

TD-2016-2



ESTACIÓN EXPERIMENTAL DE AULA DEI
CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS



Consejo Superior de Investigaciones Científicas
Estación Experimental de Aula Dei
Dpto. de Suelo y Agua
Grupo de Erosión y Evaluación de Suelo y Agua



Universidad de Zaragoza
Facultad de Ciencias
Dpto. de Ciencias de la Tierra
Programa de Doctorado en Geología

Spatio-temporal dynamic of soil erosion and sediment supply in a Pyrenean catchment: modelling erosion and fingerprinting sediment apportionments

Memoria presentada por

Leticia Palazón Tabuenca

Licenciada en Geología, para optar al grado de
Doctor en Geología por la Universidad de Zaragoza

Directora: Dra. Ana Navas Izquierdo

Zaragoza, Octubre de 2015

R-15047



Acknowledgments

This doctoral thesis has been accomplished at the Department of Soil and Water of the Estación Experimental de Aula Dei (State Agency Consejo Superior de Investigaciones Científicas, EEAD-CSIC) to which I appreciate the hospitality and support. The research for this doctoral project has been funded by the CICYT projects: MEREDOCAR (CGL2008-0831) with a contract from the "*Programa Personal Técnico de Apoyo*"; and EROMED (CGL2011-25486) from the Ministry of Science and Innovation (MICINN) and TRAZESCAR (CGL2014-52986-R) from the Ministry of Economy and Competitiveness (MINECO). The thesis has been developed in Zaragoza during the period 2010-2015 and comprises eight scientific papers, of which six are published and two are under review.

First of all, I would like to express my special thanks to my thesis supervisor Dr. Ana Navas (EEAD-CSIC). She gave me the opportunity to discover the scientific research universe proposing me the option to do the doctoral project developed in this thesis. Her wide experience, dedication and passion for research are contagious and have highly helped me in the development of this thesis. Thank you very much for many in-depth discussions about fieldwork development, office and lab work, for constructive comments during paper writing and review and for your patience, encouragement and support during the entire time of this doctoral project. You helped me finding the right way in all the highs and lows moments of my doctoral study.

Many people have participated and contributed to the development of this thesis in one or another way those who I want to show my gratitude:

To the research group of "Erosión y Evaluación de Suelo y Agua" of the EEAD-CSIC Dr. Javier Machín for his invaluable contributions and assistance in the field work, Drs. Santiago Beguería and Borja Latorre who highly contributed with their knowledge in their respective fields, Teresa López and Maribel Poc for the analytical determinations, Teresa Guillamón for literature/reference reviews, my colleagues Leticia Gaspar, Laura Quijano, Marta Angulo, Roberto Serrano, Guillermo Sánchez and Miquel Tomas for his advice, encouragements and help. To all these and all those who have been in the research group during this period, thanks for sharing this time with me.

To all those, from inside and outside the Experimental Station, who have accompanied and support me during the fieldwork campaigns, with a special mention to Andrés Ayarza (RIP), from the "Casa de labor" of the Station, with who I made most of the sampling. Likewise, I want to thank all those who have helped with the processing of the samples.

To the staff and colleagues of the “Estación Experimental de Aula Dei” and to the colleagues of the Campus of Aula Dei. Thanks for your help and for sharing this time with me.

To the department of Earth Sciences of the University of Zaragoza.

To Drs. William H. Blake and Hugh G. Smith from the School of Geography of the Plymouth University and from the School of Environmental Sciences of the Liverpool University, respectively, for their contributions in the developing and English corrections of the relevant articles of which are co-authors and also for the time shared in The Scripps Institution of Oceanography of the University of California San Diego (USA).

To my husband Gabriel for being always there for me and in special for all of his invaluable help and support in the collection of samples.

To my parents Mari Paz and Rafael, and my sister Paula who have helped, inspired and supported me during all my live and who are always with me whatever it happens.

Finally, I want to thank my friends for being there in my spare time.

All have been essential and fundamental part of this work.

Leticia Palazón Tabuenca
Zaragoza, October 2015

Agradecimientos

Esta tesis doctoral se ha realizado en el Departamento de Suelo y Agua de la Estación Experimental de Aula Dei (EEAD-CSIC), a la que agradezco su hospitalidad y los medios prestados. El trabajo para este proyecto de tesis ha sido financiado con cargo a los proyectos de la CICYT: MEREDOCAR (CGL2008-0831) con la ayuda de un contrato correspondiente al Programa Personal Técnico de Apoyo; y EROMED (CGL2011-25486) del Ministerio de Ciencia e Innovación (MICINN) y TRAZESCAR (CGL2014-52986-R) del Ministerio de Economía y Competitividad (MINECO). La tesis se ha desarrollado en Zaragoza en el periodo 2010-2015 y comprende ocho artículos científicos, de los cuales seis están publicados y dos se encuentran en proceso de revisión.

