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PhD Yearbook | 2019

Chair:
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DOCTORAL PROGRAM IN ENVIRONMENTAL AND INFRASTRUCTURE ENGINEERING

The Doctorate in Environmental and Infrastructure Engineering has been operating since the academic year 2008/2009. The program introduces doctoral students to the world of research on key theoretical and technological elements associated with water, environment, hydraulic and transportation infrastructures, geology, as well as geomatics.
In this context, the program is grounded on environmental, civil, and industrial applications where water is the primary unifying element.
The doctorate program is characterized by a strong inter- and multi-disciplinary structure and is organized according to the following key thematic areas.

1) *Hydraulic Engineering*, where major research themes include: fluid mechanics; fluid-structure interactions; hydraulic measurements; river hydraulics; sediment mechanics; hydraulic risk assessment and management; flow and transport processes in porous systems; hydraulic networks, hydro-energy; oil and gas development and applications.
2) *Hydrology, hydraulic structures, water resources and coastal engineering*, where the main research topics include: hydrology and water resources, with emphasis on the main physical processes of the hydrological cycle, water and energy budgets; hydrogeological hazard and mitigation strategies, including hydrological extremes, floods, droughts and precipitation, early warning operative systems, snow avalanching and flood risk; hydraulic networks engineering; and coastal engineering.
3) *Environmental technologies*, with focus on: water and wastewater treatment technologies (including disposal/reuse of wastewater, sludge management and disposal, anaerobic digestion processes; management and planning of environmental resources (including water quality modelling, knowledge-based decision support systems); solid wastes management (including Life Cycle Assessment of energy and resource recovery initiatives); phenomenology of the atmospheric environment and treatment of gaseous emissions; contaminated soils and their remediation.
4) *Transport infrastructures and geology*, with focus on: transport networks, including functional interactions with regional, national and international territory; sustainable development, in terms of dynamics of development and its relations with the infrastructure system; technological innovation, including methods and indicators for performance characterization of infrastructure construction and maintenance techniques; hydrogeological risk, landslide hazard; water resources identification and management, pollution problems.
5) *Geomatics*, with focus on: physical geodesy and satellite geodesy; positioning and navigation; surface surveying with optical or other sensors, such as SAR, LIDAR; digital photogrammetry and image analysis; remote sensing; geographic information systems; cultural heritage reconstruction and archiving.

The curriculum of PhD students has been tailored to the general and specific research questions associated with the multifaceted interactions between the water sphere and the key evolving anthropogenic activities responding to the needs of modern society.
Career perspectives include opportunities at Universities, Research Centers, public bodies and Authorities, as well as private companies / industry. Small and medium size enterprises (SMEs) which cannot afford the development of an in-house specific know-how program may also require such highly professional profiles to guarantee critical innovation and competitiveness.

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IMPACT OF IRRIGATION TECHNIQUES ON SOIL MOISTURE DYNAMIC

Imen Ben Charfi - Supervisors: Chiara Corbari, Marco Mancini

There is no doubt, that we are facing a serious challenge in our-days of producing enough food to feed the growing population in the world and the scarcity of water resources in many regions. the main aim here is to produce more by using a better management of water agricultural practices (irrigation is the higher consumer of water). The modelling of irrigation water distribution under the different irrigation systems have under studies in the last few decades toward to increase the efficiency.
This study aimed to develop in a first step a model that simulates the water distribution pattern in wind condition under sprinkler irrigation system by using the ballistic theory that computes the droplets trajectory discharged by the sprinkler's nozzle.
The model was developed also to simulate and predict the water distribution of center pivots in different spatial (different sizes of pixels) and temporal basis (hourly and daily basis) from the simulated water distribution of the sprinkler. The computer model was developed using MATLAB software (The Mathworks Inc, MA, USA) to model the water distribution pattern under single sprinkler irrigation system and center pivot. The resulting model was tested and used in the case study area of Barrax, Spain.
The second step of the thesis is the evaluation of the impact of the sprinkler irrigation technique on the water fluxes estimates through a distributed energy water balance model FEST-EWB. The model is validated against ground and satellite data of land surface temperature and evapotranspiration. The last step of the thesis is the optimization of irrigation.
The thesis activities will contribute to the SIM project (Smart Irrigation Modelling, www.sim.polimi.it) activities in its main objective.
The results of the study indicated that the parsimonious use of agricultural water through an operational web tool to reduce the use of water, fertilizer and energy keeping a constant crop yield. The instrument provides in real-time the present and forecasted irrigation water requirements at high spatial and temporal resolutions with forecast horizons from few up to thirty days, according to different agronomic practices supporting different level of water users from irrigation consortia to single farmers. It combines the state of the art of satellite monitoring, meteorological forecast and hydrological modelling allowing a smart irrigation that identifies the right amount of water at right time needed for optimal crop production. The instrument then allows to quantify the impacts on water saving and on economic and environmental benefits with specific indicators which are computed for the different levels of end-users.

