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Assistance with magnetic susceptibility measurements – Soil samples from the archive of the Agropedology Institute, Sarajevo.

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1 INTRODUCTION

Soil samples from across Bosnia and Herzegovina (BiH) were collected during field campaigns spanning several decades (1960's to 1990's). The samples are archived and held at the Institute of Agropedology (IA) in Sarajevo. The archive was partially destroyed during the conflict but over 3000 samples were salvaged. A project funded by CCMAT (under the ITEP umbrella) arranged the organization and georeferencing of the remaining samples. CCMAT also funded IA personnel to carry out magnetic susceptibility measurements of a selected sub-set of the remaining archive samples. This report details the procedures for;

1. the selection of a sample set for magnetic measurement and
2. the production of national maps of soil magnetic properties based on the measurements of the soil samples.

2 SELECTION OF A SUB-SET OF SAMPLES FOR MAGNETIC MEASUREMENTS

A subset of samples (1000) was required for magnetic measurements. After the sample organising and georeferencing was complete, IA provided Cranfield University with soil type and attribute data for all 3005 topsoil samples in the archive. Initially, the selection was to be based on knowledge of soil type and magnetic properties from a literature database; however the limited number of samples within the range of soil types excluded the use of this data to assess variability and hence guide sample selection. A proportional selection method was adopted with the following nested approach to ensure that all soil types within the archive were included in the sample sub set;

1. if total number of samples for soil type in archive <30 then all samples included in subset
2. if total number of samples for soil type in archive is between 30 and 100, 50% are included in the subset

3. if total number of samples for soil type >100 in archive then number selected is proportional to the remaining samples of the 1000 subset.

Table 1 shows the total number of samples selected for the sub-set for each soil type in the original archive.

In order to aid the selection of specific samples within the soil type groups the proportional selection method was implemented again but using soil parent material (geology) within each soil group. The information of soil parent material was not available from the attribute data provided with the samples, but was derived from the BiH SOTER[1] database. This database contains national BiH mapped information of soil type, terrain and geology at a scale of 1:200,000. A join between the mapped geological unit and the location of the archive sample provided a general indication of likely soil parent material for the archive sample. This may not correspond exactly to the soil parent material of the sample as the mapped units represent the dominant or general geology of a specific area. Selection of samples was undertaken by an independent statistician to avoid bias in sample selection. Figure 1 shows the distribution of the archive samples and highlights those chosen for the sub-set.

[1] Inventory of post-war situation of land resources in Bosnia and Herzegovina (2002) UN Food and Agriculture Organisation. GCP/BIH/002/ITA. [Available as an ArcView project from the Institute of Agropedology, Sarajevo].

Soil Type	Total sub-set	Total in archive
Calcaric Cambisols	17	17
Calcaric Fluvisols	29	29
Calcic Gleysols	2	2
Cambic Podzols	1	1
Chromic Cambisols	9	9
Chromic Luvisols	21	21
Chromic Luvisols + Humic Cambisols	1	1
Dystric Cambisols	53	97
Dystric Fluvisols	3	3
Dystric Leptosols	17	34
Dystric Podzoluvisols	4	4
Dystric Regosols	7	7
Eutric Cambisols	57	250
Eutric Cambisols + Chromic Cambisols	1	1
Eutric Fluvisols	28	108
Eutric Gleysols	21	43
Eutric Leptosols	157	710
Eutric Regosols	21	42
Eutric Vertisols	7	7
Ferralic Cambisols	9	9
Ferric Acrisols	6	6
Fibric Histosols	13	13
Gelic Histosols	11	11
Gleyic Cambisols	3	3
Gleyic Luvisols	3	3
Haplic Acrisols	4	4
Haplic Luvisols	3	3
Humic Cambisols	65	282
Lithic Leptosols	140	635
Lithic Leptosols + Chromic Cambisols	2	2
Mollic Cambisols	4	4
Mollic Fluvisols	3	3
Mollic Gleysols	38	77
Mollic Leptosols	54	225
Rendzic Leptosols	29	110
Stagnic Luvisols	27	54
Stagnic Podzoluvisols	23	47
Terric Histosols	3	3
Umbric Fluvisols	5	5
Umbric Gleysols	29	29
Umbric Leptosols	17	17
Umbric Regosols	21	42
Urbic Anthrosols	1	1
Vertic Cambisols	17	17
Vertic Luvisols	14	14
Grand Total	1000	3005

Table 1 *Number of samples in original archive and number selected for the sub-set for each soil type.*

