - S3	0.98 - 0.99
S4 - NS	0.96 - 1.0	S3 - S2	0.93 - 0.95
S4 - NS	0.99 - 1.0	S3 - S2	0.93 - 0.99
S4	0.95 - 0.98	S3 - S2	0.94 - 0.98
S4 - S3	0.97 - 0.98	S2 - S1	0.98 - 1.0

Non - Soil Formations

Recent River Deposits

Hardrock Outcrop

NS - No Suitability
S4 - Marginal Suitability
S3 - Moderate Suitability
S2 - Good Suitability
S1 - High Suitability

Topography

Settlement

Road

Field Boundary

975 Elevation Point [m]

1613 Peak [m]

River

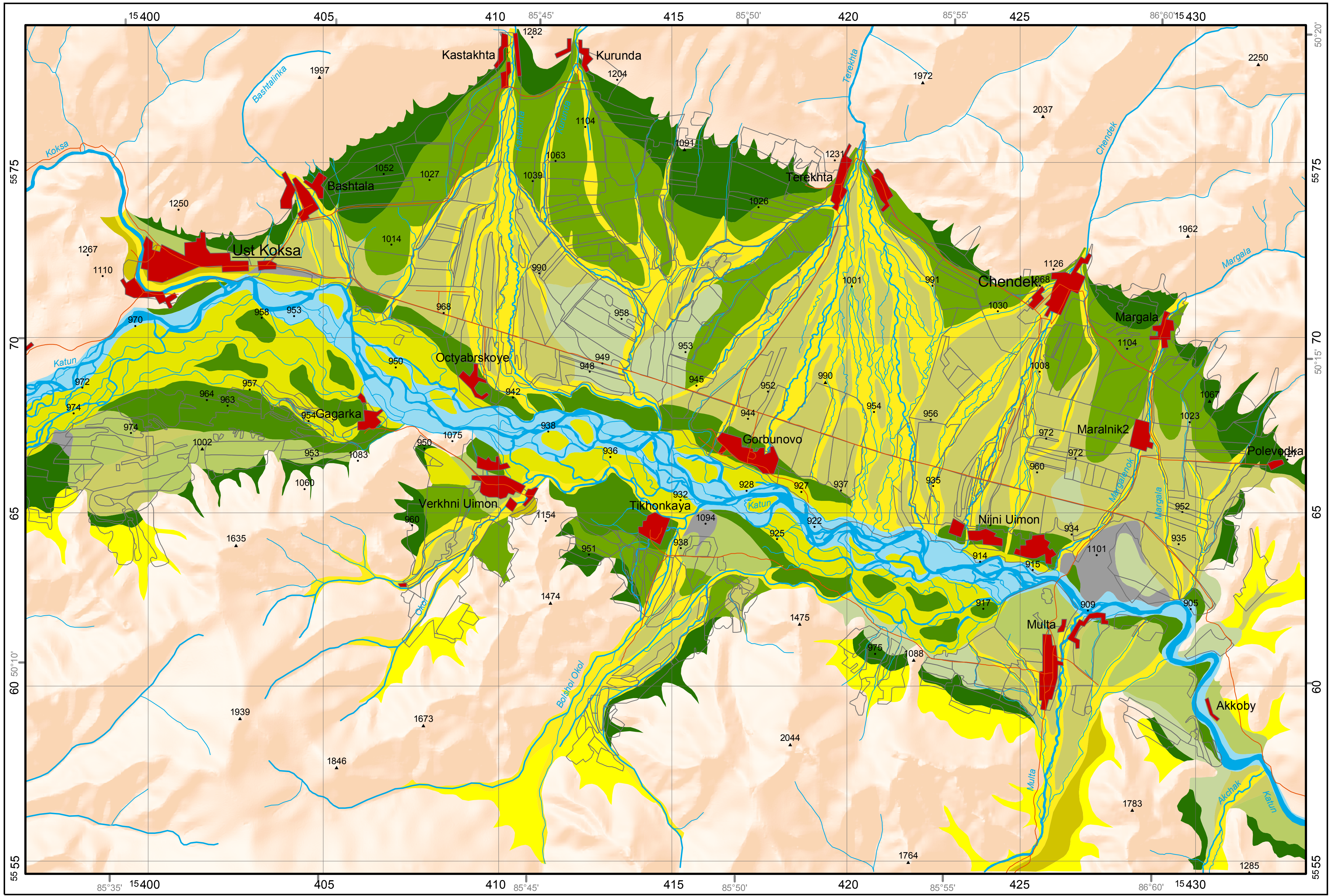
TECHNISCHE UNIVERSITÄT DRESDEN

Map B10

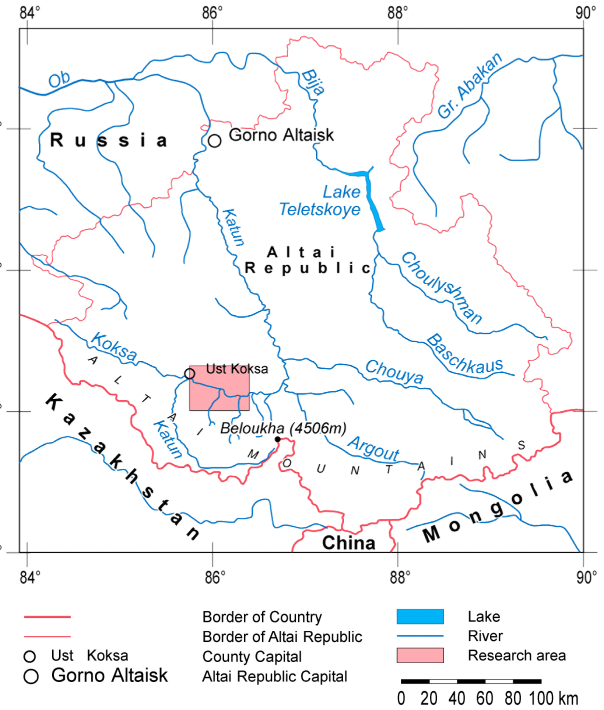
Uimon Basin
Altai Republic

South Siberia, Russia

Land Suitability for Potatoes Based on Fuzzy Logic GMF Approach



0 2 4 6 km



Provision of relief information:
Ust Koksa Landuse Committee (Altai Republic, Russia) and DEM from ALTAI 200 (Institute for Cartography, Dresden University of Technology, Germany)