Key words: smart irrigation,soil moisture, water distribution pattern sprinkler, ballistic model, centerpivot

THE LAND-WATER-FOOD NEXUS

Davide Danilo Chiarelli

Supervisors: Prof.ssa Maria Cristina Rulli, Prof. Paolo D'Odorico

Water and soil are essential but limited resources that support food security and livelihoods across the planet. Population growth, richer diets, and growing bioenergy demand continue to increase competition for these natural resources. In many places soil and water are already being utilized at unsustainable rates (i.e., rates that exceed the pace with which natural systems can regenerate these resources), and there is widespread agreement that humanity must find alternative strategies to meet future human demand and achieve environmental goals together. There is therefore a pressing need to better understand current practices in the use of soil and water resources and to identify solutions that promote a more sustainable management of soil and water resources. By using a nexus approach, it is possible to better understand the synergies and trade-offs of a particular strategy and to highlight pathways that can align with sustainability and food security goals.

My thesis work addresses several important needs along these lines by using a Land, Water and Food nexus approach at multiple spatial scales to analyse competition for freshwater and soil by various human uses including the food and industrial sectors. In order to assess global water requirements in agricultural areas and the impact on water and food security of global environmental change (e.g., land use change, climate change, urban expansion), I first developed a spatially distributed vertical soil-water balance model. This model allowed me to evaluate the total amount of water required by crops (i.e., crop water requirement (CWR)) and to disaggregate this demand between green water (GW) (i.e., water provided through rainfall) and blue water (BW) (i.e., water provided through irrigation from surface or groundwater). I then applied this model to evaluate to what extent, in water-limited countries (where there is either a physical lack of freshwater resources or economic water scarcity), improvements in crop yields may be achieved by providing more irrigation water. Interesting results have been obtained for India, where a crop replacement scenario has been assessed to individuate more sustainable uses of freshwater resource and fertile land. Along with sustaining food production, freshwater and fertile soil maintain Earth ecosystems and support other human activities, such as cash crops and timber production. Thus, I focused my attention on rubber plantations that have been experiencing unprecedented and rapid expansion during the last 15 years. Nowadays rubber fields occupy more than 10million hectares and require 149 km3 of water (125 km3 of GW and 24 km3 of BW), significantly affecting food security in some countries such as Indonesia, Thailand and Vietnam. Recognizing the limitation of the agricultural system, the need to reduce greenhouse gas (GHG) emissions, the growing demand for energy and food, and the susceptibility of agricultural yields to climate fluctuations, many governments and corporations have become increasingly active in the purchase of land in response to this uncertainty. Specifically, I analysed the drivers of LSLA such as need of land, lack of water the associated impacts on deforestation and land degradation.

