Uncertainty of saturated hydraulic conductivity measurements: comparative assessment of different determination methods

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Abstract

Vadose zone related processes (i.e. water movement, contaminant transport) depends highly on soil hydraulic parameters. Saturated hydraulic conductivity (KSAT) is a key parameter for the soil water movement. KSAT have a crucial impact on water movement from the soil surface to ground water. This parameter is required as input for many ecological, environmental and agricultural models, not only to characterize the plant-soil-atmosphere interactions, but also to characterize compacted liners used for landfills as final cover that are subjected to restrictive regulations. A special understanding and care should be given to the sources of variability of KSAT in particular in time and space. The method used to determine the saturated hydraulic conductivity is considered as a source of variability of this parameter among many others. While various laboratory methods and in-situ measurement techniques have been developed to measure the KSAT, their implementation remains expensive and time consuming. Modelling based techniques such as parameter estimation and pedotransfer functions have gained a large popularity as alternatives to the former traditional KSAT parameter measurements. In this study, together with the assessment of spatial variability of KSAT within an agricultural land and a landfill we compared different methods for the KSAT determination. The comparison was carried out between in-situ and laboratory measurements by fitting equations to the experimental evaporation method as well as assessing the applicability of some pedotransfer functions (PTFs) for the KSAT estimation.

***KEY WORDS:** saturated hydraulic conductivity, Guelph, evaporation method, pedotransfer, laboratory experiments; landfill , agricultural field*

Study sites

Agricultural field-Site A

The study site is a maize field (45°13’31.70’’ N, 9°36’26.82 E) located in Northern Italy-Lombardy region (figure 1). This field belongs to the Consortium of Muzza Bassa Lodigiana (MBL). It is a surface irrigated field that covers an area of 6ha.

Disturbed and undisturbed soil samples were collected at different points A01, A02, A03 and A04, at different soil depths surface, 20 cm and 40 cm. We limited our measurements to the first 40 cm of the soil, since the top soil is more susceptible to variability due to agronomic practices and biological activities than deeper layers.

Figure 2. location of sampling points-Secugnago site

The selection of sampling points aimed at assessing the spatial variability of soil properties as well to assess any possible effect of surface irrigation at different locations of the field as presented in figure 2: Within this study site, part of the field was used for maize cultivation from which A01, A02, A03 were collected while another part of the field was left uncultivated for more than 8 successive years from which the sample A04 was taken.

Figure1. location of study sites

Landfill-Site B

Figure 3. Scarpino landfill- Genoa Italy

This site is a landfill, established in 1968 on Monte Scarpino, for municipal solid waste (MSW) of Genoa and its province. This landfill spans over 100 hectares in the upstream part of a flashy stream located in one of the rainiest area of Italy. The landfill is one of the largest in Europe and operates since the early sixties collecting waste at a rate of about 1000 tons/day. The landfill vertical profile displays several deposits of wastes subdivided by layers of compacted soil, for a total depth ranging from 40 to 70 meters.

The site was monitored for several years showing a high fluctuations of leachate level especially under high rainfall rates conditions. A compacted soil layer was designed as final cover in order to reduce the amount of water infiltrated through the waste. For this site, previous measurements were carried out on the original capping allowed to have an idea about the spatial variability of the saturated hydraulic conductivity. During the new measuring campaign measurements were performed on a compacted soil liner that was designed as final cover in order to reduce the amount of water infiltrated through the waste.

Methods

Within both study sites soil sampling for laboratory experiments and field measurements using Guelph permeameter were performed, only for site B double ring infiltrometer tests (DRI) were performed in order to compare the two in-situ KSAT measuring methods (Guelph and DRI). Soil samples and in-situ measurements on the top soil of the two study sites were used in order to compare the in-situ and laboratory measuring techniques. The study site A was used to test different fitting equations for the KSAT estimation accuracy using the evaporation method data (Brooks and Corey and Van Genuchten) and to evaluate the relevance of selected pedotransfer functions (PTF) for KSAT estimation for the selected study area.