Primero, me gustaría expresar mi especial agradecimiento a mi directora de tesis Dra. Ana Navas (EEAD-CSIC). Ella me dio la oportunidad de descubrir el campo científico de la investigación proponiéndome la opción de hacer el proyecto doctoral desarrollado en esta tesis. Su amplia experiencia, dedicación y pasión por la investigación son contagiosas y me han ayudado mucho en el desarrollo de esta tesis. Muchísimas gracias por las innumerables discusiones sobre el desarrollo del trabajo de campo, de laboratorio y oficina, por tus comentarios más que constructivos durante la escritura y revisión de los artículos y por tu paciencia, ánimo y apoyo durante toda la duración del proyecto de tesis. Ella me ha ayudado a encontrar el camino correcto en todos los altos y bajos momentos de mi estudio de doctorado.

Son muchas las personas que han participado y contribuido en el desarrollo de esta tesis doctoral de una forma u otra a quienes quiero mostrar mi agradecimiento:

Al grupo de investigación de Erosión y Evaluación de Suelo y Agua de la EEAD. Al Dr. Javier Machín por sus aportaciones e inestimable ayuda en el trabajo de campo, a los Drs. Santiago Beguería y Borja Latorre que aportaron sus valiosos conocimientos en sus respectivas especialidades, a Teresa López y Maribel Poc por las determinaciones analíticas, a Teresa Guillamón por las revisiones bibliográficas, a mis compañeros Leticia Gaspar, Laura Quijano, Marta Angulo, Roberto Serrano, Guillermo Sánchez y Miquel Tomas por sus consejos, ánimos y ayuda. A todos ellos y a todos aquellos que han pasado por el grupo durante este periodo, gracias por compartir este tiempo conmigo.

A todos aquellos, de dentro y fuera de la estación, que me han acompañado y ayudado en el desarrollo del trabajo de campo, con una mención especial para Andrés Ayarza (DEP), de la Casa de labor de la estación, con el que he realizado la mayor parte del muestreo. De la misma forma, quiero dar las gracias a todos aquellos que me han ayudado con el procesamiento de las muestras.

A todo el personal y compañeros de la Estación Experimental de Aula Dei y a los compañeros del campus Aula Dei. Gracias por vuestra ayuda y haber compartido todo este tiempo conmigo.

Al departamento de Ciencias de la Tierra de la Universidad de Zaragoza.

A los Drs. William H. Blake y Hugh G. Smith de la Escuela de Geografía de la Universidad de Plymouth y de la Escuela de Ciencias Medioambientales de la Universidad de Liverpool, respectivamente, por sus contribuciones y las correcciones del inglés en el desarrollo de los correspondientes artículos en los que son coautores y también por el tiempo compartido en la Scripps Institution of Oceanography de la Universidad de California San Diego (EEUU).

A mi marido Gabriel por estar ahí siempre para mí y en especial por toda su inestimable ayuda y apoyo en la toma de muestras en el trabajo de campo.

A mis padres M^a Paz y Rafael, y a mi hermana Paula quienes me han ayudado, inspirado y apoyado a lo largo de toda mi vida y están siempre a mi lado pase lo que pase.

Finalmente, quiero dar las gracias a mis amigos por estar ahí en mi tiempo libre.

Todos ellos han sido parte imprescindible y fundamental de este trabajo.

Leticia Palazón Tabuena
Zaragoza, Octubre 2015

-List of publications included in the thesis in the order of appearance:

This work was prepared for the degree of doctor philosophiae at the Department of Earth Sciences at the Zaragoza University by a compendium of publications. The thesis comprises eight scientific papers, of which six are published and two manuscripts are in review. All publications are either peer reviewed or are currently in peer review process.

Paper I:

Palazón, L. and Navas, A. Effect of climatic characterization on river discharge in an alpine-prealpine catchment of the Spanish Pyrenees using SWAT model. *River research and applications* (in review).