BIOLOGICAL H_2-MEDIATED *IN-SITU* BIOGAS UPGRADING

Viola Corbellini

Tutor&Supervisor: Full professor Francesca Malpei

In the current context of global energy demand increasing, and developing countries population expansions, renewable energy generation has to grow due to its key role in reducing global greenhouse gas emissions and offering enormous potential for replacing fossil fuels. The recently proposed Power-to-Gas technology consists of the highly smart integration of such naturally fluctuant renewable as eolic and solar power sources off-peaks to generate hydrogen via water electrolysis that can be oxidized to methane and water. A quite recent process intensively investigated to achieve H_2 methanation is the biological reaction of H_2 and with external CO and CO_2 sources into CH_4. This technology represents also an innovative option method for biogas upgrading which seems to be cheaper/lower energivoros if compared to currently available biogas upgrading technologies on the market.
The biological biogas process exploits a well-known archaeal methanogenic metabolism of the hydrogenotrophic methanogens, autotrophs that utilize CO_2 for growth purpose and hydrogen as an electron donor, producing bio-methane. This process has been studied in two different set-ups, distinguished by where the H_2 is provided with respect to the anaerobic digestion process: *in-situ* option, in which H_2 is delivered directly inside the biogas digester and there biologically coupled with the endogenous CO_2 produced by means of the autochthonous hydrogenotrophic methanogens; the *ex-situ* option, in which CO_2 from external sources (e.g. biogas, CO_2 storage, syngas) and H_2 are injected together inside a reactor containing selected hydrogenotrophic cultures, resulting in their conversion to CH_4.
The general main goal of this PhD thesis was to deepen the study of the biological upgrading process by means of *in-situ* hydrogen injections. A first study aimed to provide fundamental elements to propose a simple protocol to measure the specific hydrogenotrophic methanogenic activity (SHMA), moving towards a standard activity measurement. Manometric batch tests assessing the specific hydrogenotrophic methanogenic activity of three anaerobic sludges taken from municipal full-scale digesters were assessed. Two different experimental set-ups were utilized for comparison: an automatic manometric device and a manual measurement system. Statistical analysis was carried out aimed at assessing the reproducibility of replicates for each sample of sludge performed with the two different apparatus. The SHMA standard measure will support the implementation of the process at full-scale in evaluating the initial substrate loads that can be treated and could allow to carry out toxicity tests with respect to certain substrates. The activity determinations were conducted at substrate concentration well above Ks value to ensure to operate in the zero order kinetics conditions. Both apparatus allowed measuring the SHMA but some constraints related to the automatic tightness were observed, further investigations are needed to test the reproducibility of another automatic system. A noteworthy major result is that the statistical non-reproducibility may not lead to an error in the estimation of the kinetics; vice versa statistically reproducible replicas can lead to errors in the estimation of the kinetic parameter. Further experimentation was focused on a rapid enrichment strategy capable of limiting the organic degradation unbalance and allowing a fast start-up phase of the *in-situ* biogas upgrading reactors, at pilot or full-scale. This fundamental theme has been perused with 2+1 control lab-scale CSTRs filled with anaerobic sludge collected from a full-scale WWTP. The experimentation lasted 50 days divided into 5 phases: the anaerobic digestion start-up followed by four H_2 injection phases (H_2/CO_2 ranging from 1:1 to 4:1 on a molar basis). Despite a temporary slight increase in the total concentration of VFA during phase II (2.56 $gHac \cdot L^{-1}$), and in phase III a mild pH increment indicating the expected CO_2 depletion (anyway below 7.4), the strategy proposed was effective. In the last phase, in the biogas, the methane content of about 80% was achieved, thus suggesting that the use of H_2/CO_2 above the stoichiometric value could further improve the biological biogas upgrading. An innovative biological upgrading set-up, called Hybrid, was designed and assessed in a continuous experiment lasted 4 months at DTU University (Denmark). This innovative design exploits the combination of the *in-situ* and the *ex-situ* processes in a combined configuration. The system consists of a double-stage reactor composed of a CSTR, working as a conventional anaerobic digester and where the H_2 is injected (*in-situ* biogas upgrading), and an up-flow reactor, receiving the upgraded biogas from the CSTR, together with the unutilized H_2. The overall objective of the work was to perform initial methane enrichment in the *in-situ* reactor, avoiding deterioration of the process due to elevated pH levels and subsequently to complete the biogas upgrading process in the *ex-situ* chamber. The CH_4 content in the first stage reactor reached on average 87% and the corresponding value in the second stage was 91%, with a maximum of 95%. A remarkable accumulation of Volatile Fatty Acids (VFA) was observed in the first reactor (*in-situ*) after 8 days of continuous H_2 injection reaching a concentration of 5.6 gTVFA/L. Nevertheless, after an adaptation period of one hydraulic retention time (HRT), the system started to recover from the stress and the VFA decreased to 2.5 g/L. No pH drop was recorded during the period characterized by increased VFA concentration mainly due to the consumption of the endogenous CO_2 by hydrogenotrophic methanogenesis. Indeed, the bicarbonate contained in the liquid phase of the biogas reactor was coupled with the injected H_2, and thus the pH was maintained within the range for optimal methanogenesis (i.e. slightly increased from 8.3 to 8.5) despite the high VFA accumulation. The effect of H_2 injection on the microbial community in both reactors was analyzed by 16S rRNA gene amplicon sequencing which revealed an increment in the relative abundance of hydrogenotrophic methanogens and homoacetogens in *in-situ* reactors, while the microbial community in the *ex-situ* chamber was more simple dominated by hydrogenotrophic methanogens. Finally, based on results of previous experiments, biological *in-situ* biogas upgrading from sewage sludge and in continuous-mode was investigated during a period of more than 7 months with 2 parallel CSTRs (11L), fed on a mixture of sewage sludge at mesophilic conditions (OLR of 1.5 $gCOD\ L^{-1}\ d^{-1}$). H_2 gas injections were progressively increased from 0:5:1 to 7:1 (H_2/CO_2 ratio) with pH controlled to 7.4. Maximum methane content of 83% and a minimum of 5% of CO_2 and 91% of H_2 utilization were achieved at 7:1 H_2/CO_2 ratio. A noteworthy ethanol accumulation, during the very first H_2 Phase (H_2/CO_2 of 0.5:1) occurred (up to 2.5-3 $gCOD\ L^{-1}$). Nonetheless, maintaining the H_2 feeding, ethanol was rapidly depleted, thus indicating the system was able to withstand the new operative conditions. A significant alkalinity reduction due to CO_2 depletion in the liquid phase of 50% and 17% in R1 and R2 was registered. Also in this work, the effect of H_2 injection on the microbial community in both reactors was analyzed by 16S rRNA gene amplicon sequencing. Results revealed a new shape of the core microbial community able in co-operating to the parallel organic substrate degradation and CO_2 conversion to extra methane. More in detail, the anaerobic consortia presented a slight variation of the bacterial community in which also homoacetogens were detected, and to an archaeal community mostly composed by hydrogenotrophic methanogenic and only one acetoclastic methanogenic species.

