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Utilizing new and innovative tools to mitigate surficial erosion in Mediterranean environments

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Abstract

Aim of study: Soil erosion is a serious environmental problem since it can have major impacts on the human society. Climate change is only expected to exacerbate soil erosion. The aim of this study was to use new technologies to measure more accurately and address holistically soil erosion mitigation in Greece.

Area of study: The study area was on Thasos Island, Greece that has flat and steep slope areas, different types of land-uses and frequent wildfires that allowed to assess soil erosion under different conditions.

Material and Methods: Soil erosion was estimated at two different scales (micro and macroscale). For the miscrocale, different sensors along with the use of ultrasonic technology were employed to measure erosion and other influencing factors. For the macroscale, firstly a soil loss equation in GIS was utilized. In addition, an Integrated Information System was developed for stakeholders.

Main results: A new tool that measures accurately and continuously soil erosion was developed. The Automated Soil Erosion Monitoring System (ASEMS) can monitor and store important environmental variables at a specific location (microscale). The variables it measured were: i) soil erosion/deposition (ground level changes), ii) soil moisture, iii) soil temperature, iv) rainfall and v) air temperature. Finally, an Integrated Information System (I^2S) that allowed to mitigate soil erosion for large areas (macroscale) was developed.

Highlights: New tools (ASEMS and I^2S) and a calibrated equation in GIS were developed that could be utilized by government agencies in Greece to accomplish sustainable, effective and cost-efficient mitigation of soil erosion. These tools are also applicable in other regions of the Mediterranean.

Keywords: Ultrasonic Sensor, Integrated Information System, Erosion Models, Erosion Risk Maps, Climate Change

Akdeniz çevresinde meydana gelen yüzeysel erozyonu azaltmaya yönelik yeni ve yenilikçi araçların kullanılması

Özet

Çalışmanın amacı: Toprak erozyonu toplum üzerinde büyük etkilere sahip olabileceğinden ciddi bir çevresel sorundur. İklim değişikliğinin sadece toprak erozyonunu şiddetlendirmesi beklenmektedir. Bu çalışmanın amacı, Yunanistan'da toprak eroyonunundaki azalmayı bir bütün olarak ele alan yeni teknolojiler kullanarak daha doğru bir şekilde ölçmektir.

Çalışma alanı: Çalışma alanı, düz ve dik yamaç alanları ile farklı arazi kullanım alanları bulunan, sık olarak orman yangıları görülen, farklı koşullar altında toprak erozyonunu değerlendirme imkanı veren Thasos adası, Yunanistan'dır.

Materyal ve Yöntem: Toprak erozyonu iki farklı ölçekte değerlendirildi (mikro ve makro ölçek). Mikro ölçekte, erozyon ve diğer etkileyici faktörleri ölçmek için ultrasonic teknoloji ile birlikte farklı sensörler kullanıldı. Macro ölçekte, öncelikle GIS'de mevcut olan bir toprak kayıp eşitliğinden yaralanıldı. Buna ek olarak, paydaşlar için bir Entegre Bilgi Sistemi geliştirildi.

Sonuçlar: Doğru ve sürekli olarak toprak erozyonunu ölçen yeni bir araç geliştirildi. Otomatik Toprak Erozyonu İzleme Sistemi (ASEMS) belirli bir yerdeki çevresel değişiklikleri izleyebilir ve depolayabilir (mikro ölçek). Sistemin ölçebildiği değişkenler: i) toprak erozyonu/çökelmesi (taban seviyesi değişiklikleri), ii)toprak nemi, iii) toprak sıcaklığı, iv)yağış ve v)hava sıcaklığıdır. Son olarak, geniş alanlar (makro ölçek) için toprak erozyonunu azaltmaya imkan veren bir Entegre Bilgi sistemi (I2S) geliştirildi.

Önemli Vurgular: Yunanistan'da devlet kuruluşlarının sürdürülebilir, etkili ve düşük maliyetli olarak toprak erozyonunu hafifletmede başarılı olabilmeleri için yararlanabilecekleri yeni araçlar (ASEMS and I2S) ve GIS'de calibre edilmiş bir eşitlik geliştirildi. Bu araçlar Akdeniz'in diğer bölgeleri için de uygulanabilir durumdadır.

Anahtar Kelimeler: Ultrasonik Sensör, Entegre Bilgi Sistemi, Erozyon modelleri, Erozyon Risk Haritaları, İklim Değişikliği

Introduction

Soil erosion is the natural phenomenon of the removal and transportation of the soil particles by forces such as water and wind. The exponential increase in the world population has led to numerous anthropogenic activities that intervene on the natural environments and lead to accelerated soil erosion rates (Yang et al. 2003). Activities that increase erosion rates include agriculture, urbanization road construction and dams that remove or substantially alter the natural vegetation (Bakker et al. 2008; Montgomery 2007). Accelerated soil erosion rates lead to decreased soil quality and potential land degradation and this is why many scientists consider soil erosion a threat as important as climate change.