Projection: Gauss-Krueger
Ellipsoid: Krassovsky
Datum: Pulkowo 42/83

Author:
K. Kelgenbaeva (2007)
(Institute for Cartography,
Dresden University of Technology, Germany)

Legend

Membership Function (MF)
Range from 0 (worse) to 1 (best)

S4 - NS	0.91 - 1.0	S4 - S3	0.96 - 0.97
S4 - NS	0.95 - 0.98	S3	0.95 - 0.97
S4 - NS	0.97 - 0.98	S2	0.93 - 0.95
NS - S4	0.92 - 0.99	S2 - S1	0.98 - 0.99
S4	0.94 - 0.97	S2 - S1	0.98 - 1.0

Non - Soil Formations

Recent River Deposits
Hardrock Outcrop

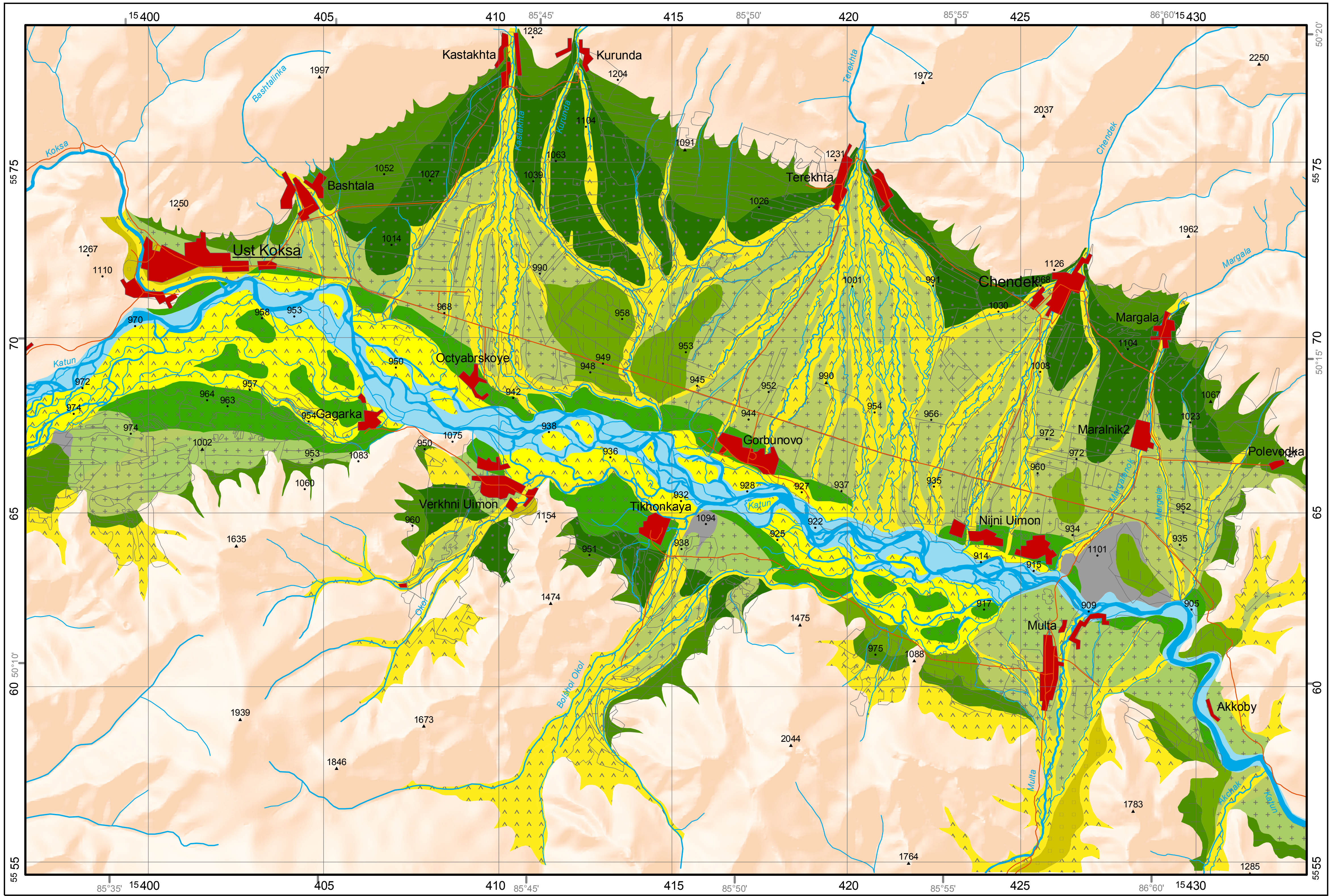
NS - No Suitability
S4 - Marginal Suitability
S3 - Moderate Suitability
S2 - Good Suitability
S1 - High Suitability

Topography

Settlement
Road
Field Boundary
975 Elevation Point [m]
1613 Peak [m]
River

TECHNISCHE UNIVERSITÄT DRESDEN

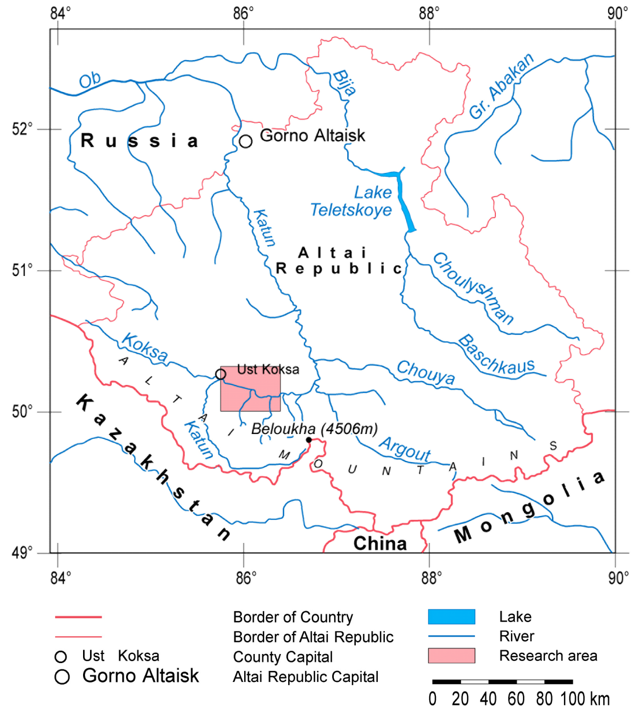
Map B11



Uimon Basin
Altai Republic

South Siberia, Russia

Combined Land Suitability for Summer Wheat, Sunflowers and Potatoes Based on Fuzzy Logic GMF Approach



