A numerical model approach to evaluate the efficiency of indigenous rainwater harvesting techniques for agriculture

POLITECNICO DI TORINO

Paolo Tamagnone[1], Elena Comino[1], Luis Cea[2] and Maurizio Rosso[1]

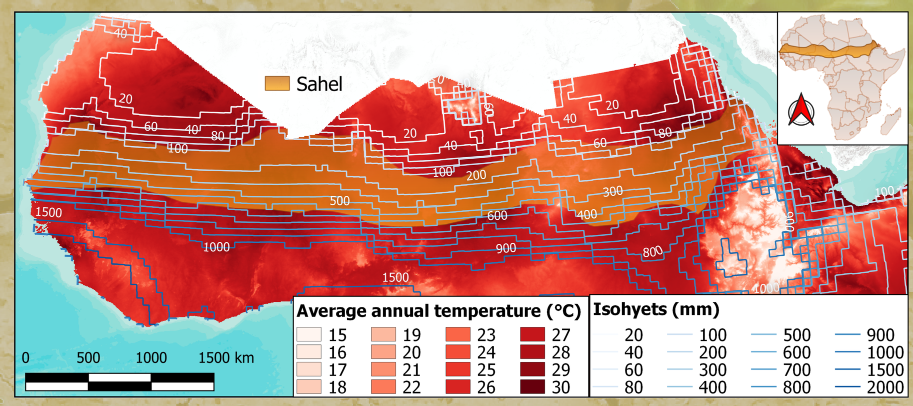
[1]Department of Environment, Land and Infrastructure Engineering, Politecnico di Torino, 10129 Torino, Italy; **paolo.tamagnone@polito.it**

[2]Environmental and Water Engineering Group, Department of Civil Engineering, Universidade da Coruña, 15071 A Coruña, Spain

UNIVERSIDADE DA CORUÑA
Water and Environmental Engineering Group

Context and problematics

The sub-Saharan climate is experiencing a marked increase in temperature and intensification of precipitation intensity and variability. Besides, longer dry spells are compromising the reliability of local agricultural practices. The present study provides a comprehensive investigation about the benefits induced by using indigenous rainwater harvesting techniques (RWHT) against hydrometeorological threats affecting the Sahelian areas [1,2]. Different RWHT have been tested in term of runoff retention, infiltration increase into the root zone, soil water stress mitigation and water deficit reduction. To achieve these purposes, hydrological processes at the field scale have been investigated using a two-dimensional distributed hydrological model.



Geolocation of the Sahelian strip and long-term climate data: average temperature and isohyets of the sub-Saharan area.

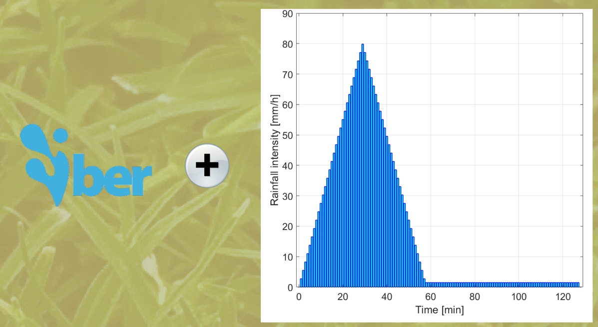
Objectives of the study

The study makes use of the ecohydrological numerical modelling to provide an assessment of the multiple benefits induced using indigenous Rainwater Harvesting Techniques (RWHT) in sub-Saharan regions. A series of investigations have been designed to achieve the evaluation of:
(1) the hydrological performances of RWHT in terms of runoff reduction, infiltration and storage increase;
(2) the ecological benefit induced by the mitigation of crop water stress.

Methodology

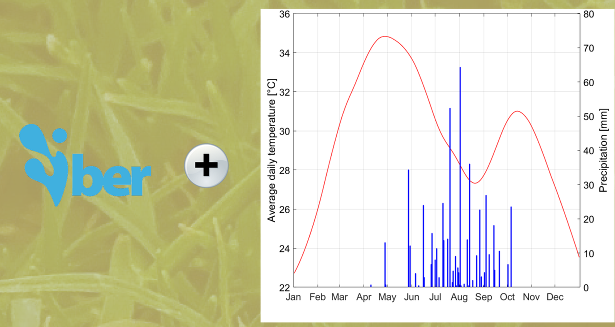
The efficiency of the tested RWHT have been evaluated through hydraulic modelling analysis. The numerical model chose for achieving the pourpose was Iber [3]. In order to consider the crop live cycle into the water balance, a new methodology has been implemented in the model and tested. The approach is based on the computation of the evapotranspiration rate according to the FAO 56 single-crop coefficient method [4].
The model was applied for two different analyses:

short-term analysis: the aim is the evaluation of the entire range of possible hydrological performances of RWHT, evaluating typical scenarios of Sahelian farm fields, at the time scale of the single rainfall event.



