



**THE POTENTIAL OF SATELLITE IMAGERY IN  
SOIL COMPACTION STUDIES FOR  
IMPLEMENTATION OF PRECISION FARMING**

By

**NORASMANIZAN BT ABDULLAH**

**1031210458**

A thesis submitted in fulfillment of the requirements for the degree of  
Master of Science (Environmental Engineering)

**School of Environmental Engineering  
UNIVERSITI MALAYSIA PERLIS (UniMAP)**

2013

**THE POTENTIAL OF SATELLITE IMAGERY IN  
SOIL COMPACTION STUDIES FOR  
IMPLEMENTATION OF PRECISION  
AGRICULTURE**

**NORASMANIZAN ABDULLAH**

**UNIVERSITI MALAYSIA PERLIS**

2013

© This item is protected by original copyright

## ACKNOWLEDGEMENT

ALHAMDULILLAH, I am thankful to the Almighty Allah, for with His blessings this master research finished successfully. Indeed, with His blessings, i'm able to get strength, guidance and faith to finish this research.

I would like to express my deepest appreciation to my supervisors, Mrs Ayu Wazira Azhari and Assoc. Prof. Dr. Mahmad Nor Jaafar for the guidance, materials and advices throughout the course of this work. They have spent a lot of time in guiding my research work and checking my thesis.

A million thanks to all UniMAP's staffs and lecturers especially the School of Environmental Engineering who are always sharing ideas, knowledge and skills with me. Also not forgetting the Dean of School of Environmental Engineering for his moral support and his attention to all environmental postgraduate students. My gratitude also goes to all the agencies and departments whose supplies the data for this research project.

Thanks to my friend as we always discuss together and give me support when facing problems. Last but not least, I want to thank my siblings, my beloved parents, Siti Fatimah Binti Draman and Abdullah Bin Razali @ Mohd Ghazali, also my husband Mohd Sabri Hussin, a great thanks for all their sacrifices and patience during the completion of my research project.

## TABLE OF CONTENTS

	<b>PAGE</b>
<b>THESIS DECLARATION</b>	i
<b>ACKNOWLEDGEMENT</b>	ii
<b>TABLE OF CONTENTS</b>	iii
<b>LIST OF FIGURES</b>	viii
<b>LIST OF TABLES</b>	xii
<b>LIST OF APPENDICES</b>	xiii
<b>LIST OF ABBREVIATIONS</b>	xiv
<b>ABSTRAK</b>	xviii
<b>ABSTRACT</b>	xix
<b>CHAPTER 1: INTRODUCTION</b>	
1.1 Introduction	1
1.2 Problem Statement	3
1.3 Aim and Objectives	4
1.3.1 Aim	4
1.3.2 Objectives	4
1.4 Scope and Limitations	5
1.4.1 Scope	5
1.4.2 Limitations	5
1.5 Background of Study	6
1.5.1 Characteristic of Study Area	9
1.6 Outline of Chapters	11

## CHAPTER 2: LITERATURE REVIEW

2.1	Introduction	13
2.1.1	Definition of Remote Sensing	14
2.2	Characteristic of Sensor System	14
2.2.1	SPOT 5	14
2.2.2	Landsat TM	16
2.3	GIS Capabilities	18
2.3.1	GIS for Environmental Decision Making	19
2.3.2	GIS Integration	19
2.4	Global Positioning System	20
2.4.1	GPS Soil Mapping	20
2.5	Spectral Reflectance	22
2.5.1	Characteristics of Images	24
2.5.2	Spectral Reflectance of Soil	24
2.5.3	Spectral Reflectance of Soil Moisture	25
2.6	Digital Image Processing	26
2.6.1	Image Resampling	27
2.6.2	Radiometric Correction	28
2.6.3	Extraction Reflectance Value	29
2.6.4	Georeferencing	29
2.7	Implementation of Precision Farming in Malaysia	30
2.7.1	GIS, GPS and Site Specific Agriculture	31
2.7.2	GIS and GPS integration in Site Specific Management	32
2.8	Soil Compaction	34
2.8.1	Causes and Consequences	35
2.8.2	Soil and Crop Symptoms of Compaction	37
2.8.3	Compaction Issues	38
2.8.4	Effect of Compaction to Crops	39
2.8.5	Plant Response to Subsoil Compaction	41
2.8.6	Soil Susceptibility to Compaction	41

