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Rainwater harvesting as alternative water source in Morocco

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Keywords : Anti-Atlas Mountains, Water Scarcity, Rainwater Harvesting, Water Management

The native population of remote communities in south Morocco's Anti-Atlas Mountains suffers from recurring droughts and struggles to satisfy basic daily necessities due to poor income and difficult access to isolated little settlements. Water scarcity endangers local cattle and agricultural activity, resulting in severely tough living circumstances. The situation worsens as (i) climate models predict severe droughts in the future, (ii) the water table retreats due to overexploitation of groundwater to meet irrigation demand, and (iii) groundwater quality deteriorates due to a poor sanitation system in which domestic wastewater is poured directly outdoors or into traditional septic tanks. In this research, we highlight and advocate efficient and cost-effective alternatives for improved water management in Anti-Atlas rural communities. Rainwater harvesting (RWH) systems may be used to supplement home and agricultural water supplies. The long-term outcomes of this study will help to improve the living conditions of the local population by providing an easily accessible water source and, as a result, a healthy and balanced rural lifestyle, preserving small-scale agriculture as the region's main source of income, and reducing rural-to-urban migration waves to the city, which will, in turn, reduce pressure on the cities and aid in the preservation of the local and original Amazigh culture. Other projected environmental benefits of RWH include increased water table owing to reduced pumping, biodiversity preservation in such dry locations, and the promotion of environmental awareness and sustainable development education. The installation of RWH setups in rural regions in pilot sites will serve as a baseline for bigger projects spanning wider areas, helping to persuade authorities and decision-makers that RWH is an effective water management strategy.

A Multidisciplinary Approach for Groundwater Potential Mapping in a Fractured Semi-Arid Terrain (Amezmiz Basin, Western High Atlas, Morocco)

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Mots-clés : Amezmiz basin; frequency ratio; Shannon's entropy; AHP model ; GIS; Remote sensing

This study is focused on developing an approach for spatial mapping of groundwater by considering four types of factors (geological, topographical, hydrological, and climatic factors), and by using different bivariate statistical models, such as frequency ratio (FR), Shannon's entropy (SE) and AHP Models. The developed approach was applied in a fractured aquifer basin (Amezmiz Basin, Western High Atlas, Morocco), to map the spatial variation of groundwater potential. Fourteen factors (14) influencing groundwater were considered in this study, including slope degree, slope aspect, elevation, topographic wetness index (TWI), noued density, plane curvature, profile curvature, drainage density, lineament density, faults density distance to rivers and fault network, normalized difference vegetation index (NDVI), and lithology. The potential maps produced were then classified into five classes to illustrate the spatial view of each potential class obtained. The predictive capacity of the frequency ratio, Shannon's entropy and AHP models was determined using two different methods, the first one based on the use of flow data from 58 boreholes drilled in the study area, to test and statistically calibrate the predictive capacity of each model. The results show that the percentage of positive water points corresponds to the most productive areas (high water flow). On the other hand, the low water flows are consistent with the predicted unfavorable areas for hydrogeological prospecting. Additionally, the second validation method involves the integration of 900 Hz apparent resistivity data to identify conductive zones that are groundwater circulation zones. The interpretation of the geophysical results shows that the high-potential zones match with low apparent resistivity zones, and therefore promising targets for hydrogeological investigation. The FR, SE and AHP models have proved very efficient for hydrogeological mapping at a fractured basement area. The results suggest that the proposed approach is very important for hydrogeological mapping of fractured aquifers, and the resulting maps can be helpful to managers and planners to generate groundwater development plans and attenuate the consequences of future drought.

Improvement of water management under severe scarcity and climate change in the upper drâa catchment

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key word: climate change, water crisis, business sustainability, IWRM, communities

Upper Drâa catchment is characterized by an arid climate with huge contrast spatial and seasonal water availability. Climate change models indicate decrease of precipitation and increase of drought frequency and severity. The economic dynamic in the territory is diverse: solar energy, tourism, mining and agriculture. Therefore, business sustainability of these sectors requires sufficient water management under scarcity and lack of supply. In order to sustain the socio-economic growth of the region and its resilience toward the water crisis, Integrated Water Resources Management (IWRM) practices need to be checked to date and adopt an inclusive approach involving all stakeholders including drinking water providers businesses and farmers communities. In this work, based on current critical situation data, we propose a dynamic framework of management by sub-basin and by communities while adapting some key principles neglected in classical management: precision monitoring, focus on controlling demand and supporting local know-how management skills. The efficiency of water management could be assessed more effectively using simple and reliable indicators like: crop yield, soil stability and demand control. By collecting data from users and stakeholders continuously and getting feedback from them to refine the practice. Emerging methods of data collection like citizen science and crowdsourcing could contribute to this end in addition to earth observation and IT technologies. Moreover, this approach can provide sustainable water management which concerns three pillars (Economic, social and Environmental) of sustainability.

Using satellite remote sensing data to describe the environmental process that links the water, energy, and carbon cycles at the surface

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Key words: Evapotranspiration, hydrological regimes, stage I, stage II

Evapotranspiration (ET) is the main driver of the environmental process that links the water, energy, and carbon cycles. ET is often limited by available energy which defines the energy-limited evaporation regime (stage I). But under some climates (e.g., arid and semi-arid) and in some seasons (e.g., dry seasons) the capacity of soils to transfer enough water to the land-atmosphere boundary at the surface becomes limiting. Under such conditions, the ET becomes water limited (stage II). The threshold between energy-limited and water-limited ET regimes is (SM^*) dependent on seasonal soil water content as well as other near-surface atmosphere conditions. The aim of this work is the use satellite observations only (soil moisture (SM) from NASA's Soil Moisture Active Passive (SMAP) satellite and diurnal temperature (dT) from the geostationary satellite MSG-SEVIRI) to assess the surface inertia to climate variability and define the regions with the most variable environmental forcing and that set to the "tipping-point" in Sahel region. Specifically, to identify and implement an unsupervised classification scheme to categorize regions according to their dominant hydrological regimes in the same region. Therefore, SM at the drydown periods is correlated to dT in order to define whether the region is set to stage I, stage II, or transitional (Stage I and Stage II) regime. For this axis we raise the question of extracting SM^* at 9 km resolution by filling the gap at temporal scale of the missed data. For this purpose, the simple methodologies have been proposed, the first one by linearly interpolating SM data (using 3 days moving average method), the second one by linearly interpolating dT data (using 3 days moving average method), and the third one where a machine learning algorithm is used to predict SM from LST and NDVI (Normalized Difference Vegetation Index). The results of the classification using the three methodologies will be presented during the conference.

Improving evapotranspiration estimates by assimilating thermal and microwave data into SAMIR in a semi-arid region

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Key words: Evapotranspiration; Data assimilation; FAO-dualK_c; Soil moisture; Land surface temperature.

Accurate estimation of evapotranspiration (ET) is of crucial importance in water science and hydrological process understanding especially in semi-arid/arid areas since ET represents more than 85% of the total water budget. FAO-56 is one of the widely used formulations to estimate the actual crop evapotranspiration (ET_{c act}) due to its operational nature and since it represents a reasonable compromise between simplicity and accuracy. In this vein, the objective of this paper was to examine the possibility of improving ET_{c act} estimates through remote sensing data assimilation. For this purpose, remotely sensed soil moisture (SM) and Land surface temperature (LST) data were simultaneously assimilated into FAO-dualK_c. Surface SM observations were assimilated into the soil evaporation (E_s) component through the soil evaporation coefficient, and LST data were assimilated into the actual crop transpiration (T_{c act}) component through the crop stress coefficient. The LST data were used to estimate the water stress coefficient (K_s) as a proxy of LST (LST_{proxy}). The FAO-K_s was corrected by assimilating LST_{proxy} derived from Landsat data based on the variances of predicted errors on K_s estimates from FAO-56 model and thermal-derived K_s. The proposed approach was tested over a semi-arid area in Morocco using first, *in situ* data collected during 2002-2003 and 2015-2016 wheat growth seasons over two different fields and then, remotely sensed data derived from disaggregated Soil Moisture Active Passive (SMAP) SM and Landsat-LST sensors were used. Assimilating SM data leads to an improvement of the ET_{c act} model prediction: the root mean square error (RMSE) decreased from 0.98 to 0.65 mm/day compared to the classical FAO-dualK_c using *in situ* SM. Moreover, assimilating both *in situ* SM and LST data provided more accurate results with a RMSE error of 0.55 mm/day. By using SMAP-based SM and Landsat-LST, results also improved in comparison with standard FAO and reached a RMSE of 0.73 mm/day against eddy-covariance ET_{c act} measurements.

Insights on the trade-offs between climate change-induced dryness and agricultural water use within a water stressed area: The case of Souss basin

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Abstract

The Souss basin is characterized by a semi-arid climate and suffers from a severe deficit, and irrigated agriculture is the primary consumer of water. In addition, Recent climate attributes in Souss is characterized by gradual warming and unpredicted trends in rainfall variability. Climate change is affecting negatively Souss's agriculture through changes in precipitation and temperature with impacts on water availability. Therefore, understanding the agricultural water usage and demands over the basin is essential for adaptation in the water and agriculture sectors, especially that water resources are already scarce in the region. This study aims to assess the climate change impacts on surface water management by analyzing agricultural unmet demand from allocated surface water from reservoirs, including under previous dry episodes. ModSim 8.1, a generic river basin management decision support system (DSS), for water allocation modeling, was selected for that study. Once calibrated and validated over the period from 1990 to 2019 using recorded data about physical processes and hydraulic infrastructures features and management. The simulations succeeded in replicating different deficit episodes at the various irrigated perimeters. The simulation period shows a considerable decrease in the supply levels of the different dams, the supplies of the different dams have decreased during the last years (2012-2019) between 38% and 89% for the different dams of the basin. The differences among different supply sources fluctuate during the simulation period, resulting from changes in the available water inputs to the reservoirs each year. As result, the average total unmet demand for surface water from reservoirs in irrigated areas reached 201 Mm³ between 1990-2019. The monthly average demand increases by 55% in the dry season, compared to the demands in the rest of the year. The significant amount of unmet demand across all demand sites suggest that demands are satisfied by the withdrawal of water from groundwater resources. The adopted simulation approach has shown to be a useful decision support tool to understand the interaction between water resources use in agriculture and climate change-induced dryness in the Souss basin. Decision makers require reliable tools to represent the basin's various trade-offs in relation to adaptation in agriculture water resources. Thus, additional investigation improving the representation of groundwater/surface water interaction is required to enhance the evaluation of the consequences of different uses at the basin level.

Keywords: Water allocation modelling; ModSim; Agricultural water demand; Souss basin.

Geochemical and isotopic study of the aquifer of the lower valley of Medjerda (NE Tunisia): towards a better management of the resource.

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Key words: Hydrogeology, hydrochemistry, isotopes, salinity, Northeast Tunisia.

Aquifers are important water resources in coastal areas where there are high population densities and intense agricultural activity. The lower valley of Medjerda is part of north eastern Tunisia and it contains a water table lodged in the alluvium of the Plio-Quaternary. Due to its location on the coast and its continuity with the sebkhas, this aquifer undergoes significant variations on the quantitative and especially qualitative level, under the effect of both natural and anthropogenic pressure. This work is devoted to a geochemical and isotopic study of this aquifer in order to specify the mechanisms of acquisition of the salt load based on the analysis of major and trace chemical elements, water isotopes and tritium, to improve resource management.

Two types of facies have been highlighted, one is sodium chloride, the other is of calcium chloride type. Interpretation of the data shows that groundwater salinity has several main origins: dissolution/precipitation of minerals from the aquifer formation, cation exchange and saltwater intrusion from sebkhas.

Oxygen-18 range is $-6/-2\text{‰}$ vs V-SMOW, most points are on or above the Global Meteoric Water Line (GMWL) consistent with the LMWL (Local Meteoric Water Line) of the Bizerta region. The 7 most enriched points ($\delta^{18}\text{O} > -4,1\text{‰}$), which stand out from the other points, are below the GMWL with deuterium excesses below $\pm 8,5\text{‰}$. They are aligned on a straight line with a slope of 4.2, signifying either of an evaporation process by infiltration of evaporated water, or direct evaporation of the water of the aquifer when the level of the water table is sub-surface), either a mixture with the water of the sebkha or a mixture with water of marine origin).

Tritium presents values (1.8 to 2.5 TU) corresponding to the waters resulting from the recent infiltration of the precipitations through the plain and the limit of the basin and the mixing waters with an older component (0.9 to 1.1 TU) and an even older one with a Tritium measurement below the detection level.

Turning date palm waste into biochar for improved soil hydro-physical characteristics and tomato (*Solanum lycopersicum* L.) growth under varying irrigation in calcareous sandy soils

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Keywords: Water retention; Hydraulic conductivity; Cumulative infiltration; Deficit irrigation; Partial root drying

Improving soil health, water conservation, and crop productivity is of critical importance for sustainable agricultural development, especially in arid and semi-arid regions. Biochar has attracted a huge attention of the researchers as a potential soil amendment to improve soil hydro-physical characteristics for sustainable water management in arid and semi-arid areas to boost crop productivity. However, limited studies are available to investigate effects of biochar application on soil water storage and plant water composition. Therefore, the effectiveness of date palm waste-derived biochar in improving soil hydro-physical properties and tomato growth was explored in lab-scale and greenhouse trials. Date palm tree was turned into biochar through pyrolyzing at 300°C (BC3), 500°C (BC5), and 700°C (BC7) and separated into various size fractions i.e., D_{0.5} (<0.5 mm), D₁ (0.5–1 mm), and D₂ (1–2 mm). Calcareous sandy soil was filled in columns, where top 10 cm of soil layer was mixed with the produced biochars at application rates were 1%, 2.5%, and 5% along with a control (without biochar). Thereafter, the columns were irrigated with 25 cm³ water per week for 6 weeks to complete 6 wetting–drying cycles. Results demonstrated that the saturated hydraulic conductivity was decreased, whereas, cumulative evaporation increased with biochar application. Application of BC3 and BC5 resulted in 10.2% and 13.3% higher cumulative evaporation, respectively, while BC7 reduced the cumulative evaporation. On the other hand, D_{0.5}, D₁ and D₂ resulted in 5.0%, 7.7% and, 7.8% increase in cumulative evaporation, respectively as compared to control. Thereafter, the effectiveness of the produced biochar on soil water conservation, water infiltration, salt-distribution, and tomato growth was explored in pot trials (4% application rate of biochar) under regulated deficit irrigation (RDI: 40%, 60%, and 80% of ET_c) and partial root drying (PRD) system by using fresh and saline water. Biochar application resulted in 5.48%–8.11% increment in soil moisture than control (where soil moisture level decreased by 24.95%–27.38%). Soil salinity was in the range of 0.5–1.4 dSm⁻¹ under biochar applications as compared to control (0.7–2.1 dSm⁻¹). Cumulative infiltration after one minute was 1.89–2.79 cm and 1.74–2.79 cm under biochar treatments and control, respectively, while, infiltration rate was 0.98–2.63 cm min⁻¹ and 1.48–1.68 cm.min⁻¹ for fresh and saline water, respectively. Overall, biochar application significantly improved the hydro-physical characteristics of sandy soil, subsequently enhancing water conservation and boosting tomato plant growth.

Trend Analysis of Rainfall in Bayech catchment, southwestern of Tunisia during 1984-2019 in the context of climate change

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Abstract

Shortage of water in the river in relation to rainfall change especially in arid areas plays a pivotal role in water sharing like Bayech catchment. In attempt to understand the rainfall changes, many index used to analysis of rainfall such as SPI (Standardized Precipitation Index), chronological graphical treatment method of the information (MGCTI) and breakage indices. These trends have been proposed over a period of 37 years of measurement and for 25 rain gauges. Statistical methods have shown the severe and lasting nature of the climatic drought observed in the study area where water resources are limited, not very renewable and excessively exploited. As well as, climatological or hydrological study, it is necessary to have homogeneous climatic data series for the results to be statistically significant. This is how we first started with the homogenization of rainfall data using the regional vector method which made it possible to homogenize the time series but also to complete the missing data. This method made it possible to obtain an operational rainfall database. To study the rainfall variability, several methods were applied: regional vector indices, statistical tests for the detection of breaks and the standardized rainfall index. The analysis of the rainfall by the MCGTI allows for a two-dimensional approach (time and space) and therefore makes it possible to clearly visualize the rainfall situation in the study area. The first thing to note, the high variability of the values expressed by an absence of homogeneity of the color ranges over the major periods (Nouaceur and Murărescu, 2016). Second, a trend towards some compliance from 2004 is more uniform across the bayech catchment. The number of years of disputed precipitation, with a negative index, is very high. Drought was severe in 1989 and 1993. During these years, the regional index exceeded -1.6. The last years of the rainfall series (from 1995) marked the return to favorable conditions for rainfall, with the exception of 1998, 2000 a negative index of -1.5 was recorded. We thus find the three phases which marked the rainfall of the study site: The first phase, 1984, and from 2004 to 2006, 2013 and 2014 is considered normal to dry tendency and the second phase begins in 1990 and ends in 1992. Significant wet and very wet years occur at all stations. However, the last phase, 1987, 1998, 1994, 2008 to 2013, is characterized by an increase in dry and very dry years (92%). The MCGTI method confirms that there is agreement with the SPI index during the cycles considered, wet, dry and normal. In addition, the chronologies studied by SPI index are distinguished by two years with heavy annual rainfall: the years 1990 and 2003 with an index close to 3.4 and two very dry years 1998 and 2005 with a rainfall index of -1.8 (severe drought). We note it is decrease in wet years and its increase in dry years. We can therefore confirm the decrease in I_p in the Bayech watershed and therefore in the climate, which is becoming increasingly dry.