PREPROCESSING OF SENTINEL-2 OPTICAL IMAGES: A NEW PROCEDURE FOR CLOUDS AND SHADOWS MASKING

Roberta Fagandini - Supervisor: Prof. Giovanna Sona

Sentinel-2 is a multi-spectral optical imaging mission belonging to the Copernicus Programme, an initiative managed and coordinates by the European Commission and the European Space Agency.
The inherent characteristics of Sentinel-2 images can provide an important contribution in many remote sensing applications, from land cover change to coastal and sea surface monitoring.
However, being an optical satellite system, Sentinel-2 images are affected by the disturbances typical of an optical sensor.
For this reason, before dealing with possible remote sensing applications, the research addresses two main issues, which can strongly compromise the usage of Sentinel-2 optical images: the atmospheric effects and the presence of clouds and their related shadows.
Optical sensors are unable to penetrate clouds leading to related anomalous reflectance values.
Because of the lack of thermal bands in the Sentinel-2 dataset, the problem of cloud and shadow detection is still an open issue.
In fact, most of the algorithms proposed in literature rely on the use of thermal bands to identify clouds and to compute cloud altitude, which is an essential information in order to generate the shadow mask through the projection of clouds. For instance, the state of the art about cloud and shadow detection is mainly represented by the Fmask algorithm developed for Landsat images, which takes advantage of thermal bands to identify clouds and shadows. In fact, it starts from the assumption that cloud are colder than land and water surface.
A multi-temporal approach can be more robust, especially in the case of lack of thermal bands, and in this regard several methods have been developed and proposed in literature. Nevertheless, multi-temporal approaches strongly increase data volumes and computational costs.
For this reason, the research work focused on the development of a procedure for cloud and shadow detection over a single Sentinel-2 image within the GRASS GIS environment.
The developed procedure is made of two main steps. The former consists of a series of spectral rules which return two rough masks, one for clouds and one for shadows. The second step instead takes advantage of the relative position of clouds and shadows to remove possible misclassifications.
The applied spectral rules represent essentially values thresholds, comparisons and calculations between bands and they lead to two different rough maps of clouds and shadows.
These rules have been defined starting from a method, proposed in literature and developed for Suomi NPP VIIRS instrument, which have similar spectral bands to the Sentinel-2 sensor, and conveniently refined modifying the existing rules and adding new ones.
Concerning the cloud detection, the rules proposed in literature lead to quite satisfactory results, and therefore they have been implemented within the procedure, with the addition of a new rule to reduce misclassifications.
The most challenging aspect was the definition of the procedure for shadow detection, the existing method indeed returned anomalous results. For this reason the shadow detection algorithm has been developed ex novo.
The definition of general spectral rules for the identification of shadows is more complex.
Unlike opaque clouds, which have spectral characteristics similar to each other, for instance high reflectance values in all bands, pixels in correspondence with shadows have more heterogeneous reflectance values depending on the characteristics of the shadow itself. For instance, darker shadows are more easily identifiable than the softer ones, which are mainly affected by the reflectance of all objects covered by the shadow itself.
To summarise, both cloud and shadow procedures return respectively a rough cloud mask and a rough shadow mask, which require further improvements and elaborations (e.g. transformation from raster to vector, cleaning geometries, removing small areas, checking topology, etc.).
After the application of spectral rules, some misclassifications can still occur in the shadow mask.
In order to remove these anomalous results and to increase the quality of final results, the second step of the whole procedure has been implemented.
Clouds and shadows are spatially intersected in order to remove misclassified areas. This means that all those shadow geometries which do not intersect at least one cloud geometry are removed.
This “cleaning” procedure consists in the translation of the cloud mask as a function of the sun zenith and azimuth angles and of the clouds height.
The result is the final shadow mask in which possible misclassifications are excluded.
The results of the new procedure have been mostly evaluated from a visual point of view, comparing them with the RGB composite of the related image. At the moment of writing indeed, the validation of results remains the main open issue because of the lack of reliable official sources of cloud and shadow masks or of ground truths with which compare the results.
Roughly speaking, it is however possible to state that from a visual perspective the results are satisfactory in terms of number of clouds and shadows detected and of accuracy in the identification of boundaries.
The developed procedure has been implemented as a GRASS GIS add-on module, i.sentinel.mask. Another GRASS GIS add-on module for the preprocessing of Sentinel-2 images, i.sentinel.preproc, has been developed.
Both modules have been accepted as a project of the program for the development of open source software promoted by Google, the Google Summer of Code, successfully accomplished in 2018.

NUMERICAL MODELLING OF FLOW-INDUCED NOISE EMITTED BY CONTROL DEVICES

Luca Fenini - Supervisor: Prof. Stefano Malavasi

This study explores different numerical approaches for the investigation of the noise emitted by a gas flowing inside a pipeline and perturbed by the presence of a flow-control device. Laws about maximum human noise exposure force industries to cut down the acoustical emissions coming from any possible source, control devices included. The characterization of control valves› noise emission is thus a crucial task for the manufacturers of these devices. This is the motivation that raised up this research on the aero-dynamic noise.