2.9	Soil Cone Penetrometer	42
	2.9.1 Measuring Soil Compaction	44
2.10	Correlation of Reflectance Data and Soil Compaction	45
2.11	Moisture Content Measurement	47
	2.11.1 Moisture Content and Soil Compaction	47
2.12	Vegetation Indexes	49
2.13	Geostatistical Method	50
2.14	Band Math Basics	52
2.15	Map Projection	53
	2.15.1 Soil Compaction Mapping	54
	2.15.2 Map Accuracy Standard	55
2.16	Land Evaluation	55
2.17	Chapter Summary	57

### **CHAPTER 3: RESEARCH METHODOLOGY**

3.1	Introduction	58
3.2	Methodology	59
3.3	Field Data Acquisition	60
	3.3.1 Fieldwork Sampling	60
	3.3.2 Gravimeter Method	61
	3.3.3 GPS Observation	63
	3.3.4 Satellite Imagery	64
	3.3.5 Ancillary Data	66
	3.3.6 Cadastral Data	67
3.4	Software processing	68
3.5	Field Data processing	69
	3.5.1 Soil Compaction Classification	69
	3.5.2 Digital Image Processing	70
	3.5.3 Pre-processing Image	71
	3.5.3.1 Image Layers Stacking	71

3.5.3.2	Image Reprojection	72
3.5.3.3	Image Mosaicking	72
3.5.3.4	Geometric Correction	73
3.5.3.5	Radiometric Correction	74
3.5.3.6	Image Subset	80
3.6	Spectral Indexes	80
3.6.1	Normalized Difference Moisture Index	81
3.6.2	Vegetation Indexes	82
3.6.2.1	Soil Adjusted Vegetation Index (SAVI)	83
3.6.2.2	Modified Soil Adjusted Vegetation Index (MSAVI)	83
3.6.3	Soil Index	84
3.6.3.1	Bare Soil Index (BSI)	84
3.7	Extracting Reflectance Value	84
3.8	Regression Method	85
3.9	Geostatistical Method	86
3.10	Classification of Soil Compaction Status	87
3.11	Prediction of Soil Compaction	89
3.12	ISODATA Classification	89
3.13	Map Registration	91
3.14	Digitizing Map	92
3.15	Overlaying Map	92
3.16	Map Composition	93
3.17	Analysis of Variance (ANOVA)	94

## **CHAPTER 4: RESULT AND ANALYSIS**

4.1	Introduction	95
4.2	Attribute Data of GPS Points Soil Sampling	96
4.3	Soil Compaction Data and Reflectance Data Value	97
4.4	GPS Points Soil Sampling Overlaid with Satellite Images	98
4.5	Image Processing	100

4.5.1	Image Layer Stacking (Landsat TM)	100
4.5.2	Image Mosaicking	101
4.5.3	Geometric Correction	102
4.5.4	Root Mean Square Error	103
4.5.5	Image Subset	104
4.5.6	Image Transformation	104
4.6	Georeferencing	105
4.7	Soil Strength Profiles	106
4.8	Moisture Content Analysis	107
4.9	Spectral Reflectance Analysis	111
4.9.1	Spectral Reflectance of NDMI	111
4.9.2	Spectral Profile of Landsat 5 TM	114
4.9.3	Spectral Indexes Analysis	115
4.10	Correlation Analysis	117
4.10.1	Linear Regression	117
4.10.2	Polynomial Regression	118
4.10.3	Correlation Analysis of Reflectance Data and Soil Penetration Data	120
4.10.4	Correlation Analysis of Spectral Indexes and Soil Penetration Data	121
4.11	Soil Compaction Status Maps	123
4.11.1	Classification of Soil Compaction	123
4.11.2	Soil Compaction Mapping	124
4.12	Prediction Model Test	128
4.12.1	Unsupervised Classification (SAVI Index)	128
4.12.2	Prediction Map of Soil Compaction	129
4.13	Land Evaluation Analysis	131
4.14	Accuracy Assessment	134

## **CHAPTER 5: CONCLUSION AND RECOMMENDATIONS**

5.1	Summary of Findings	135
5.2	Recommendations	138
	<b>REFERENCES</b>	139
	<b>APPENDICES</b>	147
	<b>LIST OF PUBLICATION</b>	160