Keywords: SPI, MGCTI, climate change, Tunisia.

Water resources management in semi-arid region impacted by climatic and anthropogenic scenarios using the WEAP model: case study of Merguellil watershed

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Abstract: Water scarcity in semi-arid region is the main factor limiting agricultural production also rainfall irregularity in time and space face to the continues increase of water demand of different sectors, all that has led to overexploitation of surface and groundwater resources mainly because of agriculture, and this is the case of Merguellil Basin situated in the central of Tunisia. The WEAP (Water Evaluation and Planning system) model was used to analyze the actual and future water balance of the Merguellil watershed, and to identify the evolution. The main objective of this study is to analyze climate and anthropogenic scenarios in Merguellil watershed, using remote sensing tools to estimate crop pattern. Climatic scenarios were tested for RCP4.5 and RCP8 scenario. Simulations show a rapid decrease of the water storage for the four aquifers in the basin especially for Kairouan aquifer under different scenarios. In addition, scenario combination between the increase of irrigated area and climatic scenarios will make the situation more difficult to manage by 2050.

Approche hydrodynamique et application des moyens géochimiques et isotopiques afin d'élucider les processus de salinisation et la contamination des eaux souterraines dans une zone côtière critique : cas de la nappe de Mornag (Nord-est de la Tunisie).

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Mots-clés : Hydrodynamique, hydrochimie, isotope stable, plaine Mornag, NE Tunisie.

La plaine de Mornag (Nord-est de la Tunisie) se trouve au débouché de l'oued Meliane. Dans ce contexte semi-aride (pluies moyennes autour de 454 mm.an⁻¹), le flux migratoire de la population vers les villes côtières et la multiplication des activités industrielles et agricoles, lors de ces dernières années (1990-2000), a suscité une forte croissance de la demande en eau. En même temps, différents aménagements affectent l'ensemble du fonctionnement hydrologique : multiples ouvrages de conservation des eaux et des sols, petits et moyens, d'une part, grands barrages de protection contre les crues majeurs sur l'Oued Meliane et l'installation d'un barrage sur l'Oued El Hma pour la recharge de cette nappe d'autre part. En effet, la distribution de l'eau de surface dans la plaine de Mornag et dans le sous-sol a donc considérablement évolué du point de vue quantitatif et qualitatif et continue à évoluer. Dans la plaine de Mornag, à l'aval du bassin de l'Oued Meliane, la nappe alluviale Quaternaire est devenue la seule ressource en eau disponible. Elle est actuellement exploitée sans réel contrôle, ce qui conduit à une baisse sensible de son niveau (de 0,25 à 1 m/an). Elle n'est plus alimentée comme en régime naturel par les crues de l'oued, désormais entièrement bloquées par les barrages. Cette situation est aggravée par l'irrégularité des pluies d'une année à l'autre. Ainsi, ces contraintes anthropiques et naturelles ont conduit à l'augmentation de la minéralisation et à une dégradation de la qualité hydrochimique tant par l'augmentation de la salinité ($0.98 < \text{Salinité} < 8.5$) que par l'évolution des faciès chimiques des eaux souterraines de la nappe phréatique de Mornag. Ce travail est consacré à l'étude des processus de la salinisation des eaux souterraines par l'analyse physico-chimique et isotopique de 25 points d'eau (20 puits et 5 forages) répartis dans la zone. Deux types de faciès ont été révélés, l'un est chloruré-sodique dans le centre du bassin et la frange côtière ; l'autre faciès est de type sulfaté-chloruré-calcique caractérisant les eaux exploitées dans les bordures du bassin. L'influence marine (aérosols et intrusion marine), le retour d'eau d'irrigation, la contamination par les eaux usées urbaines et celles évacuées par la

cimenterie Carthage sont parmi les causes de l'augmentation de la salinité des eaux souterraines. Le mélange eau douce-eau salée est fortement modifié par les phénomènes de précipitation/dissolution et d'échanges de bases inverses.

Dynamique et salinité d'une nappe côtière : Interaction eaux-roches et influence du biseau salé (Grombalia, NE Tunisie)

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Mots-clés : Nappe côtière; minéralisation ; interaction eaux-roches ; processus d'échange cationique; retour des eaux d'irrigation

Les ressources en eau de la nappe côtière de Grombalia (Nord-est de la Tunisie), constitue la principale source d'approvisionnement en eau potable, agricole et industrielle, vu la rareté des eaux de surface dans la région. L'exploitation intensive de cette nappe, depuis les années 50 et l'important essor économique (multiplication des activités industrielles et agricoles), ont provoqué un accroissement des besoins en eaux de la nappe du bassin de Grombalia. Cette forte sollicitation a eu comme conséquences une augmentation de la minéralisation et une dégradation de la qualité hydrochimique (vers une salinisation) des eaux souterraines. La présente étude a mis en œuvre des outils graphiques et statistiques multivariés afin de cerner les facteurs naturels et anthropiques contrôlant la minéralisation des eaux souterraines de Grombalia et la qualité de l'eau, en vue de promouvoir le développement durable. Pour tenter d'atteindre cet objectif, la salinité des eaux de la nappe côtière de Grombalia a été approchée à partir de l'étude de l'évolution dans l'espace des éléments chimiques majeurs et traces, en utilisant les diagrammes de Piper, de Durov étendu, le diagramme HFE-D et l'étude des rapports ioniques. En s'appuyant sur ces méthodes, ce travail a permis de démontrer que les principaux facteurs qui contrôlent la minéralisation des eaux souterraines de Grombalia sont liés essentiellement à l'interaction eaux-roches, en particulier la dissolution de l'halite existant dans les dépôts salins, d'autres processus ont également une incidence sur la salinité, tels que le retour des eaux d'irrigation vers la nappe, l'impact des rejets industriels et l'incursion d'eau salée sous la Sebkhah El Maleh. En outre, les fortes salinités observées à la frange côtière (5814mg/l) sont expliquées par une contamination par les eaux de mer (embruns marins, aérosols et probable appel d'eau marine). Cette dernière hypothèse est justifiée par les fortes teneurs en chlorures dues à la présence de réactions d'échange cationique inverse et un faciès de type chloruré sodique. Toutefois, les résultats obtenus indiquent que les ressources en eau du

bassin de Grombalia sont très vulnérables aux contraintes naturelles et anthropiques et nécessitent une intervention adéquate des décideurs en termes de gestion, de protection et de planification.

Cartographie du potentiel des eaux souterraines dans une zone semi-aride fracturée à l'aide des modèles frequency ratio et Shannon's entropy (cas du bassin versant d'Ameln, boutonnière de Kerdous, Anti-Atlas occidental, Maroc).

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Mots-clés : Anti-Atlas ; Kerdous ; Bassin Ameln ; Frequency ratio ; Shannon's entropy.

Cette étude développe une approche de cartographie spatiale des eaux souterraines en contexte montagneux, sur des formations discontinues et fracturées de socle (bassin d'Ameln dans les montagnes occidentales de l'Anti-Atlas au Maroc) et sous climat semi-aride. L'objectif étant d'optimiser les travaux de recherche d'eau, en s'orientant vers des secteurs à potentiel. Quatre types de facteurs (géologiques, topographiques, hydrologiques et climatiques), déclinés en 15 paramètres sont pris en compte. Deux modèles statistiques bivariés ont été adoptés, à savoir les modèles de Frequency ratio (FR) et Shannon's entropy (SE). Les cartes produites ont été classées en cinq classes pour illustrer la vue spatiale de chaque classe de potentialités obtenues.

La capacité de prédiction des modèles de Frequency ratio et Shannon's entropy a été validée par deux approches différentes : la première se base sur les débits de 49 forages de la zone d'étude, qui ont permis de tester et de calibrer statistiquement les résultats des modèles, la seconde méthode de validation a consisté à intégrer des données de résistivité apparente 7200 Hz, afin de cerner les zones conductrices qui sont des zones de circulation des eaux souterraines.

L'histogramme de tendance d'évolution des points d'eau positives, en fonction de chaque classe de potentialités obtenu, suggère que le modèle FR était plus précis pour que le modèle SE pour prédire les zones potentielles des eaux souterraines. Les résultats montrent que l'approche proposée est opportune pour la cartographie hydrogéologique des aquifères montagneux fracturés. Les cartes obtenues peuvent aider les gestionnaires et les planificateurs de générer des plans de développement des eaux souterraines, afin de s'adapter à la rareté de l'eau et aux conséquences des sécheresses.

Application de l'indice de qualité des eaux (IQES) pour l'évaluation de la qualité des eaux souterraines de la plaine des Angads, Oriental, Maroc

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Mots-clés : Qualité, Eaux souterraines, Angad, Oriental, Maroc.

La plaine des Angads fait partie du bassin de la Moulouya situé au Nord-Est du Maroc. Avant l'approvisionnement de la ville d'Oujda à partir du barrage Machraa Hammadi en 2007, les eaux souterraines de la nappe phréatique étaient l'unique ressource pour toutes les activités domestiques, agricoles et industrielles. Les eaux de la nappe sont toujours exploitées par la RADEEO, l'ONEP et les particuliers qui ont installé des forages et des puits. Afin d'évaluer la qualité hydrogéochimique de la nappe phréatique des Angads, les paramètres majeurs (CE, TDS, Na⁺, K⁺, Ca²⁺, Mg²⁺, Cl⁻, HCO₃⁻, SO₄²⁻, NO₃⁻, NH₄⁺) ont été suivis sur 75 puits répartis sur la totalité de la plaine.

Nous avons déterminé pour les différents échantillons d'eau une première analyse chimique et l'indice de qualité des eaux souterraines (IQES) et sa distribution spatiale sur la nappe.

Les résultats obtenus montrent que la Conductivité Electrique varie de 510 à 5840, avec une moyenne de 2198 µS/cm. Le TDS varie de 540 à 3600, avec une moyenne de 1580 mg/L. Trois facies hydrochimiques ont été définis dans le diagramme de Piper, 68% des échantillons sont chlorurés et sulfatés calciques, 23% sont chlorurés sodiques et 9% sont Bicarbonatés calciques. Les éléments prépondérants sont Cl⁻, Ca²⁺, Na⁺, HCO₃⁻ et Mg²⁺. Les nitrates varient entre 2,4 et 228,5 mg/L, montrant un dépassement de la valeur imposé par la norme (50 mg/L) pour 42,7% des échantillons étudiés. Cette contamination massive est due d'une part à l'utilisation des engrais naturels et chimiques et au rejet directement dans le sol (puisard) dans un certain nombre de maison en dehors de Oujda et qui ne sont pas reliées au réseau de eaux usées.

Enfin, l'indice de qualité des eaux souterraines (IQES), pour les échantillons étudiés, se situe entre 28,1 et 226,6, avec une moyenne de 96.5. La classification des eaux se fait en fonction de la valeur de IQES, < 75, d'excellente à bonne qualité (35% des points), pauvre pour un IQES compris entre 75-100 (55% des points) et impropre à la consommation IQES > 150 (10% des points).

High-Resolution Monitoring of the Snow Cover on the Moroccan Atlas Through the Spatio-Temporal Fusion of Landsat and Sentinel-2 Images

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Keywords: Snow cover, Image fusion; Sentinel-2; Landsat-8; Normalized Difference Snow Index.

Mapping seasonal snow cover dynamics provide essential information to predict snowmelt during spring and early summer. Such information is vital for water supply management and regulation by national stakeholders. Recent advances in remote sensing have made it possible to reliably estimate and quantify the spatial and temporal variability of snow cover at different scales. However, due to technical limitations, there is a trade-off between the spatial and temporal resolutions of currently available satellite sensors. In addition, cloud contamination and poor atmospheric conditions may increase the discontinuity of satellite data. Therefore, data from a single satellite are insufficient to capture rapid snow dynamics more accurately, especially in semi-arid areas where snowfall is highly variable in space and time. Considering these limitations, the combined use of the next generation of multispectral sensor data from the Landsat-8 (L8) and Sentinel-2 (S2) with a high spatial resolution (varying from 10 to 30 m), provides unprecedented options for such applications. Hence, our study aims to show how the synergistic use of these optical sensors can effectively support research on snow cover mapping by using multisensor image fusion techniques to provide a very dense and detailed time series of the Normalized Snow Difference Index (NDSI). Among the existing fusion methods, we used the Enhanced Spatial and Temporal Adaptive Reflectance Fusion Model (ESTARFM), the Flexible Spatio-Temporal Data Fusion Model (FSDAF), and the Pre-classification Flexible Spatio-Temporal Data Fusion Model (Pre-classification FSDAF) to merge L8 and S2 data. The results show that the Pre-Classification FSDAF method creates more accurate fused NDSI and retains more spatial detail than the other methods by generating the lowest Root Mean Square Error (RMSE = 0.12) and the highest Correlation Coefficient (R = 0.96). This method has been used to create high-resolution merged snow series to fill gaps in satellite data sets and directly compensate for the lack of ground-based snow cover data.

Simulation of irrigation in the Ebro River basin: new meteorological and physiographical datasets to better describe agriculture.

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Keywords: Anthropic processes, irrigation simulation

Irrigation has a significant impact on the continental water and energy cycles of those basins where it exists. The impact of anthropic factors on the continental water cycle can be studied using land-surface models (LSM). For this, high-quality forcing and physiographic data, as well as accurate representations of crop covers, irrigation methods, and actual irrigated areas are necessary.

This work presents a new dataset to simulate irrigation using a LSM, at a spatial resolution of 1 km, over the Ebro basin (the largest Mediterranean Spanish basin). This basin is highly anthropized with many dams and canals that, among other uses, are dedicated to irrigated agriculture and farming, which represents 92% of the total water consumption. The dataset consists of a meteorological forcing and the following maps: land cover, actual irrigated areas, and irrigation methods per area.

The physiographic maps have been developed after performing a validation study of the ECOCLIMAP-SG land cover map (Druel et al., 2021), which is the default dataset used with SURFEX v9, that showed poor results over the Ebro basin. In addition, the irrigated areas provided by this database are also overestimated over this basin. The meteorological forcing dataset has been created to improve previous versions of SAFRAN regarding spatial resolution and number of stations.

The land cover and actual irrigated areas maps were developed using SIGPAC data (Agricultural Plot Geographic Information System) provided by the Spanish Ministry of Agriculture, Fisheries and Food. First, each cultivated species informed per plot in SIGPAC was classified according to the ECOCLIMAP-SG covers. Second, SIGPAC information about potentially irrigated areas was combined with LAI increments computed by LDAS-Monde (Albergel et al. 2017) for two summer days (20/08/2017 and 10/08/2019). LDAS-Monde is a tool based on SURFEX that can assimilate satellite-derived LAI from the Copernicus Global Land service in ISBA. Next, irrigated areas identified in the latter map were divided into traditional and modern irrigation districts, and the land cover map was used to differentiate between herbaceous and tree crops in modern districts to assign sprinkler or drip methods respectively, resulting in an irrigation methods map.

The meteorological forcing dataset is based on the SAFRAN meteorological analysis system (Durand et al., 1993), which uses an optimal interpolation algorithm to interpolate observed data, in this case, from the Spanish State Meteorological Agency and the Catalan Meteorological Service, using ERA5 as first guess (for all variables except precipitation). Compared to previous versions of SAFRAN in Spain

(Quintana-Seguí et al, 2016, 2017), this one increases the resolution to 1 km, at the expense of limiting the geographical area to the Ebro basin and has a higher density of stations in the basin's Catalan part.

The dataset sensitivity has been analyzed comparing two simulations performed with the SURFEX LSM. Both used SAFRAN's new version, but one of them was performed with the default land cover and irrigation-related maps, while the other one employed the new dataset presented in this work.

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Streamflow prediction using machine learning techniques: application case in the Moroccan Atlas sub-basin

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Mots-clés: AI modelling, streamflow forecasting, Tensift.