Figure 4. HYPROP-UMS and KSAT-UMS devices

Undisturbed soil samples were collected for laboratory measurements of KSAT, and bulk density determination together with disturbed soil samples that were used to measure other soil properties, organic matter content and soil texture, that were used as inputs for PTFs. Replicates soil samples for the same sampling point were collected from least possible distance (20 cm) in order to avoid the effect of spatial variability and within the same day during which field measurements were taken in order to avoid the temporal variability of soil properties.

To summarize, measurements were carried out using :

- Falling head method – KSAT UMS device in the laboratory
- Evaporation method – HYPROP UMS device in the laboratory
- Guelph permeameter – Field
- Double ring infiltromenter – Field
- Pedotransfer functions – Indirect method

Figure 5. Guelph and double ring tests-Landfill

Results

Different KSAT determination techniques

- Guelph permeameter measurements underestimated the KSAT value with one order of magnitude difference as compared with the laboratory falling head method for the agricultural field. Furthermore, this result may not be always valid since, tested for an artificial homogeneous soil at the landfill study site, the laboratory falling head and in situ tests gave quite similar results, this could make the validity of some tests depends highly on the tested soil conditions.
- Field methods exhibit the advantages of larger sampled volume with a direct contact with the surrounding soil. The disadvantages of these methods are mainly the boundary conditons, the flow field, and sampled volumes that are not exactly known. Guelph permeameter gave lower values of KSAT probably due to the borehole preparation and air entrapment.
- Field measurements usually yield lower values of KSAT due to the air entrapped during the measurements and the soil can’t reach full saturation.

Table2. Average Field vs laboratory KSAT measurements -Top soil

	Location	Guelph	KSAT-UMS	Double ring
		(cm/day)	(cm/day)	(cm/day)
Site A	A01	0.27	1.4	-
	A02	2.08	30.75	
	A04	39.92	509.2	-
Site B	S	0.07	0.33	0.13

- Evaporation method data fitted to Brooks and Corey or to Van Genuchten, yielded different KSAT values. The saturated hydraulic conductivity estimation from the evaporation method depends on the selected parametric equation during the fitting process of experimental results of the HYPROP. For this reason the equation that gives more accurate result should be well selected for the determination of KSAT for a given study site.
- Basic soil properties required as inputs for tested pedotransfer functions, ROSETTA (Schaap et al., 1996) and HYPRES (Wösten et al., 1999) were measured. The tested soil texture of the study area (Site A) was included within both data bases from which these pedotransfer functions were developed. The evaluation of these PTFs, has proven that tested PTFs for this study site yielded an overestimation of KSAT with one order of magnitude more as compared to the laboratory measurements.

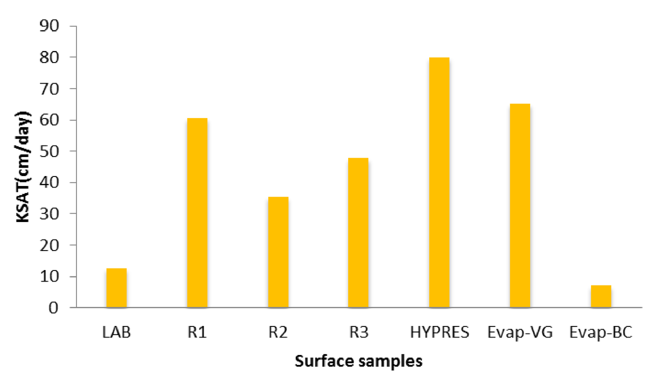

Figure 8. Average Saturated hydraulic conductivity of surface samples

KSAT spatial variation

Table1. Saturated hydraulic conductivity at different locations and depths- Site A

Sample	Depth(cm)	Ksat (m/s)
A01	S	1.68E-07
	20	1.98E-07
	40	1.95E-07
A02	S	3.69E-06
	20	3.36E-06
	40	1.28E-07
A03	S	6.95E-07
	20	6.12E-07
	40	2.37E-07
A04	S	6.11E-05
	20	4.05E-06
	40	1.22E-07