© This item is protected by original copyright

## LIST OF FIGURES

NO.		PAGE
Figure 1.1	Study area of Perlis	2
Figure 1.2	Effects of compaction on pore space	6
Figure 1.3	Nitrogen and potassium deficiency symptoms in corn	7
Figure 1.4	Spectral signatures of natural and human-made materials	8
Figure 1.5	Precision farming concept	9
Figure 1.6	Agrotechnology Research Station views from the satellite (Landsat 5 TM)	9
Figure 1.7	Agrotechnology Research Station, Sg Chuchuh	10
Figure 2.1	Sensor of SPOT 5	15
Figure 2.2	Drawing of Landsat 5 satellite	16
Figure 2.3	Vector data and raster data	18
Figure 2.4	Data integration	19
Figure 2.5	Positioning with GPS point	22
Figure 2.6	Spectra curve	23
Figure 2.7	Reflectance spectra of five soil types	25
Figure 2.8	Gravimeter water contents	26
Figure 2.9	Pixels representing digital number	29
Figure 2.10	Impacts of soil compaction	34
Figure 2.11	Reduced root growth due to compaction from raindrop impact tillage, and wheel tracks	36
Figure 2.12	Depth of compaction depending on axle load and soil moisture increases	36
Figure 2.13	Slow and irregular plants grow	39
Figure 2.14	Roots deformation	39
Figure 2.15	Plant distribution	40
Figure 2.16	Root growth decreases linearly with increasing resistance	43
Figure 2.17	Compaction profile created from a penetrometer	45

Figure 2.18	Close up of Landsat TM	48
Figure 2.19	Interpolation concept of ordinary kriging method	51
Figure 2.20	Kriged maps of NPK	52
Figure 2.22	Band Math processes	53
Figure 2.23	Compaction map	54
Figure 3.1	Working procedure	59
Figure 3.2	Hand held static penetrometer	60
Figure 3.3	Materials of water content measurement	62
Figure 3.4	GPS principles and GPS segments	63
Figure 3.5	Satellite images of Landsat TM	65
Figure 3.6	SPOT 5	66
Figure 3.7	Cadastral map	67
Figure 3.8	Workflow of DIP	70
Figure 3.9	Image layers stacking characteristic	71
Figure 3.10	Image mosaicking procedure	73
Figure 3.11	GCP points of geometric correction	74
Figure 3.12	COST model for DN reflectance conversion with atmospheric correction	78
Figure 3.13	Function definition of model	79
Figure 3.14	Model maker	82
Figure 3.15	Point view of pixel	85
Figure 3.16	Attribute table of pixel values	85
Figure 3.17	Trendline options of regression type	86
Figure 3.18	The semivariogram/covariance modelling	87
Figure 3.19	Prediction map of soil compaction status	88
Figure 3.20	Classification properties	88
Figure 3.21	Band Math function	89
Figure 3.22	ISODATA parameters	90
Figure 3.23	Density slice	90
Figure 3.24	Map registration	91
Figure 3.25	Spatial reference properties	92

Figure 3.26	Digitizing procedure	93
Figure 3.27	Significance testing	94
Figure 4.1	Attribute data of GPS points soil sampling	96
Figure 4.2	GPS points of field-work sampling (Landsat 5 TM-02 February 2005)	98
Figure 4.3	GPS points of field-work sampling (Landsat 5 TM-16 February 2010)	99
Figure 4.4	Image stacking outputs	100
Figure 4.5	Image mosaicking of Landsat 5 TM	101
Figure 4.6	Result of geometric correction	103
Figure 4.7	Graph of RMS error	103
Figure 4.8	Image subset of Landsat 5 TM	104
Figure 4.9	Reproject image output info	105
Figure 4.10	Residual error of map registration	105
Figure 4.11	Soil strength profile	106
Figure 4.12	Soil water content measurement in different level of soil compactness	109
Figure 4.13	Water content analysis at different level of soil compaction	110
Figure 4.14	Correlation of water content and soil compaction data	110
Figure 4.15	Relationship between of soil compaction data and moisture index reflectance data	111
Figure 4.16	Correlation of NDMI vs soil compaction (5 cm ground surface)	112
Figure 4.17	Correlation of NDMI vs soil compaction (15 cm ground surface)	112
Figure 4.18	Correlation of NDMI vs soil compaction (30 cm ground surface)	112
Figure 4.19	NDMI image of Landsat 5 TM (16 February 2010)	113
Figure 4.20	Spectral profile of Landsat 5 TM (25 February 2005)	114
Figure 4.21	Spectral profile of Landsat 5 TM (16 February 2010)	115
Figure 4.22	SAVI image of Landsat 5 TM (16 February 2010)	116