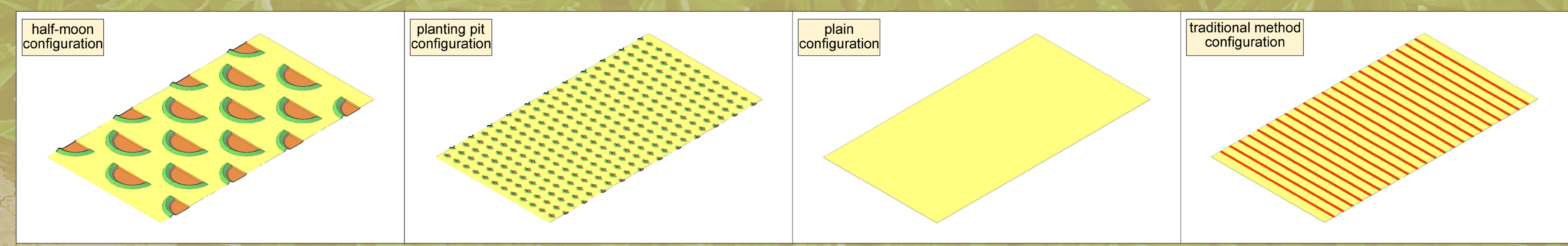
\+ Monte Carlo simulations run using a vast set of model parameters

long-term analysis: the hydrological balances over the entire wet season have been performed for each RWHT, and the potential crop water stress mitigation has been evaluated.



\+ FAO 56 single-crop coefficient method

The hydrological efficiency of most used RWHT (HM-half moon or PP-planting pits) was compared to a untreated configation (PL) and a traditional sowing method (TM). For each RWHT, multiple configuration have been analyzed varying the depth of the ponds excavation.



All plots present a constant slope of 1% towards downstream. Coloring: red represents the treated surfaces (tilled areas), green displays ridges (realized from the excavated terrain), yellow are the untreated surfaces (crusted areas).

Hydrological efficiency

The impact of the analyzed configurations in the hydrological processes was evaluated in terms of four different efficiency measures:

Outflow reduction (ϕ_V) calculated as the reduction on the cumulated volume of water that flows out of the domain with and without the implementation of RWHT (***Vol.out***$_{RWHT}$ and ***Vol.out***$_{PL}$ respectively)

$$\phi_V = 1 - {}^{Vol.out_{RWHT}}/_{Vol.out_{PL}}$$

Infiltration increase (ϕ_I) calculated as the increase on the cumulated volume of water infiltrated in the sub-surface with and without the implementation of RWHT (I_{RWHT} and I_{PL} respectively)

$$\phi_I = {}^{I_{RWHT}}/_{I_{PL}} - 1$$

Water stress mitigation (ϕ_S) calculated as the increase on soil moisture needed to reach the availability threshold with and without the implementation of RWHT (θ_{RWHT} and θ_{TM} respectively)

$$\phi_S = {}^{(\theta_{RWHT} - \theta_{TM})}/_{(p \cdot \theta_{FC} - \theta_{WP})} \cdot 100$$

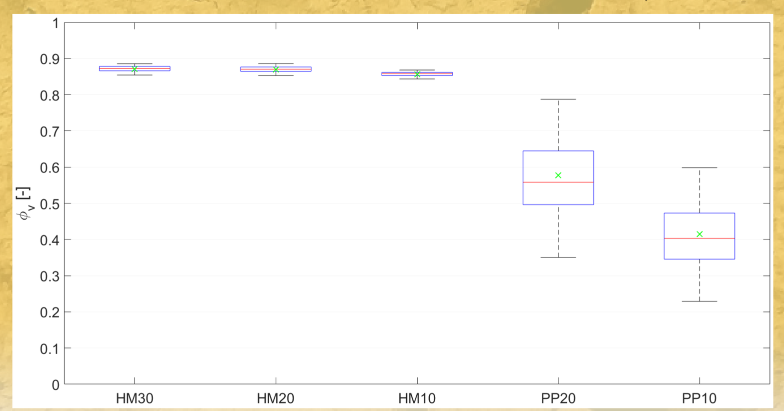
Water deficit reduction (R) calculated as the reduction on cumulative plant water deficit with and without the implementation of RWHT ($CWPD_{RWHT}$ and $CWPD_{TM}$ respectively)