Accurate forecasting of streamflow is essential for an efficient water management, but it remains challenging due to the complexity of hydrological systems. Several hydrological models have been employed for streamflow prediction. However, the need for a robust and parsimonious simulation technique remains. This study compares the performance of four data-driven models, namely Linear Regression (LR), Support Vector Regression (SVR), Random Forest (RF) and XG-boost for streamflow forecasting at a daily time step in the Rheraya sub-basin of Tensift, Morocco. A time series of 13 years of daily Precipitation (P_t), snow cover area (SCA_t) and streamflow (Q_t) data from 2003 to 2016 were used to develop and evaluate the models. Two groups were formed from the dataset for training and testing models. Three input scenarios were constructed based on P_t , SCA_t , Q_t and their values in lag time. To evaluate and compare the accuracy of models, two performance criteria were considered including the Nash-Sutcliffe Efficiency (NSE) and the Root mean squared error (RMSE). The results indicate that SVR outperformed the other models under all scenarios, with a NSE of 0.85 and a RMSE of 0.55 compared to ((NSE= 0.48, RMSE= 1.05), (NSE=0.27, RMSE= 1.25), (NSE=-0.11, RMSE= 1.55)) of LR, RF and XG-boost respectively. It can be concluded that the SVR model is a reliable tool to reproduce daily streamflow.

Modeling of citrus evapotranspiration under different water supply conditions: case study of Beni Khalled

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Key words : Evapotranspiration, model based on Penman-Monteith , Eddy Covariance, Stress, Citrus

In Tunisia, citrus is a key sector and a major consumer of water. The situation in this region is alarming, it suffers from the degradation of its water resources in terms of quality and quantity, and the impact of climate change is increasingly felt. Since these conditions are predicted to be the most dominant in the future, and as there are insufficient information about different levels of stress, an accurate estimate of crop water requirements in these conditions is necessary for an appropriate management of available water resources. The objective of this work was to use a modelling approach to simulate accurately evapotranspiration (ET) at hourly time step. The studied site is a citrus orchard located in the technical center of Beni Khalled-Cap Bon. The planting density is 4m*5m. Its area is 4080 ha and water supply is performed by drip irrigation systems. The study is conducted over the period from 2014 to 2018 which was characterized by a high interannual meteorological variability with extreme events of drought and floods. Especially irrigation restriction has occurred in 2016 due to a water deficit in the Medjrda Canal since the beginning of the year. And irrigation with saline water was applied from August 2016 to August 2017. Evapotranspiration (latent heat flux, LE) and sensible heat flux (H) have been measured in this site since 2013 using Eddy Covariance station. These measurements have been used to calibrate an hourly evapotranspiration (ET) model based on the Penman-Monteith equation which has been calibrated for citrus orchard under well-fed conditions in previous work (Rana et al, 2005). The aim of this study was to calibrate this model for different water supply conditions using the Bowen Ratio (H/LE) as a stress index. We have found a significant relationship between the Bowen Ratio values and one of the calibration coefficients. This result means that this coefficient is not an empirical one as expected because it varies according to a stress level. After the calibration step, evapotranspiration was simulated using this calibrated model. The comparison between filtered Eddy Covariance measurements (LE) and simulated ET with was correct. Values of Root Mean Square (RMSE) varied between 0.09 mm for no-stress conditions and gradually decreased with each stress level to reach 0.02 mm for the most severe stress level.

Analysis and forecast of crop water demand of some irrigation districts across Southeastern Ebro's river basin (Catalonia, Spain): estimation of ET through Copernicus-based Inputs

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The sustainability of irrigated agriculture is strongly linked to the improvement of water use efficiency. This can be primarily achieved by improving water management and use at farm and/or irrigation district (ID) level. To improve the efficiency of water management into IDs passes by closing the water supply-demand gap. Knowledge of water supply is based on information on impounded volumes, current flows, historical series and information from snow reserve models. It is in relation to the crop water demands where the uncertainty is greatest, because although there are historical series of demands, there is no knowledge of the crops in real time and its potential water consumption, so it is impossible to characterize the demands throughout the irrigation campaign. ID managers demand the development of tools to support decision-making in planning and water management. Analysis of the temporal and spatial variability of water demands are necessary to encompass the diversity of irrigators and to evaluate the operational and management decisions of the irrigation districts. Also, modeling water demands in future climate change scenarios will be useful for ID managers to make decisions about changes in land use and/or levels of maximum water restrictions to adopt in conditions of water scarcity.

The present study aims to take advantage of the analysis of time-series of actual evapotranspiration (ET_a) obtained with the two-source energy balance (TSEB) applied as part of the SEN-ET program, to quantify, compare, and analyze differences in crop water demands in several ID located in the Ebro basin during five consecutive growing seasons (2017-2021). IDs are characterized by having different water allocations and regulations in water management, irrigation systems and crops. A deep comparison analysis between ID and crop's water demand by crop type has been carried out. In addition, a projection of water demands in the area were assessed until 2100 based on the simulation of ET_a under six different climatic models (bcc-cms1, CNRM-CM5, Inmcm4, MIROC-ESM, MPI-ESM-MR, MRI-CGCM3) and three different scenarios based on the Representative Concentration Pathways (RCP).

Évaluation spatiotemporelle de l'évapotranspiration réelle sur le bassin versant Lebna nord-est de la Tunisie

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Mots-clés : ETR, Kc, NDVI, spatialisation.

L'évapotranspiration (ETR) est une composante du bilan hydrique qui régit les pertes d'eau d'un couvert végétal en fonction de la réserve en eau du sol, le stade de développement de la végétation et les conditions climatiques. L'estimation de l'ETR permet ainsi de caractériser le fonctionnement des cultures face à des situations hydriques extrêmes et de quantifier l'efficacité d'utilisation de l'eau essentiels pour la gestion des ressources en eau à l'échelle d'un bassin versant. Les mesures de l'ETR in-situ sont parfois coûteuses. Cependant, la télédétection constitue un outil prometteur pour l'estimation est le suivi de la dynamique saisonnière de l'ETR à l'échelle d'un bassin versant. Ce travail a donc pour objectif la quantification de l'évapotranspiration réelle à l'échelle du bassin versant Lebna en Tunisie en se basant sur une estimation spatialisée du coefficient cultural (Kc) des principales cultures en fonction de l'indice de végétation normalisé NDVI. Les mesures de l'évapotranspiration réelle des principales cultures (Blé, Avoine, fève,) et sur la végétation naturelle (parcours) et de l'évapotranspiration de référence (ET₀) ont permis de calculer le coefficient cultural. Les indices de végétation normalisé ont été calculés en utilisant des images Landsat. Les résultats ont montré une forte corrélation entre les NDVI et les coefficients culturaux pour les couverts végétaux étudiés. Le coefficient de corrélation obtenu est de l'ordre de 0,7 pour le blé, l'avoine et la fève et de 0,8 pour la végétation naturelle. Les relations ont été utilisées pour la spatialisation du Kc en fonction de l'NDVI en premier temps, et la spatialisation de l'évapotranspiration réelle en fonction du Kc pour les différentes classes des cultures, dans un second temps. Les résultats obtenus sont utilisés pour l'estimation et la spatialisation de la productivité de l'eau pour les classes des cultures étudiées et à l'échelle du bassin versant. Finalement, l'évaluation de l'impact des différents scénarios d'occupations de sols et de changement climatiques futurs au niveau du bassin sur la productivité de l'eau.

Comparison of Continuous and Event-Based Rainfall-Runoff modeling using Soil Moisture Accounting Algorithm in the semi-arid basin (Moroccan High Atlas)

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The Mediterranean regions are characterized by heavy rainfall events that lead to flooding. The vulnerability to floods in the Moroccan High Atlas, particularly in the Tensift basin, has increased during the last decades. Therefore, rainfall-runoff models can be very useful for flash flood forecasting. Indeed, soil moisture can strongly modulate the magnitude of floods and is thus a critical parameter to be taken into account in flood modeling. However, a comparative application of continuous and event-based hydrological modeling is essential in mountainous watersheds with torrential characteristics in order to identify the most suitable method regarding the analyzed flood characteristics and to identify the uncertainties related to the estimation of the initial moisture conditions before the occurrence of a flood event.

The aim of this study is to compare daily soil moisture measurements obtained by time domain reflectometry (TDR) with satellite soil moisture products (European Space Agency Climate Change Initiative, ESA-CCI) and (Soil Moisture Active Passive SMAP) in order to estimate the initial soil moisture conditions continuously and for each event at the Sidi Rahal station located downstream of the Ghdat basin and to assess the interest of the implementation of soil moisture in the hydrological model. Therefore, a continuous and event-based modeling approach from 2011 to 2018 at a daily time step, on 30 flood events, has been performed using a physical-based precipitation-runoff model (HEC-HMS), applying the Soil Moisture Accounting algorithm "SMA", in order to identify the appropriate modeling approach for the studied basin through calculating the model sensitivity after simulation and calibration of the 30 events.

Both measured and satellite soil moisture data were used in the validation process. The implementation of the soil moisture and the application of the SMA method allowed a better representation of the watershed response in order to achieve a better estimation of the discharge during flood events and to improve the quality of the flood forecast. This was accomplished by exploiting the significant physical connection between soil moisture dynamics and precipitation. Subsequently, a sensitivity analysis was performed to assess the calibration of the model with an optimization method. The result of the sensitivity analysis showed that soil storage and tension storage are the sensitivity parameters. The NSE performance criterion is between 0.76 and 0.95 for event-based modeling and 78% for continuous modeling. The correlation between precipitation and soil root moisture of the 3 products is between ($R^2 = 0.73$ and 0.82). The results demonstrate the interest in understanding and comparing continuous and event-based modeling to properly assessing flood risk. This methodology is very satisfactory for reproducing rainfall-runoff events in this small Mediterranean mountainous watershed.

Keywords: Soil moisture; Flooding; remote sensing; Hydrological modeling, CN method, Mediterranean basin.

MODELING OF A CONFINED AQUIFER : THE SAIS BASIN OF (MEKNES-FES BASIN, MOROCCO)

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Abstract

The Fez-Meknes region in northern Morocco is characterised by a Mediterranean climate. The deep aquifer in this region supplies agricultural activities and domestic water.

The information on this aquifer is still fragmentary and not sufficient, due to its large extent and important depth. In order to improve the knowledge of this aquifer, a 3D geological model was developed in this study. It was constructed from information supplied by seven geological maps, a digital terrain model and more than 100 boreholes. After processing, the data were processed by a Geographic Information System (GIS) and the compiled boreholes were analysed, encoded and integrated into the Groundwater Modeling System (GMS) software. For this, four lithostratigraphic sets were considered: the Paleozoic, Triassic, Jurassic, Miocene and Plio-Quaternary. The model developed allows us to visualise the general geometry of the basin and more particularly that of the Jurassic aquifer, which is gradually sinking towards the north.

The model allowed us to approach the depth of the deep aquifer at any point in the study area and to follow its evolution in depth under the Miocene cover.

The present study has therefore allowed us to develop a conceptual model that is very useful in the reinterpretation of existing geophysical data, to have an extension of the aquifer with a higher degree of certitude, the aim of which is essential for the development of a hydrogeological model; in order to represent the hydrodynamic functioning of the aquifer and to simulate different scenarios in order to evaluate the effects of climatic variability and exploitation.

Keywords: 3D modeling, GMS, GIS, Sais basin, hydrogeology, geometry, Morocco.

IrriTer, a digital twin approach to assess and forecast site-specific crop water requirements at irrigation district scale

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Key words : irrigation, modelling, fAPAR, digital twin, remote sensing.

In the Mediterranean region, agricultural water use accounts for a large share of the water demand and is key for food security and socio-economic stability in rural areas. At the same time, both farm irrigation management and distribution are not trivial tasks, since crop water requirements are site-specific and vary in time due to weather, agronomic practices and other factors. In this context, the availability of EO data opens the opportunity to develop tools for the supervision and management of irrigation, scalable from farms to districts and basins. Time series of observed biophysical parameters of the vegetation and estimates of actual crop evapotranspiration (ET_a) are promising resources for these applications. Those data can be assimilated in digital twins that integrate observations from different sources with soil water balance models, enabling the assessment of irrigation performance and management decision making. In this study we describe an approach that assimilates EO data and simulates the water balance variables of the soil-crop system at each individual plot. The goal is to obtain a dynamic view of irrigation performance scaling from individual plots to the basin, quantifying at real time the progress of crop growth and seasonal water balance, including forecasts of the forthcoming water demand. This approach has been implemented in the lower Ter River basin (Catalonia, Spain), on an area of 675 km². A separate digital twin was defined for each of the 25000 agricultural plots listed in the Land Parcel Identification System. For each plot, the agricultural scenario was set up according to open data of EU CAP's Single Farm Payment and a soil map classification of the area. This included the list of crops declared from 2015 to 2021, the irrigation method and the soil class. From these basic categoric data, more detailed parameters of the crop, soil and irrigation method were assigned according to the description of actual agricultural scenarios on the area. The development of the crop and its soil water balance is simulated in real time for each field, using a customized model based in a rationale similar to FAO's AquaCrop, with additional adaptations for permanent crops, localized irrigation and discontinuous canopies. Simulations are updated on a daily basis, using online weather data from the Meteorological Service of Catalonia. In parallel, as soon as new Sentinel-2 images are available, fAPAR is computed with the PROSAIL radiative transfer model and assimilated in the model. The output are maps and time series with the estimated ET_a, irrigation and available soil water at each plot. These maps are updated

daily. Time series cover the whole year, on a week basis, including the forecasts for the remaining part of the year.

Diurnal and seasonal dynamic of interferometric coherence and backscattering coefficient at C-band over an olive orchard in a semi-arid area

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Keywords: Interferometric coherence, Backscatter coefficient, C-band, Olive, diurnal

This work aims to assess the ability of C-band radar data for monitoring the vegetation hydrological functioning in a semi-arid Mediterranean environment where up to 80-90% of water resources are used for irrigation. To support the sustainable use of water resources in agriculture, quantitative estimates of key variables such as water stress, evapotranspiration and soil moisture must be considered and radar remote sensing is a promising tool for this objective.

Within this context, an experiment was developed on a drip-irrigated olive orchard in the Chichaoua region (center of Morocco). The orchard field is about 2.4 ha, the trees are about twenty years old, 3 m high, and are planted every 5x5 m². This study focuses on the diurnal and seasonal variations of the backscattering coefficient and the interferometric coherence with a radar set composed of 7 C-band horn antennas at the top of a 20 m high tower. The setup has allowed measurements at 4 polarizations (VV, VH, HV, and HH), which provided radar acquisitions with high temporal frequency at a 15 minutes time step since March 2019. The study site is visible through three different Sentinel-1 passages, the acquisitions are available every 10 days, allowing comparison with in situ radar measurements.

The backscattering coefficient and the interferometric coherence are analyzed. The results show daily cycles correlated with the diurnal variations behavior in tree water content (sap flow) and wind speed, with daily amplitude ranging from 3 dB in winter to 5 dB in summer for the backscattering coefficient. While, at a seasonal scale, the backscattering coefficients at all polarization's show a low temporal frequency profile amplitude.

Regarding the interferometric coherence, the diurnal evolution estimated between two consecutive measurements (i.e., 15 minutes) shows a clear diurnal cycle regardless of polarization, with an amplitude of variation between 0.7 in the summer and 0.3 in winter, with a high sensitivity to rain events.

However, additional work, more in-depth with other in situ measurements, are underway to link this radar diurnal and seasonal cycle to the water content of Olive trees according to their phenological behavior. This would bode well for water stress monitoring using radar sensors embedded in space, especially since Sentinel-1 offers, for the first time, the ability to combine radar

acquisitions at high time frequencies (6 days) in C-band with a high spatial resolution (20 m) to optimize water use and monitor crop growth and development.

Future Pyrenees water cycle evolution combining hydrological models

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Keywords: Pyrenees, water cycle, hydrological modelling, future scenarios.

The Pyrenees are a mountain range with significant environmental importance, as it has a great climatic variability, ranging from Atlantic to Mediterranean climates, but it also has high sensitivity to climate change. In addition, this mountain range serves as a water source for more than 15 million people, as well as industry, agriculture, and valuable ecosystems.

Humans are altering the functioning of this system. For instance, greenhouse gas emissions can have a substantial impact on the climate, and hence all aspects of the water cycle, affecting it on both a spatial and temporal scale. As a result, understanding and studying its future evolution is critical for its management, particularly in surface flows, which are the main source of water resources.

Hydrological modelling is a crucial tool to analyse possible hydrological changes over time, as well as trends in future water resources availability. But hydrological models need forcing climatic data for the simulation time period. Global Climate Models (GCM) are used to estimate the future climate, which among other factors, depends on greenhouse gas concentrations, estimated for different Representative Concentration Pathways (RCP). The CLIMPY project provided these data for the Pyrenees region, which are used in this work.

No hydrological model is able to perfectly simulate the hydrological system, so using a diversity of models can help to assess, to some extent, the uncertainty associated with this modelling. Thus, we studied the future evolution of the main components of the water cycle in the Pyrenees for this century using two hydrological models (the fully distributed model SASER and the semi-distributed model SWAT). The comparison of simulations using different GCM and two RCPs (RCP45 and RCP85) allows us to detect, evaluate, and analyse changes in the main components of the water cycle, their trends, as well as the main sources of uncertainty.