Paper II:

Palazón, L., Navas, A. (2013) Sediment production of an alpine catchment with SWAT. *Zeitschrift Fur Geomorphologie*, 57 (2): 69-85, DOI: <http://dx.doi.org/10.1127/0372-8854/2013/S-00136>

Paper III:

Palazón, L., Navas, A. (2014) Modeling sediment sources and yields in a Pyrenean catchment draining to a large reservoir (Ésera River, Ebro Basin). *Journal of Soils and Sediments*, 14(9): 1612-1625, DOI: 10.1007/s11368-014-0911-7

Paper IV:

Palazón, L., Navas, A. (2016) Land use sediment production response under different climatic conditions in an alpine-prealpine catchment. *Catena*, 137: 244-255, DOI: 10.1016/j.catena.2015.09.025

Paper V:

Palazón, L., Gaspar, L., Latorre, B., Blake, W. H., Navas, A. (2015) Identifying sediment sources by applying a fingerprinting mixing model in a Pyrenean drainage catchment. *Journal of Soils and Sediments*, 15(10):2067-2085. DOI: 10.1007/s11368-015-1175-6.

Paper VI:

Palazón, L., Latorre, B., Gaspar, L., Blake, W.H., Smith, H.G., Navas, A. (2015) Comparing catchment sediment fingerprinting procedures using an auto-evaluation approach with virtual sample mixtures. *Science of the Total Environment*, 532:456-466. DOI:10.1016/j.scitotenv.2015.05.003

Paper VII:

Palazón, L., Gaspar, L., Latorre, B., Blake, W.H., Navas, A. (2014) Evaluating the importance of surface soil contributions to reservoir sediment in alpine environments: a combined modelling and fingerprinting approach in the Posets-Maladeta Natural Park. *Solid Earth*, 5, 963–978, DOI:10.5194/sed-6-1155-2014

Paper VIII:

Palazón, L., Latorre, B., Gaspar, L., Blake, W.H., Smith H. G., Navas, A. Linking catchment modelling and sediment fingerprinting to quantify sediment dynamics in a Spanish Pyrenean river system. *Science of the Total Environment* (in review).

Authorship statement

I am the first author of all of the included papers and the corresponding author. Therefore, I am the responsible of a large part of the writing of the manuscripts, the figure and tables preparation as well as for the processes of revision. None of my co-authored will use the papers to obtain the degree of doctor philosophiae as all of them are already Doctors.

La **Dra. Ana M^a Navas Izquierdo**, Investigadora Científica del Consejo Superior de Investigaciones Científicas (CSIC) en la Estación Experimental de Aula Dei (EEAD), Zaragoza, España,

CERTIFICA:

Que Dña. Leticia Palazón Tabuena ha realizado bajo mi dirección el trabajo que, para optar al grado de Doctor en Geología, presenta con el título:

Spatio-temporal dynamic of soil erosion and sediment supply in a Pyrenean catchment:
modelling erosion and fingerprinting sediment apportionments

Que el trabajo se corresponde y adecua al Proyecto de Tesis Doctoral aprobado por el Departamento de Ciencias de la Tierra de la Universidad de Zaragoza con fecha del 4 de Noviembre de 2013, y ratificado por la Comisión de Doctorado en Geología con fecha del 11 de Noviembre de 2013.

AUTORIZA:

La presentación de la tesis "Spatio-temporal dynamic of soil erosion and sediment supply in a Pyrenean catchment: modelling erosion and fingerprinting sediment apportionment" en la modalidad de compendio de publicaciones.

Y para que conste a los efectos oportunos, firmo el presente documento en Zaragoza, a 23 de Octubre de 2015.



Fdo.: Dra. Ana María Navas Izquierdo

Contents

Acknowledgements	I
Agradecimientos	III
List of publications included in the thesis	V
Authorship statement	VI
Autorización del director para el depósito de la tesis.....	VII
Contents.....	IX
Resumen.....	XIII
Chapter 1.....	1
1. General introduction	3
1.1 Research objectives.....	9
1.2 Study area	10
1.3 Methods	14
1.4 Research contributions	18
References.....	19
Chapter 2.....	23
Effect of climatic characterization on river discharge in an alpine-prealpine watershed of the Spanish Pyrenees using SWAT model (Paper I)	
Abstract.....	25
1. Introduction.....	25
2. Materials and Methods.....	27
2.1 Study Area	27
2.2 The SWAT model and input data	29
2.3 Model parameterization	31
2.4 Climatic scenarios.....	33
2.5 Model evaluation	35
3. Results and Discussion	34
4. Conclusions.....	37
Acknowledgments.....	38
References.....	38
Chapter 3.....	41
Sediment production of an alpine catchment with SWAT (paper II)	
Abstract.....	43
1 Introduction.....	43
2 Study Area	45
3 Materials and Methods	48
3.1 SWAT model.....	48
3.2 The Linsoles catchment model setup.....	49
3.2.1 Model input	49
3.2.2 Model parameterization and evaluation.....	51
4 Results and Discussion	54
5 Conclusions.....	57
Acknowledgments.....	57
References.....	57