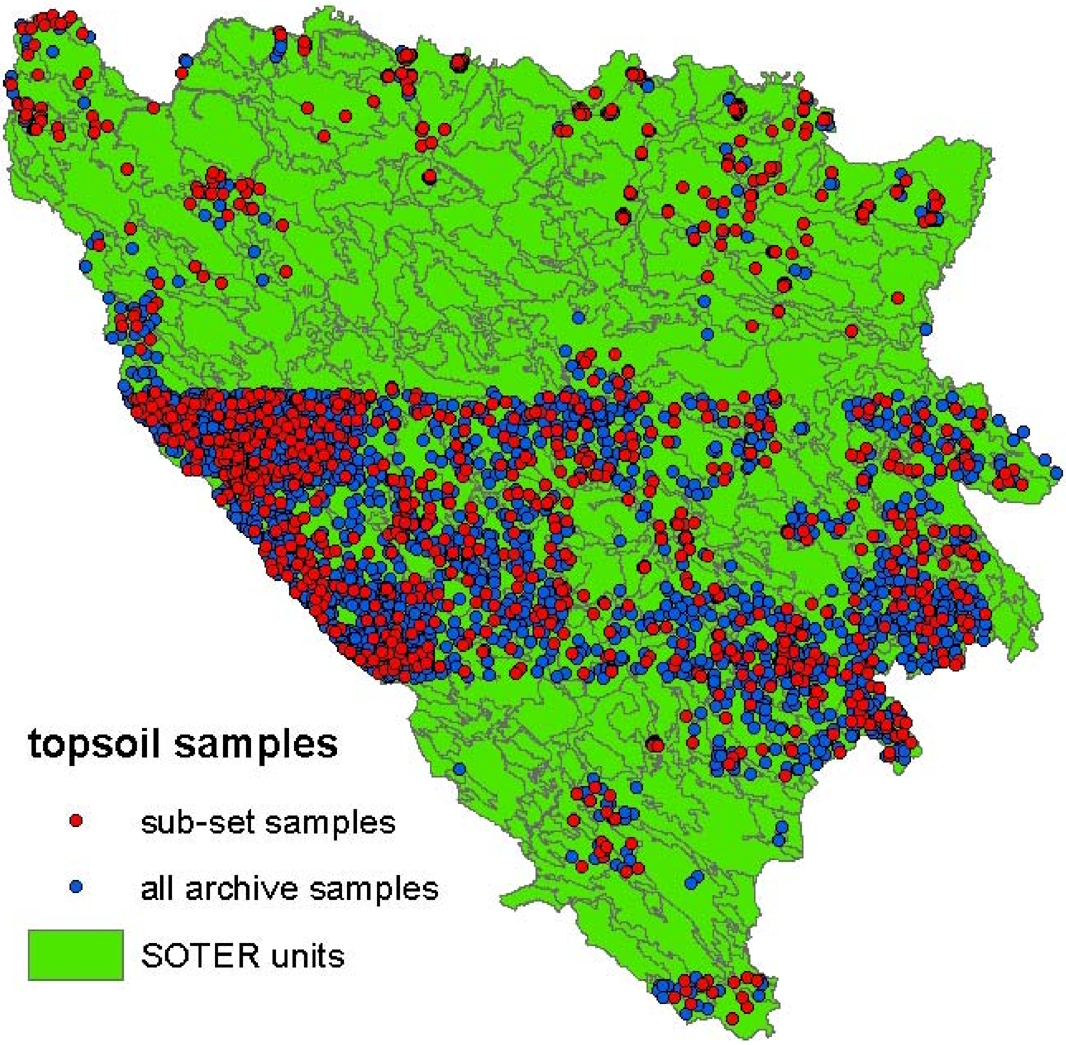


Figure 1 *Location of all archive samples and the sub-set of 1000 samples selected for magnetic analysis. SOTER boundaries in green.*

3 DISSEMINATION OF SELECTION PROCEDURE AND TRAINING

During a visit to the Institute of Agropedology in Sarajevo the methodology of sample selection was discussed with soil scientists at the institute. Each sample has a unique identifier, which was used to select the specific samples for the sub-set for magnetic measurements. It was not possible to locate four of the samples from the original list and they were replaced with samples from geographically adjacent areas. The samples were checked for suitability for measurement with the Bartington susceptibility system and subsequently could be used in their original state (dried and sieved at 2mm). The Bartington equipment was provided by CCMAT and the measurement protocol was disseminated via a training session with IA, CCMAT and Cranfield University personnel. Training followed standard operating procedures detailed in the Bartington Magnetic susceptibility manual (Bartington Instruments Ltd.) and further advice given on issues not covered specifically by the manual that may be encountered during measurement. The samples were prepared, weighed and measured in the Bartington Susceptibility system by IA personnel (July-September, 2005).

4 MAGNETIC SUSCEPTIBILITY DATA AND MAPPING

4.1 Magnetic susceptibility data

Magnetic measurements were obtained from IA in September 2005 and checked for consistency. The data base consisted of a unique identifier for each soil sample (the profile number), soil attributes obtained during and after sampling (descriptive and measured data) and the new magnetic data (soil weight, volume-specific low and high frequency susceptibility). Volume specific magnetic susceptibility was converted into mass specific values and frequency dependent susceptibility calculated (appendix 2). Each sample has a value for low frequency susceptibility (χLF), frequency dependent susceptibility (χFD) and frequency dependent percent (χFD%). Data was filtered to take into account the problems with χFD calculations due to the limited sensitivity of the Bartington at low χLF values.

If χHF > χLF then χFD set to zero

If χLF > χHF but χLF <15, χFD% set to zero

The data available for each point was derived from the original soil data obtained from IA and the derived magnetic data. In order to obtain information of soil parent material and land use for each sample, the point data was linked with the shapefiles (polygons) from the BiH SOTER data. It should be noted that the parent material and land use may not represent these actual attributes at the point samples because the SOTER data represents the general lithology and dominant land use within specified units (polygons). However, this information provides an indication of the likely soil parent material and land use for the sampling point. Information of soil parent material and land use with the soil type data was included to assess the contributing effects of geology and land use to the variation of soil magnetic properties.

4.2 Statistical analysis

The data used in the statistical analysis included soil type, associated soil parent material, land use and the magnetic properties χLF, χFD and χFD%. Figures 2 to 4 show summary histograms of the magnetic variables for all of the samples.