Provision of relief information:
Ust Koksa Landuse Committee (Altai Republic, Russia) and DEM from ALTAI 200 (Institute for Cartography, Dresden University of Technology, Germany)

Projection: Gauss-Krueger
Ellipsoid: Krassovsky
Datum: Pulkowo 42/83

Author:
K. Kelgenbaeva (2007)
(Institute for Cartography,
Dresden University of Technology, Germany)

Legend

Membership Function (MF)
Range from 0 (worse) to 1 (best)

Class	MF	Class	MF
S4 - NS	0.96 - 1.0	S2 - S1	0.98 - 1.0
S4 - NS	0.99 - 1.0	S2 - S1	0.98 - 0.99
NS - S4	0.92 - 0.99	S1 - S2	0.98 - 1.0
S4 - S3	0.97 - 0.98	S2 - S1	0.99 - 1.0
S3 - S2	0.93 - 0.99		

Crop Suitability

W, S, P, W/S, W/P, S/P, W/S/P

W - Summer Wheat
S - Sunflowers
P - Potatoes

Non - Soil Formations

Recent River Deposits
Hardrock Outcrop

NS - No Suitability
S4 - Marginal Suitability
S3 - Moderate Suitability
S2 - Good Suitability
S1 - High Suitability

Topography

Settlement
Road
Field Boundary
975 Elevation Point [m]
1613 Peak [m]
River

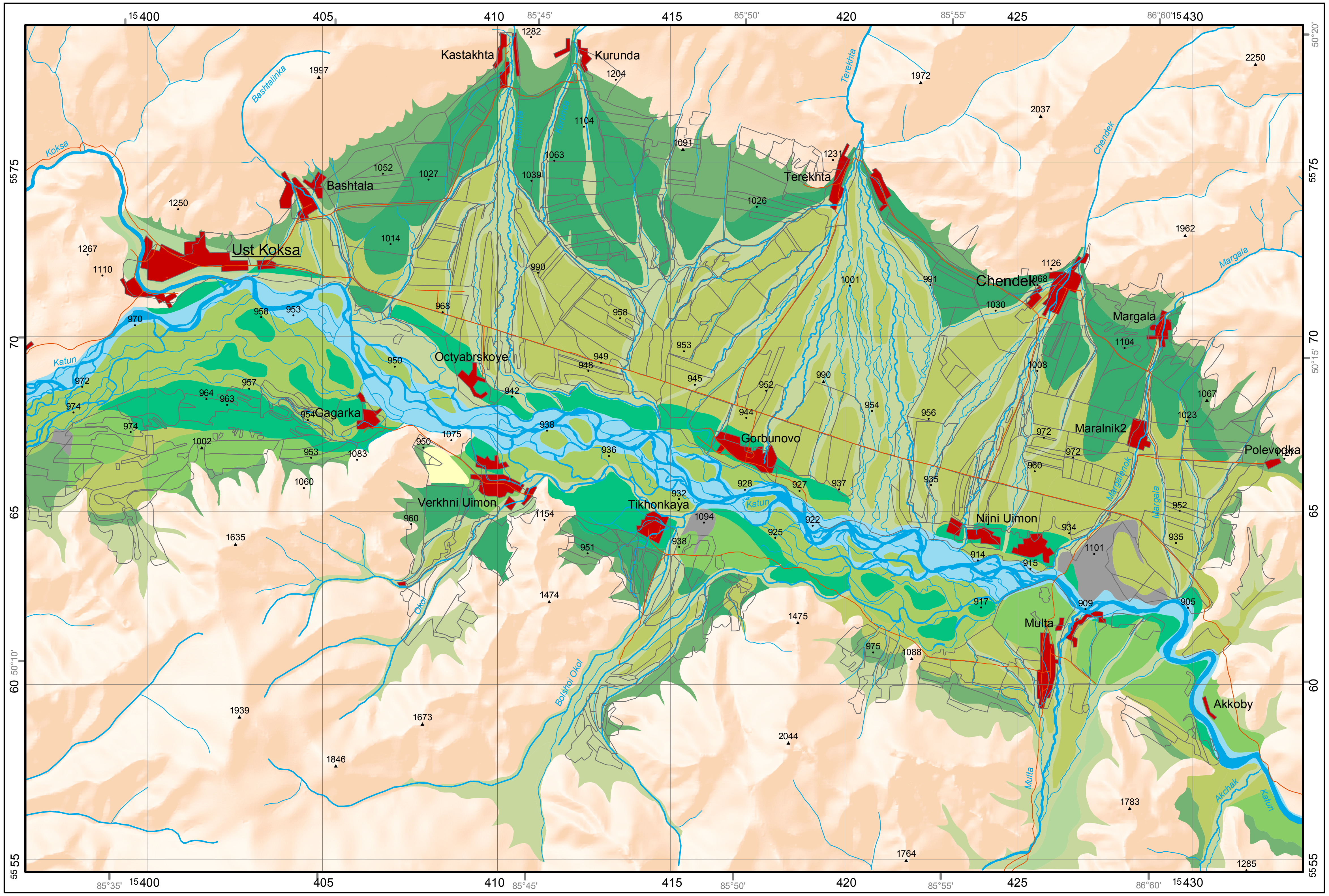
TECHNISCHE UNIVERSITÄT DRESDEN

Map B12

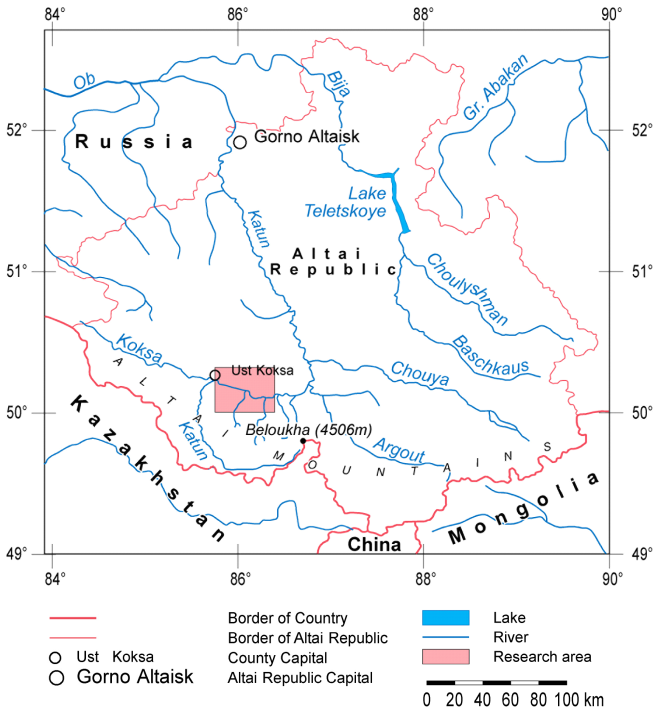
Uimon Basin
Altai Republic

South Siberia, Russia

Land Suitability for Summer Wheat Based on Fuzzy Set Theory - JMF Approach



0 2 4 6 km



Provision of relief information:
Ust Koksa Landuse Committee (Altai Republic, Russia) and DEM from ALTAI 200 (Institute for Cartography, Dresden University of Technology, Germany)

Projection: Gauss-Krueger
Ellipsoid: Krassovsky
Datum: Pulkowo 42/83

Author:
K. Kelgenbaeva (2007)
(Institute for Cartography, Dresden University of Technology, Germany)

Legend

Membership Function (MF)

Range from 0 (worse) to 1 (best)

NS	0.08
S3	0.53
S2	0.60
S2	0.65
S2	0.72
S2	0.76
S2	0.78
S1	0.81
S1	0.87

Non - Soil Formations

- Recent River Deposits
- Hardrock Outcrop

NS - No Suitability
S4 - Marginal Suitability
S3 - Moderate Suitability
S2 - Good Suitability
S1 - High Suitability

Topography

- Settlement
- Road
- Field Boundary
- 975 Elevation Point [m]
- 1613 Peak [m]
- River