Chapter 4.....	61
Modeling sediment sources and yields in a Pyrenean catchment draining to a large reservoir (Ésera River, Ebro Basin) (paper III)	
Abstract.....	63
1 Introduction.....	63
2 Materials and Methods.....	64
2.1 Study Area	64
2.2 The Soil and Water Assessment Tool (SWAT) model	65
2.3 The Barasona catchment model setup.....	65
2.3.1 Model input	65
2.3.2 Model parameterization.....	68
3 Results and discussion	70
3.1 Barasona sediment inflow.....	70
3.2 Sediment yield from the main subcatchments	71
3.3 Relating sediment production to the characteristics of Pyrenean structural units.....	72
4 Conclusions.....	74
Acknowledgments.....	75
References.....	75
Chapter 5.....	77
Land use sediment production response under different climatic conditions in an alpine-prealpine catchment (paper IV)	
Abstract.....	79
1. Introduction.....	79
2. Materials and Methods.....	80
2.1 Study Area	80
2.2 Modeling approach	82
2.2.1 SWAT model.....	82
2.2.2 The Barasona catchment model setup and erosion assessment	82
3. Result	83
3.1 The sediment production from the different land uses.....	83
3.2 Sediment productions in the northern and southern parts of the catchment.....	84
3.3 Scenario with an increase of 2°C temperature	84
4. Discussion.....	88
5. Conclusions.....	89
Acknowledgments.....	89
References.....	89
Chapter 6.....	91
Identifying sediment sources by applying a fingerprinting mixing model in a Pyrenean drainage catchment (paper V)	
Abstract.....	93
1. Introduction.....	93
2. Materials and Methods.....	95
2.1 Study Area	95
2.2 Sample collection.....	95
2.3 Sample analysis	96
2.4 Sediment fingerprinting procedure and statistical analysis for source discrimination.....	98
2.5 Mixing model and optimization.....	99
3 Results.....	100

3.1 Source fingerprinting discrimination	100
3.2 Mixing model: source apportionments	103
4 Discussion	105
5 Conclusions.....	108
Acknowledgments.....	108
References.....	108
Chapter 7.....	113
Comparing catchment sediment fingerprinting procedures using an auto-evaluation approach with virtual sample mixtures (paper VI)	
Abstract.....	115
1. Introduction.....	115
2. Materials and Methods.....	116
2.1 Study Area	116
2.2. Sample selection and analysis.....	117
2.3. Virtual sample mixtures and fingerprinting procedure auto-evaluations	118
2.4. Statistical analysis for source discrimination.....	118
2.5. Estimation of source contribution	118
3. Results.....	119
3.1. Statistical discrimination of tracer properties	119
3.2. Estimation of source contribution	120
3.3. Auto-evaluation of fingerprinting procedures.....	120
4. Discussion	120
5. Conclusions.....	124
Acknowledgments.....	124
References.....	124
Chapter 8.....	127
Evaluating the importance of surface soil contributions to reservoir sediment in alpine environments: a combined modelling and fingerprinting approach in the Posets-Maladeta Natural Park (paper VII)	
Abstract.....	129
1. Introduction.....	129
2. Study Area	131
3. Materials and Methods.....	133
3.1 The SWAT model.....	133
3.1.1 SWAT inputs.....	134
3.1.2 Catchment parameterisations in SWAT	134
3.2 Sediment fingerprinting procedure	135
3.2.1 Sediment and soil sampling.....	135
3.2.2 Laboratory analyses.....	135
3.2.3 Statistical analysis for source discrimination.....	137
3.2.4 Multivariate mixing model	137
4. Results.....	137
4.1 Soil-specific sediment yields by the SWAT model	137
4.2 Soil and sediment source contributions	138
5. Discussion	140
6. Conclusions.....	141
Acknowledgments.....	142
References.....	142

Chapter 9.....	145
Linking catchment modelling and sediment fingerprinting to quantify sediment dynamics in a Spanish Pyrenean river system (paper VIII)	
Abstract.....	147
1. Introduction.....	148
2. Materials and Methods.....	149
2.1 Study Area.....	149
2.2 Sample collection.....	151
2.3 Sample analysis.....	152
2.4 SWAT model assessment.....	153
2.5 Fingerprinting procedure.....	155
3. Results.....	157
3.1 Sediment production by SWAT model.....	157
3.2 Fingerprinting sediment contributions to the reservoir sediment.....	160
4. Discussion.....	167
5. Conclusions.....	169
Acknowledgments.....	170
References.....	170
 Chapter 10.....	 175
10. Conclusions.....	177
 Appendix.....	 181
Journal quality indicators.....	183
Curriculum Vitae.....	185