SWAT simulations used the atmospheric forcing dataset provided by the CLIMPY project, applying a bias correction based on delta change. CLIMPY provides data of minimum and maximum temperature and precipitation, however SASER needs more parameters thus we completed the

climatic dataset using an analogues methodology, which extends the method developed by Clemins et al. (2019) to build on a multivariate high-resolution reanalysis dataset to infer projected ancillary variables from P & T projections based on analogue resampling. The refined method is a multisite and multivariate resampling method based on analogy of spatially distributed P and T daily anomalies. The baseline climatology is considered as linearly transient for temperature variables, and large-scale additional transient changes in T are passed on ancillary variables based on present-day anomaly relationships.

The hydrological models simulate the water cycle for the 1981-2005 and 2006-2100 periods, under the 4.5 and 8.5 RCPs, and using 6 GCMs: bcc.csm1.1, CNRM.CM5, inmcm4, MIROC.ESM, MPI.ESM.MR, and MRI.CGCM3. Thus, we obtain 24 simulations, a wide range of results that allows us to discuss future climate trends in the Pyrenees and their uncertainty.

This work is a contribution to the EFA210/16 PIRAGUA project.

Evaluation of an irrigation scheduling tool using spatial remote sensing

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Keywords: Irrigation scheduling, Remote sensing, Semi-arid areas, Sat'Irr, TSEB.

An irrigation management tool is evaluated in two ways. A field survey to assess the propensity of Moroccan farmers to use an irrigation scheduling tool, then a water budget approach coupled with optical remote sensing observations (Sat'Irr) is compared with an energy budget approach using thermal remote sensing observations (TSEB).

The socio-economic survey of a group of farmers on the Haouz plain made it possible to assess their needs and practices regarding irrigation management. The evaluation also focused on how this group of users perceived irrigation management technology, their expectations regarding using this kind of tool, and their recommendations to improve it.

Multiple demands existed, but the need for increased water resources stood out the most. Only a minority of respondents gave the need for irrigation scheduling a top priority. Farmers appear to be satisfied with their observational methods explaining this low level of interest. The Haouz's declining water table appears to be well known, yet no one seems to be taking personal responsibility for it. The sample was too small to draw any firm conclusions, but it seems that there is a possibility of moving

towards greater control of irrigation with an irrigation scheduling tool such as Sat'Irr.

The technical part of this study consisted of evaluating and validating two models for estimating actual crop evapotranspiration on a corn plot under a semi-arid climate and drip irrigation. Sat'Irr was run with Sentinel-2 NDVI observations to derive the basal crop coefficient (ref) and the fraction cover. The water budget was run with local observations of rainfall and irrigation amounts. TSEB does not need water inputs to estimate the latent heat flux but needs an accurate estimation of albedo, leaf area index, and land surface temperature (LST). The model was run first with LST derived from the net radiometer measurements, and second with LST retrieved from Landsat 8/9.

Both models were compared to a flux tower installed from September to December 2021.

The results of both models are satisfactory ($r=0.85$, bias=-0.37 & 0.38 for TSEB and Sat'Irr respectively, root mean square error lower than 1 mm per day), despite differences in some specific conditions, in particular, a small overestimation of Sat'Irr during vegetation development and after water inputs, and a

slight underestimation of TSEB during development related to high values of surface temperature.

An average 3K difference between Landsat and in situ LST was found so that the energy budget derived from Landsat was mostly producing sensible heat flux instead of latent heat flux. The low spatial resolution of Landsat thermal data (100 m) might be responsible for this overestimation of LST on this small corn plot.

How to use global soil moisture products to estimate antecedent soil wetness conditions for flood modelling in a semi-arid region?

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Keywords: Flood modelling, Soil Moisture, Semi-arid, and SCS-CN

Intense rainfall events lead up to devastating floods in the Mediterranean region. In Maghreb countries such as Morocco, there is a severe need to flood forecasting systems to mitigate their effects. It is challenging to develop such a system for ungauged catchments. However, remote-sensing products could compensate for the lack of observed data. The soil moisture content can significantly modify the magnitude of flood events and is, therefore, an essential component for flood modelling. In this study, different soil moisture products (ESA-CCI, SMOS, SMOS-IC, ASCAT, and ERA5 reanalysis) are evaluated against in situ measurements and one continuous soil-moisture-accounting. The results indicate that the SMOS-IC satellite product and the ERA5 reanalysis have the strongest correlations with observed soil moisture and SMA model outputs. Comparing the various soil moisture datasets allowed the estimation of the initial soil moisture condition for an event-based hydrological model using the Soil Conservation Service Curve Number (SCS-CN). The ASCAT, SMOS-IC, and ERA5 products behaved equally well in validation to simulate floods, outperforming daily in-situ soil moisture data that may not be truly representative of catchment soil moisture conditions. Due to the faster depletion of soil moisture after precipitation in these semi-arid areas, the daily time step may not properly reflect the saturation condition immediately before a flood occurrence. ERA5 and in situ data were found to better represent the initial soil moisture conditions of the SCS-CN model at the hourly time step compared to the daily time step. This research could be employed to construct effective flood modelling and forecasting systems in semi-arid countries where soil moisture observations are unavailable. The ASCAT, SMOS-IC, and ERA5 products performed equally well in validation to simulate floods, outperforming daily in situ soil moisture measurements that may not be representative of the whole catchment soil moisture conditions.

Characterizing the ability of groundwater to artificial recharge

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Keywords : Artificial groundwater recharge, Evapotranspiration, groundwater aquifers, Water catchment, Hydrogeological parameters

The success of the artificial groundwater recharge is essentially based on the right choice of site for carrying out the operation, the existing methods for the choice of potential sites favoring artificial recharge are lacking in terms of the number of criteria entering at stake and in terms of assigning weight to each criterion.

The methodology developed as part of my research consists of characterizing the ability of groundwater to artificial recharge, with a view to identifying the sectors most favorable to this operation; the development of this new methodology is based on two stages; the first is theoretical and consists of identifying the most relevant parameters for the natural and artificial recharge of groundwater and assigning them a representative weight; the second step concerns the application of the methodology on the groundwater aquifers of the Oum Er Rbia basin with a view to its validation. The success of this last stage requires the availability and use of data in sufficient quantity and reliability relating, in particular, to the climatic, geological, hydrological, hydrogeological and water quality parameters (identified in the first stage), as well as the results of artificial recharge experiments carried out by the river basin agency of Oum Errabi on the water tables of the basin, particularly those of Beni Amer, Beni Moussa and Dir; all these data were obtained from the agency within the framework of a collaboration agreement.

From this research, it is highlighted that the parameters of evapotranspiration and precipitation remarkably influence the potentiality of the land for the artificial recharge of the aquifers; it is therefore important to expand the potential distribution maps to detect the best surface water catchment area. We clearly see that areas rich in surface water do not necessarily mean the great potential of the groundwater table for recharge, and that several other factors determined by the methodology developed give more reliable information.

Climate change impact on water resources: a case study of Settât-Ben Ahmed watersheds, Morocco

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Keywords: Climate change, extreme event, hydroclimatic variability, Settât-Ben Ahmed watersheds, Morocco.

The objective of this study is to contribute to a better understanding of the regional climate and its impacts on water resources in a climatic change context. The study focuses on the analysis of the spatial and temporal variation of precipitation, temperature, flow indices and piezometric level in the Settât-Ben Ahmed watersheds in North West of Morocco during the period between 1981-2019. The spatial and temporal characteristics of climatic and hydrological parameters (averages and extremes) are examined based on daily observations. The evolution observed at the level of the climate of the region through climatic indices, **shows a rather decreasing trend of the annual total rainfall**, but the general trend of the heavy rainfall threshold is generally increasing. On the other hand, average, maximum and minimum temperatures have significantly increased over time, and the number of hot days is increasing while the cool days index has shown a clear decrease. Hydrologically, **the frequency of days with high flows has decreased**, but the general trend in the evolution of maximum flows is rather positive. Also, the frequency of zero flows has increased. The decrease in rainfall and the increase in temperature have globally generated a decrease in surface and groundwater resources. This study has produced important results at the regional and local levels. It has allowed us to refine our knowledge and to understand the spatiotemporal distribution of the mean and extreme hydroclimatic regimes at Settât-Ben Ahmed Plateau.

Cartographie de la pollution de l'aquifère par le lixiviat issu de la décharge de Médiouna, Maroc

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Mots-clés : Tomographie des résistivités électriques, lixiviat, Pollution, Médiouna

Les déchets issus de l'activité humaine et industrielle constituent un véritable péril pour la santé de l'homme et son environnement. Ainsi, le recours aux décharges demeure l'une des solutions pour recueillir tous les types de déchets à l'état brut et mélangé. Dans le cas où elles ne sont pas contrôlées ou à ciel ouvert, comme la décharge de Médiouna, elles peuvent malheureusement poser un risque majeur pour le milieu naturel et principalement les ressources en eau.

L'ancienne décharge de Médiouna constituait le principal site de collecte des déchets du Grand Casablanca. L'un des problèmes majeurs liés à sa mise en place est la production du lixiviat qui s'infiltré dans l'aquifère et constitue une source majeure et importante de contamination. Par conséquent, la cartographie de l'extension de ce liquide reste une solution pour atténuer l'effet de la pollution par les lixiviats. A cet effet, plusieurs approches d'investigation sont utilisées, telles que les méthodes géophysiques. Entre autres, les méthodes géoélectriques par tomographie des résistivités électriques (TRE) permettent notamment d'obtenir de bons résultats.

Dans ce contexte, l'objectif de la présente étude est de cartographier l'étendue de la contamination des eaux souterraines causée par les lixiviats aux alentours de l'ancienne décharge de Médiouna. Pour atteindre cet objectif, nous avons fait usage de la tomographie de résistivité électrique combinée à l'analyse hydrochimique. Cette méthode d'imagerie géophysique nous permettra de déterminer la migration et l'extension spatiale des lixiviats issus de cette décharge. Huit profils TRE ont été réalisés dans la zone d'étude ; un profil en amont et sept en aval de la décharge. L'emplacement des profils a été sélectionné en fonction de la direction de l'écoulement des eaux souterraines et de manière à croiser les linéaments existants et mis en évidence par la carte structurale. La longueur de chaque profil est de 355 m avec une distance inter-électrode de 5 m.

Les résultats obtenus à partir des cartes de résistivité électrique montrent, vers l'extrémité nord et à proximité de la décharge, des valeurs de résistivités faibles, de l'ordre de 20 Ω .m, associés à des

valeurs de conductivité électrique élevées, de l'ordre de 11,03 mS/cm. Ainsi, ce résultat confirme la contamination des eaux souterraines par les circulations du panache de lixiviats. Les cartes de résistivité apparente confirment que ce panache de lixiviat est guidé en profondeur par les discontinuités. Par ailleurs, les profils exécutés en aval de la décharge montrent à la base un niveau conducteur dont les valeurs de la résistivité varient entre 20 et 76,8 Ω .m et qui correspond au toit de l'aquifère cambrien, formé essentiellement de quartzites, affecté par les lixiviats.

D'autre part, les cartes de répartition spatiale de différents paramètres physico-chimiques ont montré des fortes teneurs et fortes minéralisations dépassant la norme de potabilité fixée par l'OMS. Les fortes valeurs de ces paramètres sont surtout concentrées au milieu et proximité de la décharge. Leur répartition suit le sens d'écoulement des eaux de la nappe primaire. Ces fortes teneurs sont à l'origine de la percolation des liquides issus de la décharge de Médiouna.

Une analyse complète de la dynamique des eaux souterraines en réponse aux changements du climat, de l'eau et de la végétation dans la région du Haouz, Maroc

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Mots-clés : Niveau piézométrique, Pluie, Eaux de surface, Végétation, Pompage

L'aquifère du Haouz connaît de multiples difficultés environnementales et socio-économiques dues à la croissance du secteur agricole et à l'intensité de l'irrigation. De ce fait, les eaux souterraines subissent, en plus de l'aridité climatique, une pression anthropique largement liée au secteur agricole. Plusieurs études ont été menées pour mieux comprendre le problème de la surexploitation de l'aquifère du Haouz. Cependant, il est encore très important de réaliser une analyse innovante et complète des données hydroclimatiques, afin de définir la relation entre les paramètres hydrogéologiques, météorologiques, hydrologiques et agricoles, en utilisant des outils statistiques. Dans la présente étude, une attention particulière a été accordée aux principaux facteurs qui ont un impact direct sur la fluctuation de la nappe phréatique, en mettant l'accent sur le niveau piézométrique, les précipitations, l'écoulement des eaux de surface et la végétation. Les données ont été principalement recueillies auprès de l'Agence du bassin hydraulique de Tensift et des données satellitaires. L'analyse de la relation entre ces facteurs a montré la présence de deux systèmes d'exploitation distincts. Le premier se manifeste dans les zones où le pompage est faible, caractérisé par un équilibre naturel entre les précipitations, les eaux de surface, le couvert végétal et le niveau piézométrique, alors que le second est perceptible au niveau des zones à forte irrigation et où l'équilibre naturel du cycle de l'eau est perturbé. Cette étude nous a permis de produire des résultats et des illustrations graphiques pertinents qui aideront les décideurs à mieux comprendre les risques et les défis liés à la vulnérabilité des eaux souterraines dans la région du Haouz, et à promouvoir une gestion efficace et intégrée des eaux souterraines.

Caractérisation hydrogéochimique des eaux souterraines de la commune de Tata et évaluation de leur pouvoir entartrant

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Mots-clés : Eau souterraines, Tata, Entartrage, hydrogéochimie

Compte tenu de la diminution des taux de précipitations, l'absence des eaux de surface et la prédominance du climat aride, les eaux souterraines deviennent la seule ressource pour la consommation et l'agriculture dans la région de Tata (sud du Maroc). De plus, l'entartrage des équipements hydrauliques fait partie des problèmes importants dans cette région oasienne, causant des problèmes techniques importants avec des pertes économiques non négligeables. La compréhension des caractéristiques hydrochimiques des eaux souterraines et de l'origine de phénomène d'entartrage est très importante pour améliorer la gestion et la protection des ressources en eau locales. Cette étude vise à déterminer les processus hydrogéochimiques significatifs contrôlant les eaux souterraines et leur potentiel d'entartrage dans la commune de Tata. À cet objectif, une approche combinant des méthodes statistiques multivariées et graphiques a été utilisée. Soixante échantillons d'eau souterraine ont été collectés à partir de puits publics situés dans la commune de Tata, puis analysés pour les paramètres physico-chimiques durant toute une année de 2021.

Les résultats des analyses physico-chimiques révèlent que les eaux souterraines ont une très légère tendance vers une composition acide. Les cations présentent un ordre d'abondance de type $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$ et pour les anions, leurs concentrations diminuent dans l'ordre $\text{HCO}_3^- > \text{SO}_4^{2-} > \text{Cl}^- > \text{NO}_3^-$. La comparaison des concentrations en ions majeurs avec les normes de l'Organisation mondiale de la santé (OMS) montre que tous les paramètres sont dans les limites acceptables de l'OMS, à l'exception des ions Ca^{2+} , HCO_3^- , SO_4^{2-} . En conséquence, le diagramme de Piper montre que les eaux souterraines sont composées de trois faciès hydrochimiques : Ca-Mg- HCO_3 , Mg-Ca-Cl, et Ca-Mg- SO_4 . Quant au diagramme de Gibb, il indique que les interactions eau-roche sont les principaux mécanismes géochimiques influençant la chimie des eaux souterraines dans la zone d'étude. La dissolution de la calcite, de la dolomite, du gypse, du sulfate de magnésium et de l'anhydrite dans l'aquifère étudié est la principale réaction contribuant à la chimie de l'eau. De plus, les indices chloro-alcalins indiquent que l'échange d'ions est un processus hydrogéochimique non négligeable

contrôlant la chimie des eaux souterraines étudiées. La méthode thermodynamique de Legrand-Poirier-Leroy (LPL), qui a pour but de déterminer le potentiel entartrant des eaux souterraines, révèle que tous les échantillons sont classés comme des types d'eau calcifiants.

A method for robust estimation of snow seasonality metrics from Landsat and Sentinel-2 time series data at national scales with Google Earth Engine

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Keywords: Google Earth Engine, Landsat 8, Sentinel-2, Atlas Mountains, Snow cover, Cloud filtering, Gap filling, snow metrics.