Climate change is leading to conditions that will alter soil erosion processes. Climate models are forecasting more intense precipitation events even in regions were the total precipitation will decrease, changes in the ratio of the precipitation forms (snow to hail to rainfall), increase evapotranspiration rates and longer periods of drought (Nearing et al. 2004). These changes will cause many and complex changes to soil erosion processes that are very difficult to predict and understand. These many and complex changes will make it even more difficult to predict the exact impacts of climate change on soil erosion although it is expected that the increased rainfall intensity and drought periods (Giupponi and Shechter 2003) should enhance water runoff and consequently soil erosion (Routshek et al. 2014).

Climate change and the increase in the human population and their needs will only put more pressure on the soil resources making soil erosion mitigation an even greater priority. It is already considered one of the most serious environmental threats worldwide for natural and anthropogenic ecosystems. Understanding future conditions regarding soil erosion is a necessity for sustainable management. Numerous methodologies have been used to assess the threat of erosion and official frameworks for soil monitoring have established for most European countries (Morvan et al. 2008). Still there is no European Union common policy (such as the Water Framework Directive or Floods Directive) to assess the erosion (European Commission 2002 and 2006).

Another important factor in regards to understanding, evaluating and predicting soil erosion is its temporal and spatial variability (Renschler and Harbor 2002). Soil erosion is not continuous but rather can have different rates depending on the climatoedaphologic conditions. Certain conditions increase soil erosion vulnerability and lead to accelerated soil erosion. It is important to understand these "critical conditions" to help the mitigation of soil erosion (Vrieling et al., 2008). In addition it has been stated that field plot erosion measurements can either over or underestimate soil erosion rates (Akbarzadeh et al. 2016). This makes it important to estimate erosion rates at larger scales, ideally at the watershed scale, along with indicating the most important areas for soil erosion conservation measures. This high variability of erosion along with the lack of a common European Union policy indicates that tools and methods needs to be established or developed based on new and innovative technologies that have been adapted to assess geomorphologic processes while considering climate change implications.

One of the regions in Europe that should be a priority is the Mediterranean region. This region is already extremely prone to erosion because of the climate that leads to sparse vegetation and because it has been inhabited for thousands of years (Cerdan et al. 2011, Zaimes et al. 2012). Many agricultural lands of the region are now unsustainable and there are very few natural ecosystems that remain that are typically as patches. In addition, this region also has frequent wildfires that lead to areas that are extremely susceptible to increased water runoff and soil erosion (Shakesby 2011, Neary et al. 2008).

Greece as part of the Mediterranean region also has and continues to experience severe erosion throughout the entire country. It has been reported that more than a quarter of the country's total land area (~35,000 km^2) experiences severe soil erosion problems (Mitsios et al. 1995). While the number of publications and research conducted on soil erosion in Greece has increased over the years, minimal systematic and holistic efforts have been done to reduce erosion (Koutalakis et al. 2015) and a strategic management plan for the country is needed due to the current socioeconomic conditions of the country and climate change implications.

The objective of the study was to provide land managers new tool to enhance the mitigation of soil erosion in Greece that would be able to be adopted in the rest of the Mediterranean. To meet this objective the following activities were completed: a) developed a new system that measures continuously and accurately soil erosion at a specific location (microscale). In addition this system also included other sensors to measure parameters that impact soil erosion. b) Used an established erosion equation for the Balkan region coupled with new technologies specifically Geographic Information System (GIS) to indicate areas