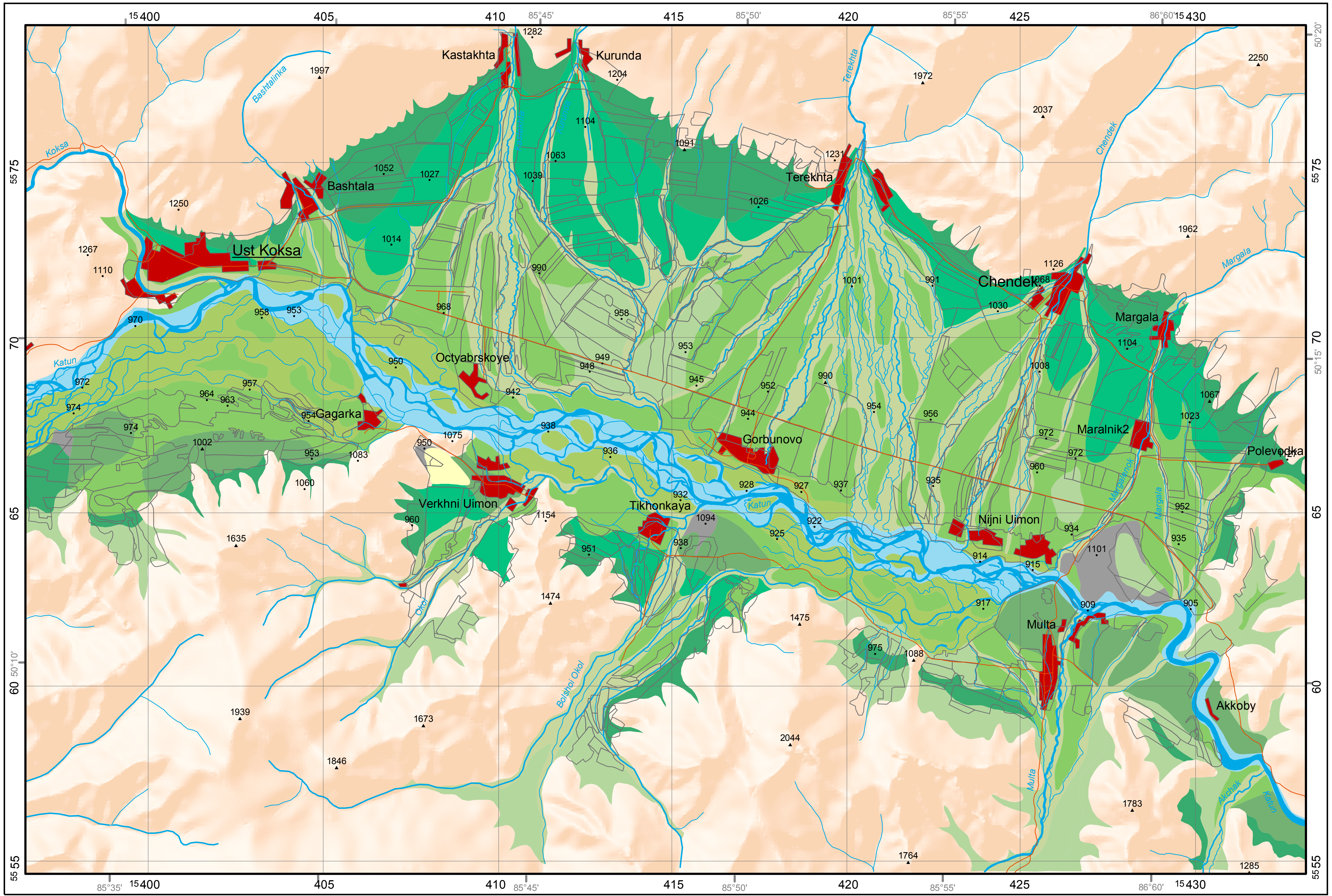
TECHNISCHE UNIVERSITÄT DRESDEN

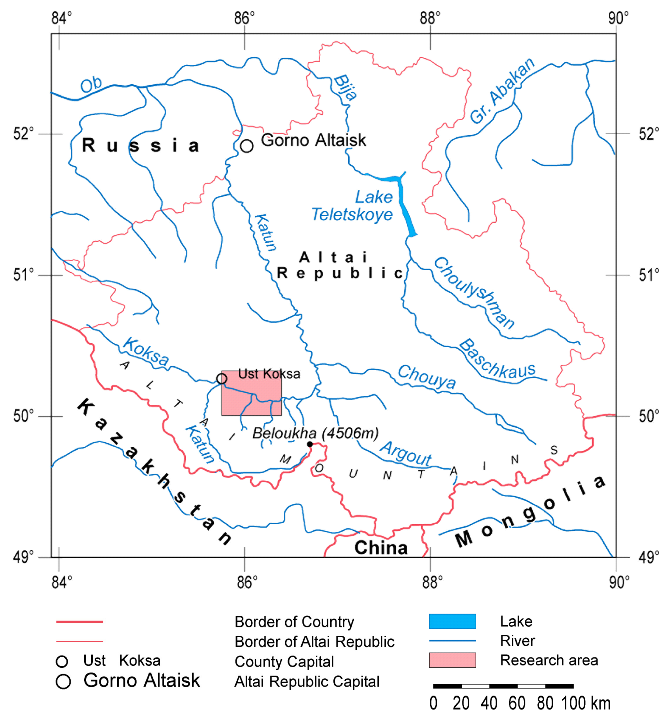
Map B13

Uimon Basin
Altai Republic

South Siberia, Russia

Land Suitability for Sunflowers Based on Fuzzy Set Theory - JMF Approach





Provision of relief information:
Ust Koksa Landuse Committee (Altai Republic, Russia) and DEM from ALTAI 200 (Institute for Cartography, Dresden University of Technology, Germany)

Projection: Gauss-Krueger
Ellipsoid: Krassovsky
