INFILTRATION TO SURFACE RUNOFF RATIO ESTIMATIONS WITH SURFACE GEOPHYSICS IN THE TOPSOIL OF LOESS DEPOSITS (ZALA REGION, HUNGARY)

Imre Müller
Pannon University
Georgikon Faculty of Agronomy
Department of Meteorology and Water Management
P.O. Box 71. 8361 Keszthely
E-mail : imre.muller@unine.ch

Abstract

Three geophysical methods were applied to estimate infiltration to surface runoff ratio of topsoils in Loess environment. The test field (Tilaj, Zala county), divided in fallow land and plough-land, present similar magnetic susceptibilities and seismic velocities, but a significant difference is showed up by electrical resistivities, with a short Wenner array (a=0.5m). Due to the biological activities, the fallow land remain porous and permeable, thus favour good infiltrations. In this area the distribution of resistivities is heterogeneous and varies between 58 and 178 Ohmm. In the plough-land, also treated with chemicals, the biological activities diminish in the topsoil, producing clogging, and reduction of porosity and decrease of permeability. Surface runoff and erosion appears. In this part of the test field resistivities are low, 23 - 40 Ohmm and homogeneously distributed.

Keywords: topsoil, infiltration, surface runoff, surface geophysics

Összefoglalás

Három különböző geofizikai módszer paramétereivel próbáltuk megkülönböztetni azt a két egymással határos területet, egy régen parlagon heverő gyepet és egy művelés alatt lévő szántót, ahol a beszivárgás és a felszíni lefolyás aránya között nagy különbség figyelhető meg. A Löszön kialakult talajon (Tilaj, Zala megye) a mágneses szuszceptibilitás és refrakciós szeizmika egyforma értékeket mutatott ki a mintaterület mind két részén, de a geoelektromos szelvényezés, Wenner felállással (a=0.5 m), igen jelentős különbséget talált. A gyepet életben tartó biológiai folyamatok jó porozitást és permeabilitást biztositanak a talajnak és egyben jo beszivárgást is. Itt az ellenállások heterogén eloszlásúak, 58 - 178 Ohmm értékek között váltakozva. A szántóföld vegyszerekkel is kezelt talaja viszont biológiai aktivitás hiányában erősen tömörödik, porozitása és permeabilitása csökken. Itt a felszíni lefolyás és az erózió dominál. Erre a területre homogén eloszlású alacsony ellenállások a jellemzőek 23 - 40 Ohmm értékekkel.

Introduction

Vast regions of Hungary are covered with Quaternary eolian sediments, the Loess. These fine and well sorted dusts, with variable thickness, are mainly composed of siliceous grains more or less cemented with carbonate. Their terrestrial origin is marked by the presence of small fossil Gastropodes (Pupa muscorum, Succinea oblonga, Helix hispida) as indicated by Papp & Kertész (1965). In the region of Zala (Western Hungary) the thickness of these porous deposits vary generally between 2-10 m, overlaying Tertiary Pannonian clays, marls and sandstones (Hertai 2003). Loess terrains are fertile and precious compared to tertiary clays and marls, which seem to be poor quality for agriculture. Loess has low permeability: K about 10^{-6} – 10^{-7} m/s (Petro 2003) but constitutes often local aquifers feeding small springs with stable temperature and chemistry.