The analysis presented in this thesis is made with a numerical approach which is a suitable tool for obtaining information in shorter times and with lower costs than the experimental approach. Numerics is used for the investigation of different aspects of the aero-dynamic noise that are about the physical description of the noise dynamics (generation mechanisms, interaction with the flow and propagation) and about its intensity prediction.

The study has been conducted with the industrial purpose to achieve the information of interest in the lowest time. Because of the complexity of the phenomenon, the numerical models and approaches are chosen as the most efficient for collecting only the information of interest. In fact, suitable numerical methods for a complete description of all the aero-acoustic features would have complexity and burden that go far over the industrial resources and return a large amount of uninteresting data.

The physical investigation of the noise generation and propagation downstream of an orifice is thus performed thanks to the resolution of a system of Acoustic Perturbation Equations (APE) developed in literature. The noise dynamic within the pipe reveals the nature of the acoustic sources and returns noise prediction along the duct. In particular, the noise prediction 1 meter downstream of the control device plays a relevant role because it is identified by the international standards as the reference measure for the acoustical characterization of a device.

The APE system proposed in literature returns a noise description wider than what is sought by valves› manufacturers. An innovative APE system is thus presented as a faster way to collect the information of interest without wasting resources in the simulation of undesired details. This system is tested and its reliability on the noise prediction far from the device is verified.

An even faster approach for obtaining estimation about devices› noise emission is based on the application of the prediction procedure described by the international standards that rule the aero-dynamic noise. In this procedure four parameters are identified as the fundamental for the acoustical characterization of a device; valves› manufacturers must provide their values to the customers.

Different numerical methods can be used for the evaluation of each of them. In this work the focus is on the application of numerics for the estimation of the valve correction factor for acoustical efficiency A_η which is the parameter the external noise is most sensitive to. Aero-acoustic models are applied to fluid-dynamic simulation in order to estimate A_η taking into account its dependency on the flow condition unlike the international standards that provide only constant values for it.

A plant for experimental tests on small devices is finally designed in order to collect further data for future analysis on the aero-dynamic noise.

ASSESSING BASIN EVAPOTRANSPIRATION FROM AERODYNAMIC RESISTANCE ANALYSIS AT FIELD SCALE

Erika Ferrari

Supervisors: Prof. Marco Mancini, Eng. Chiara Corbari

Evapotranspiration (ET) plays a key role in the hydrological cycle and land-atmosphere interaction, thus, a correct evaluation of this variable is fundamental in several fields of application, such as sustainable water management, at the basin scale, and irrigation planning, at the field scale.
In fact, the estimation of atmospheric turbulent fluxes (H and LE) at the land surface has long been recognized as the most important process in the determination of the exchanges of energy and mass among hydrosphere, atmosphere and biosphere.
Since the aerodynamic resistance to heat transfer (r_{ah}) highly affects the evaluation of these variables, the study is focused on r_{ah} estimation.

Different parameterizations for r_{ah} were examined, so as to understand the most reliable ones, for different vegetation height and surface roughness. In particular, aerodynamic resistance for heat transfer is calculated by using nine equations, chosen from literature (either in accordance with the Monin-Obukhov theory or empirical, with different assumption and levels of simplification). These r_{ah} models are validated by comparing sensible heat flux estimated using each r_{ah} equation against H measured by eddy covariance stations, for two cases study: maize canopy and forest (Fig. 1). This analysis is carried out also distinguishing the different growing phases of the vegetation for the maize crop analyzed: from bare soil through the emergence of the crop and to full vegetative development.

In order to estimate r_{ah}, the evaluation of roughness lengths for momentum and for heat transfer, z_{0m} and z_{0h}, is needed. Theoretically, the aerodynamic roughness length is not a geometric parameter, but a dynamic one, depending not only by the structure and formation of surface roughness but also on near-surface windflow conditions. Conceptually, the distinction between z_{0m} and z_{0h} is suggested by consideration of the different transport mechanisms for heat and momentum, in the presence of aerodynamically rough flow close to the surface. In fact, the transfer of momentum is effected by pressure fluctuations in the turbulent wakes behind the roughness elements, while for heat transfer no such dynamical mechanism exist. Thus, the analogy is not valid over rough surfaces in general, but, most of the empirical equations for r_{ah} analyzed do not take into account this difference. Hence, the whole analysis presented is carried out also using modified forms of the original equations for r_{ah}, imposing the condition $z_{0m} \neq z_{0h}$.
In practice, it is difficult to accurately calculate land surface aerodynamic roughness lengths; for the local analysis z_{0m} and z_{0h} are calculated firstly from the logarithmic profiles of wind speed and air temperature, as usual. However it is not possible to apply these formulations to the basin scale for distribute surface energy fluxes estimates, thus, z_{0m} and z_{0h} are retrieved also using simplified formulas, depending only by the vegetation height.