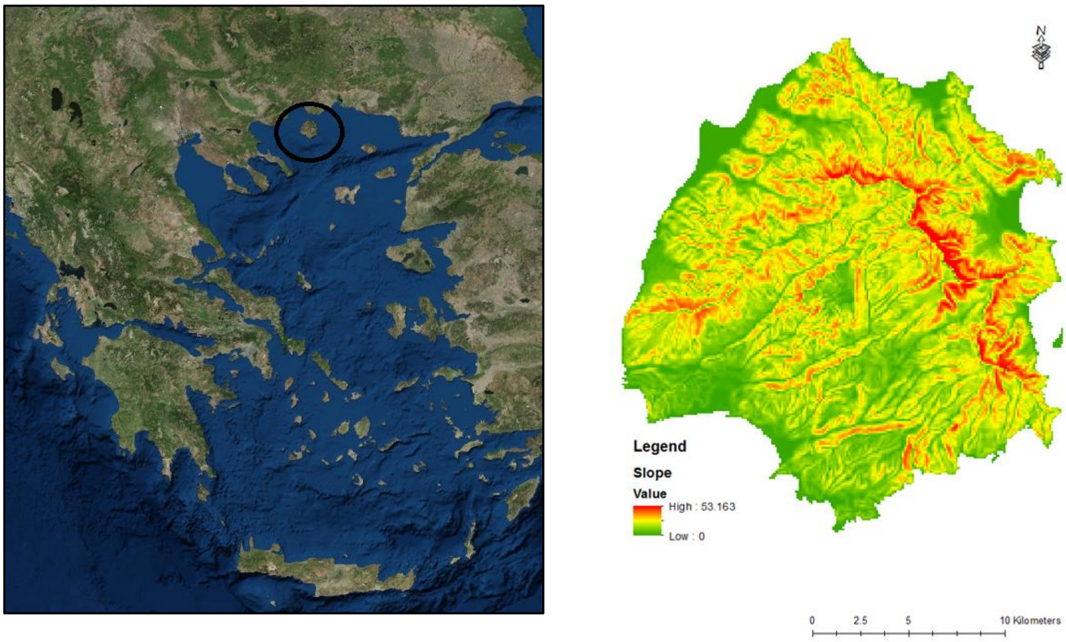


Figure 1. The study area was Thasos Island of Greece. a) Satellite image of Greece that also depicts the location of Thasos Island (source: ESRI, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGP, IGN and the GIS User Community) and b) the slope map of Thasos Island (maps prepared by P. Koutalakis).

That should be prioritized in regards to soil conservation measures (macroscale). c) Developed a Decision Support System on soil erosion that provides stakeholders support to stakeholders to make science based decisions that will enable them to mitigate soil erosion (macroscale).

Material and Methods

Study Area

The study area was Thasos Island (40^o 34"-40^o 48" N, 24^o 30"-24^o 46" E) located in the Eastern Macedonia Region in Northern Greece (Figure 1). It is the most northern island of Greece and has experienced numerous catastrophic wildfires beginning in the 1980s (Ranis et al., 2015) (Figure 2). This has to do with the climate of the area that is characterized as hot-summer Mediterranean (Csa) at the coasts and warm-summer Mediterranean (Csb) in the center of the inland. The average annual temperature is 15.8^oC, and the average annual precipitation is 800 mm. The island is almost circular with a perimeter of approximately of 102 km and occupies an area of approximately 378 km^2 with the inner terrain of the island mountainous and the highest peak at an elevation of 1203 m.

The island's position, altitude, soil, and climate provide ideal conditions for the development of rich flora. The main tree species in the mountainous regions tend to be dominated by *Pinus nigra* at the higher altitudes while the mid-altitudes are occupied by *Pinus brutia*. Shrubs species also occupy large areas that can be either characterized as understory or dominant species. The most dominant species is *Quercus coccifera*. *Olea Europaea* is the species that occupies the lowlands and semi-arid parts of the islands that is highly cultivated.

While the entire island was studied, emphasis was given to the Kalirahi watershed. The main reason was because the majority of watershed was burned in August of 2013 and experienced extensive erosion in the spring of 2015 (Figure 2).

Automated Soil Erosion Monitoring System (ASEMS) (microscale)

The new system of sensors that was developed can measure continuously and provide this data wireless to the researcher. Specifically, it is called the Automated Soil Erosion Monitoring System (ASEMS) and uses an ultrasonic sensor to detect ground level changes (erosion and deposition). The sensor emits ultrasonic pulses and receives the reflected ones. The distance from the sensor to the reflector (ground) is determined by

Figure 2. The severe wildfire in Kalirahi watershed of Thasos Island in August of 2013 led to severe surface runoff events in the spring of 2015. This led to the wash out of this gravel road in Kalirahi watershed in Thasos Island by the excessive runoff the led to erosion (left). The eroded material were deposited along the seacoast and in the sea (right).

Figure 3. The set up of the Automated Soil Erosion Monitoring System (ASEMS) that includes a ultrasonic sensor, soil moisture and temperature sensor, air temperature sensor and a rain gauge (left). A close up of the ultrasonic sensor and soil moisture and temperature sensor can also be seen (right).

measuring the propagation time. This allowed detecting changes continuously with an expected accuracy of up to 1 mm. In addition, another sensor was installed near the ultrasonic sensor that measures soil moisture and temperature. Finally a rain gauge and air temperature sensor were also installed. Most erosion measuring techniques have been developed to measure monthly, seasonally or yearly, although few semi-continuous and continuous techniques have been developed (Lawler 1993, 2005). Soil erosion is an episodic event and most older techniques cannot explain erosional processes, completely. The continuous measurements of ASEMS allow to determine the exact time of the erosional event and the conditions in regard to precipitation, soil moisture and temperature and sir temperature, important parameters for soil erosion processes.