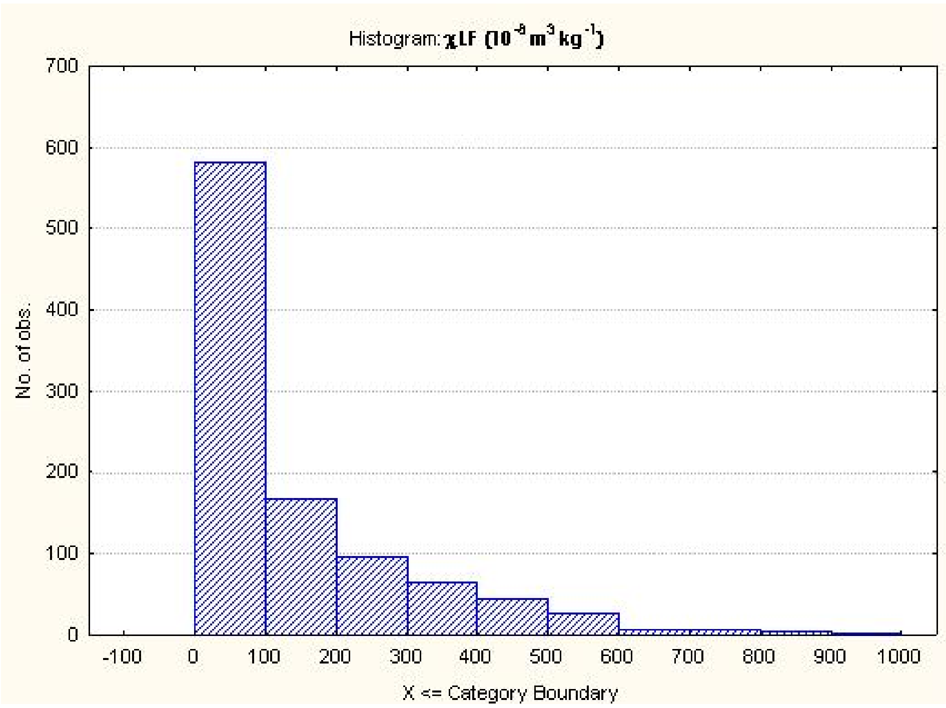


Figure 2 *χLF (10^{-8} m^3 kg^{-1}) for all samples from the sub-set (n=999)*

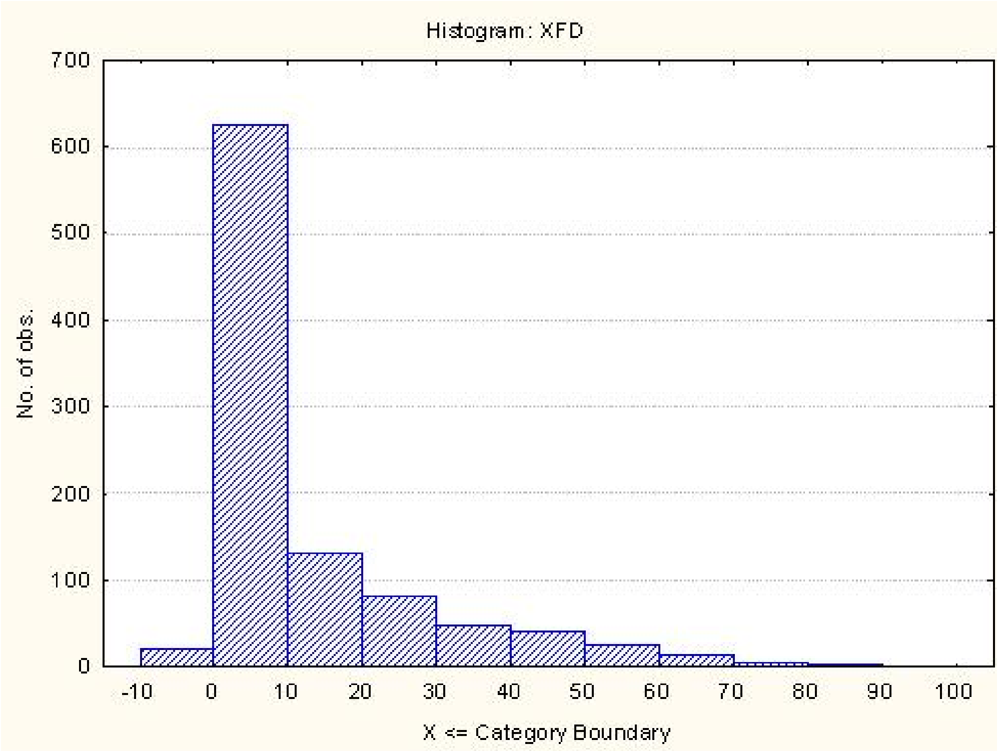


Figure 3 *χFD (10^{-8} m^3 kg^{-1}) for all samples from the sub-set (n=999)*

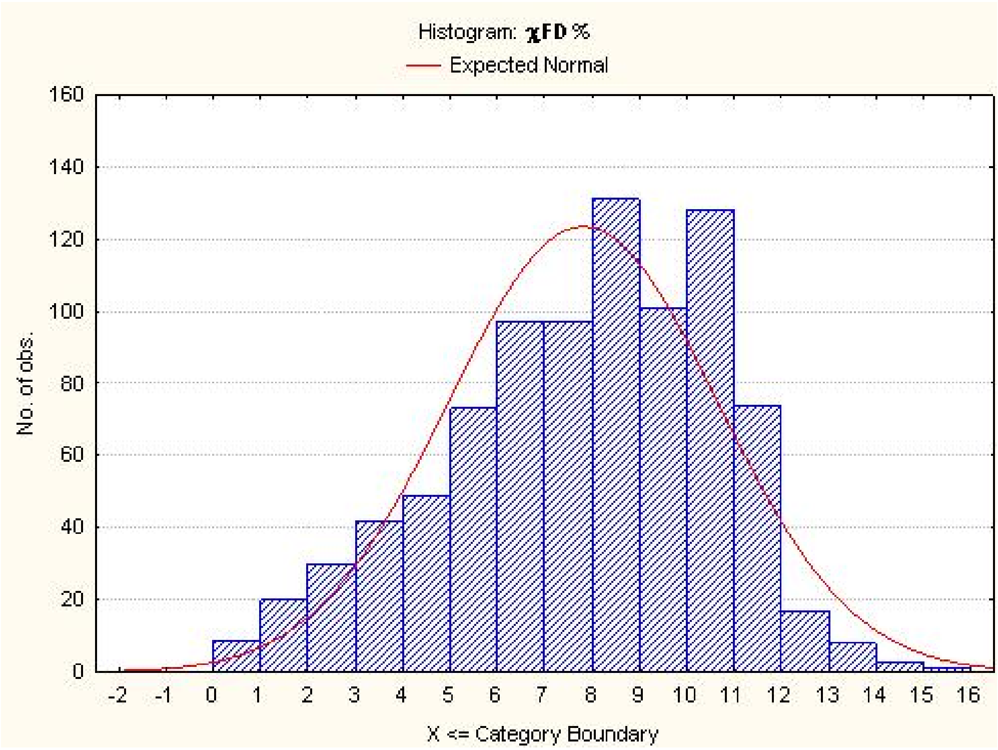


Figure 4 *χFD% for all samples from the sub-set (excludes samples set to zero)*

Figures 2 and 3 indicate the data is skewed for χLF and χFD and transformation to a normal distribution was therefore required to allow further statistical tests. Appendix 3 details histograms of transformed χLF and χFD using natural logarithms. Analysis of variance was carried out to investigate the possible sources of variation of the magnetic data. Parent material, land use and soil type all significantly contributed to χFD (10^{-8} m^3 kg^{-1}), χLF (10^{-8} m^3 kg^{-1}) and χFD %. There was not sufficient data in each individual soil type, parent material and land use group to consider any interactions between these properties. Consequently, the samples were grouped to account for the spread of variation in the magnetic properties in relation to parent material, land use and soil type.

Parent material

Parent materials could be divided into 3 groups which represented the spread of variation when considering all 3 magnetic properties. These are

- *Marine unconsolidated rock (PM1)*
- *Limestone and colluvial unconsolidated rock (PM2)*
- *All other parent materials (PM3)*

Land use

The only grouping that represented the spread of variation was between *arable land -rainfed* (including *predominantly arable*) and all other land uses. This did not apply within the *Marine unconsolidated rock* parent material group where there was no effect of land use.

Soil type

Soil type was reduced to soil major groups (e.g. Cambisols rather than Eutric Cambisols) as the original number of different soil types (n=45) was too large to distinguish between them. Within the 5 groups already identified, (PM1, PM2Arable, PM2Other, PM3Arable, PM3Other) major soil groups were identified as those having the greatest effects. The groups were resolved to 10 groups as defined in table 2, with the associated median values for each of the magnetic properties. The groups where χFD% is missing (1, 2 and 6) are those where the median χFD% was not significantly different to zero (c.f. section 4.1 where low susceptibility samples are set to zero).