Fig. 1 - Eddy covariance stations

From this punctual analysis the most significant equations, among those analyzed, are selected and implemented in the distributed hydrological model FEST-EWB (Fig. 2), with the purpose of estimating surface heat fluxes at a distributed scale.
In order to verify the effect of using different models for r_{ah} also at a distributed scale, the comparison between Land Surface Temperature (LST) maps, simulated by each r_{ah} model, and LST Modis Satellite product was carried out. Different behaviors of the models are observed, accordingly to changes in the vegetation coverage.

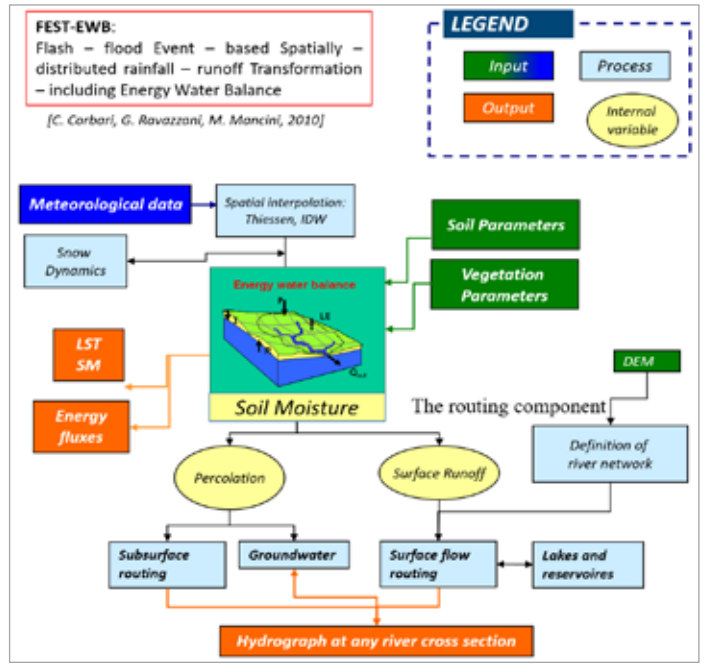

Fig. 2 - FEST-EWB functioning scheme.

Eventually, the punctual analysis is also used to retrieve multiplicative correction factors to be applied to the selected r_{ah} parameterizations for the estimation of H, Le and ET at the basin scale. In particular, different correction factors are calculated, upon eddy covariance measurements, minimizing the errors between respectively H or r_{ah}, observed and estimated, and differentiating between bare soil and vegetation cases. The new empirically corrected parameterizations are, then, implemented in the model FEST-EWB and the LST maps simulated using these new r_{ah} equations, are compared with the satellite product in order to evaluate the performances of each model. Concluding the entire study permits to evaluate the effect of using different rah models at a the basin scale for surface heat fluxes estimates, after their validation at the field scale with eddy covariance measurements, and, eventually, to identify the most suitable ones for the different conditions of vegetation coverage and vegetation height analyzed.

POROUS SURFACES FOR PERMEABLE PAVEMENT: CLOGGING AND FILTRATION MECHANISMS

Mariana Marchioni – Supervisor: Prof. Gianfranco Becciu
Co-supervisor: Prof. John Sansalone