The ASEMS was initially tested in the laboratory. Afterwards the system was placed in a field in the Department of Forestry and Natural Environment Management of Eastern Macedonia and Thrace Institute of Technology Campus in Drama Greece to test it in actual field conditions. After two months, the ASEMS was calibrated and ready to be installed in actual study sites.

Specifically, because of the cost, two ASEMS were installed. Before installation an extensive survey of the Kalirahi watershed was conducted in order to find sites that were close to each other but at the same time had different characteristics. Eventually, one ASEMS was installed in a site with shallow slopes and with overstory vegetation while the other was installed in a site with substantially steeper slopes and with no overstory vegetation cover. This would allow to examine the ASEMS in two different environments, specifically a site with low erosion rates (first site) and high erosion rates (second site).

The Gavrilovic Equation within a G.I.S. environment (macroscale)

To estimate the potential erosion and the sediment yield for the entire island the Gavrilovic equation was used. This specific equation was chosen because it has been developed for the Balkan peninsula. A parametric distributed model based on this equation was developed in G.I.S. The mean annual soil loss is estimated by the following equations (1, 2, 3) (Gavrilovic, 1988):

$$W = T \cdot \pi \cdot F \cdot h \cdot \sqrt[3]{z}$$

Equation 1. The Gavrilovic Equation.

$$T = \sqrt{{}^{t}/_{10} + 0.1}$$

Equation 2. The equation to estimate the temperature coefficient.

$$z = x \cdot y \cdot (\varphi + \sqrt{J})$$

Equation 3. The equation to estimate the erosion coefficient.

where: W is annual average erosion (m^3/year), T is the temperature coefficient, t is the annual average temperature (°C), π is the number 3.14159…, F is the area of the watershed (km^2), h is the mean annual rainfall (mm), z is the erosion coefficient and x, y, φ and J are coefficients dependent on vegetation, geologya and basin's erosive degree, respectively, and J the average slope steepness of the watershed (%). These values of x, y and φ are optained by tables that have been calibrated for the Balkan region.

To estimate the sediment yield equations 4 and 5 were used that follow:

$$G = W \cdot DR$$

Equation 4. The sediment yield equation based on the Gavrilovic Model.

$$DR = \frac{O \cdot D}{0.25 \cdot (L + 10)}$$

Equation 5. The equation to estimate the retention coefficient.

where: O is the perimeter of each sub-basin in km, D is the average elevation of each sub-basin in km and L is the length of each waterway in km. The retention coefficient is estimated by combining the values of the above mentioned parameters.

Soil Erosion Integrated Information System (SE-I^{2}S) (macroscale)

One of the objectives of the project was to develop a tool that could be used by land managers to mitigate soil erosion problems in Greece. Required characteristics of the tool were easy to use and accessible to all. Specifically a Decision Support Systems (DSS) was utilized to handle the large amount of data needed to manage soil erosion because of the many factors that influence it. The ability of DSS to handle large amounts of data has led to many researchers using them in decision making process in regards to environmental problems (Toll and Barr 2001; Zhou et al., 2004). The DSS in our case is the Soil Erosion Integrated Information System (SE-I^{2}S) that considers the major parameters that affect or cause soil erosion and presents the best managerial practices for soil erosion prevention. The input data in the SE-I^{2}S were collected from an extensive literature review along with the information from land managers and stakeholders in Greece that completed an electronic questionnaire regarding the mechanisms that create soil erosion. Another literature review found the best management practices for soil erosion and was also utilized. Finally, the SE-I^{2}S is