Variation in magnetic properties within these groups is illustrated in figures 5 to 7. The groups are not mutually exclusive and many show a spread of data for all magnetic parameters. However, grouping is necessary in order to produce mapped units of magnetic parameters because spatial interpolation of the point data from the samples was not possible due to the limited and biased geographical spread of the sample points (see figure 1).

	Final group	**χLF**	**χFD**	**χFD %**
1	*Marine unconsolidated rock/Podzoluvisols*	9.46	0.22	
2	*Marine unconsolidated rock/Other soils (not Podzoluvisols)*	13.54	0.525	
3	*Limestone and colluvial unconsolidated rock/ Arable/all soils*	69.115	6.735	10.475
4	*Limestone and colluvial unconsolidated rock /Other land use/Leptosols*	249.775	23.96	9.94
5	*Limestone and colluvial unconsolidated rock/Other land use/Other soils(not Leptosols or Gleysols)*	86.04	7.33	8.415
6	*Limestone and colluvial unconsolidated rock /Other land use/Gleysols*	10.16	0.48	
7	*Other parent materials/Arable/Other soils(not Regosols or Leptosols*	26.65	1.55	6.78
8	*Other parent materials/Arable/ Regosols or Leptosols*	132.23	13.7	9.185
9	*Other parent materials/Other land use/Regosols, Anthrosols, Leptosols or Podsols*	74.48	4.33	6.71
10	*Other parent materials/Other land use/Other soils (not Regosols,Anthrosols,Leptosols and Podsols)*	47.34	3.17	6.325

Table 2 *Samples grouped by their contribution to the variation in magnetic properties, with median values of for each group. χLF and χFD units = 10^{-8} m^3 kg^{-1}*

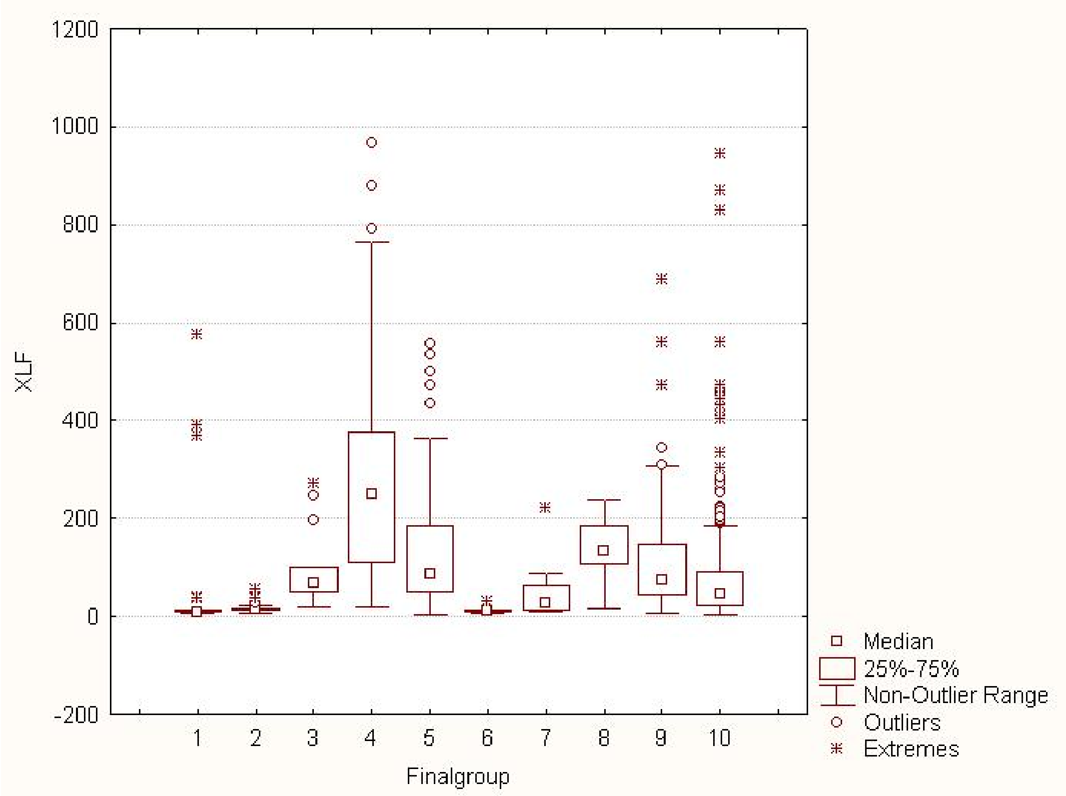


Figure 5 *Summary of χLF (10^{-8} m^3 kg^{-1}) for groups identified in table 2. Boxes indicate interquartile range (25^{th} to 75^{th} percentile), median and range of samples.*