Urbanization growth ultimately affects the hydrological cycle reducing infiltration and evapotranspiration, directing most of the stormwater to the sewer system and so increasing flood risk. This situation is intensified by the "heat islands" effect where the higher temperatures in densely populated areas ultimately enhance precipitation. When washing off impermeable surfaces, runoff transports particulate matter (PM) loads and PM-bound chemicals generated by anthropogenic, biogenic activities and infrastructure. Diffuse non-source discharge from rainfall-runoff processes is currently the major source of receiving water impairment. The traditional urban drainage management has become impractical in current urbanization scenarios, pushing towards comprehensive measures that promote infiltration on its source. These measures are commonly known as SuDs (sustainable urban drainage systems) and propose different solutions to achieve a long term and sustainable urban drainage management, acting both on runoff volume and pollutants load. One way to reduce runoff volume is through the reduction of impervious areas. This can be achieved by reducing the development area, promoting infiltration or disconnecting the impermeable areas from the municipal drainage system. There are many practices on this approach, such as permeable pavements, infiltration trenches, green roofs, detention reservoirs. Permeable pavement act on both runoff water volume and pollutants load. It can be described as an infiltration system on which runoff infiltrates through a permeable layer or other stabilized permeable surface. Permeable pavement operates on runoff volume through retention and infiltration. Runoff pollutant load can be reduced by mechanisms of sedimentation, filtration, adsorption, biodegradation and volatilization and water quality can be enhanced by nutrient, sludge, metals and hydrocarbons removal. Dry deposition PM deposited on the surface of permeable pavements decrease water infiltration until unsatisfactory performance. Clogging is influence by the surface pore structure and the PM granulometric indices, blocking the connected porosity. Pollutants loads partition on PM fractions allowing physical separation through filtration mechanisms. This research investigates aspects of runoff volume and pollutant load on porous asphalt (PA) and pervious concrete (PC) that are commonly used as surface on permeable pavement through an experimental plan. A rainfall simulator was developed to measure on laboratory runoff volume and hydraulic conductivity on initial conditions and under the effect of sediments load. Part of the porous asphalt specimens were analyzed with x-ray micro-CT tomography (XRT) to obtain pore structure parameters. Dry deposition (PM) was sampled on four different locations in Milan (Italy) and was obtained the accumulation rate and granulometric indices. The laboratory and field results were used to model permeability and filtration mechanism. Infiltration measurements on initial conditions showed the permeability dependence on porosity and clogging. Rainfall simulation was then used to assess runoff volume and permeability response under different conditions. Permeability is normally measured on permeable pavement using falling head permeameter due to simplicity, especially on field, but this device does not yield darcyan hydraulic conductivity (ksat) and should be used only on qualitative bases. Knowing also that k results are highly dependent of test method and test conditions it would be crucial to have a single test method to evaluate permeable pavement with a database of acceptable results to be used for acceptance/ refusal. Further on, specimens that were considered completely clogged through permeability standards, therefore showing a low infiltration rate, still functioned on runoff volume reduction. Although important, infiltration is not the only parameter impacting rainfall-runoff transformation and thus to evaluate permeable pavement a globally parameter analysis should be considered. The roughness and slope showed to be important factors on runoff volume. Permeable pavements guidelines in fact recommend a maximum 5% slope to facilitate water infiltration. Pore structure parameters that are complex to obtain through conventional methods were obtained through XRT. Once established a code to obtain the parameters the test became simple and would allow to obtain results relatively easier and faster than the conventional methods. However, the method cost would be currently impractical outside research environment. The total porosity results were in accordance with the ones obtained through bulk density. The total porosity and effective porosity, both obtained through XRT, presented analogous results and confirmed visual observation of highly interconnected pores. The second part focused on pollutants load present on runoff. Four dry deposition PM samples were collected on highly inhabited area in Milan (Italy) and was obtained the accumulation rate (build-up) and granulometric indices. The accumulation rate showed to be dependent on the surroundings conditions and was observed a positive aspect on PM retention on zones with tree presence. A broader sample program should be considered to include more roads with various surroundings conditions to confirm correlations between certain conditions and build-up and more sampling on different dates on the same area to confirm the accumulation rate. The granulometric indices confirm dry deposition PM as a hetero-disperse non-uniform aggregate. The particle size distribution analysis provide a tool to design porous surface to remove a given percentage of aggregates. Research evidence of metals and other pollutants partitioning into fractions of PM could be used to predict the removal of certain PM-bound pollutants mass on a given PM size. Retaining the coarse material would mean to remove the largest part of the metal inventory. The filtration mechanisms were investigated experimentally and using a mechanistic model based on pore media and particle diameter. For the studied specimens and loads the dominant mechanism was the accumulation on surface, namely "cake". The majority part of the loads remained on the porous surface or core through straining. This "cake" results on permeability reduction while function on retaining finer material that otherwise would pass through, hence has an effect of reducing service life while improve pollutants load removal efficiency. The "cake" can be easily removed through maintenance but the process should be done with attention to avoid leach the contaminated material. Used to design separation and investigate the clogging mechanism. The results showed the efficiency of both type of tested materials (PC and PA) for runoff volume reduction and pollutants load removal under the tested conditions. The permeability model showed that the falling head permeameter did not yield a darcyan hydraulic conductivity. The filtration mechanism model showed good accordance between measured and modeled results.

Fig. 1 - Permeable pavement installed at Gaetano di Castillia street, Milan (Italy).

EXPLORATORY APPROACHES IN SPATIAL ASSOCIATION ANALYSIS: METHODS, COMPLEMENTS, AND OPEN GIS TOOLS DEVELOPMENT

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During the last three decades, Information Technology has brought terrific advances in data management and tooling but still leaving the duty to scientists of converting data into spendable knowledge. Among the variety of the available information, geospatial data is nowadays recognized as one of the most promising as well as challenging subject to unpin valuable cognition of the world we live in. Geospatial data broadly includes all the information describing a physical object or a generic event that can be represented by numerical values in a geographic coordinate system. Access and interaction with geospatial data are of the utmost importance to explore natural, human, and social systems and provide outstanding opportunities to gain insights into complex phenomena such as climate change, disease surveillance, disaster response, critical infrastructures monitoring, transportation, and many others. In general terms, besides that most of the geospatial information can be still handled with the available geospatial theory, tools, and methods, there is an emerging need for establishing spatial enablement into general data analysis frameworks for advancing leading-edge research as well as good practices within all those domains exploiting geospatial data.