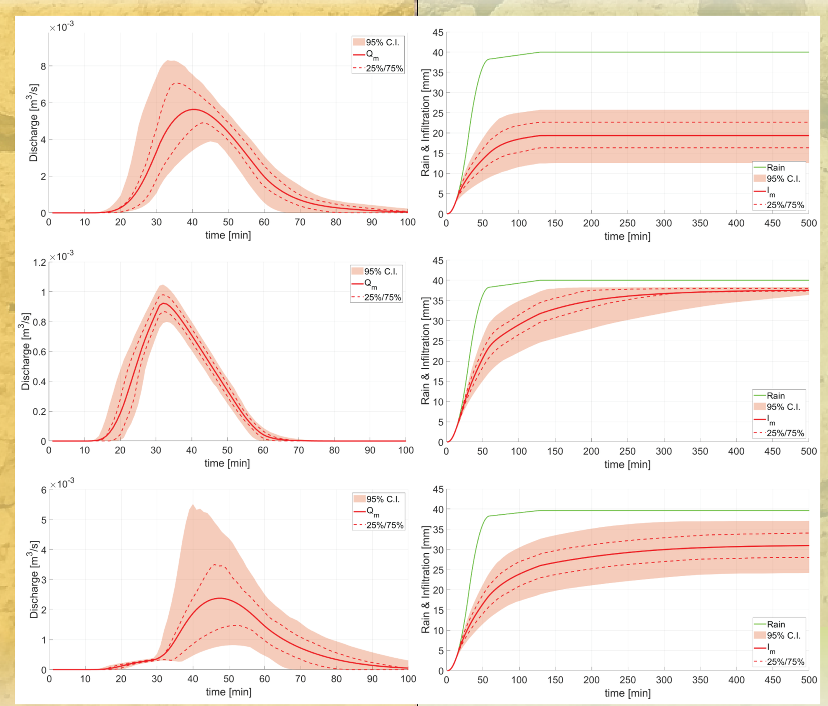
$$R = {}^{CPWD_{RWHT}}/_{CPWD_{TM}} \cdot 100$$

Characteristics and identification codes for the different RWHT configurations analyzed

Configurations	Excavation depth (cm)	Code
Plain	0	PL
Traditional sowing method	0	TM
Half-moon	10	HM_{10}
	20	HM_{20}
	30	HM_{30}
Planting pits	10	PP_{10}
	20	PP_{20}

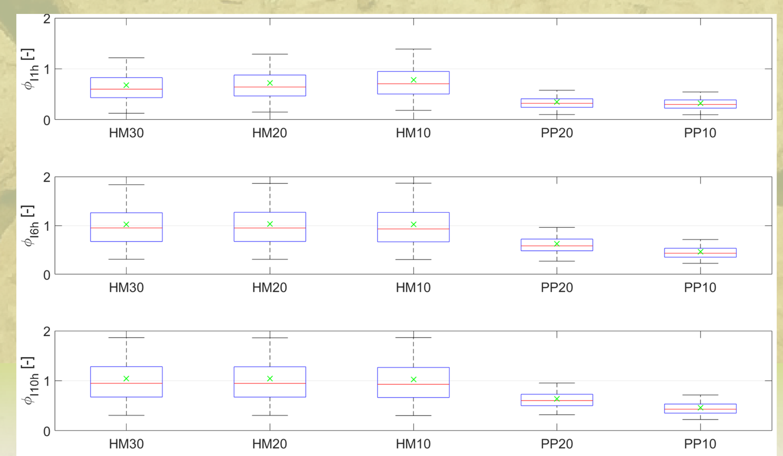
The HM configurations show an efficiency of more than 30% higher than the PP configurations. For both RWHT, the configurations with the deeper pond have a higher performance than the shallow ones. For PP configuration, halving the depth of the excavation leads to a 15% drop in ϕ_V.

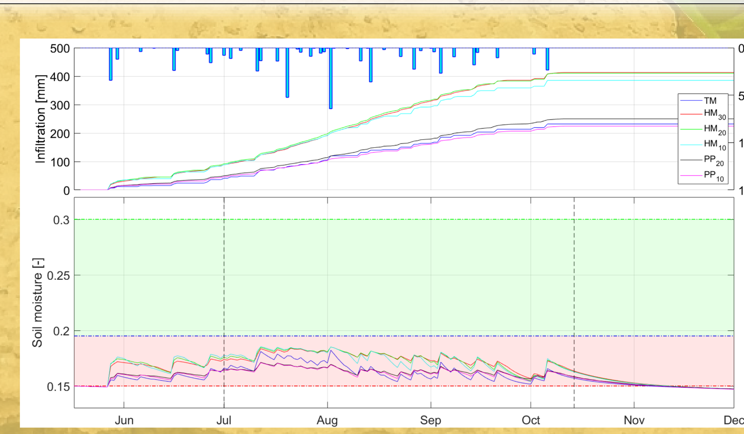




Hydrographs and infiltration computed for the Monte Carlo simulations in the PL (first row), HM30 (second row) and PP20 (third row) configurations.