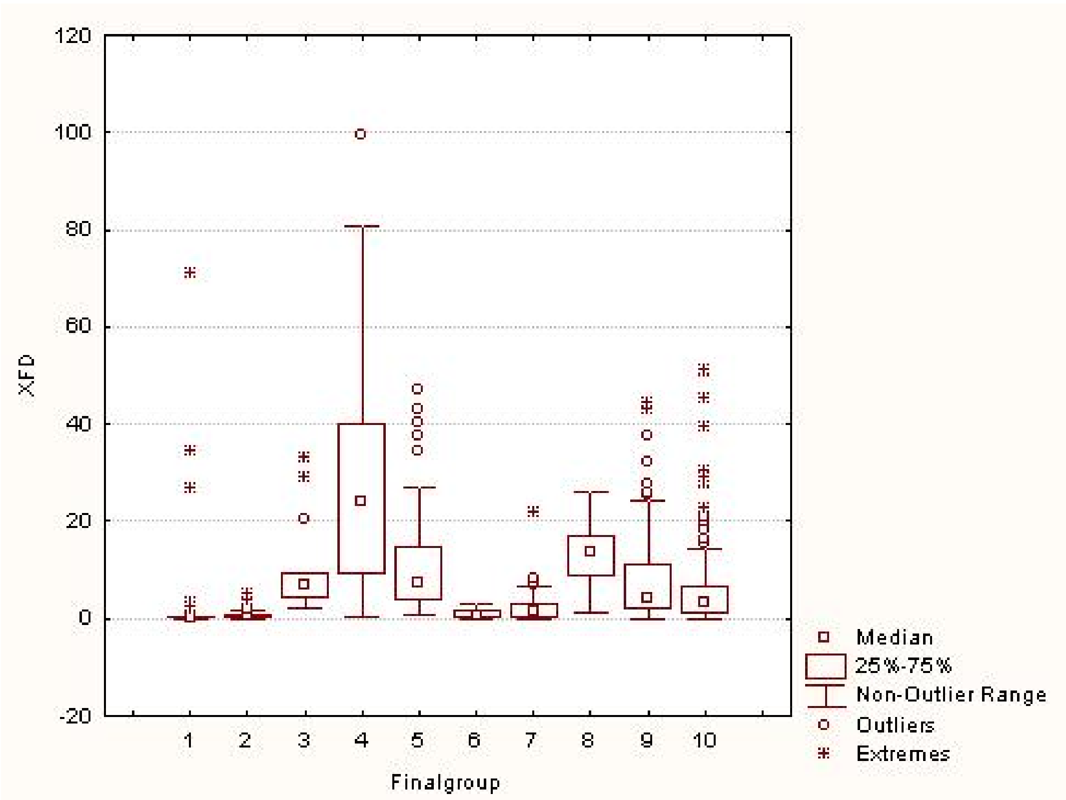


Figure 6 *Summary of χFD (10^{-8} m^3 kg^{-1}) for groups identified in table 2. Boxes indicate interquartile range (25^{th} to 75^{th} percentile), median and range of samples.*

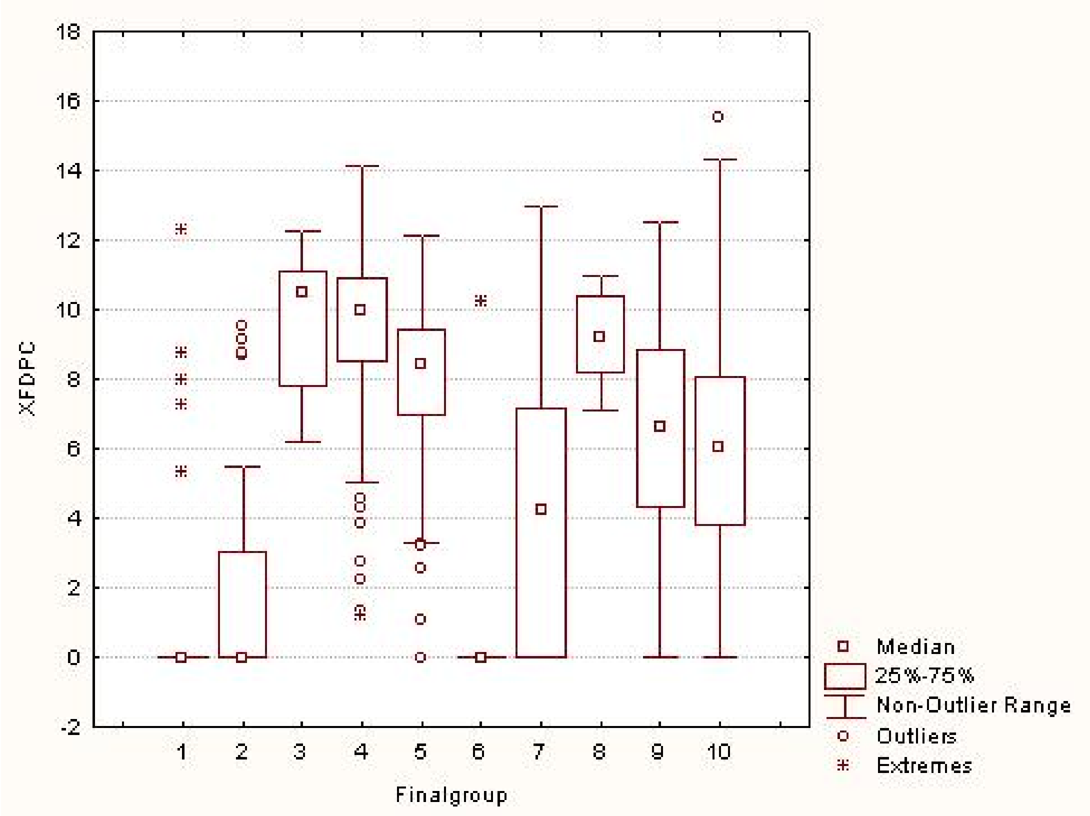


Figure 7 *Summary of χFD% for groups identified in table 2. Boxes indicate interquartile range (25th to 75th percentile), median and range of samples.*

4.3 Mapping

As spatial interpolation of the point (sample) data was not possible, mapping was achieved by using previously determined soil type boundaries from the BiH SOTER database. This gives an indication of regional distribution (mapping scale 1:200,000) of soils in BiH. The country is divided into mapping units (polygons) with information of the dominant and secondary soil type that covers the mapping unit. The dominant soil type in each mapping unit was selected as representative of the soil type within the mapped region and consequently used to assign the magnetic properties of that unit.

Mapping units were categorised by assigning a group from table 2 to the unit based on the combination of soil type, soil parent material and land use. The median values for each magnetic property were assigned for each group, resulting in a mapped distribution of magnetic properties. Median values were used rather than the mean because mean values of a skewed distribution are not representative of the average value for the sample group. Figure 8 provides a summary of the statistical and mapping steps used to produce final soil magnetic property maps.

Figures 9 to 11 show the median magnetic properties of the group assigned to the mapped unit for χLF, χFD and χFD% respectively. It should be emphasised that the values represent the likely median of the magnetic property within the mapped unit and may not be indicative of specific points within the unit. As a national map was required, mapping was produced at 1:200,000 scale so that sub-regional contrasts across BiH could be effectively illustrated.

5 CONCLUSIONS

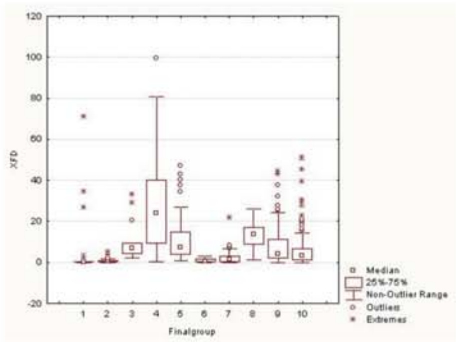
- Soil types were reduced to 10 groups that also included soil parent material and land use influences on the variability of magnetic parameters χLF, χFD AND χFD%.
- Median values for magnetic properties of the groups were assigned to polygons from the BiH SOTER database for dominant soils.
- Mapped outputs indicate sub-regional contrasts in χLF, χFD and χFD% across Bosnia and Herzegovina.