Datum: Pulkowo 42/83

Author:
K. Kelgenbaeva (2007)
(Institute for Cartography,
Dresden University of Technology, Germany)

Legend

Membership Function (MF)
Range from 0 (worse) to 1 (best)

Class	MF	Class	MF
NS	0.11	S2	0.65
S3	0.46	S2	0.69
S3	0.49	S2	0.74
S3	0.53	S2	0.79

Non - Soil Formations

- Recent River Deposits
- Hardrock Outcrop

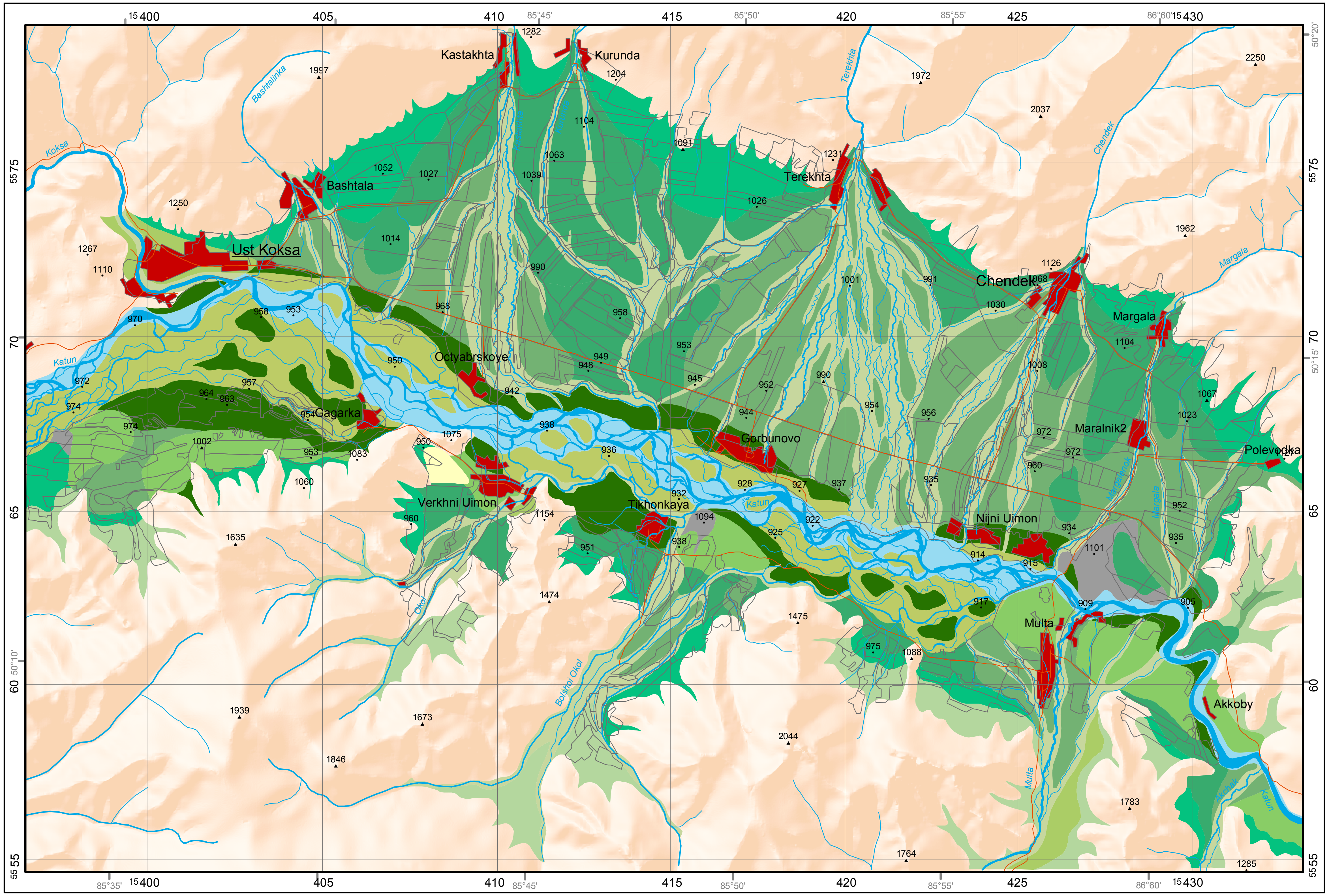
NS - No Suitability
S4 - Marginal Suitability
S3 - Moderate Suitability
S2 - Good Suitability
S1 - High Suitability