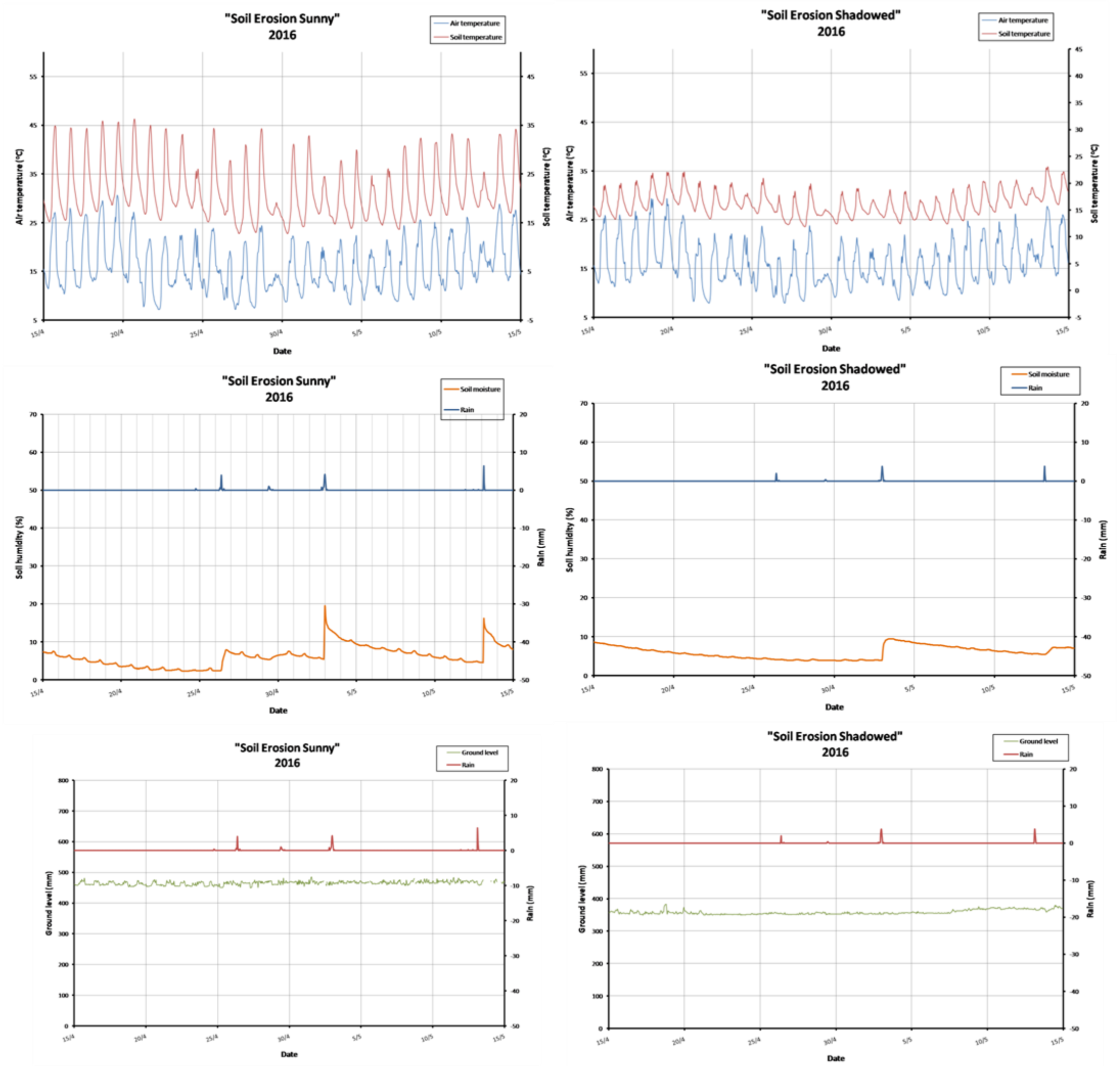


Figure 4. The collected data from the ASEMS from 15/04/2016 till 15/05/2016. The ASEMS were established in sites with an overstory tree cover and a shallow slope (left side) and with no tree cover and a steep slope (right side). The graphs show different measurements by the ASEMS specifically: air temperature with a blue line and soil temperature with red line (different scales to show the temperatures clearly) (top figures), b) Rainfall with a blue line and soil moisture with an orange line (middle graphs) and c) Rainfall with a red line and ground level a green line (bottom graphs).

easily accessible and available to everyone through the website www.map-erossion.eu by selecting the link «Expert System».

Results and Discussion

The ASEMS were in the field for approximately 1 ½ years and appear to be performing quite well. Results from both systems can be seen in Figure 4 for the period from mid April till mid May of 2016. In regard to the temperatures, the site with no tree cover showed greater diurnal variation for both soil and air temperature. This indicated greater potential impact on the soil, from freeze-thaw and desiccation erosional processes. In addition in the ASEMS with overstory tree cover, air temperature had greater diurnal variation compared to soil temperatures. This was not the case for the ASEMS with no tree cover since in many cases the soil temperature diurnal variation was equal of greater than the air temperature. This clearly showed the major impacts that overstory tree cover can have on the