6 ACKNOWLEGEMENTS

This project was funded by the European Commission through the Institute for the Protection and Security of the Citizen, Joint Research Centre, Ispra, contract number 250640. The outputs contribute to a wider project ‘Soil Characterisation for Assessment of Metal Detector Performance’ led by CCMAT under an ITEP work plan. Thanks to personnel at the Institute of Agropedology for their warm hospitality during the visit to Sarajevo.

Sample data

Soil type
Magnetic parameters
Associated soil parent material and land use



Statistical grouping

Based on amount of variability of soil magnetic parameters explained by soil group, soil parent material and land use

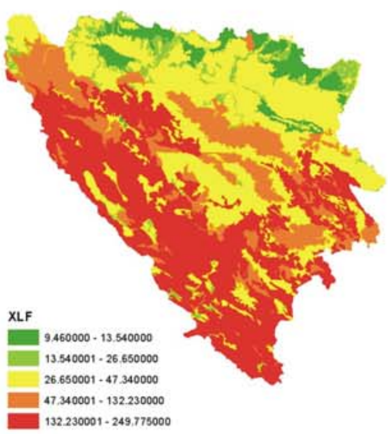
10 groups

BiH SOTER data

Soil type
Soil parent material
land use

Polygons mapped at 1:200,000

Each polygon assigned a group based on the combination of soil, soil parent material and land use



Mapped magnetic parameters

Median value for each group assigned to polygon

Figure 8 *Summary of statistical grouping and mapping of soil magnetic properties in BiH*