The timing of annual snow melt and snow fall with any potential change in that timing has broad ecological implications and thus impacts human livelihoods, particularly in and around high latitudes and mountainous systems. In this context, snow cover variability can be monitored using in situ measurements, modeling studies, and remote sensing applications. However, weather stations tend to be few in number and do not provide long data records. Consequently, the use of satellite remote sensing especially medium to high resolution products such as Landsat 8 and sentinel-2 data can be an effective tool in the monitoring and mapping of snow cover, providing an opportunity for determining snow onset and melt dates across broad geographic regions. However, the use of such data has some difficulty because of their increasing volume, which creates new challenges in handling such datasets that require new methods to extract relevant information from a data science perspective. In this context, the Google earth engine as a platform that allows analyzing geospatial information has offered us the ability to calculate the first and last day of snow cover annually at a pixel level, providing the ability to track the seasonal and inter-annual variability in the timing of snowmelt toward a better understanding of how the hydrological cycles of higher latitudes and mountainous regions. Still, cloud cover is considered as a limiting factor at higher latitudes. For that, a combination of Landsat 8 and Sentinel-2 NDSI (Normalized Difference Snow Index) data, spatial and temporal filtering algorithms, the compositing and smoothing of snow cover extent over multiple days has been found to reduce the uncertainties in snow cover resulting from cloud cover. The outcome of the present study has provided a regular monitoring during the season, with a time step fine enough to follow the snow cover and melt over a large area of snow coverage. Additionally, to the to the extraction of a spatially and temporally detailed set of seasonal snow cover metrics over a semi-arid region precisely the Moroccan Atlas Mountain range from a combination of Landsat 8 and

Sentinel 2 data products using GEE platform, including snow cover duration, first day of snow and the last day of snow (snowmelt) dates.

LSTM-based Deep Learning Approach for Prediction and Predictive Snow Depth in Atlas, Morocco.

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Keywords

Snow depth, Snow water equivalent, Machine Learning, Artificial Intelligence, Modeling

Abstract

Water resources management has always been a challenging task in the Moroccan context where ground measurements are scarce and climatic and physical conditions are very heterogeneous. In the last decade, machine learning and deep learning have emerged as a promising tool for developing watershed planning process due to their high-performance, accuracy and predictive capability.

For Many Moroccan basins, snowmelt is a key component for hydrological cycle (e.g in Tensift and Oum Er Bia). Snow water equivalent (SWE) is the snow-related variable that is most used input in runoff modelling over basins with snow influence, as it expresses the total quantity of water stored in the snowpack. However, measurements of SWE are expensive, and not continuously accessible in real-time. This motivates a search for alternative ways of estimating SWE from measurements that are more widely available and continuous over time and distributed in space. Sturm et al. (2010) estimated SWE measurements to be 20 times more expensive than snow depth measurements. SWE can also be calculated, however, using snow depth and the volumetric mass density of snow.

To overcome these challenges, we propose in this work, a new deep learning-based framework approach to predict snow depth at a local scale using meteorological variables recorded through the available Automatic Weather Stations installed in the Atlas Mountain (Oukaimden and M'Goun). In order to spatialize the retrieved model at the basin level, variables from Reanalysis data ERA5 will be used as a predictor of snow height. To this end, the deep learning as long term memory (LSTM) algorithm was used to compare the prediction accuracy of the proposed model and a dataset including weather variables was used to train, test and validate our model.

Dynamics of groundwater recharge near a wadi in the semiarid piedmont of the High-Atlas of Marrakech (Morocco)

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Keywords: alluvial aquifer, piedmont, water table fluctuation, multisource recharge.

In arid to semiarid basins, mountain front recharge (MFR) linked to streamflow losses is often considered the primary source of groundwater recharge of the subjacent alluvial aquifers. This MFR was described as episodic, generating a dynamic of alternating episodes of recharge and discharge. The present study is carried out at the semiarid piedmont of the High-Atlas of Marrakech, near the Rheraya wadi that is one of the main streams of the Tensift basin (Central Morocco). The objective is to analyze the processes of groundwater recharge and its temporal variability during two hydrological years, one with an extremely wet climate (2014–2015) and the other with a typical semiarid climate (2015–2016). To this aim, the water table fluctuation was measured from a well located at 10 m from the active channel of the Rheraya Wadi. The groundwater recharge was assessed by the water table fluctuation (WTF) method using the Episodic Master Recession (EMR) algorithm.

The results have shown that in the normal year, the recharge was effectively episodic. In the wet year an exceptional high recharge was recorded following an extreme flood, which has deeply replenished groundwater. In addition, a steady state of groundwater took place induced by a steady recharge rate, a dynamic rarely observed in such a context. For several recharge events during the study period, the assessed recharge seemed not to be from an individual water source. It is rather multisource, mainly from streamflow, but possibly from precipitation, underflow, or irrigation return. Consequently, the used EMR algorithm in this context estimated the general recharge that could encompass various sources. Therefore, in semiarid stream-dominated systems, different recharge patterns (unsteady and steady), various potential sources of recharge and effects of extreme hydrological events are to consider when assessing and predicting groundwater recharge.

Curve number values estimation using rain gauges and TRMM satellite data assessment into HEC-HMS hydrological model in the Upper basin of Oum Er Rbia, Morocco

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Mots-clés : Rain data measurement; TRMM; rainfall-streamflow modeling; SCS-CN Method; HEC-HMS; Upper Oum Er Rbia basin.

The consistency of hydrological process modeling is tied to the availability of long-term gauged data, which is limited. Multisensors and satellite-based products could be considered as a solution to close the gaps, particularly in unequipped areas. The HEC-HMS hydrological model is used as a proxy in this work to evaluate the added value of three sets of rainfall time series (rain gauge data, interpolation, and precipitation generated from TRMM datasets) to simulate streamflow produced by the Oum Er Rbia upper basin across the entire period (2000-2011). Statistical criteria are used to compare and assess the performance of various rainfall inputs. The model was calibrated based on SCS-CN estimation and comparing streamflow obtained from interpolated gauged and average values of TRMM data to identify the accurate CN in the study area. An investigation of CN sensitivity was performed during the calibration phase. The obtained results demonstrate that CN is critical in direct flow modeling, with an ideal value of 30 to 40 in our case study. Furthermore, utilizing TRMM precipitation data on a daily time scale, the hydrological model performs poorly. It has resulted in significant overestimations in streamflow calculations, especially during severe rain events. The interpolated rain gauges simulation model is slightly better than the TRMM average value.

Une gestion technique rationnelle de l'eau est-elle possible ?
La modernisation des techniques d'irrigation face aux enjeux et aux réalités locales des agriculteurs : cas de Oulad El Gaïd et Bouidda - Haouz de Marrakech

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Les discours institutionnels portant sur la question hydraulique prônent les modèles de gestion de l'eau visant la rationalité des usages et son économie comme les seules alternatives aux gaspillages de l'eau et ce dans les contextes de fortes tensions tant en termes d'approvisionnement qu'en termes de distribution. Les pratiques agricoles traditionnelles et notamment les techniques d'irrigation par gravitation ont souvent été décriées et vues comme consommatrices d'eau et désuètes face aux nouvelles techniques d'irrigation notamment le goutte-à-goutte. S'arrêter seul constat d'économie de l'eau eu égard à la quantité d'eau nécessaire théoriquement à l'irrigation d'une culture ne peut en réalité rendre compte de l'ensemble des pratiques agricoles constatées sur les différents terrains. L'économie et la gestion dite « rationnelle » de l'eau ne peuvent être appréhendées et mesurées par les seuls critères techniques. L'anthropologie de l'eau et de l'irrigation révèle que la gestion technique de l'eau n'a réellement de sens et de portée que lorsqu'on l'inscrit dans le cadre de la gestion sociale de la ressource. Les pratiques des communautés agricoles révèlent de nombreuses innovations tant techniques que sociales mobilisées pour parer aux différentes contraintes écologiques, techniques, économiques et politiques.

Dans ce cadre, nous avons entamé, cette année, une nouvelle recherche -de collaboration entre les sciences dures et les sciences sociales (anthropologie)- intégrant un outil scientifique SATTIR visant la gestion rationnelle de l'eau d'irrigation dans la région de Bouidda. Cette recherche vise à identifier les agriculteurs disposés à recourir à cet outil pour conduire l'irrigation de leurs parcelles en fonction des données scientifiques basées sur les photos satellitaires, l'humidité des sols et les températures. Les investigations anthropologiques visent à confronter les savoirs scientifiques (outil SATTIR) aux savoirs et savoir-faire populaires des agriculteurs.

Notre communication reviendra, dans un premier temps, sur les résultats de la modernisation des techniques d'irrigation dans le cadre de la reconversion du collectif gravitaire à l'individuel par goutte-à-goutte notamment dans la zone d'Oulad Gaïd et, dans un second temps, sur les premiers résultats de l'expérimentation de l'outil SATTIR à Bouidda.

Étude hydrochimique et isotopes stables des eaux minérales embouteillées au Maroc en relation avec la géologie

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Résumé

Les eaux en bouteille sont parmi les produits dans l'alimentation humaine les plus importants. Dans cette étude, la composition physico-chimiques et les isotopes stables de l'oxygène et l'hydrogène des eaux embouteillées au Maroc ont été étudiés pour identifier leurs origines et leur caractéristiques hydrochimiques. Un total de 11 marques nationales d'eaux minérales en bouteille, collectées sur le marché Marocain, ont été analysées. Les processus et les facteurs contrôlant la chimie des eaux minérales ont été identifiés sur la base de la combinaison des méthodes géochimiques classiques, hydrochimiques et d'isotopes stables (^2H et ^{18}O).

Les résultats des rapports ioniques et les représentations graphiques plus complexes montrent que les mécanismes d'interaction eau-roche, la dissolution des minéraux carbonatés et silicatés influencent la chimie des eaux minérales. Les caractéristiques hydrogéochimiques des eaux d'origine du plateau de Oulmès montrent des faciès chimiques Na-HCO_3 , les eaux de Sais et Moyen Atlas et Rif sont de type Ca-HCO_3 . Le processus industriel de production et l'ajout naturel ? de CO_2 peut influencer la composition isotopique des eaux. Cette étude a également permis de mettre en relation le chimisme des eaux minérales embouteillées au Maroc avec les terrains géologiques dont elles sont issues.

Mots-clés: hydrogéochimie, origine des eaux, isotopes stables, eau minérale embouteillée, Maroc

Water management: conventional methods or innovative systems thinking using System Dynamics?

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Keywords : System Dynamics; Systems thinking; Integrated water resources management; Climate change.

Water planning and management issues have significant short and long-term effects. They are often contentious issues under constant pressure from population growth, intensive irrigation, climate change effects, and short-term politics. Indeed, conventional analysis of water resource systems can often propose unsustainable management strategies. However, systems thinking seeks to further understand the interactions and feedback between subsystems that determine the overall behavior of a system. System Dynamics, a policy-based approach that assesses the effect of policy changes on a system, facilitates a holistic understanding of water resource systems and policy decision-making. This approach also facilitates participatory modeling and analysis of system behavioral trends, which are essential for sustainable water management. The water resources field has not used the full capacity of System Dynamics in integrated water resources management. Yet, this critically important phase is provided by System Dynamics, which offers unique qualitative tools to improve the understanding of complex problems. Our study provides an overview of the System Dynamics approach, highlights water resource management methods used in Morocco and internationally, and compares water resource management using dynamic systems models to conventional integrated models, citing the advantages and disadvantages of each method. It is clear that traditional management approaches focus on increasing supply and reducing demand without considering the complex interactions and feedback loops that govern the behavior of water resources. Although these approaches can provide quick fixes, they often lead to unexpected, sometimes catastrophic, and delayed results. Therefore, water management should take a holistic approach that considers the interrelated physical (water inputs and outputs) and behavioral (decision rules, perceptions) processes of the system. In contrast to reductionist approaches, System Dynamics adopts a system-level view to model and analyze the complex structure (cause-and-effect relationships, feedback

loops, stock and flow diagrams, latency, reference modes of dynamic behavior, and system archetypes) that generates systemic behavior and demonstrates the use of these qualitative tools for the holistic conceptualization of water resource problems. The model simulation allows for the assessment of long-term impacts on the overall system, exploration of leverage points, and communication of results to decision-makers.

Impact of deficit irrigation on a young Argan (*Argania spinosa* (L.) Skeels) plants: physiological and biochemical behavior

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Mots-clés : *Argania spinosa* (L.) Skeels, irrigation deficit, semi-arid, drought, water management.

The argan tree (*Argania spinosa* (L.) Skeels) is endemic to Southwestern Morocco. Argan forest is growing exclusively in the dry lowlands and is particularly fragile to climate change. In addition, UNESCO declared the argan forest as a Biosphere Reserve in 1998. However, the limited availability of water in Mediterranean ecosystems and the future scarcity of water resources lead to the reduction of water use for irrigation in arid and semi-arid regions. In this context, the objective of this study was to evaluate the physiological and biochemical behavior of young argan plants subjected to different irrigation deficit regimes (D1= 15 L; D2= 10 L and D3= 5 L). The study was done on young argan plants during three consecutive summers (2017-2019). Several physiological and biochemical variables were evaluated. The study showed significant results. Indeed, the irrigation regime influenced very significantly the leaf water status, pigment contents, osmolytes accumulation, oxidative damage and antioxidant enzymes activity. The D3 (5L) irrigation regime recorded the lowest leaf water potential, stomatal conductance, relative leaf water content, total chlorophyll and carotenoid content, free proline, soluble sugars, hydrogen peroxide, malonyldialdehyde and antioxidant enzyme accumulation (SOD, POD and PPO) values compared to the other two irrigation treatments (D1 and D2). Although our results revealed changes in water status, physiological and biochemical processes in argan seedlings, the 10 and 15 L irrigation regimes resulted in less stressed seedlings. Thus, in a context of limited availability of water resources, we can recommend the irrigation regime D2 (10 L) to forest managers for better water management.

Performance of modelling based on statistical methods in spatial floods prediction: case of the Oum Er-Rbia watershed, Morocco

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Mots-clés: Floods, frequency ratio, weighting factor, weight of evidence, Oum Er-Rbia watershed.

Floods are one of the most devastating disasters. Overall, as the effects of climate change and the dramatic global rise of urbanization are becoming more apparent an increasing number of people live in areas at risk of flooding continuous to grow rapidly. The main objective of this study is to delineate flood prone area in high Oum Er Rbia watershed. An initial extensive field survey and interpretation of google earth images allowed us to identify 60 flood locations. Of the total of historical flood locations, 70% were randomly used for training and 30% were used for validation of the models. Fifteen determining factors including, elevation, slope, aspect, curvature, stream power index (SPI), topographic position index (TPI), topographic ruggedness index (TRI), topographic wetness index (TWI), distance from road, distance from river, stream density, rainfall, lithology, normalized difference vegetation index (NDVI), land use, were used to map the flood prone areas. The frequency ratio, weighting factor, and weight of evidence methods was used to determine the correlation between each class of flood factors and flood occurrences. Finally, a final hazard maps were prepared and reclassified into five classes, i.e., very low, low, moderate, high, very high susceptibility. The results of the models were found reliable with ROC value for validation of Frequency Ratio, Weighting Factor, Weight of Evidence model of 75%, 73%, and 76% respectively and the performance of models, of 71%, 73%, and 75% respectively.

The findings result of this study can play a key role in flood hazard management, and can be used by local disaster management, planners, and agencies dealing flood risk management.

Suivi en continu haute résolution de la qualité des eaux de l’oued Sebou : Dynamique et modélisation d’un hydrosystème.

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Mots-clés : Suivi haute résolution, sonde multiparamètre, Qualité de l’eau, Oued Sebou, Modélisation.

Dans le contexte des changements climatiques associés au développement urbain, au surpeuplement et l’anthropisation des milieux naturels, Il est primordial d’anticiper l’ampleur de ces événements extrêmes et des risques souvent inédits. Le partage entre les différents acteurs d’une information fiable et adaptée aux enjeux est un élément majeur du développement. En réponse à ces changements globaux, il est important de pouvoir, suivre sur le long terme les réponses du fonctionnement d’un hydrosystème pour être en mesure d’assurer une meilleure gestion quantitative et qualitative. Le bassin du Sebou occupe une place importante dans cette stratégie nationale étant donné son grand potentiel de ressources en eau et les défis majeurs qui sont posés en matière de gestion et de maîtrise des ressources en eau au niveau du bassin. O’SEBOU est un projet de recherche déployé sur le terrain, instrumentant l’eau à l’aval du bassin versant du Sebou pour mesurer en continu, modéliser et gérer la qualité de l’eau. La station d’observation Mechra Bel Ksiri commune avec l’Agence du Bassin Hydraulique du Sebou est, depuis le 17 juin 2020, équipée d’une sonde multiparamètres YSI-EXO2 avec différents capteurs optiques intelligents et de haute précision mesurant en temps réel et en continu au pas horaire des paramètres physicochimiques tels que : la température, la turbidité, l’oxygène dissous, la conductivité, le pH , le potentiel redox, les teneurs en nitrates et en chlorures. Le système de suivi et d’alerte se fait à travers une plateforme web : Q-Tel SurfaceWater pour la visualisation et une application Smartphone (Smart Q-Tel (Application Mobile) permettant l’observation en temps réel des variations des polluants dans l’oued Sebou. La transmission automatique des mesures se fait via le réseau 4G vers une plateforme de télémessure centrale. Les paramètres, mesurés par ces capteurs, sont ensuite calibrés par des analyses chimiques au laboratoire sur des échantillons prélevés, une fois par semaine, au niveau de la même station. Les résultats obtenus permettent de détecter les périodes de rejets polluants instantanés et les forts rejets saisonniers. Pour la période entre le 11/06/2021 et le 15/04/2022 on a

déte té deux types de rejets polluants, le premier type dont la conductivit  ne d passe pas 1250 s/cm par rapport   la moyenne (725 s/cm) et le second dont la conductivit  atteint des valeurs importantes (2881 s/cm, 1610  s/cm et 1639  s/cm) et souvent accompagn  d'une sous saturation excessive en oxyg ne dissous. Le suivi d'autres param tres tels que l'oxyg ne dissous, la temp rature et la teneur en nitrates permet de mettre en  vidence l' volution nycth m rale et saisonni re et de mod liser leur comportement en utilisant une approche « data-centric ». Celle-ci d montre qu'il est possible de d velopper des mod les simples bas s une base de donn e temporelle afin d'estimer la variabilit  des param tres physico-chimiques dans le milieu fluvial et ainsi d' liminer le biais introduit par les mesures ponctuelles. En outre, les mod les d'apprentissage automatique peuvent s'adapter efficacement   des ensembles de donn es de s ries chronologiques complexes et fournir un outil de pr diction robuste pour la pr diction en milieu naturel.