Figure 4.23	MSAVI image of Landsat 5 TM (16 February 2010)	116
Figure 4.24	BSI image of Landsat 5 TM (16 February 2010)	116
Figure 4.25	Linear regressions of significant reflectance data (Band 5) and soil penetration data for 5 cm ground surface	117
Figure 4.26	Linear regressions of significant vegetation index (SAVI) and soil penetration data for 5 cm ground surface	118
Figure 4.27	Polynomial regressions of significant reflectance data and soil penetration resistance data for 5 cm ground surface	119
Figure 4.28	Polynomial regressions of significant vegetation index (SAVI) and soil penetration resistance data for 5 cm ground surface	119
Figure 4.29	Results of soil compaction classification	123
Figure 4.30	Status map of soil compaction using the kriging method	127
Figure 4.31	SAVI image output	129
Figure 4.32	Prediction of soil compaction using SAVI index	129
Figure 4.33	Comparison of soil compaction status map and prediction soil compaction based on satellite image (SAVI index)	130
Figure 4.34	Output image analysis	130

## LIST OF TABLES

NO.		PAGE
Table 2.1	The characteristics of SPOT 5 image	15
Table 2.2	The characteristics of Landsat 5 TM image	17
Table 2.3	Soil and crop symptoms of tillage and traffic-induced compaction	37
Table 2.4	Interpretation of penetration resistance measurements	43
Table 2.5	Criteria and ratings of soil and land qualities	56
Table 3.1	Data types of satellite data	64
Table 3.2	Data types of hardcopy map	66
Table 3.3	Reading range of penetration resistance	69
Table 3.4	Projection parameters	72
Table 3.5	AOI of Landsat 5 TM image	80
Table 3.6	Index formula	81
Table 4.1	Soil data sampling and reflectance data value	97
Table 4.2	Total RMS error	102
Table 4.3	Linear regression of significant reflectance values and soil compaction	121
Table 4.4	Polynomial regression of significant reflectance values and soil compaction	121
Table 4.5	Linear regression between spectral indexes and soil penetration data	122
Table 4.6	Polynomial regression between spectral indexes and soil penetration data	122
Table 4.7	Land evaluation at Agrotechnology Research Station	133
Table 4.8	Model summary	134
Table 4.9	ANOVA result	134

## LIST OF APPENDICES

NO.		PAGE
APPENDIX A	Soil water samples	147
APPENDIX B	Hardcopy map	148
APPENDIX C	Residual error of geometric correction	149
APPENDIX D	Earth Sun Distance (d) in astronomical units	151
APPENDIX E	COST model of radiometric correction	154
APPENDIX F	Accuracy Assessment Report	155

© This item is protected by original copyright

## LIST OF ABBREVIATIONS

µm	Micrometer
2D	Two Dimensional
ANOVA	Analysis of Variance
AOI	Area of Interest
ArcGIS	GIS software products produced by Esri
ARSM	Agency of Remote Sensing Malaysia
ARVI	Atmospherically Resistant Vegetation Index
AutoCAD	Computer Aided Design or Computer Aided Drafting software
AU	Astronomical Units
B	Blue Band Reflectance
BSI	Bare Soil Index
CI	Cone Index
COST	Improved Image Based Dark Object Model
CWC	Critical Water Content
d	Earth Sun Distance
DInSAR	Differential Interferometry
DIP	Digital Image Processing
DN	Digital Number
DAO	District Agriculture Office
DOA	Department of Agriculture
ENVI	Environment for Visualizing Images