In views of the above, this research aims at introducing methods as well as suggesting novel solutions for investigating characters (e.g. patterns, trends, and correlation structures) of geospatial data. The use of Exploratory Spatial Data Analysis (ESDA) is entitled as a key tool to enable geospatial data character investigations. ESDA can be broadly defined as a framework including a number of statistical methods, visualisation techniques and software tools to identify spatial patterns and trends as well as to accurately discover and account for spatial relations characterising most of the geospatial dataset. The character that is mainly considered here is the spatial association. The spatial association is defined as the measure of the degree at which similar things are also similarly arranged in space. This relationship characterises most of the geospatial data that is measured as a result of nonstationary or heterogeneous spatial processes taking place in the real geographical space. Therefore, the analysis of spatial association by means of ESDA techniques is key to point out interesting patterns, underlying influences, and significant effects characterising each geospatial dataset and - in turn - the spatial process that generate it.

A critical literature review on the available methods to measure and map the spatial association is performed together with a description of the available software tools to implement them. Particular attention is paid to Free and Open Source Software (FOSS) tools which are freely distributed with open licenses allowing users to access, modify and redistribute them for any purpose. In contrast to copyrighted, closed-source proprietary alternatives, FOSS enables free access to the source code in order to favour the application reuse and customisation. Moreover, the most meaningful software tools are selected also by considering their integration into the most popular Geographic Information System (GIS) platforms. The development of an ESDA plugin - called Hotspot Analysis - for one of the most popular FOSS GIS (i.e. QGIS) is described in detail. The plugin application to real case studies is presented. These focus on the spatial association patterns of heterogeneous geospatial datasets ranging from Airbnb lodging reviews to soil consumption data.

According to the outcomes of the literature reviews, most of the discussion of spatial association has been situated in a univariate context. With respect to spatial association mapping, the most popular statistics are known as Local Indicators of Spatial Association (LISA). These statistics allow to analyse and map local properties of spatial association - such as the presence of spatial clusters or outliers - of any quantitative geospatial dataset. However, traditional LISA have been developed to deal with single a spatial variable per time thus to perform univariate spatial association analysis. This represents a strong limitation by considering the amount of information today potentially available at any location on Earth. In fact, the analysis of complex spatial processes often requires the simultaneous consideration of multiple variables - i.e. multivariate analysis - to properly grasp their characterizing patterns allowing for their better comprehension and modelling. The second part of the research work is therefore dedicated to the formulation of LISA extensions enabling multivariate clusters and outliers classification and mapping. A general methodology to perform multivariate spatial association analysis is designed and implemented by means of the Python programming language. As a case study, the multivariate analysis of some social vulnerability indices for the City of Melbourne is presented and discussed (Fig. 1).
The early test of the outlined multivariate spatial association mapping procedure proves to be promising to all those disciplines that require simultaneous explorations of multiple variables to be linked with any complex spatial process under investigation. Future directions for the work will focus on additional validations of the proposed methodology. Concerning the software side, the source code produced within this work requires substantial improvement. The extension of LISA to the multivariate context implies higher computational costs due to the concurrent analysis of multiple variables. The introduction of parallel computing to cut down the multivariate LISA computational time is advised due to the critical role of this factor to the practical application of this technique.
The same applies by considering the analysis of high-resolution datasets for large geographic regions that is one of the frontiers of the modern geospatial data analysis.

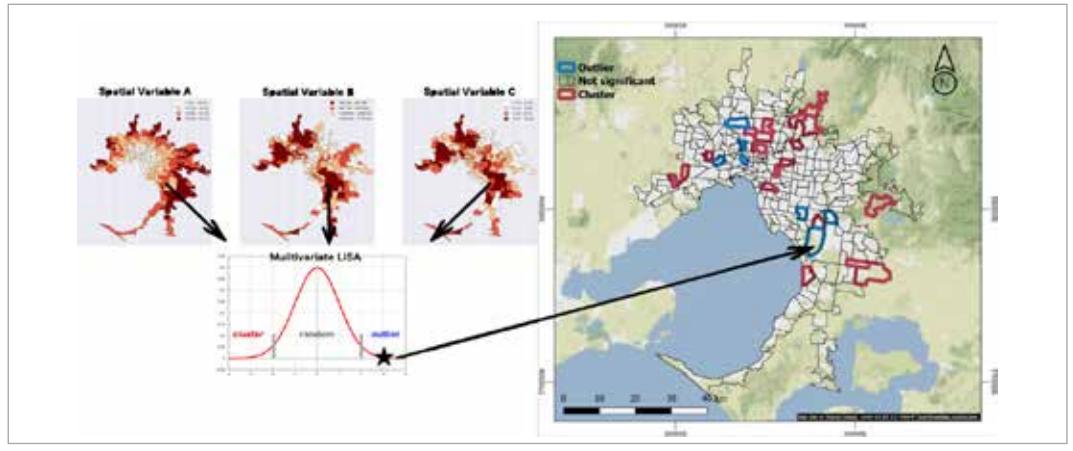

Fig. 1 - Schematic for the multivariate clusters and outliers mapping using LISA in a GIS software environment.