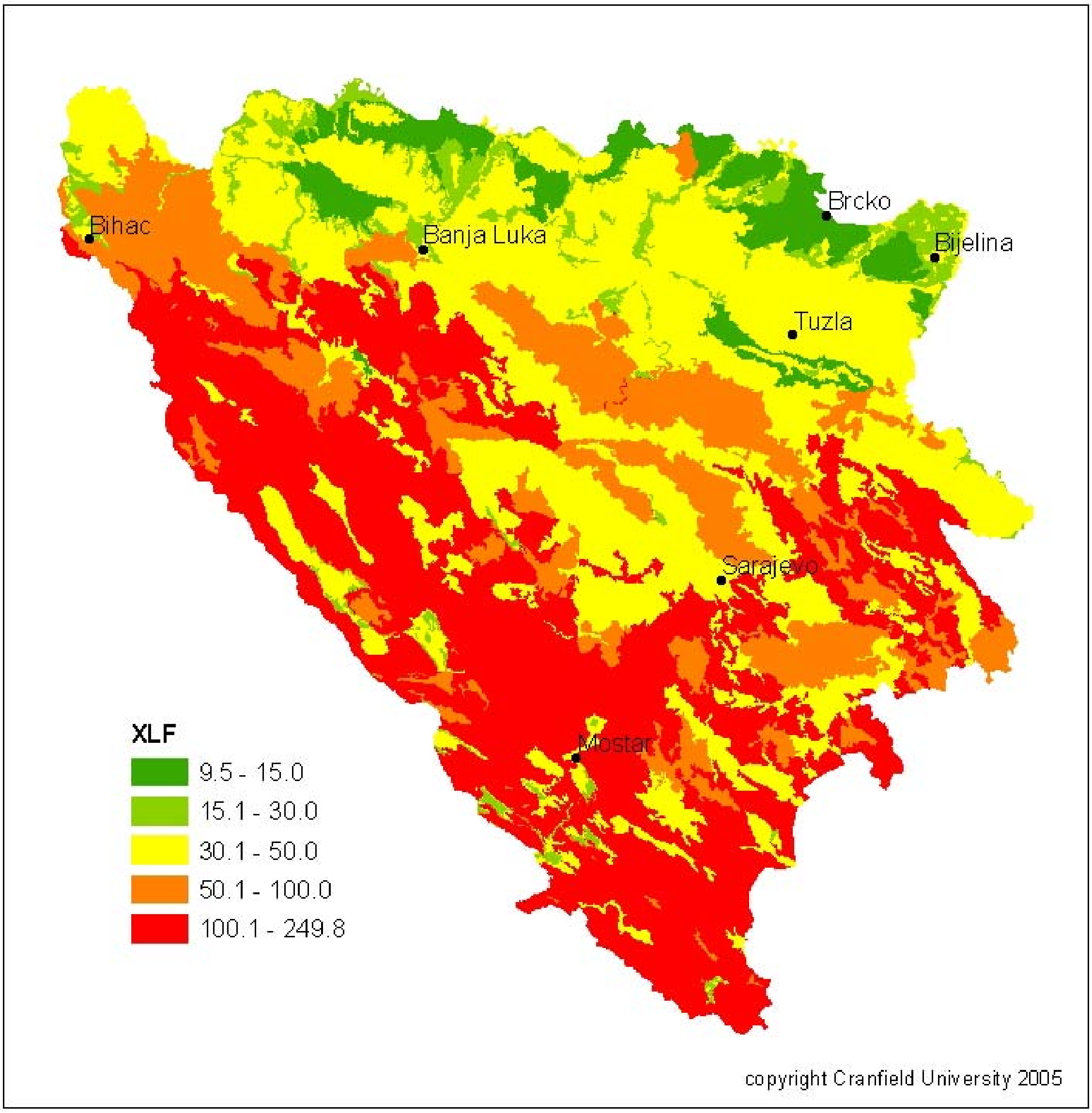


Figure 9 *Topsoil χLF (10^{-8} m^3 kg^{-1}) of dominant soils in BiH*

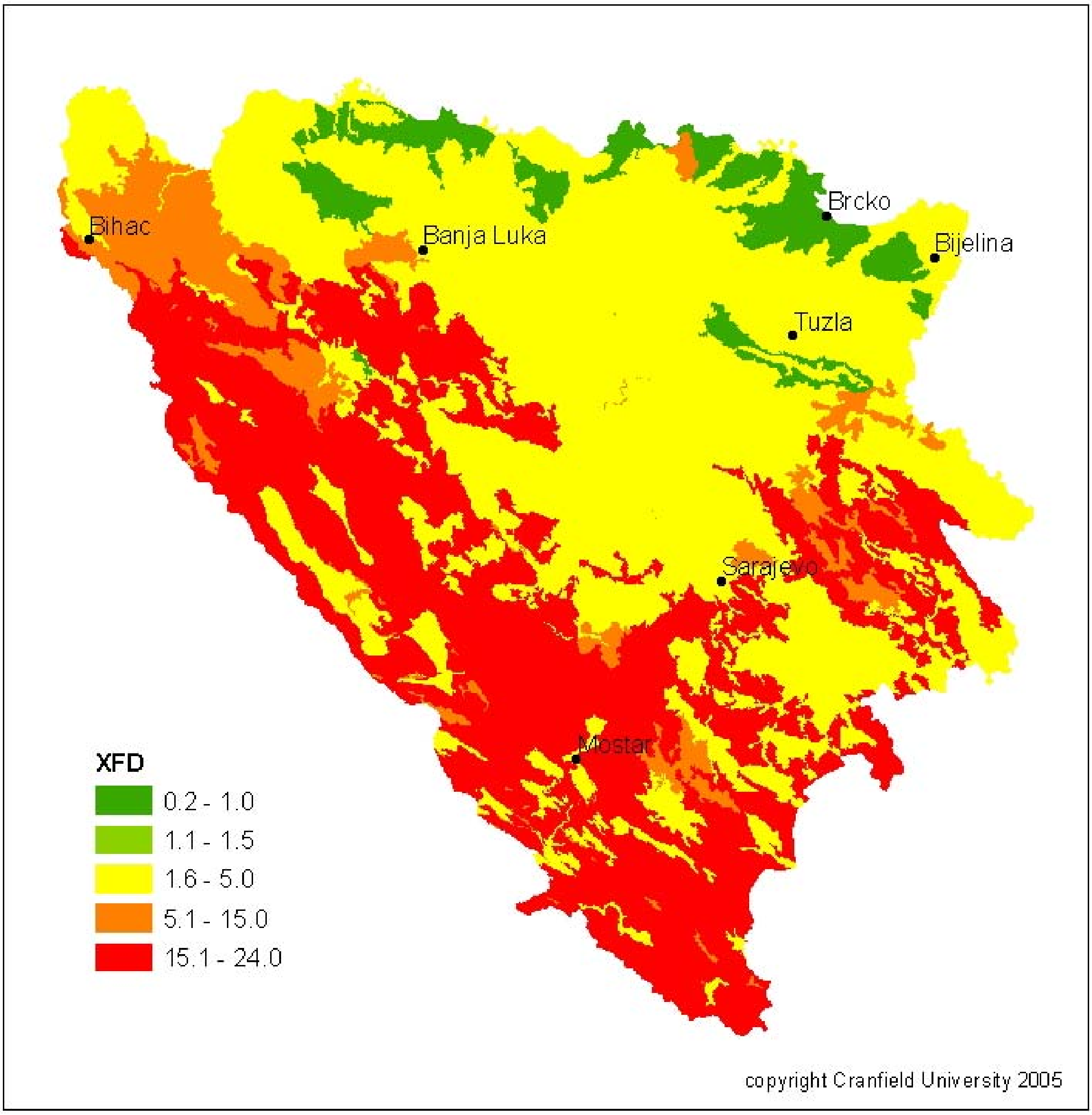


Figure 10 *Topsoil* χ*FD (*$10^{-8}\ m^3\ kg^{-1}$*) of dominant soils in BiH*

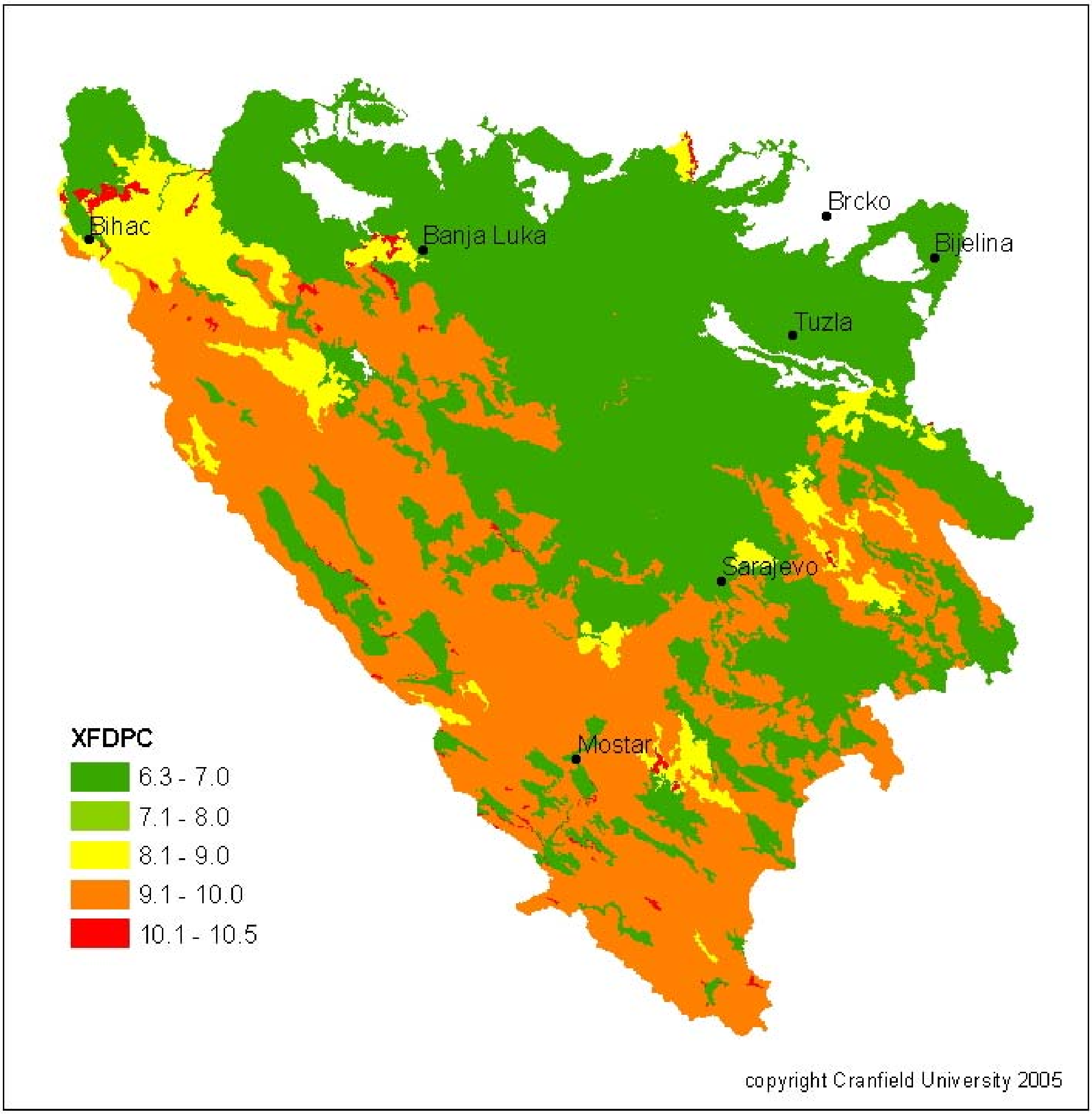


Figure 10 *Topsoil χFD% of dominant soils in BiH*

7 REFERENCES

Bartington Instruments Ltd. *Operation Manual for MS2 Magnetic Susceptibility System*. OM0408. Bartington Instruments Ltd. Available for download at: http://www.bartington.co.uk/pdfs/opmanuals/om0408.pdf

8 APPENDICES

Appendix 1

Data and equipment

Bosnian soil archive: topsoil samples and attribute data (including magnetic data) provided by the Institute of Agropedology, Sarajevo.