EVI	Enhanced Vegetation Index
EOS	Earth Observation Satellite
ERDAS	Remote Sensing software designed by ERDAS. Inc
F	Test Statistic
F.A.O	Framework for Land Evaluation
ft	Feet
g	gram
G	Green Band Reflectance
GCP	Ground Control Point
GIS	Geographical Information System
GPS	Global Positioning System
ha	Hectare
ISODATA	Interactive Self Organizing Data Analysis Techniques
JERS-1	Japanese Earth Resources Satellite 1
JUPEM	Department of surveying and mapping
Kpa	Kilopascal
L	Soil Brightness Correction Factor
LANDSAT	Land Remote Sensing Satellite
LUTS	Land Use Types
m	Meter
MBD	Maximum Bulk Density
Mpa	Megapascal
MSS	Multispectral Satellite Scanner

MRSO	Malayan Rectified Skew Orthomorphic
MSAVI	Modified Soil Adjusted Vegetation Index
NASA	National Aeronautics and Space Administration
NDVI	Normalize Difference Vegetation Index
NDMI	Normalize Difference Moisture Index
NDWI	Normalize Difference Water Index
NPK	Nitrogen Phosphorus Potassium
NIR	Near Infra-Red Band Reflectance
NCRAN	Natural Resources Canada
OSAVI	Optimized Soil Adjusted Vegetation Index
P	Significance Level
PSI	Pound Square Inch
R	Red Band Reflectance
RGB	Red Green Blue Band Reflectance
RMSE	Root Mean Square Error
RS	Remote Sensing
R <sup>2</sup>	Coefficient of Determination/Square Correlation Coefficient
SAR	Synthetic Aperture Radar
SATVI	Soil Adjusted Total Vegetation Index
SAVI	Soil Adjusted Vegetation Index
SMGM	Soil moisture Gaussian model
SPSS	Statistical Package for the Social Sciences
SPOT	Satellite Pour l'Observation de la Terre

SRI	Simple Ratio Index
SWIR	Short Wave Infra-Red Band Reflectance
TIR	Thermal Infra-Red
TM	Thematic Mapper
USGS	United States Geological Survey
USDA-ARS	United States Department of Agriculture's Agriculture Research Service
UTM	Universal Transverse Mercator
WGS	World Geographic System

© This item is protected by original copyright

## Potensi Imej Satelit dalam Kajian Pemadatan Tanah untuk Pelaksanaan Perladangan Tepat

### ABSTRAK

Objektif kajian ini adalah untuk menilai potensi imej satelit dan GIS (sistem maklumat geografi) dalam kajian pemadatan tanah dengan menyiasat pantulan spektrum dalam menghasilkan peta pemadatan tanah bagi pelaksanaan pertanian tepat. Ia menganalisis hubungan yang signifikan antara data pemadatan tanah dan data pantulan Landsat 5 TM imej. Kajian ini mengenal pasti kawasan yang berpotensi mengalami tanah padat dengan menganalisis indeks spektrum kandungan lembapan (NDMI), indeks tumbuh-tumbuhan (SAVI, MSAVI), indeks tanah (BSI). Hubungan di antara pembolehubah disiasat menggunakan pekali penentuan ( $R^2$ ). Keputusan pengukuran 'gravimeter' menunjukkan ada hubungan yang signifikan terhadap kandungan air dalam pemadatan tanah. Oleh itu, data pantulan NDMI telah dikaji dan ia didapati mempunyai hubungan yang signifikan ( $R^2=0.755$ ) dengan data penembusan tanah. Regresi linear 'band' SWIR juga menunjukkan korelasi yang signifikan tertinggi ( $R^2=0.84$ ) dengan ( $p<0.05$ ) berbanding dengan beberapa gelombang nampak iaitu 'Band' 1, ( $R^2=0.209$ ) 'Band' 2, ( $R^2=0.142$ ), 'Band' 3, ( $R^2=0.382$ ) dan 'Band' 7, ( $R^2=0.305$ ). Ungkapan regresi linear telah digunakan dalam meramalkan kawasan padat menggunakan 'Band Math' dan status peta pemadatan telah dicipta menggunakan kaedah geostatistik. Model matematik indeks spektrum juga menunjukkan korelasi dengan korelasi yang signifikan iaitu SAVI ( $R^2=0.724$ ), MSAVI ( $R^2=0.725$ ) dan BSI ( $R^2=0.422$ ). Maklumat yang digabungkan daripada peta pemadatan tanah dan teknologi angkasa adalah berharga untuk petani dan penanam dalam rawatan tanah, aktiviti pembajakan dan seterusnya dalam pelaksanaan pengurusan pertanian spesifik.