Inondations liées à la nappe phréatique dans un milieu urbain sahélien : Origine et processus de mise en place

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Mots-clés : Sahel, Nappe phréatique, remontée, inondation, télédétection.

Niamey, la capitale du Niger a connu une croissance démographique continue (+4%), accompagnée par une extension urbaine rapide insuffisamment maîtrisée. Cette croissance, combinée aux effets de changements climatiques ainsi que d'un changement drastique d'occupation des sols (urbanisation de champs cultivés, déforestation des plateaux et érosion des versants) bouleverse le cycle de l'eau, conduisant ainsi à la superposition de trois types d'inondations : i) inondations pluviales (période de mousson) ; ii) inondations fluviales (fleuve Niger) ; et iii) inondations provoquées par la hausse du niveau de la nappe phréatique. Dans plusieurs quartiers, la nappe affleure désormais de manière pérenne et dégrade des conditions sanitaires déjà fragiles. Cette étude vise à préciser le fonctionnement des aquifères dans la ville de Niamey grâce à la combinaison de données géologiques, géophysiques, hydrogéologiques et d'images satellites ou de photographies aériennes historiques (1954, 1964 et 1975). La comparaison des photos aériennes et des images satellites démontre une importante déforestation avec pour conséquence l'augmentation des ruissellements vers la ville et l'infiltration d'une part importante de ces eaux. Les investigations hydrogéologiques permettent d'identifier, dans les zones inondées par la nappe, un aquifère superficiel peu capacitif (porosité efficace de quelques %) et peu perméable (2.10^{-6} à 1.10^{-4} m/s), sus-jacent à un niveau argileux peu profond (~ 10 m) et reposant sur le socle précambrien (schistes, granites). Cette configuration limite les flux et a induit l'apparition de mares permanentes créées par la nappe dans le thalweg des vallées dans, et autour, de la ville. Ainsi, dans Niamey, une hausse pouvant atteindre de vingt à quarante mètre a été observée entre 1961 et 2021 avec des fluctuations piézométriques saisonnières d'ordre pluri-métrique à la suite de la saison des pluies. Au-delà des impacts sanitaires, cette trajectoire pénalise le foncier et provoque localement la dégradation ou le déplacement d'axes de circulation. Contenir le niveau de la nappe apparaît à terme indispensable pour un assainissement durable de la ville de Niamey (ODD n°6) et des solutions sont envisagées.

agrosystèmes semi-arides du bassin fluvial du sahel central

Colloque "Gestion de l'eau en zones Semi-arides, Outils, Changements globaux" (GESOC), Marrakech, 7-10 Nov. 2022

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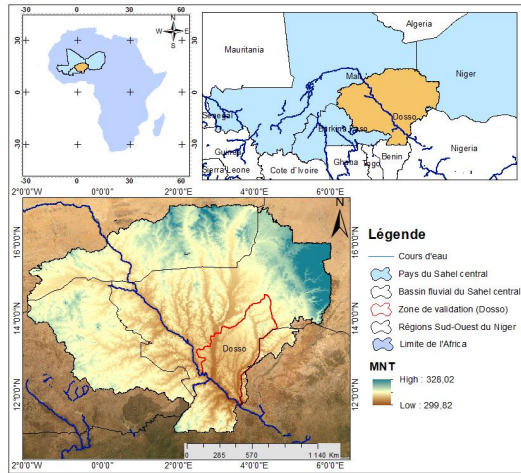
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INTRODUCTION

Les agrosystèmes des milieux semi-arides sahéniens constituent la principale source d'approvisionnement alimentaire et de subsistance de 80% de la population. Depuis les années 1980, ces agrosystèmes font face à une dynamique environnementale complexe, très contrastée et irréversible par endroit. Les aléas climatiques extrêmes comme les sécheresses prolongées constituent le principal moteur de cette dynamique.

De nos jours, les progrès récents des technologies géospatiales et de l'IA offrent des nouvelles perspectives pour interconnecter et modéliser conjointement les dynamiques à la fois climatiques, environnementales et anthropogéniques à n'importe quelle échelle d'analyse. Ainsi, cette étude se concentre sur la modélisation multivariée des paramètres de la sécheresse agricole en incluant de manière objective le maximum des variables et processus qui conduisent à un état de sécheresse.

ZONE D'ÉTUDE



Cadre physique, climatique

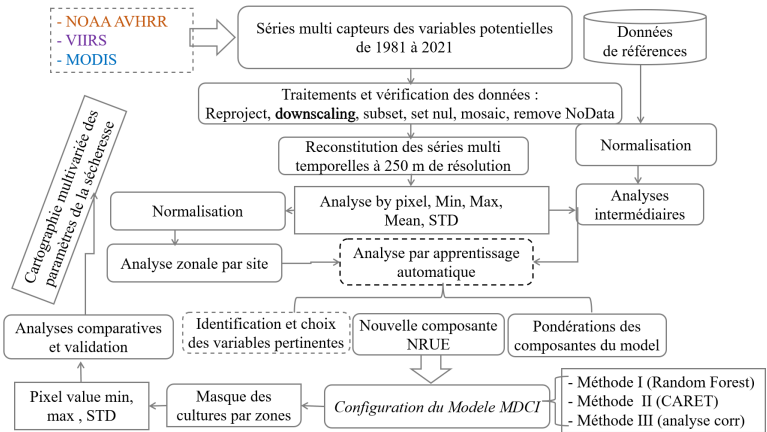
- ✓ Superficie: 340 723 km²
 - ✓ Topographie peu contrastée
 - ✓ Climat tropical à trois zones distinctes: sahélo-saharienne 150 à 250 mm; sahélo-soudanienne 250 à 500 mm, Sahélo-soudanienne 500 à 750 mm
 - ✓ Tmax journalières moyennes se situent entre 31 et 41°C
 - ✓ Record Tmin/max: 7 / 49°C
- Importance socio-économique**
Agriculture est la principale activité de la population pratiquée sur des systèmes des productions pluviaux.

Localisation et caractéristiques de la zone d'étude

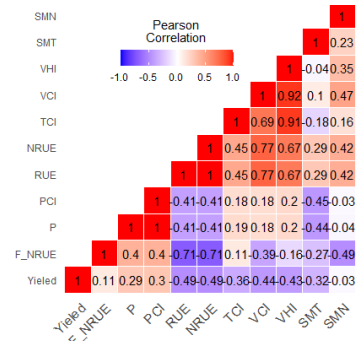
OBJECTIFS

- Développer un modèle composite multivarié pour le suivi de la sécheresse agricole.
- Etablir des statistiques géospatiales des zones exposées aux risques extrêmes multivariés.

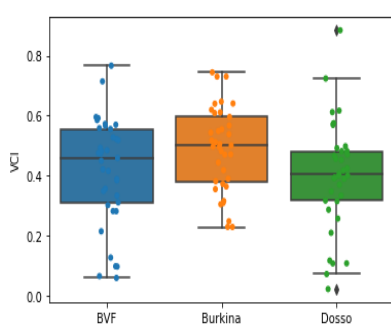
DONNÉES ET MÉTHODES



Méthodologie de la modélisation multivariée de la sécheresse

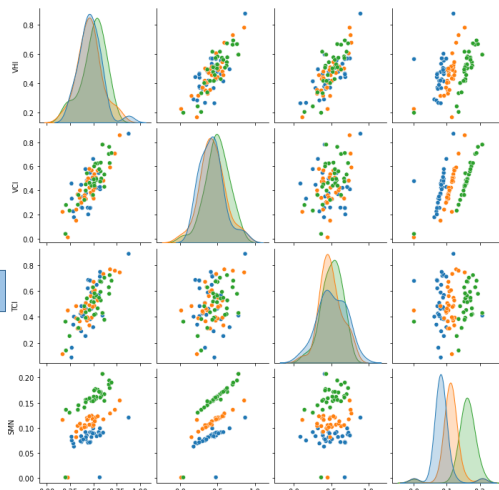


Corrélogramme des variables



Boîte à moustache comparative de VCI

RÉSULTATS ET DISCUSSIONS

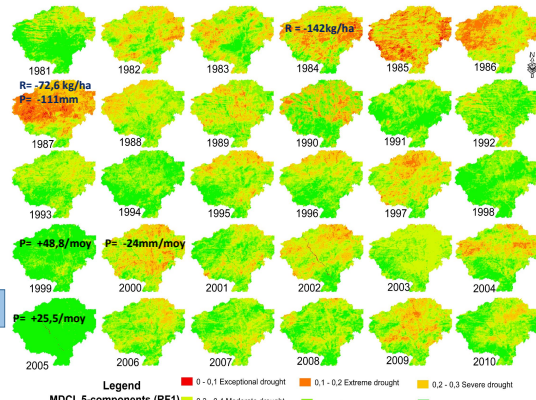


Les distributions des valeurs mensuelles de VHI, TCI et VCI, montre peu de différences pour les trois premiers mois de la saison agricole.

L'indice de la végétation lissé (SMN) indique une distribution bien contrastée entre les mois de juin, juillet et août.

Le SMN étant un indice basé uniquement sur l'état de la végétation, cette distribution corrobore avec l'évolution des valeurs de l'NDVI tout au long de la saison agricole.

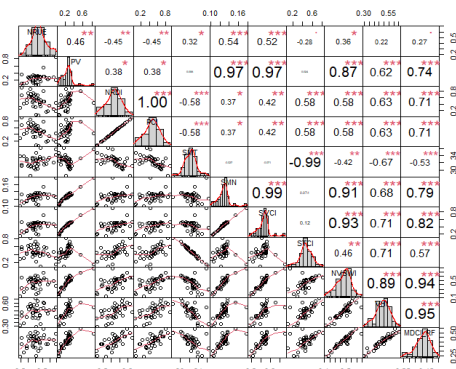
Classification de la distribution mensuelle



Le MDCI a permis de retracer l'historique des paramètres de la sécheresse (début, intensité, gravité et cessation). La climatologie des conditions de la sécheresse est fournie à six niveaux d'intensité de la sécheresse.

Les impacts des sécheresses historiques des années 1984, 1985 et 1987 sur les rendements agricoles est de -142kg/ha (1984) et de -72kg/ha (1987).

Cartographie multivariée sur 30 ans (modèle I)



Le MDCI montre une relation statistique hautement significative avec les autres indicateurs avec une corrélation maximale de 0.95 avec le VHI avec un p-value de

De même la variabilité temporelle du MDCI traduit la variabilité des anomalies des rendements agricoles et celle des indices de référence VHI et NVSWI.

Statistique de validation du modèle MDCI

CONCLUSION

Le modèle composite multivarié pour le suivi de la sécheresse (MDCI) développé présente une adéquation très élevée avec l'indice de santé de la végétation (VHI) et l'indice d'approvisionnement en eau des cultures (NVSWI). De même, l'indice des conditions de l'état de l'environnement mis au point s'est avéré particulièrement utile dans la modélisation multivariée des paramètres de la sécheresse agricole avec un score explicatif de 23% comparable à la composante climatique du modèle qui s'établit à 20% par apprentissage automatique.

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Agronomical response of *Olea europaea L.* cultivar Menara to sustained and regulated deficit irrigation

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Abstract

The availability of water to agriculture in Morocco is an issue of growing concern particularly in Dry areas due to climate change. Olive production is the main crop suffering from water shortage limiting fruit yield. Moreover, olive orchard areas were increased during last decades achieving recently 1.2 million hectares mobilizing more water resources. Thus, new water saving strategy is needed. Sustainable irrigation strategies based on the deficit irrigation, such as sustained (SDI) and regulated deficit irrigation (RDI), should be developed and tested in order to promote olive sector resilience to climate change and water scarcity.

The aim of this study is to evaluate the impact of SDI and RDI on olive trees and water saving. The experiment was conducted in the field on 12 years old trees of 'Menara' cultivar planted with 154 trees/ha density in research station of Saada at INRA Marrakech. For RDI, four water regimes were tested : T1 (RDI 100-70% _{ETc}), T2 (RDI 100-60% _{ETc}), T3 (RDI 80-70% _{ETc}), T4 (RDI 80-60% _{ETc}). For SDI, two water regimes were evaluated: T5 (SDI70% _{ETc}) and T6 (SDI60% _{ETc}). All treatments were compared to the same control: T0(100% _{ETc}). The daily irrigation water amounts were estimated by using (FAO, 1998) method. Total water amounts applied were 242, 218, 210, 185, 177, 169 and 145 mm for T0 to T6 respectively by using drip irrigation system. Agronomical parameters were assessed.

The results showed that SDI and RDI studied strategies have significant influence on studied parameters. Under T5 and T6, branch length decreased by 23.5% and 25.7% respectively compare to control (T0) recording the lowest value of this parameter. For RDI, no significant difference was noted between T0, T1 and T3 for vegetative growth and inducing highest values of this parameter. However, these later decreased by 16.1% and 23.1% under T2 and T4 respectively compare to T0. Similarly, no significant difference showed between T0, T1 and T3 for fruit yield. Nevertheless, this parameter decreased significantly by 22.5%, 23.9% and 24.8% under T2, T4 and T6 respectively. Increasing water stress decreased significantly fruit size by 25.74% and 50.81% for T4 and T6. Compare to T0, fruit weight decreased by 10.9% for T1 and to an average of 25.3% for T2 to T6.

However, fruit oil content increased by 1.35% when water supply was reduced by 40% of the irrigation amounts (T6), probably as a consequence of lower water content in the olive. T3 in RDI is the optimal regime to adopt for all agronomical parameters except oil yield for which SDI is the most optimal strategy.

Key words: Olive tree, regulated and sustained deficit irrigation, agronomical parameters.

Hydrogeochemical processes of Azigza Lake (Middle Atlas, Morocco) inferred from monthly monitoring

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Keywords: Karst, Middle Atlas, Azigza Lake, hydrogeochemical processes, Seasonal changes.

Abstract

The High Oum-Er-Rbia basin, located in the Moroccan Middle Atlas, is a karstic region with very significant water sources that have essential functions regarding agriculture, hydropower production, industrial and drinking water. The region holds abundant wetlands, especially springs, rivers and natural lakes. These systems are very sensitive to the effects of climate change, experiencing considerable lake level, water chemistry, and biological fluctuations in response to regional hydrological balances. This study presents an investigation of the hydrogeochemical processes that control the chemical composition and variability of Azigza Lake, a typical tectono-karstic lake system in the Moroccan Middle Atlas region. A monthly monitoring and sampling water has been implemented from July 2013 to October 2014. Azigza Lake system waters show relatively low salinity due to the fresh water input from the Liasic karst formation. Lake waters are slightly alkaline and are calcium-magnesium-bicarbonate type. The water geochemistry is mainly controlled by carbonate weathering by Water–Rock interaction and is further modified by cation exchange and precipitation of carbonate minerals. The hydrochemistry of the lake showed obvious responses to seasonal changes in precipitation and evaporation, with elevated conductivity during the wet period. During the beginning of the wet season, groundwater evolution could be explained by a simple first flush stormwater. The rapid response of lake water to subsurface and underground waters confirms the dominance of an underground conduct flow regime. These changes and behaviours highlight the sensitivity of Azigza system to regional hydrological and climatic changes.

Evaluation de la qualité des eaux souterraines situées dans quelques périmètres irrigués de la ville de N'Djamena : Cas des sites de Digangali, Moursal, Sabangali et Walia.

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Mots clés : Périmètres irrigués, Eaux souterraines, Hydrochimie, N'djamena.