In the last fifty years not only climate is changing but also important transformations happened in the agricultural practice, introducing modification even in the water-cycle. These new methods compact the surface, destroying the superficial porosity of the soil, indispensable to favour fast infiltration under heavy rain or rapid snowmelt. On the other hand the compacted topsoil accelerates the development of an excessive surface runoff and thus the land-erosion. The disappearance of the fertile overburden by erosion would be a dramatic issue for agriculture. Several research projects tend to quantify the Loess degradation parameters. One of them, proposed by B. Csepinszky, measures in situ and on line, the erosion parameters in a field laboratory, assisted by a meteorological station and hydrometry. These exact methods are indispensables and constitute the best approach, but are expensive and time consuming. Our aim is to find out and propose a fast and simple geophysical test for qualitative estimation of infiltration to surface runoff ratio, in different setting of the land use. To experiment an adequate technique a small test site were delimited for the comparison of different geophysical methods, regarding the topsoil characteristics in both cultivated and non cultivated areas. This test site in the Zala department (Tilaj village) has the following UTM (1984) coordinates: 33 T 0656145 / 5186195; 06562000 /5185973; 0656143 / 5185958; 0656070 / 5186178.

The area is situated on a slightly sloping hill and can be divided in two parts by the coordinates: 0656098 / 5186047 and 0656170 / 5186075. The NW part is a yearly re-cultivated plough-land with intensive use of fertilisers and herbicides. The SE part is a long time not more cultivated prairie, a fallow land. On the cultivated area important surface runoff can be observed after each heavy rain or snowmelt event, with significant erosions phenomena, like erosions channels. On the fallow land, in the same period of weathering the surface runoff is rather negligible and the meteoric water infiltrates.

Material and Methods

Geophysical survey

The challenge for the surface geophysics is to characterize the infiltration to surface runoff ratio indirectly, with some simple but contrasting geophysical parameters, thus permitting to clearly discriminate the two parts of the test field having the same overburden. Several methods were tested to determine if any significant difference exists in the physical properties of these two domains, using magnetic susceptibility survey, refraction seismics and geoelectrical survey. Principles of these methods are extensively explained in several treatises (Kearey & Brooks 1993, Milsom 1989), therefore only a short summary is presented below.

The magnetic susceptibility is the ability of a rock to become temporarily magnetised while a magnetic field is applied to it. This temporary magnetisation is called induced magnetisation:

$$\text{Induced magnetisation} = \text{susceptibility} \times \text{magnetic field} \qquad (1)$$

The value of the susceptibility of a rock depends on both the type of magnetic mineral (Magnetite, Hematite) and its concentration. Susceptibility itself has no units and the value is given by rationalised SI units. It can be measured directly in the field with a Kappameter. If magnetite is present in the rock, it is dominant for the susceptibility. The working hypothesis to undertake susceptibility measurements is that floods could introduce changes in the relative homogeneous distribution of the small but heavy magnetite particles and if sorting occurs during floods, the magnetite concentration and thus the susceptibilities could change in the test field. Over hundred measurements were done, in both areas, with a field kappameter (Mini-Kappa, Geofizika Brno). In the entire region the magnetic susceptibilities vary between 0.1 – 0.38 x 10^{-3} but doesn't exist any spatial anomaly. This means that in the test field of Tilaj the susceptibility is not a useful parameter to characterise and discriminate the surface runoff conditions between the two domains.

Seismic energy, a small earthquake, generated by a sledgehammer blow, can follow three main pathways under the ground from the source to receivers. The direct ray, the refracted ray and the reflected rays. They take different time to reach the receiver geophones and give the time-distance diagram. The velocity of the direct ray in the shallow depth is simply the distance along the surface divided by the arrival time measured by the seismograph. The velocities found from travel-time diagrams give a good indication of the type of rocks that form the layers, though rock types have a range of velocities due to consolidation. In general, velocity increases with compaction, so alluvium and loose sands have a very low velocity (300-500 m/s), cemented sediments, like Loess or sandstones, have a higher one (800-1500 m/s). The idea to apply refraction seismic in the test site is to detect some velocity differences in the topsoil between the plough-land and the fallow-land. Consolidation tends to increase the velocity in the same rock type thus reducing infiltration and favour surface runoff. Six refraction lay-out were done with a 6-chanel digital OYO seismograph, 1 m spaced geophones and 8 kg sledgehammer as seismic source. The time resolution was better than 0.1 millisecond. Using a rule of Thomb, that the geophone line should be ten times the depth, the penetration in the topsoil were limited to about 0.6 m. The measured velocities vary between 360 m/s and 395 m/s. These differences are not sufficient to discriminate, based on velocity contrasts, between the two areas of the test site.