The infiltration is a process that starts with the first drop and continues in the hours following the rainy event ($\phi_{I,x,y,t}$). For all HM configurations, the efficiency is similar. Conversely for PP, PP20 shows an efficiency incresely higher than PP10.

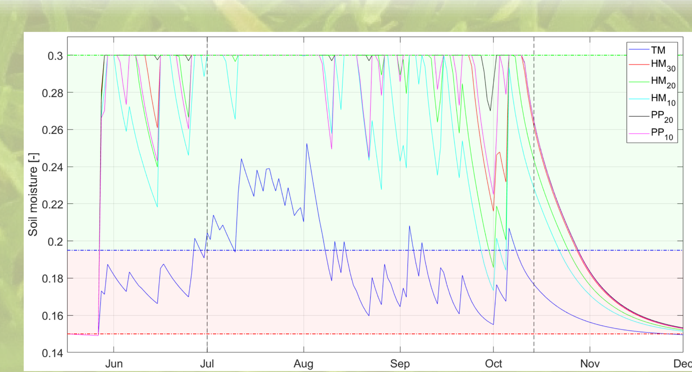




Infiltration and soil moisture trend for the millet at the field scale over the wet season. When the level of water content drops down the red area, the crop is water stressed. The upper and lower limits are the soil moisture at saturation and permanent wilting point, respectively.

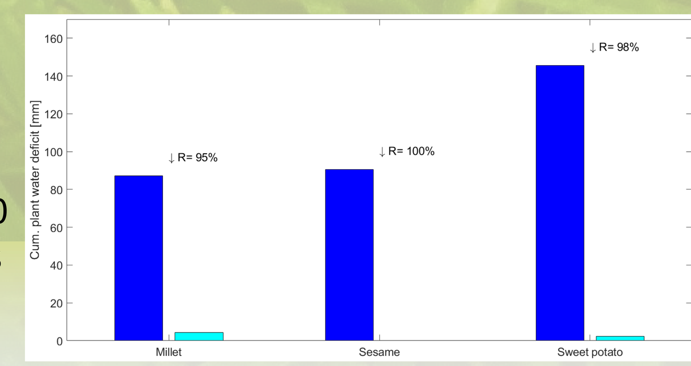
The higher level of soil water content induced by the RWHT indicates that there is an improvement of the hydrological efficiency of the whole system, meaning the farm field. HM configurations show an efficiency markely higher than PP configurations.

RWHT	ϕ_s [%]
HM_{30}	23.02
HM_{20}	22.92
HM_{10}	20.72
PP_{20}	3.75
PP_{10}	2.85



Infiltration and soil moisture trend for the millet at the pond scale over the wet season. The TM trend shows that for almost half of the growing period the crop suffers stress. Conversely, the use of HM30, PP20 and PP10 totally prevents the onset of water stress conditions.

Cumulative plant water deficit induced by the use of the TM (blue bars) or adopting HM10 (cyan bars) for three traditional Sahelian crops. R is the deficit reduction when HM10 are used. The maximum reduction is obtained for the sesame since deficit is reduced to zero.



References

[1] Tamagnone, P.; Comino, E.; Rosso, M.
Rainwater harvesting techniques as an adaptation strategy for flood mitigation.
Journal of Hydrology 2020, 586, 124880.

[2] Tamagnone, P.; Comino, E.; Cea, L.; Rosso, M. (Under revision)
Rainwater Harvesting Techniques to Face Water Scarcity in African's Drylands: Hydrological Efficiency Assessment.
Water 2020, ..., ...

[3] Cea, L., Blade, E.
A simple and efficient unstructured finite volume scheme for solving the shallow water equations in overland flow applications.
Water Resources Research, 51(7), 5464–5486.

[4] Allan, R.; Pereira, L.; Smith, M.
Crop evapotranspiration-Guidelines for computing crop water requirements.
FAO Irrigation and drainage paper 56; 1998.

WSF 2020 The 8th World Sustainability Forum
14 – 19 September 2020, Geneva, Switzerland