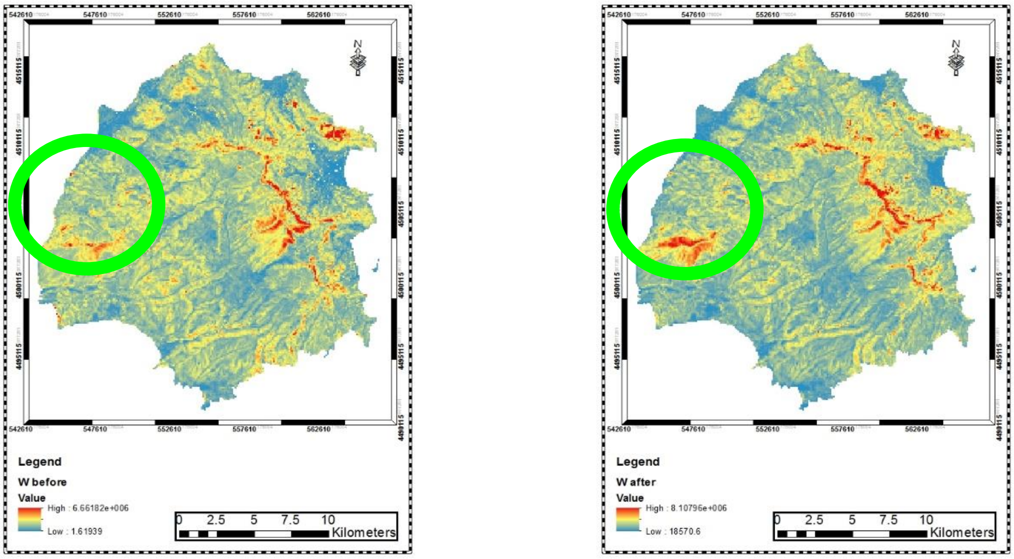
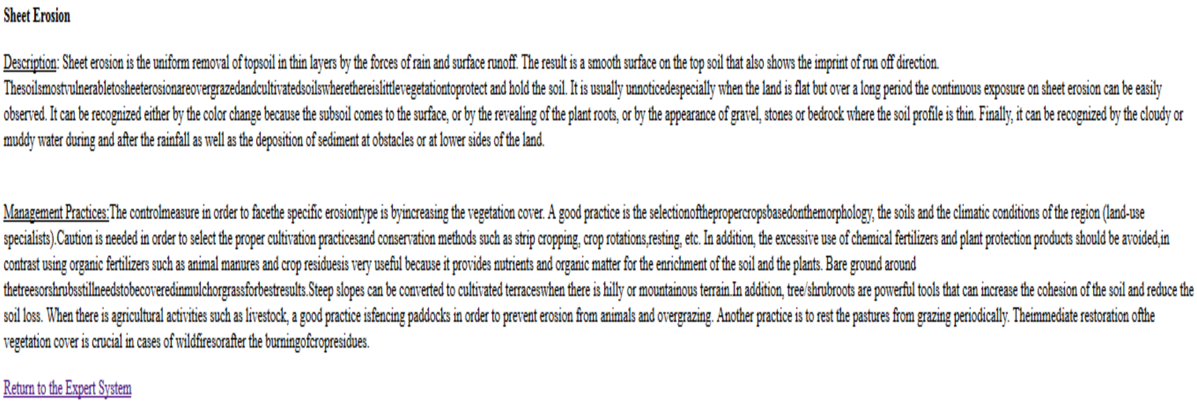


Figure 5. Thasos Island erosion potential map developed based on the Gavrilovic equation with a G.I.S. environment before (left graph) and after (right graph) the wildfire in Kalirahi watershed in August 2013 (maps were developed by Paschalis Koutalakis). For the vegetation cover Landsat images before and after the wildfire will utilized. Kalirahi watershed in indicated with a green circle.

microclimate of an area. Moving on to the second set of graphs (middle) the impact of vegetation was also very evident. Specifically the spikes in soil moisture were significantly more pronounced after precipitation events in the ASEMS with no tree cover compared to the other ASEMS, something expected. Unfortunately during the study periods no significant erosion events occurred that did allow to test to the full extent the ultrasonic sensors. Still the diurnal variation of the sensor (bottom figures) is troubling not and might indicate that additional calibration might be required to achieve the 1 mm accuracy that was the goal of the study. Overall this tool, with the necessary adjustments will be able to provide accurate soil erosion measurements along with insight on the process that lead to surficial erosion at the microscale (specific location).

Using the Gavrilovic equation within a G.I.S. environment provided some excellent maps that could be used by land managers and also decision makers in regard to were conservation measures should be implemented in order to mitigate the severely eroding areas on the island. In addition by comparing the two maps, the impacts of wildfires are quite evident on the erosion potential. Soil erosion potential multiplied after the wildfires. Measures after wildfires should be taken as soon as possible to avoid major catastrophes to the fragile burned soil ecosystem. In addition ground surveying, in some of the map location showed severe erosion, indicating the validity of the produced maps. Similar maps should be developed for the rest of Greece especially in areas after wildfires.