Figure 6. Saturated hydraulic conductivity map of the cropped part of the field- Site A

High number of macropores (earthworms channels, grass roots) was observed for the samples collected at the sampling point A04 while none was found within the cropped part of the field. This part presented the highest KSAT values. Instead lower values of KSAT were recorded at 20cm and 40 cm depths that was justified by the high bulk density, low organic content values and less macropores. Within the cultivated part of the field a maximum difference of one order of magnitude was found between (A01, A02 and A03). Comparing these samples to those collected from A04, the uncultivated part of the field, showed higher KSAT value for surface samples, lower bulk density and more earthworms channels. As presented in the KSAT map (figure 6) of the cropped part of the field as well the values found at different soil depths (Table 1) this parameter was spatially variable vertically and horizontally.

The landfill surface is subdivided in zones by artificial slopes. These zones display different surface caps with different infiltration capacities. The leachate level was continuously monitored at the outlet of the drainage system located downstream the landfill. Soil moisture profiles at different locations of the landfill cap were also monitored. It was observed that mainly under high rainfall rates, the areas with high saturated hydraulic conductivity values contributed more to infiltration rates thus more leachate production. These areas as presented in the figure 7 , are located in the upper part of the landfill. This yielded also slope stability problems.

The values of measured saturated hydraulic conductivity values at different locations of the landfill are higher than the values required according to Italian regulations. For this reason a new compacted cap was designed (still under tests).

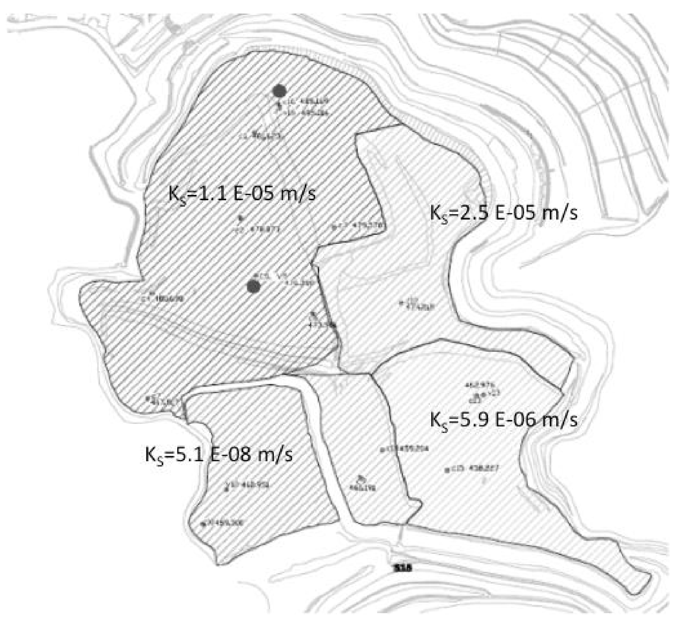

Figure 7. Average Saturated hydraulic conductivity of the operative part of the landfill-Site B

Conclusions

The experiments were carried out at two different study sites (agricultural field and landfill), yet they allowed to derive the same conclusions. The Saturated hydraulic conductivity is subjected to spatial variation. The method used to determine the saturated hydraulic conductivity is considered as a source of variability of this parameter among many other factors of variability (i.e.: land use, agronomic practices, roots, pedo-fauna, soil layering and others). This parameter for hydrological simulations should be defined with high accuracy since it highly impacts the water movement. The uncertainty in the prediction of the saturated hydraulic conductivity depends on the method used to define this parameter. Field and laboratory measurements that are usually considered as the most accurate determination methods may also exhibit a certain level of error, depending on the study site conditions, sample collection and disturbance, and instrument installation. Further studies are required to confirm results of this research. The variability of the saturated hydraulic conductivity due to the measuring technique in interaction with other sources of variability should be studied.