Geoelectrical resistivity survey investigates variations of electrical resistance of rocks, by passing an electrical current to flow through the ground, using wire connected electrodes. The resistivity of rocks usually depends upon the amount of water present in their pores or fractures and on the amount of salts dissolved in it. The main uses of resistivity surveying are therefore for mapping the presence of rocks of differing porosities and permeabilities. Techniques have been designed to determine the vertical structures of a layered earth, as vertical electrical sounding, the VES, or lateral variations, as electrical profiling.

The resistivity characterise the material independent of its shape. It is measured in Ohmm by multiplying the resistance R (Ohm) with a geometrical factor (K).

$$Ohmm = R \ x \ K \qquad (R = Volt/Amper) \qquad (2)$$

Having four electrodes, two for current injection (mA) and two for measure potential differences (mV), we can lay out a resistivity array adapted for the type of investigation being made. The K factor depends on the particular array being used. To perform our electrical profiling the Wenner array were the best adapted for investigate the topsoil in a very shallow depth. The four electrodes were then equally spaced, 0.5 m from each other, along a straight line. With this separation referred to "a", the geometrical factor is:

$$K = 2 \; x \; \Pi \; x \; a = 3.14 \qquad (3)$$

So the resistivity is obtained by: Ohmm = 3.14 x milliV/milliA
The depth penetration of this very short array does not exceed 0.5-0.6 m. A precise DC resistivity meter with cooper electrodes served to achieve the numerous measurements in both sector of the test field.

Results and Discussion

Results of the geoelectrical survey are represented below (Fig. 1) and reveal a significant difference to discriminate the two domains. 36 measurements were done in the test field.
In the cultivated plough-land the topsoil resistivities vary only between 23 and 40 Ohmm, hardly contrasting with those measured in the fallow-land between 58 and 178 Ohmm. Probably, in the not cultivated prairie, as stated by Gobat & al. (1998) and Ensslin & al. (2000), the undisturbed biological activities, interactions of plants, microorganisms and animals, contribute to dislocate the soil. The topsoil is living. These heterogeneous, loose and porous sediments, characterized by relatively high electrical

resistivities are rather permeables and infiltrate heavy rains and fast snowmelts.

On the cultivated plough-land, treated by chemicals, the original and natural biological activities are destroyed and the topsoil become dead. The porosity is then clogged by fine silt and clay particles. This phenomenon is showed up by low electrical resistivities, thus indicating bad infiltration capacity and the development of intense surface runoff.

The resistivity distribution is homogeneous in the cultivated part, contrasting with a heterogeneous distribution in the fallow-land. We can clearly discriminate the two domains by appearance of a homogeneously low resistive area in opposition with a heterogeneous higher resistive part.