L'objectif de cette étude est d'évaluer la qualité chimique et l'état de pollution des eaux souterraines utilisées dans les périmètres irrigués situés en bordure des fleuves (le Chari et son affluent le Logone) de la ville de N'djamena, et d'évaluer leurs adéquations des fins d'irrigation. Au total treize (13) échantillons d'eaux souterraines, soit neuf (09) puits et quatre (04) forages ont été prélevés du 20 au 25 mai 2017. Les zones concernées par cette étude sont : Digangali, Moursal, Sabangali et Walia, qui se situent à cheval entre le 3ème, 6ème et le 9ème arrondissement. Pour réaliser cette étude, deux démarches ont été entreprises : La première consiste à effectuer des mesures in situ (pH, T°, CE et profondeur de la nappe) et la seconde à réaliser les analyses chimiques et organiques. Les conductivités électriques des eaux varient entre 308 et 1223 $\mu\text{S}/\text{cm}$ et le pH entre 6,40 et 7,43. Les résultats des analyses chimiques montrent que certains paramètres ont des teneurs supérieures à la norme fixée par l'OMS, Ainsi, 54% des points d'eau ont des teneurs en $\text{NO}_3^- > 50 \text{ mg/l}$ et teneurs en $\text{NO}_2^- > 0,1 \text{ mg/l}$ et environ 23% des points d'eau ont des teneurs en $\text{NH}_4^+ > 0,5 \text{ mg/l}$ soulignant ainsi la présence d'indice de pollution dans ces eaux.

La totalité de nos points d'eau (100 %) est appropriée pour l'irrigation, selon les valeurs du rapport de corrosivité (CR). Pour le rapport de Kelly (KR), 23% des eaux sont inappropriées et pour le pourcentage de sodium (% Na), 15 % des eaux sont bonnes, 77% sont admissibles et 8% sont inappropriées pour l'irrigation. Dans le diagramme de Wilcox La quasi-totalité des eaux sont de qualité excellente à bonne à l'exception d'un point d'eau qui est de qualité admissible. Au niveau du diagramme de Riverside, 84% des eaux appartiennent à la classe C2S1 correspondant ainsi à des eaux de salinité moyenne, donc à faible risque d'alcalinisation et 16% de ces eaux appartiennent à la classe C3S1, qui représente des eaux fortement minéralisées avec un faible risque de salinisation des sols. Au niveau du diagramme de Doneen, 54% des eaux appartiennent à la classe II, représentant ainsi des eaux d'une qualité de classe intermédiaire et sont susceptibles d'être utilisées pour l'irrigation, avec certaines précautions. , 46% des eaux à la Classe I, représentant l'eau impropre à l'irrigation.

Assessing water delivery performance of irrigation schemes: a case study of haouz plain, morocco

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Mots-clés : irrigation, evapotranspiration, performance indicators, remote sensing

This study aims to propose and evaluate a simple methodology for assessing the water delivery performance in an irrigation scheme in the Haouz plain, a semi-arid agricultural area in the south of Morocco, during two growing seasons. For that, crop evapotranspiration and irrigation water requirements are estimated and mapped over the irrigation scheme by implementing a remote sensing-based approach. Time series of high resolution NDVI imagery (Normalized Difference Vegetation Index) provide estimates of the actual basal crop coefficient (K_{cb}) and the vegetation fraction cover (f_c), which are then implemented in the FAO-56 Soil Water Balance model. The performance of the irrigation scheme was assessed with indicators reflecting the equity and adequacy. Adequacy was determined according to Relative Irrigation supply (RIS), Depleted Fraction (DF), stress coefficient (K_s) and Irrigation priority index (IPI) whereas equity was assessed according to the coefficient of variation of crop evapotranspiration (CV_t-ET). The combined analysis of these indicators was performed using different matrices that reflect the impact of the water supply condition on the uniformity of water consumption within the scheme and inform how effectively the manager has supplied irrigation water to reduce the crop water stress. The crop ET estimated by the FAO-56 method based on remote sensing was validated using the *in-situ* measurements by eddy-covariance system over the main crops in the region showing an acceptable accuracy. The results suggested that the water distribution within the irrigation scheme needs to be improved in order to achieve an efficient and productive use of water in the irrigation system.

This study showed that methods combining remote sensing techniques, models and hydro-climatic data are useful for managers since they provide interesting insights of the effectiveness of the water delivery rules in irrigation schemes.

L'évapotranspiration de la nappe phréatique en zone semi-aride : un facteur responsable de la salinisation des eaux souterraines cristallines ?

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Mots-clés : Roches cristallines, Salinisation, Modélisation, Bilan de sel

Dans les zones semi-arides, les ressources en eau contenues dans les aquifères fracturés du socle cristallin sont généralement faibles et peuvent être soumises à des problèmes de salinisation. Dans le Nord-Est semi-aride du Brésil, et plus particulièrement dans l'état du Ceará, une salinité élevée et hétérogène des eaux récentes du cristallin est observée, avec des concentrations en chlorures qui peuvent atteindre 5 g/l sans que les processus de salinisation de ces eaux ne soient encore clairement compris à ce jour. Face à la raréfaction des ressources en eau et aux changements climatiques, les eaux contenues dans ces aquifères constituent une ressource stratégique pour les populations locales. Dans ce contexte, une bonne compréhension des processus hydrologiques est nécessaire pour assurer une gestion éclairée de cette ressource. Dans cette étude, l'utilisation d'une approche multidisciplinaire de terrain a permis de caler les paramètres physiques d'un modèle simple de salinisation des eaux souterraines. Ce modèle conceptuel repose sur l'hypothèse que la salinité des eaux souterraines est dérivée des apports atmosphériques, qui vont progressivement s'évapoconcentrer dans les différents compartiments du cycle de l'eau avant d'être lixiviés en profondeur vers l'aquifère, où les eaux peuvent également se saliniser en raison de l'évapotranspiration due notamment aux strates arbustive et arborée. Dans un premier temps, l'objectif de ces simulations de bilan d'eau et de chlorure a été de déterminer le nombre d'années nécessaire pour atteindre les concentrations en chlorures mesurées dans les eaux du socle cristallin et d'identifier quels sont les paramètres du modèle qui entraînent une forte salinité des eaux. Dans un second temps, les simulations ont cherché à expliquer la dynamique de la salinité des eaux souterraines dans le socle cristallin et à déterminer quelle est la tendance actuelle : salinisation ou desalinisation. Les résultats de ces modélisations ont montré que l'aridité climatique et les forts taux d'évapotranspiration ne peuvent pas conduire à une forte salinisation de la nappe sur une période de temps de l'ordre d'une centaine d'années, mais conduisent à des concentrations en chlorures de l'ordre de quelques dizaines de mg/L, 100 à 200 mg/L tout au plus. Ainsi, le seul facteur capable de

provoquer une forte salinisation de l'aquifère (avec des concentrations de l'ordre du g/L) est la présence de conditions endoréiques souterraines (abaissement du niveau piézométrique) dues au processus de transpiration de l'aquifère par les racines des arbres de la végétation native avec un taux de transpiration équivalent à la totalité de la recharge annuelle. Ceci implique qu'il n'y a plus de relation directe entre l'âge apparent de l'eau et l'accumulation de sels dans l'aquifère, ce qui est observé dans notre zone d'étude. Les simulations suggèrent que les aquifères seraient dans une dynamique actuelle de désalinisation en raison de la déforestation de la végétation native depuis l'époque de la colonisation, et ce malgré l'influence d'infiltration d'eau évaporée dans les processus de recharge.

A combined crop water balance modeling and remote sensing approach for estimating deep percolation at the irrigation district scale

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Mots-clés : deep percolation, crop water balance model, remote sensing, in-situ data, integrated scale

Deep percolation (DP) is the water flowing under the roots when the soil's capacity to hold water is exceeded. It is an important term of the crop water budget, controlling soil salinization, potentially impacting downstream ecosystems, and being a strong indicator of water productivity. Estimating this flux at spatial scales relevant to farmers (plot-scale) and to watershed or irrigation district managers (sub-basin-scale) is thus fundamental for a sustainable management of water, soils, and downstream rivers. However, even though it can be measured or estimated locally with lysimeters or physically-based models, respectively, DP is generally neglected or considered as a residual variable in crop water balance models. Furthermore, many studies have shown the relevance of using remote sensing data to spatialize crop water fluxes. The aim of this work is thus to estimate DP from the plot-scale to the sub-basin-scale by using a crop water balance model coupled with remote sensing observations. For this, SAMIR, a crop water balance model based on the FAO-56 method using remote sensing data to constrain the modeled vegetation and the soil water status, is used. The approach is tested over the Algerri-Balaguer irrigation district in northeastern Spain where in-situ drainage flow measurements are available at an integrated (sub-basin) scale. Those data were obtained from a network of artificial drains feeding three outlets where the drainage flow is continuously measured. Additionally, two lysimeters were installed on two experimental fields of the area. Firstly, the DP simulated by SAMIR and by a physically-based model (HYDRUS-1D) are compared with the lysimeters measurements. Preliminary results indicate that both models are able to reproduce the DP amount cumulated over the season given a site-specific calibration. Secondly, the field-scale SAMIR

DP estimates are aggregated over several sub-basins and compared against the drainage flow measurements at the outlet of the associated sub-basins. A strategy for calibrating SAMIR at the sub-basin scale is proposed. The obtained results provide a first assessment of the potential of using a satellite-driven crop water balance to retrieve agricultural deep percolation at multiple spatial scales.

IDENTIFICATION DE L'IMPACT DES CHANGEMENTS CLIMATIQUES SUR L'HYDROLOGIE ET L'HYDROGEOLOGIE CAS DU BASSIN OUED ZIZ

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Résumé

La richesse de l'agriculture, l'essor démographique et l'épanouissement des activités socio-économiques sont dus essentiellement à la quantité et à la qualité des eaux. D'autres facteurs relatifs aux contextes géographique, géologique, pédologique et climatologique, sont aussi déterminants dans ce développement socio-économique.

Ce développement de plus en plus grandissant ainsi que la complexification accrue des installations économiques et industrielles, peuvent générer des impacts négatifs sur l'environnement de manière générale et sur les ressources en eau (surtout de surface) de manière particulière. Cela a conduit tous les acteurs à entreprendre des analyses systématiques de plus en plus poussées sur l'état qualitatif et quantitatif des eaux souterrain et les eaux de surface fortement sollicitées pour l'alimentation et l'approvisionnement des secteurs socio-économiques, sur les sources potentielles de leur contamination et sur les facteurs déterminants dans cette contamination. Cela a pour objectif principal de protéger la ressource en eau et de proposer des mesures d'atténuation.

Pour une meilleure identification et évaluation des impacts négatifs, nous ferons appel à plusieurs outils et méthodes d'étude : géologique socio-économique, climatologique, pédologique, hydrologique, étude de vulnérabilité et de sensibilité, étude d'impacts sur l'environnement, ...

Le présent travail consiste à la réalisation d'une étude de protection contre les inondations d'oued Ziz qui se situe dans le grand bassin de Ziz qui fait partie des zones où l'on observe un essor démographique important, une urbanisation galopante et une intensification des activités socio-économiques (principalement industrielles). Ce bassin est menacé par le risque d'inondation à cause de sa topographie et son urbanisation non contrôlée.

Cette étude a pour objectif de diagnostiquer le mécanisme d'écoulement de l'Oued Ziz, déterminer les zones inondables, un schéma d'aménagement permettant la protection des zones inondable contre les inondations. Ce travail est composé d'une étude morphologique, d'une étude hydrologique du bassin versant du centre, ainsi qu'une modélisation de l'écoulement dans l'oued réalisée sous le modèle hydraulique HEC-RAS.

Mots clés : Changement climatique, inondation, bassin versant de Ziz, environnement, HEC-RAS.

A Multiple Changepoint Approach to Hydrological Regions Delineation

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Keywords: Hydrologic regionalization; Similarity; Hydrological time series; Changepoints; Wavelet coherence

Hydrologic regionalization consists of regrouping stations and catchments in pools based on a similarity measure. Regionalization is commonly used to extract a robust signal that can be used to describe the hydrology of the region or extrapolated to a location without measured information. Obviously, the similarity measure used affects the type of hydrological behavior one would expect from stations within a region. Most regionalization methods assume a stable and/or linear relationship between parameters of interests while it is well known that the physical processes driving the behavior of hydrometeorological variables are inherently non-linear and non-stationary. In this paper, we propose a similarity measure that is based on the location of changepoints in hydrological time series. The proposed method has the unique advantage over other hydrological region delineation methods to detect regions where hydrological member stations are non-linearly correlated, and where the strength of the relation varies with time. It therefore has the potential to uncover similarities that would not have been detected by existing regionalization techniques. The proposed method is applied to the Tensift watershed located in Morocco, North Africa. The coherence of the detected regions is checked using wavelet coherence.

Assessment of Remote Sensing-based Evapotranspiration Products over Tensift Al-Haouz region, Morocco

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Keywords: Evapotranspiration, Remote Sensing, Water resources management.

Evapotranspiration (ET) is one of the critical components in the water cycle. Several fields, ranging from hydrology to agricultural and climatic sciences, need accurate information on ET's geographical and temporal distribution at regional and global scales as a vital element in optimizing water resources management. However, ET is not easy-to-measure mainly at large scale. Due to the restricted ground data availability, the focus has moved toward satellite-based products to cover observational gaps. Multiple evapotranspiration (ET) products with various Spatio-temporal resolutions at regional and global scales have been generated by leveraging readily accessible satellite images and ground-based data. However, the generated ET products exhibit high uncertainties that restrict their practical hydro-meteorological uses, notably in water-scarce places where water consumption is increasing. Extensive assessment of such big-scale predictions is essential before being employed in diverse applications. This comparative study will undergo at the site scale to evaluate the accuracies of ET products retrieved from five commonly used satellite- and model- based ET datasets (MOD16, SSEBop, ETMonitor, WAPOR, and GLEAM). The evaluation of these products will be performed based on ET measurements by Eddy covariance system over different crops (olives, citrus, wheat, sugar beet...), located in the Haouz plain, Morocco (http://trema.ucam.ac.ma/obs_trema/index.html).

Groundwater: a 'complementary' resource to the surface water network. Reflections based on observations carried out on the Haouz aquifer, Morocco

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Key words: water scarcity, groundwater, Morocco, farmers' adaptation, drip irrigation

In response to the structural water shortage, Morocco has chosen to fight against water losses by pressurising surface water gravity canals and promoting drip irrigation (Green Morocco Plan 2008-2018). The plan was based on the assumption that this traditional irrigation system wasted water. This "irrigation modernisation" through the adoption of localised irrigation was to lead farmers to lower their water consumption and therefore to better satisfy the connected farmers with the same water quantity stored in dams and supplied by public infrastructures, or even to supply water to more farmers by enlarging the irrigated perimeters. This enhanced satisfaction of water demand should also respond to another problem observed in many irrigated areas: to fight against the increasing use of groundwater, which in many contexts is becoming overexploited and threatened with collapse in the more or less distant future. This is the case of the Haouz aquifer (Marrakech plain - Morocco) which will be used to illustrate our discussion.

This presentation is based on surveys carried out in two irrigated perimeters undergoing modernisation. It seeks to show how this modernisation has in fact led farmers to consider the groundwater resource as complementary and not competitive with the surface water resource. This is due to a double process: the canal modernisation has led to a more intense exploitation of surface water (in reference to Jevons' paradox). Instead of reducing the surface water quantity mobilised following a localised and therefore more economical use, the farmers sought to make better use of the water quantity to which they were initially entitled. They have thus intensified cropping on the same plots or increased the irrigated areas, sometimes also tending to adopt higher value-added crops. But in doing so, they have increased their vulnerability to this resource, which is only delivered when reservoirs allow it. This has led farmers who can afford it to invest in boreholes, allowing them to avoid periods of surface water shortage.

To conclude, field observations suggest that the ongoing modernisation of surface water distribution to farmers and the shift to drip irrigation has led to higher water productivity, but increased vulnerability to drought, more intense groundwater use and more inequity. And this trend may be difficult to reverse, as traditional drivers such as tariff or tax incentives are ineffective once boreholes are electrified. Only a collective awareness and willingness to share the effort among all stakeholders to ensure sustainable resource use will enable this.

Farmers' adaptation strategies to water scarcity and evolving water access: lessons from the Lebna watershed, Cap Bon (Tunisia)

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Keywords: water scarcity, farmers' adaptation, socio-economic factors, psychological factors

Irrigating farmers in Tunisia are facing a variety of risks, including increasingly frequent water shortages, due to institutional, political and climate changes. To protect themselves from these risks, farmers implement a variety of adaptation strategies that can be classified into three categories: (i) water management adaptations; (ii) changes in farming practices and productions; and (iii) farm-household management options. Understanding the factors driving farmers' choices is crucial to support them in their strategies to mitigate and cope with water scarcity.

Economic literature related to farmers' vulnerability and adaptation has pointed out the role of various livelihood assets (natural, physical, financial, human and social), as important factors to reduce farmers' vulnerability. More recently, several studies, based on the Protection Motivation Theory, showed that psychological factors are of crucial importance in the adoption of water conservation practices.

Following these works, we address three research questions in this study: (i) How did Tunisian irrigating farmers adapt to various water scarcity events in the recent past? (ii) What are their strategies to adapt to future water shortages? (iii) What are the respective role of assets endowment and psychological factors to explain their past and future adaptation strategies?