The SE-I^{2}S considered the major parameters that affect or cause soil erosion and presented the best managerial practices for soil erosion mitigation for the environments of Greece. This can be accomplished by the user, by running the SE-I^{2}S and selecting the button "Determine Erosion Type." This allows the user to determine the erosion type. Specifically the erosion types examined by the system are raindrop, sheet, rill and gully. This was done by creating four rules (questions) in the DSS for each erosion type. To create the rules the "if" command is used. So the user answers


Sheet Erosion

Description: Sheet erosion is the uniform removal of topsoil in thin layers by the forces of rain and surface runoff. The result is a smooth surface on the top soil that also shows the imprint of run off direction. Thesoilsmostvulnerabletosheeterosionareovergrazedandcultivatedsoilswherethereislittlevegetationtoprotect and hold the soil. It is usually unnoticedespecially when the land is flat but over a long period the continuous exposure on sheet erosion can be easily observed. It can be recognized either by the color change because the subsoil comes to the surface, or by the revealing of the plant roots, or by the appearance of gravel, stones or bedrock where the soil profile is thin. Finally, it can be recognized by the cloudy or muddy water during and after the rainfall as well as the deposition of sediment at obstacles or at lower sides of the land.

Management Practices:The controlmeasure in order to facethe specific erosiontype is byincreasing the vegetation cover. A good practice is the selectionoftheproperCropsbasedonthemorphology, the soils and the climatic conditions of the region (land-use specialists).Caution is needed in order to select the proper cultivation practicesand conservation methods such as strip cropping, crop rotations,resting, etc. In addition, the excessive use of chemical fertilizers and plant protection products should be avoided,in contrast using organic fertilizers such as animal manures and crop residuesis very useful because it provides nutrients and organic matter for the enrichment of the soil and the plants. Bare ground around thetreesorshrubsstillneedstobecoveredinmulchorgrassforbestresults.Steep slopes can be converted to cultivated terraceswhen there is hilly or mountainous terrain.In addition, tree/shrubroots are powerful tools that can increase the cohesion of the soil and reduce the soil loss. When there is agricultural activities such as livestock, a good practice isfencing paddocks in order to prevent erosion from animals and overgrazing. Another practice is to rest the pastures from grazing periodically. Theimmediate restoration ofthe vegetation cover is crucial in cases of wildfiresorafter the burningofcropresidues.

Return to the Expert System

Figure 6. The SE-I^{2}S allows the user to find the most likely erosion type in their area of interest. Once the erosion type is determine, the system can recommend the best management practices for the specific erosion type. In this image we can see the type of erosion (sheet erosion) and what the best management practices for this sheet erosion are.

the first question in the SE-I^{2}S. Afterwards the system moves onto the next question, based on the type of the answer provided by the user in the previous answer, along with the certainty of the answer. During the design phase of the system, a mechanism was developed and embedded that can interpret the results and determine the most likely type of erosion. This way the user can determine the most likely erosion type in the area of interest. Once the type of erosion is determined the SE-I^{2}S can provide information regarding the best management practices that should be applied in order to mitigate soil erosion in the region (Figure 6).

Another major innovation of SE-I^{2}S is its online feature. This allows users to access it from everywhere they can have internet access, allowing them to find solutions wherever they are and whenever they want to. In addition, having a web access eliminates the need for the user to purchase special software and hardware. The SE-I^{2}S can be used with any computer or hand held device regardless of its operating system, its processor memory and storage capabilities.

Conclusions

In this study new and innovative tools were developed at both the micro and macroscale for the Greek environment. These tools are a major need for the country of Greece that has not had any holistic management efforts to mitigate soil erosion that severely impacts more than a quarter of the country.

The ASEMS is a new system of sensors that measures accurately and continuously soil erosion at a specific location (microscale). In addition it measures other parameters (air and soil temperature, soil moisture and precipitation) that can help understand erosional processes.

At the macroscale two different tools were developed. Specifically, an erosion equation within G.I.S. was developed that can provide maps with erosion potential. This can allow land managers to make science-based decisions on which areas should be prioritized for soil conservation implementation measures. The other tool was the SE-I^{2}S that allows users through a series of question to find the type of erosion in an area and recommended best management practices. This tool has the advantage of being online and easily accessible.

The new tools developed, if utilized by the appropriate authorities in Greece can help mitigate soil erosion. The main advantages of these tools are providing easily understandable, scientifically sound data to land managers, decision makers but also to the general public. They also allow land managers to complete their jobs cost-effectively e.g. place soil erosion conservation practices were the need is the greatest (areas with high soil erosion potential). Finally they have the potential if validated and calibrated to be used in other regions of the Mediterranean.

References

Akbarzadeh A., Ghorbani-Dashtaki S., Naderi-Khorasgani M., Kerry R., Taghizadeh-Mehrjardi R. (2016). Monitoring and assessment of soil erosion at micro-scale and macro-scale in forests affected by fire damage in northern Iran. *Environmental Monitoring and Assessment*, 188 (12), 699.