Topography

- Settlement
- Road
- Field Boundary
- 975 Elevation Point [m]
- 1613 Peak [m]
- River

TECHNISCHE UNIVERSITÄT DRESDEN

Map B14



Uimon Basin
Altai Republic

South Siberia, Russia

Land Suitability for Potatoes Based on the Fuzzy Set Theory - JMF Approach

Provision of relief information:
Ust Koksa Landuse Committee (Altai Republic, Russia) and DEM from ALTAI 200 (Institute for Cartography, Dresden University of Technology, Germany)

Projection: Gauss-Krueger
Ellipsoid: Krassovsky
Datum: Pulkowo 42/83

Author:
K. Kelgenbaeva (2007)
(Institute for Cartography,
Dresden University of Technology, Germany)

Legend

Membership Function (MF)
Range from 0 (worse) to 1 (best)

NS	0.05	S2	0.62
S3	0.42	S2	0.66
S3	0.43	S2	0.74
S3	0.50	S2	0.76
S3	0.52	S1	0.80

Non - Soil Formations

- Recent River Deposits
- Hardrock Outcrop

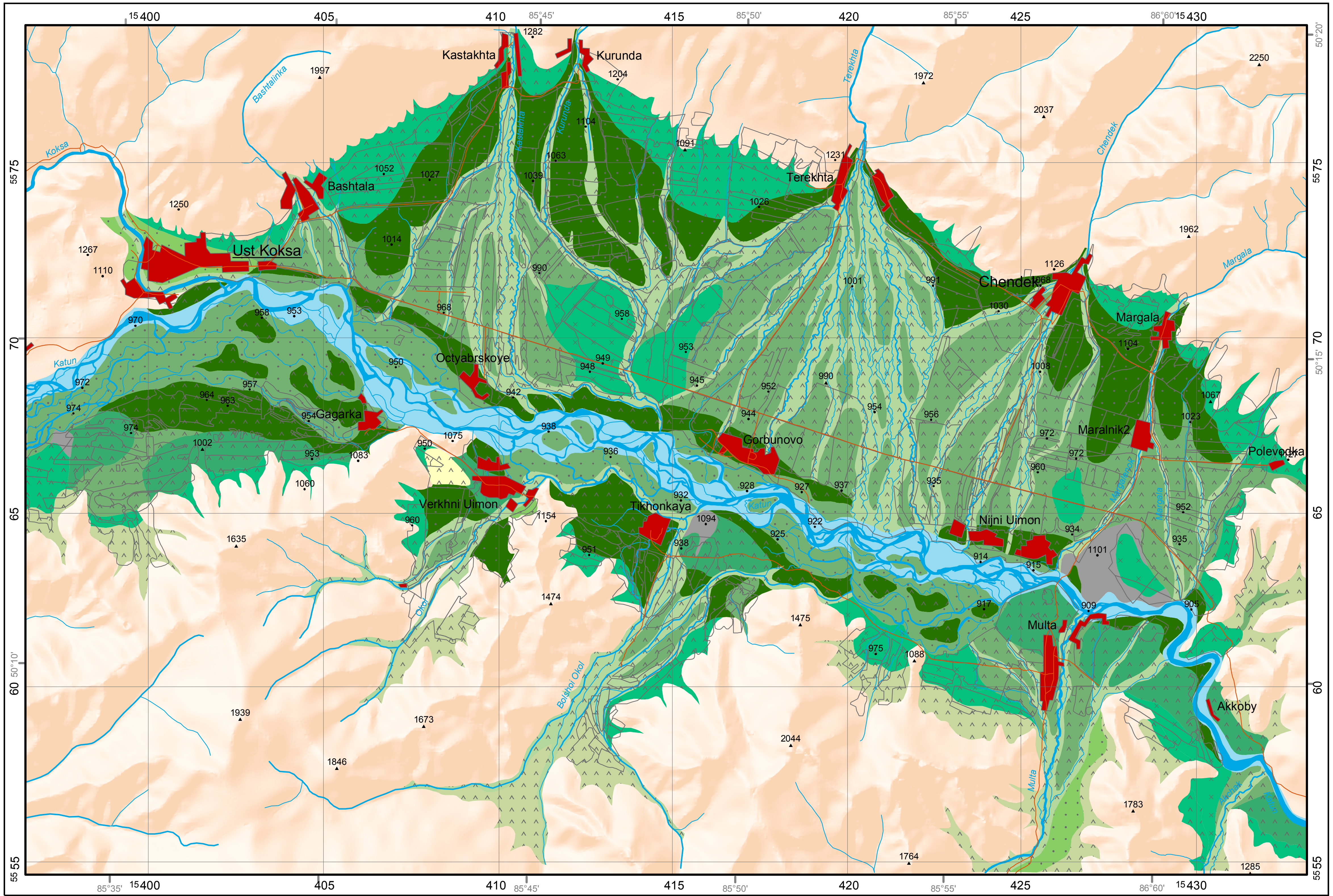
NS - No Suitability
S4 - Marginal Suitability
S3 - Moderate Suitability
S2 - Good Suitability
S1 - High Suitability

Topography

- Settlement
- Road
- Field Boundary
- 975 Elevation Point [m]
- 1613 Peak [m]
- River