Database and maps of soil and terrain characteristics of BiH at 1:200,000 scale from: Inventory of post-war situation of land resources in Bosnia and Herzegovina (2002) UN Food and Agriculture Organisation. GCP/BIH/002/ITA. [Available as an ArcView project from the Institute of Agropedology, Sarajevo].

Bartington Magnetic Susceptibility dual frequency system (meter and sensor) MS2B (provided by CCMAT) for use by IA personnel to undertake magnetic susceptibility measurements of selected topsoil samples from the Bosnian national soil archive.

Appendix 2

Assuming a sample volume of $10cm^3$ (standard sample pot used for measurement)
κ is the volume specific value of susceptibility in 10^{-5} SI.
LF and HF are high and low frequency measurements, respectively.
sample mass in grams

χLF ($10^{-8}m^3 kg^{-1}$) = (κLF/sample mass) *10
χHF ($10^{-8}m^3 kg^{-1}$) = (κHF/sample mass) *10
χFD ($10^{-8}m^3 kg^{-1}$) = $\chi LF - \chi HF$
$\chi FD\%$ = ($\chi FD/\chi LF$)*100

Appendix 3

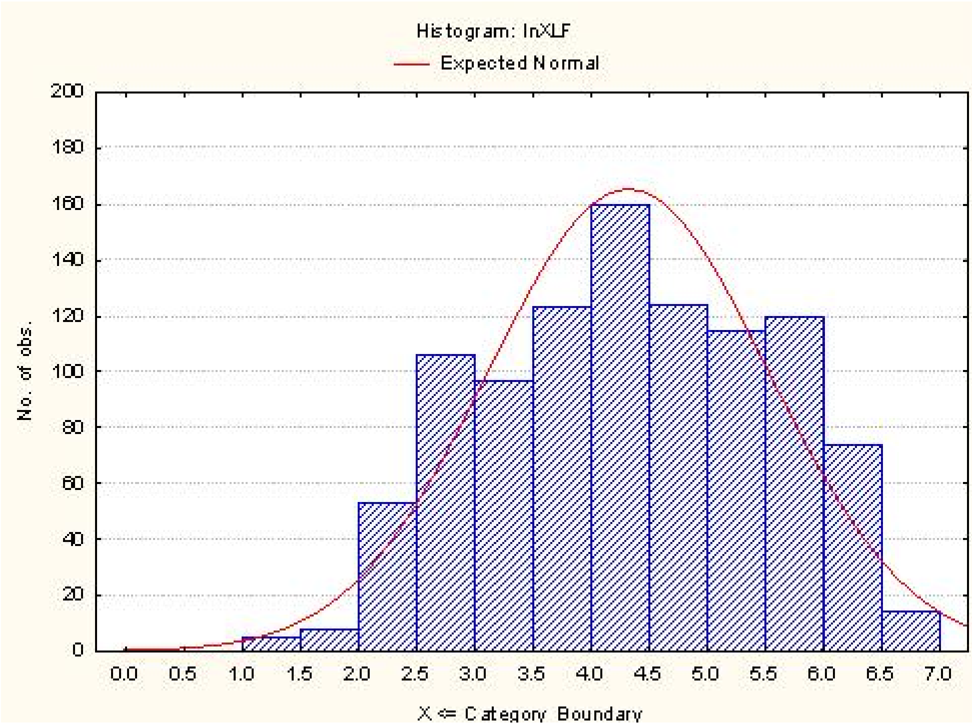


Figure A1 Natural logarithm transformation of χLF

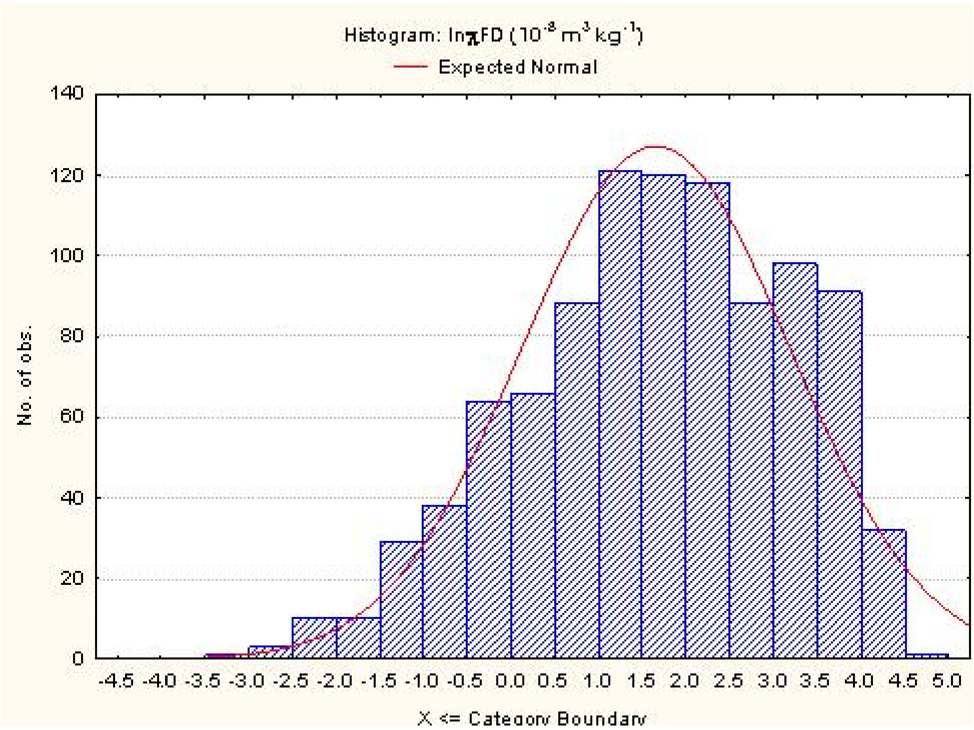


Figure A2 Natural logarithm transformation of χFD