Bakker M.M., Govers G., van Doorn A., Quetier F., Chouvardas D., Rounsevell M. (2008). The response of soil erosion and sediment export to land-use change in four areas of Europe: The importance of landscape pattern. *Geomorphology*, 98, 213-226.

Cerdan O., Desprats J-F., Fouché J., Le Bissonnais Y., Cheviron B., Simonneaux V., Raclot D., Mouillot F. (2011). Impact of global changes on soil vulnerability in the Mediterranean Basin. ASABE - International Symposium on Erosion and Landscape Evolution, pp 495- 503

European Commission. (2002). Towards a strategy for soil protection. European Commission. Brussels, Belgium.

European Commission. (2006). Thematic strategy for soil protection. European Commission. Brussels, Belgium.

Gavrilovic Z. (1988). The use of empirical method (erosion potential method) for calculating sediment production and transportation in unstudied or torrential streams (Editor White W.R. In: International Conference on River Regime) John Wiley & Sons, pp. 411–422 Chichester, UK.

Giupponi C., Shechter M. (eds.) (2003). Climate change in the Mediterranean: Socio-economic perspectives of impacts, vulnerability and adaptation. Edward Elgar Publications, Glos, UK.

Koutalakis P, Zaimes GN, Iakovoglou, Ioannou K. (2015). Reviewing Soil Erosion in Greece. World Academy of Science, *Engineering and Technology International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering*, 9(8), 816-821

Lawler D.M. (1993). The measurement of river bank erosion and lateral channel change: A review. *Earth Surface Processes and Landforms*, 18, 777-821

Lawler D.M. (2005). Defining the moment of erosion: the principle of thermal consonance timing. *Earth Surface Processes and Landforms*, 30, 1597-1615

Mitsios J., Pashalidis C., Panagias K. (1995). Soil erosion - Mitigation techniques to soil erosion. Zymel Editions, Athens, Greece.

Montgomery D.R. (2007). Soil erosion and agriculture sustainability. Proceedings of the National Academy of Science, USA 104, 13268-13272

Morvan X., Saby NPA, Arrouays D., Basa C.L., Jones R.J.A., Verheijen F.G.A., P.H. Bellamy P.H., Stephens M., Kibblewhite MG. (2008). Soil monitoring in Europe: A review of existing systems and requirements for harmonization. *Science of the Total Environment*, 391 (1), 1-12

Nearing M.A., Pruski F.F., O'Neal M.R. (2004). Expected climate change impacts on soil erosion rates: A review. *Journal of Soil and Water Conservation* 59(1), 43-50.

Neary D.G., Ryan K.C., DeBano L.F. (eds). (2008). Wildland Fire in Ecosystems: Effects of Fire on Soil and Water. General Technical Report RMRS-GTR-42. U.S.

Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, UT.

Ranis G.D., Iakovoglou V., Zaimes G.N. (2015). Ecosystem Post-Wildfire Effects of Thasos Island. World Academy of Science, *Engineering and Technology International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering* 9(10), 1242-1245.

Renschler C.S., Harbor J. (2002). Soil erosion assessment tools from point to regional scales—the role of geomorphologists in land management research and implementation. *Geomorphology* 47, 189-209.

Routschek, A., Schmidt, J., Kreienkamp, F. (2014). Impact of climate change on soil erosion - A high-resolution projection on catchment scale until 2100 in Saxony/Germany. Catena 121, 99-109.

Shakesby, R.A. (2011). Post-wildfire soil erosion in the Mediterranean: Review and future research directions. *Earth-Science Reviews* 105, 71-100

Toll D.G., Barr R.J. (2001). A decision support system for geotechnical applications. Computers and Geotechnics 28(8), 575-590.

Yang D., Kanae S., Oki T., Koike T., Musiake K. (2003). Global potential soil erosion with reference to land use and climate changes. *Hydrological Processes*, 17, 2913-2928.

Vrieling A., de Jong, S.M., Sterk G., Rodrigues S.C. (2008). Timing of erosion and satellite data: A multi-resolution approach to soil erosion risk mapping. *International Journal of Applied Earth Observation and Geoinformation*, 10(3), 267-281

Zaimes G.N., Gounaridis D., Iakovoglou V., Emmanouloudis D. (2012). Assessing soil erosion risk for Rhodes Island, Greece with a GIS-based multi-criteria decision analysis. Proceedings of the IASTED International Conference Water Resource Management (AfricaWRM 2012) September 3-5, 2012 Gaborone, Botswana, Africa, pp. 317-324.

Zhou, Q. Huang G.H., Chan C.W. (2004). Development of an intelligent decision support system for air pollution control at coal-fired power plants. *Expert Systems with Applications*, 26(3), 335-356.