TECHNISCHE UNIVERSITÄT DRESDEN

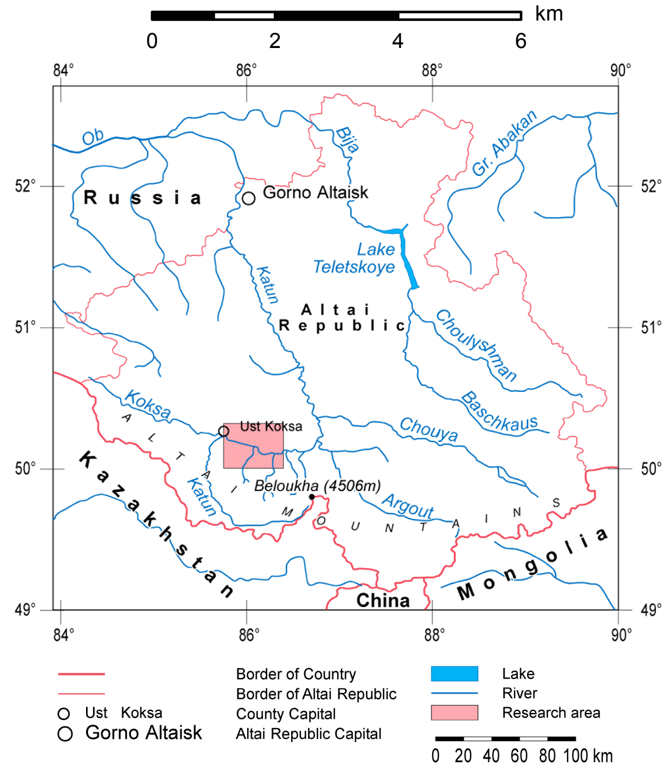
Map B15



Uimon Basin
Altai Republic

South Siberia, Russia

Combined Land Suitability for Summer Wheat, Sunflowers and Potatoes Based on Fuzzy Set Theory - JMF Approach



Provision of relief information:
Ust Koksa Landuse Committee (Altai Republic, Russia) and DEM from ALTAI 200 (Institute for Cartography, Dresden University of Technology, Germany)

Projection: Gauss-Krueger
Ellipsoid: Krassovsky
Datum: Pulkowo 42/83

Author:
K. Kelgenbaeva (2007)
(Institute for Cartography,
Dresden University of Technology, Germany)

Legend

Membership Function (MF)
Range from 0 (worse) to 1 (best)

Class	MF
NS	0.11
S3	0.49
S3	0.53
S2	0.60
S2	0.65
S2	0.76
S2	0.74
S1	0.81

Crop Suitability

W
S
P
W/S
W/P
S/P
W/S/P

W - Summer Wheat
S - Sunflowers
P - Potatoes

Non - Soil Formations

Recent River Deposits
Hardrock Outcrop

NS - No Suitability
S4 - Marginal Suitability
S3 - Moderate Suitability
S2 - Good Suitability
S1 - High Suitability

Topography

Settlement
Road
Field Boundary
975 Elevation Point [m]
1613 Peak [m]
River

TECHNISCHE UNIVERSITÄT DRESDEN

Map B16

Kartographische Bausteine (KB)

Veröffentlichungen des Instituts für Kartographie der TU Dresden

KB 1: Wissenschaftliches Kolloquium "25 Jahre Hochschulausbildung in der Fachrichtung Kartographie". 80 S., Dresden 1982. – vergriffen –

KB 2: Stams, W.: Bibliographische Zusammenstellungen 1957 bis 1981.47 S., Dresden 1982; 2,80 EUR

KB 3: Ogrissek, R. Erkenntnistheoretische Grundlagen und Erkenntnisgewinnung in der Kartographie. 78 S., Dresden 1982. – vergriffen –

KB 4: Hoffmann, F. Fortschritte der Kartographie 1969 – 1982. Sammelband ausgewählter Referate von Veröffentlichungen und Buchrezensionen,159 S., Dresden 1982. – vergriffen –

KB 5: Probleme der thematischen Kartographie und der Automatisierung der Kartenherstellung. Vortragsband, 96 S., Dresden 1983, 2,80 EUR.

KB 6: Dresdener Kartographische Beiträge " E. Lehmann und K. A. Sališcev zum 80. Geburtstag". Teil I und Teil II, 145 S., Dresden 1985; 2,80 EUR.

KB 7: Kartographiestudium an der TU Dresden. Dissertationen und Diplomarbeiten 1960-1991, 44 S., Dresden 1991; 2,80 EUR.

KB 8: Ehren-Kolloquium Friedrich Töpfer. 231 S., Dresden 1992; 2,80 EUR.

KB 9: Die Elbe im Kartenbild. Vermessung und Kartierung eines Stromes. Vortragsband, 154 S., Dresden 1994. – vergriffen –

KB 10: Schwarzbach, F.: Untersuchungen zur rechnergestützten Linienglättung, Dissertation, 103 S., 10 Anlagen, Dresden 1995; 8,00 EUR.

KB 11: Deutsche in Amerika - Die Einwanderung im Kartenbild. Kolloquiumsbeiträge und Texte zur Ausstellung (in Zusammenarbeit mit der Sächsischen Landesbibliothek – Staats- und Universitätsbibliothek Dresden), 112 S., Dresden 1995; 8,00 EUR. – vergriffen –

KB 12: High Mountain Remote Sensing Cartography. Proceedings of the International Symposium on High Mountain Remote Sensing Cartography, 26-28 Sept. 1990, Schladming (Austria). 150 S., Dresden 1996; 10,00 EUR.

KB 13: Veröffentlichungen der Mitarbeiter und Lehrbeauftragten des Studienganges Kartographie an der TU Dresden 1982-1996. Hrsg. anläßlich des Festkolloquiums "40 Jahre Kartographieausbildung an der TU Dresden", 5./6. Okto. 1997, 33 S., Dresden 1997; 5,50 EUR. – vergriffen –

KB 14: 40 Jahre Kartographieausbildung an der Technischen Universität Dresden 1957-1997; Dresden 1998; 13,00 EUR.