# **The Potential of Satellite Imagery in Soil Compaction Studies for Implementation of Precision Farming**

## **ABSTRACT**

The objective of this study is to evaluate the potential of satellite imagery and GIS (Geographic Information System) in soil compaction studies by investigating the spectral reflectance in producing soil compaction maps for implementation of precision farming. It analyzes the significant correlation between soil penetration resistance data and reflectance data of the Landsat 5 TM image. This study identifies the possible areas of soil compaction by analyzing the spectral indexes of moisture content (NDMI), vegetation indexes (SAVI, MSAVI) and soil index (BSI). The relationship between variables is investigated using coefficient of determination ( $R^2$ ). The results of gravimeter measurement showed had a significant relationship of water content level in soil compaction. Thus, NDMI reflectance data were studied and it was found that it had significant correlation ( $R^2=0.755$ ) with soil penetration data. Linear regression of SWIR channel indicated highest significant correlation ( $R^2=0.84$ ) with ( $p<0.05$ ) compared to several channels visible band of Band 1, ( $R^2=0.209$ ) Band 2, ( $R^2=0.142$ ), Band 3, ( $R^2=0.382$ ) and Band 7, ( $R^2=0.305$ ). The expression of linear regression was used in predicting the compact area using Band Math function and the compaction status map was created using geostatistical method. The mathematical models of spectral indexes also indicated a correlation with the significant correlation of SAVI is ( $R^2=0.724$ ), MSAVI ( $R^2=0.725$ ) and BSI ( $R^2=0.422$ ). The combined information of the soil compaction map and space technology is valuable for farmers and growers in land treatment, tillage activities and consequently in the implementation of site specific agricultural management.

# CHAPTER 1

## INTRODUCTION

### 1.1 Introduction

Universiti Malaysia Perlis (UniMAP) has established an Agrotechnology Research Stations at Sungai Chuchoh Campus to provide research and development platform for agriculture and engineering discipline. The research station is situated 6° 39' 07" N latitude and 100° 15' 37" E longitude. The main activities are herbal farming and mango plantation. Land use for crop production is a major issue in current farming practice, especially where precision farming technology is to be applied.

This research focuses on the potential of satellite imagery in soil compaction studies using Remote Sensing and Geographical Information System (GIS). Remote sensing GIS plays an important role in environmental study and agriculture management which can be used for great varieties of application. The aim of this study is to investigate the soil compaction status by measuring soil penetration resistance for implementation of precision farming and to determine if remotely sensed images could identify compacted regions of soil compaction based on reflectance data and soil data.

In addition, the study analyses the correlation between soil compaction data and pixel value of satellite imagery. In this study, a penetrometer tool used to collect ground

truth data and simultaneously recorded the coordinate using GPS handheld. A Landsat 5 Thematic Mapper (TM) of Perlis was acquired to identify possible areas of soil compaction. The correlation method analyses the identified areas of potential soil compaction using linear regression and polynomial regression. The map production of the soil compaction map can be used by the planner or farmers for site specific management practice.

Currently, Remote Sensing and GIS technologies are widely used in agriculture especially in precision farming and site specific management. There are several sensors that have been launched such as Quickbird, Ikonos, Spot, and Landsat. In this study, pre-processing part involves digital image pre-processing, digital image enhancement, digital image classification and GIS integration. During pre-processing part, the geometrically and radiometrically corrected image being applied for further analysis. Fig. 1.1 shows the study area that conducted in this research.

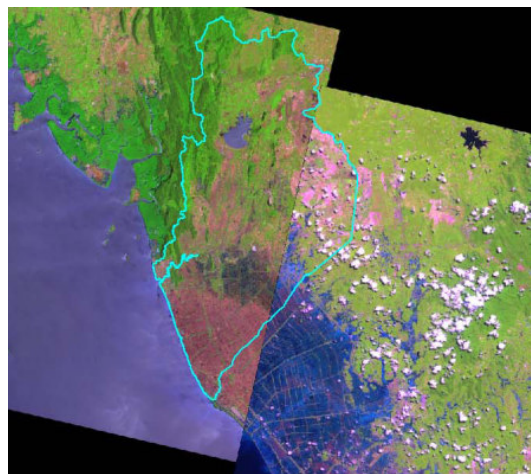


Figure 1.1: Study area of Perlis  
(Source: ARSM, 2011)