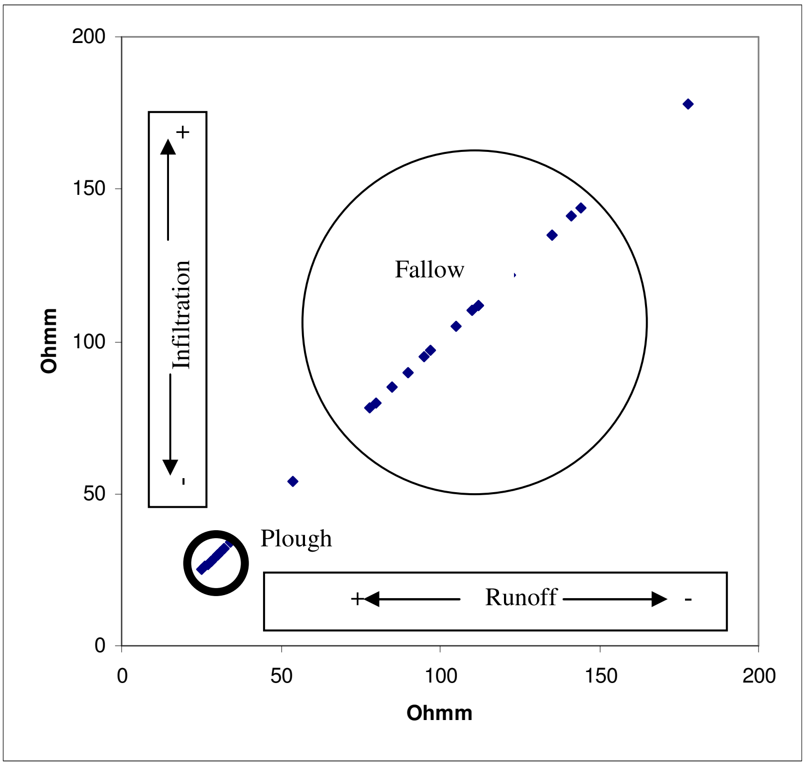

Fig. 1. Wenner (a=0.5 m) apparent resistivities distribution in plough-land

(small and thick with 16 values) and in fallow-land (large and thin circle with 20 values) at the Tilaj testfield.

Geoelectrical resistivity profiling with a short Wenner array, in Loess environment, seem to be an adequate tool for fast and extensive surface mapping to estimate topsoil permeabilities with erosion vulnerability issue. For hydrogeologists the presence of silt and clay, both having low geoelectrical resistivities, indicate low hydraulic permeabilities. Based on numerous measurements in the saturated zone of aquifers this “law” is already well documented and controlled by boreholes and pumping tests (Kelly & Mares 1993). In topsoil environments, in the unsaturated zone, the entire testfield of Tilaj must have more or less similar mineralogical constitution, but when the air-filling of pores is clogged by silt and clay particles, then the resistivities diminish hardly, because silt and clay has only 10-20 Ohmm electrical resistivity. In a very shallow depth, in the biological active zone, geoelectrical resistivities values could be than considered as “clogging” parameters, thus indicating erosion vulnerability. Vulnerability maps could be planed in hazardous areas with indication of the slope and Wenner resistivity.

Acknowledgement

I am very grateful to Mr. B. Csepinszky, who suggested me to experiment surface geophysics related to topsoil erosion and vulnerability. He gave me a lot of ideas and information.

References

Ensslin W., Krahn R., Skupin S. (2000) : Böden Untersuchen ; Biologische Arbeitsbücher – Quelle & Mayer Verlag Wiebelsheim pp.349 ISBN 3-494-01240-7

Gobat J-M., Aragno M., Matthey W. (1998) : Le sol vivant - Presses Polytechniques et Universitaires Romandes Lausanne pp. 519 ISBN 2-88074-367-2

Hartai E. (2003) : A változó föld - Miskolci Egyetemi Kiadó ISBN 963 661 581 0 pp.192

Kearey Ph. & Brooks M. (1993) : An introduction to geophysical exploration - Blackwell Scientific Publications pp.254 ISBN 0-632-02921-1

Kelly W.E. & Mares S. (1993) : Applied geophysics in hydrogeology and engineering practice - Elsevier pp. 289 ISBN 0-444-889936-1

Milsom J. (1989) : Field geophysics - Wiley & Sons pp.182 ISBN 0-471-93248-5

Papp F. & Kertész P. (1965) : Geológia - Tankönyvkiadó, Budapest 1966 pp.399

Petró I. (2003) : A Pálihálási vízbázis vízgyűjtő területének háromdimenziós hidrogeológiai jellemzése. – Diplomamunka -

Eötvös Loránd Tudományegyetem, TTK, Alkalmazott és Környezetföldtani Tanszék, 72 p. (not published, in Hungarian).