KB 15: Böhm, R.: Kartographische Reliefdarstellung mittels digitaler Bildfilterverfahren. Dissertation, 128 S., Dresden 1998; 13,00 EUR.

KB 16: Orthaber, H.: Bilddatenorientierte atmosphärische Korrektur und Auswertung von Satellitenbildern zur Kartierung vegetationsdominierter Gebiete. Dissertation, Dresden 1999, 182 S.; 13,00 EUR.

KB 17: Schaab, G.: Modellierung und Visualisierung der räumlichen und zeitlichen Variabilität der Einstrahlungsstärke mittels eines Geo-Informationssystems. Dissertation, Dresden 2000, 160 S.; 16,00 EUR. – vergriffen –

KB 18: Buchroithner, M. F. (Hrsg.): High Mountain Cartography. Proceedings of the Second Symposium of the Commission on Mountain Cartography of the International Cartographic Association held at the Alpine Centre Rudolfshütte, Austria from 29 March to 2 April 2000. 269 S., Dresden 2000; 20,00 EUR. *ISBN 3-86005-265-9*

KB 19: Koch, W. G. (Hrsg.): Theorie 2000. Vorträge des kartographischen Symposiums am 17./18. November 2000 an der TU Dresden, 130 S., 14 Anhänge, Dresden 2001; 12,00 EUR.

KB 21: Prechtel, N. (Hrsg.): Geoinformationssysteme – Theorie, Anwendungen und Problemlösungen. Vorträge der 7. Dresdner Sommerschule am 26./27. September 2002 an der TU Dresden, 128 S., 11 Farbtafeln, Dresden 2003; 12,00 EUR. *ISBN 3-86005-355-8*

KB 22: Damoiseaux, Th.: Untersuchungen zum Einsatz von Flugzeug-InSAR in der Gebirgskartographie. Dissertation, 181 S., 205 farbige Abbildungen auf CD-Rom, Dresden 2003; 16,00 EUR. *ISBN 3-86005-377-9*

KB 23: Wilfert, I. (Hrsg.): Scalable Vector Graphics (SVG) zur Internetpräsentation von Karten. Fünf Beiträge zu SVG mit drei lauffähigen Anwendungen auf CD-Rom. 172 S., 63 Abb., Dresden 2003;

12,00 EUR. *ISBN 3-86005-359-0* – vergriffen –

KB 24: Das Forstliche GeoInformationssystem von Sachsen. Beiträge zur Weiterentwicklung und Nutzung. Dresden 2006. *ISBN 3-86005-382-5* **– In Vorbereitung –**

KB 25: Lucht, A.: Farbmanagement für kartographische Druckerzeugnisse. 159 S., 20 Anl., mit CD-Rom, Dresden 2003; 12,00 EUR. *ISBN 3-86005-383-3* – vergriffen –

KB 26: Koch, W. G. (Hrsg.): Theorie 2003. Vorträge der 8. Dresdner Sommerschule für Kartographie am 25./26. September 2003 an der TU Dresden. 195 S., mit CD-ROM, Dresden 2004; 18,00 EUR. *ISBN 3-86005-410-4*

KB 27: Faby, H.: Untersuchung von kartographischen Medien und Nutzerbedürfnissen als Basis für zielgruppenorientierte touristische Internet-Anwendungen. Dissertation, 277 S., mit CD-ROM, Dresden 2004; 14,00 EUR. *ISBN 3-86005-411-2*

KB 28: Buchroithner, M. F. (Hrsg.): Proceedings of the 7th International Symposium on High Mountain Remote Sensing Cartography, 15-26 July 2002, Bishkek (Kyrgyzstan). 224 S., mit CD-ROM, Dresden 2004; 16,00 EUR. *ISBN 3-86005-435-X* – vergriffen –

KB 29: Wild, H.: Die topographischen Karten (Ausgabe für die Volkswirtschaft) der DDR und ihre Nutzung als Grundlagenkarten. 120 S., Dresden 2004; 15,00 EUR. *ISBN 3-86005-444-9* – vergriffen –

KB 30: Proceedings of the International Symposium on Cartographic Cutting-Edge Technology for Natural Hazard Management, 20-22 October 2004, Dresden (Germany). 190 S., mit CD-ROM, Dresden 2005; 15,00 EUR. *ISBN 3-86005-475-9*

KB 31: Reder, J.: Entwicklung eines halbautomatisierten Verfahrens zur Detektion neuer Siedlungsflächen durch vergleichende Untersuchungen hochauflösender Satelliten- und Luftbilddaten. Dissertation, 152 S., 56 Abb., mit CD-ROM, Dresden 2006; 15,00 EUR. *ISBN 3-86005-506-2*

KB 32: Butwilowski, W.: Einführung in die theoretische Geomorphologie – eine Alternativdarstellung. 170 S., Dresden 2007; 13,00 EUR. *ISBN 3-86005-552-6*

KB 33: Vom Militärischen- zum Sicherheitsgeowesen". Zum 75. Geburtstag von Herrn Oberst a.D. Prof. Dr. Hans-Ludwig Ewert; **– In Vorbereitung –**

KB 34: 13. Kartographiehistorisches Colloquium und 9. Dresdner Sommerschule für Kartographie, 20. - 23. September 2006 in Dresden, Vorträge und Berichte.; *ISBN 978-3-86780* **– In Vorbereitung –**

KB 35: El Nabbout, Khaled: Geo-Visualization Tools for Participatory Urban Planning The Case of Tripoli, Lebanon. Dissertation, 201 S., mit CD-ROM, Dresden 2007; 15,00 EUR. *ISBN 978-3-86780-010-5*

KB 36: Kelgenbaeva, Kamilya: Agronomic Suitability Studies in the Russian Altai Using Remote Sensing and GIS. Dissertation, 256 S., Dresden 2008; 15,00 EUR. *ISBN 978-3-86780-067-9*

Alle Bände sind zu beziehen über:
Technische Universität Dresden, Institut für Kartographie, 01062 Dresden;
Tel.: 0351 463 34809, Fax: 0351 463 37028, e-mail: steffi.sharma@tu-dresden.de