We conducted a survey with 58 irrigating farmers in four public irrigation schemes in the downstream part of the Lebna catchment, in the Cap Bon region of Tunisia. Irrigation water supplied by the public schemes either originates from the Lebna dam, or from the Medjerda-Cap Bon canal transferring water stored in dams along the Medjerda river valley. An increasing number of farmers complement their water supply with private wells tapping shallow groundwater.

Faced with drought, which is the main cause of water scarcity in the recent years, the interviewed farmers implement a high diversity of adaptations, often several of them at the same time. Adaptations related to water management (changes in irrigation doses, reallocating water among crops, water storing, seeking alternative sources) are dominant when the drought occurs, while in the medium term adaptations more often concern crop choices and management (fallowing, choice of crops with low water needs, change of varieties, diversification of crops...). Except for the decreasing of non-essential family expenses and decapitalization, adaptations affecting the household as a whole are less frequent. Both in the short and medium term, adaptation strategies vary according to the irrigation scheme, depending on the mix of water sources available to farmers. The results confirm that beyond asset endowments, farmers' adaptation strategies are influenced by their perception about their capacity to implement each measure and about measure relative effectiveness.

Evaluation of PERSIANN CCS-CDR product for drought assessment in a semi-arid basin in Morocco

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Mots-clés : PERSIANN, CCS-CDR, Drought assessment, Precipitation, Morocco.

Precipitation estimation products are becoming more vital for climatological and hydrological studies. Satellite-based precipitation products, with simultaneously, high spatial and temporal resolutions are mostly needed to assess climate change repercussions in regions suffering from data-scarcity. Past researches focused on datasets either with a poor spatial or a poor temporal resolution, therefore, showing weak performances. Precipitation estimations from Remotely Sensed Information using Artificial Neural Networks-Cloud Classification System-Climate Data Record (P-CCS-CDR) are one of the projects aiming to remedy these limitations. The P-CCS-CDR dataset provides precipitation estimates at 0.04° spatial resolution, the product is covering the period 1983 to present over the global domain of 60°S to 60°N. The main goal of this study is to evaluate the accuracy of the P-CCS-CDR product compared to observed precipitation at monthly scale and its suitability for drought assessment in a semi-arid watershed in Morocco. Several statistical indices are computed, and drought SPI (Standardized Precipitation Index) is calculated with P-CCS-CDR to estimate its suitability to simulate drought during the period from 1983 to 2020. The preliminary comparison and evaluation results of both datasets are promising, showing good correlation coefficient (CC) of 0.77 on a basin scale for monthly precipitation, poorly overestimating the observed precipitation with a 3.9% PBias and a Nash-Sutcliffe efficiency coefficient (NSE) criteria of 0.40. At the basin scale the SPI for 3 and 9 months (SPI3 and SPI9) were calculated using both observed and P-CCS-CDR datasets, the precipitation PBias were not corrected during this study, the results showed that comparing to the observed SPI, the P-CCS-CDR SPI overestimated the drought risk with 225.9% and 101.4% PBias respectively for SPI9 and SPI3, the NSE were very low compared to the previous precipitation evaluation, scoring 0.1 and 0.27 for SPI3 and SPI9. However, the correlation and determination coefficients have average scores with a 0.67 CC and a 0.44 R², demonstrating that we need to correct

the PBias before using the P-CCS-CDR data for SPI calculation. This study provides a framework for future use of the P-CCS-CDR to assess climate change impacts over semi-arid watersheds, providing an important alternative to observed precipitation datasets.

Performance assessment of the ERA5-Land reanalysis versus ground-based agrometeorological data over a south Mediterranean basin

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Abstract

Reference evapotranspiration (ET₀) is a key parameter for assessing crop evapotranspiration (ET_c). The latter, considered the crop water demand, is a critical component of the water budget and could be responsible for up to 60% of precipitation returns to the atmosphere. A reasonable estimate of ET₀ requires several climatic data, which may be lacking in areas where monitoring stations are sparse. In semi-arid and arid regions, especially the south Mediterranean, agro-meteorological ground stations are often unavailable and/or sparsely distributed with short datasets, making it difficult to have an overall proper assessment of agricultural water requirements. To overcome this challenge, the use of satellites and the reanalysis datasets could be an alternative to meet the needs for geographically and temporally distributed agro-meteorological data. In this regard, the present study explores the performance of the Penman-Monteith (FAO56-ET₀) method fed by ERA5 Land outputs in estimating daily ET₀. First, the ERA5-L data relative to air temperature (T_{2m}), surface solar radiation downwards (R_s), relative humidity (RH), wind speed (u₁₀), and reference evapotranspiration (ET₀) were compared with the corresponding in situ data on a daily basis. Overall, there was a good agreement between observed and reanalysis data. The temperature showed the best performance followed by RH, R_s, then u₁₀. This was translated to good results in ET₀ estimation under different topographical conditions. The results revealed the potential of reanalysis datasets as an alternative input for estimating ET₀ and overcoming the unavailability of certain agrometeorological data.

Keywords: ERA5-Land, Reanalysis, Meteorological data, Reference evapotranspiration, Data-scarce regions.

What do satellite data say about groundwater storage changes in Morocco?

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Mots-clés : GRACE, Groundwater depletion, rainfall, snow cover, groundwater recharge

Since the early 2000s, the earth's gravity anomalies provided by the GRACE (Gravity Recovery and Climate Experiment) mission have opened new pathways for hydrologists to monitor the changes in terrestrial water storage. They provide valuable information that can be used to complement the in-situ observations. In this work, the relevance of several GRACE solutions was examined to study the changes in TWS (terrestrial total water storage) and GWS (groundwater storage), and their link to snow and rainfall variability. The data were assessed to outline how well the GRACE-based water storage time series follow the piezometer observations. Then, the water storage was tested for trends over Morocco using the Mann-Kendall test and Sen Slope estimator. The results show that the GRACE data can fairly describe the temporal patterns of the GWL (groundwater level), with correlations up to 0.79. Moreover, terrestrial water storage was found to be subject to a strong depletion that was relatively masked by a natural recharge event. We have identified two intermittent depletion episodes (before and after the recharge event) with rates higher than those obtained for the long-term trend lines. Lastly, the TWS appeared to be strongly modulated by snow cover and rainfall distribution.

Performance of Two-Source Energy Balance-Soil Moisture model over Olive & Citrus Orchards in a semi-arid region

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Abstract

Evapotranspiration (ET) is the most essential component flux in the water balance in semi-arid regions, which are characterized by a lack and insufficient precipitation, soil moisture and groundwater depletion. Therefore, an accurate quantification of ET over an heterogeneous surface at different scales is crucial and can help the decision-makers to enhance agricultural water productivity and manage the water scarcity in order to fulfill increasing demand. Over the recent years, various remote-sensing based energy balance models (SEB) have been developed to accurately estimate actual ET. Among them, the two-source energy balance (TSEB) model that uses the land surface temperature (LST) as a key boundary condition to estimate ET across the land-atmosphere interface. However, under water-scarce conditions, LST may not constrain the soil evaporation (E) and plant transpiration (T) concurrently. Accordingly, surface soil moisture (SM) was introduced in the original TSEB as an additional constraint to improve fluxes estimates and a modified model was developed which called "TSEB-SM". In the terrestrial water cycle, the ET is dominated by plant transpiration (T). Thus, the particularity of TSEB-SM model relies on the parameterization of Priestly Taylor coefficient, that has been adjusted in accordance with the soil water content during the cropping season. In the present work, the TSEB-SM was applied to three semi-arid irrigated sites "Agdal, Tahanout & Agafay" located at Tensift basin and respectively planted with Olive and Citrus trees. The outputs of TSEB-SM are compared to in situ flux measurements derived from the Eddy-Covariance (EC) systems that were installed during a micrometeorological monitoring campaign conducted in these areas. The preliminary findings are promising. Thus, the TSEB-SM model reduces greatly the discrepancies between ET estimates and measurements with an average determinant coefficient (R^2) that reaches 0.6 and an average Root Mean Square Error (RMSE)/ Mean Bias Error (MBE) of 55 / 8 (W/m^2) for the three studied sites. With the incorporation of satellite products including Landsat LST/NDVI and microwave SM, the TSEB-SM could be potentially a robust tool for monitoring ET at a regional scale over an heterogeneous canopy cover.

Key words : Evapotranspiration ; TSEB-SM ; Trees ; semi-arid.

Gross primary productivity and yield estimation of winter wheat based on machine learning

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Keywords: Crop yield forecasting; light use efficiency ; machine learning; remote sensing, vegetation indices; weather data; Winter wheat

Population increase, urbanization, and climate change have an impact on the food security of a country's population. This food security is related to cereals, particularly wheat, as it represents the main ingredient in foods in several countries, including Morocco. Thus, monitoring and early forecasting of wheat yield are of great relevance in this regard. Recently, the use of machine learning and deep learning algorithms to help decision-makers to have a reliable forecasts of crop production became an interesting topic for research. In this context, this study aims to use different regression models for predicting wheat yield. As machine learning algorithms usually need large volume of observations for model training, due to the absence of sufficient data, we have first applied a satellite data-driven light use efficiency (LUE) model to estimate gross primary productivity (GPP), and then combined this model with the harvest index (ratio of aboveground biomass to yield) to convert the estimated wheat GPP to yield in 250 wheat fields in R3 irrigated zone (about 40 Km east of Marrakech city). We feed the dataset to three machine learning models and a deep learning model (Long Short Term Memory (LSTM)). Overall, The calculated wheat are consistent with the observed grain yield. However, The (LSTM) method exhibited the best metrics, with an $R^2 = 0.90$ and RMSE of 0.20 t ha^{-1} .

Estimation of the FAO-56 crop coefficient of winter wheat from synthetic aperture radar data

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Mots-clés : Crop coefficient, C-band, wheat crop, interferometric coherence, polarization ratio.

Estimating evapotranspiration (ET) is of primary importance for irrigation management. The model commonly used for this purpose is the FAO-56 simple approach which consists of multiplying the reference evapotranspiration ET_0 by a crop coefficient K_c . Historically, K_c is derived from optical indices, primarily NDVI. Since optical data are disturbed by the presence of clouds, the use of radar data seems more advantageous. In this context, this study is devoted to derive K_c from Sentinel-1 C-band data for the first time in the literature. The data are collected from a winter wheat field in Morocco monitored during two agricultural seasons 2016-2017 and 2017-2018. The field is equipped with an eddy covariance station allowing the estimation of ET every 30 minutes. Sentinel-1 data are processed to compute the backscattering coefficient and the interferometric coherence (ρ). The results show the existence of exponential relationships between K_c and the polarization ratio (PR) and ρ , in particular $R = 0.76$ and $RMSE = 0.18$ between K_c and ρ . These statistics are close to those obtained between K_c and NDVI. Application of these relationships provides a good estimate of ET with $R = 0.7$ and $RMSE = 0.75$ mm/day).

Integrated Hydrological Modelling for Sustainable Water Resources Management in Arid Coastal Regions: Case of Essaouira Basin (Morocco).

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Abstract

The impact of climate change (CC) and human activities on groundwater-surface water (GW-SW) interaction under arid and semi-arid conditions are not yet fully understood. This study aims to combine hydrogeochemistry, stable isotope data and hydrological modeling to improve the understanding of drivers controlling GW-SW interactions and how those processes are affected by CC and human-induced impacts in a coastal semi-arid aquifer in Morocco. Hydrogeochemical and isotopic techniques are used to constrain modeled recharge modes of the coastal aquifer. Hydrological modeling involves coupling the SWAT (Soil and Water Assessment Tool) and MODFLOW models to build an integrated hydrological model for the study area. The integrated hydrological model will be used to assess the impact of different scenarios for CC and anthropogenic activities on water resources in the region of interest. To reach this goal, a comprehensive dataset (including geological, topographical, climatic data, etc.) was compiled from different sources.

A preliminary MODFLOW simulation was calibrated based on 1990 piezometric head data, with values of 0.9 for both R^2 and NSE coefficients. A SWAT model was built for the period 2000-2010, before the Mly Abderahman dam was constructed in upstream of the study area. The SWAT model was calibrated for the period 2005-2009 using monthly discharge from the ADAMNA station. The calibration R^2 , NSE and PBIAS were good ($R^2=0.73$, $NSE=0.71$ and $PBIAS=14.2\%$). The calibrated SWAT model was then validated during 2002–2004 and 2010 with very good performance ($R^2 = 0.81$, $NSE = 0.80$ and $PBIAS=-5.8\%$).

Two remote sensing Actual Evapotranspiration (AET) data products (SSEBop version 5.0, and MODIS 16) were acquired and preprocessed. The AET estimated by the calibrated SWAT model at the subbasin level was compared with the remote sensing (RS) AET. For the subbasins in the middle and the eastern part of the study area, the AET values estimated by the SWAT model are comparable to the AET values derived from both RS products. For those subbasins, the R^2 of the correlation between the SWAT AET and the two RS products varies between 0.24 and 0.45 for the MODIS AET and between 0.27 and 0.35 for the SSEBop AET. However, for the subbasins in the western side of the study area, the SWAT underestimated the AET, especially during dry months. Those subbasins are characterized by the presence of evergreen forest vegetation. Those results denote the interest in further calibration of the SWAT model using RS AET data.

Keywords

Integrated hydrological modelling, groundwater-surface water interactions, hydro-geochemistry, water scarcity, actual evapotranspiration, remote sensing.

Spatiotemporal characteristics of meteorological drought based on remote sensing data in the Tensift Basin (Morocco)

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Over the past few decades, Morocco has experienced several major drought events that harmed the environment and society. The peril of drought lies in its impact on different parts of the entire hydrological cycle, which in turn may distinguish various typologies of drought. Drought generally originates as a meteorological phenomenon that causes water deficit in hydrological systems (rivers and water tables...) which in turn affects natural vegetation and crop yields. This ultimately results in the spread of drought to different parts of the earth-atmosphere system.

However, the spatiotemporal characteristics of droughts could improve drought monitoring, adaptation measures, and strategies for mitigating drought impacts. This study focuses on the Tensift basin, which is one of the largest basins in Morocco and is considered drought-prone due to its geographical location and climate change impacts. The spatiotemporal drought characteristics of several dry events over the past 40 years were investigated. Indeed, we define drought events through the standardized precipitation index (SPI) time series. The SPI has been commonly used for drought assessment, quantifying precipitation deficits on different time scales. The use of several time scales allowed us to highlight the spatial occurrence, temporal characteristics, and impacts of drought on different hydrological and agricultural landscapes. SPI was used to determine the severity, magnitude, duration, and spatial extent of droughts in the study area. Based on a threshold level of SPI, drought events statistics, over 40 years were derived at the watershed scale to highlight regional differences at multiple time scales. The used data were driven from multi-source satellite products and satellite drought-based indices were calculated using automated algorithms chains. Nevertheless, the sparse network of observation stations data-scarce regions, especially in developing countries, is often an obstacle to drought monitoring. To overcome this limitation, remote sensing observations of precipitation are increasingly used over large-scale regions. The results reveal significant changes in the drought patterns since 2011 in the Tensift basin. They show persistent drought events in terms of severity and extent of drought with the absence of remarkable wet periods. These open insights for monitoring droughts and timely drought assessment over a semi-arid region using a monthly time scale.

Classification of Irrigation Systems at Field Level from Remotely Sensed Soil Moisture and Actual Evapotranspiration Time- Series

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Mots-clés : irrigation systems, actual evapotranspiration, soil moisture, time-series classification, artificial intelligence

This study proposes a novel methodology for classifying irrigation systems at field scale, in order to address the lack of such maps at high resolution from remotely sensed data. This information has a critical scientific value since detailed information on irrigation practices greatly improves the understanding of human activities on the water cycle. In particular, precise knowledge of different irrigation systems is needed in order to correctly model the anthropogenic impact in various land surface models. Additionally, these maps are also useful for administrative purposes, to estimate the percentage of different irrigation systems, monitor changes in irrigation practices and consequently encourage more sustainable use of the freshwater resources. The hypothesis of this study is that time-series of two main hydrological variables, Actual Evapotranspiration (ET_a) and Soil Moisture (SM) at high resolution (20 m) show variations directly related to the different irrigation systems used. Three different Artificial Intelligence (AI) models for time-series classification were employed and compared for this specific task: two classical machine learning algorithms, Time-Series Forest and Rocket, and one deep learning model, ResNET. In order to train these models, an extensive field campaign was performed in 2020 in an intensively cultivated region in Catalunya, Spain. Data for more than 300 fields were collected, from different crop types and labelled by four different classes: flood, sprinkler, drip and not irrigation. The classification was performed using time-series from three different years in order to train the models with a more general and robust dataset, independent from specific meteorological conditions of a single year. Initially, we demonstrated how irrigation systems are correctly classified from ET_a and SM regardless of the crop type used: AI models were trained separately for each crop type and results were aggregated together and compared with a general AI model trained with all crop types. Secondly, tests were performed to identify the most

suitable AI model and also to identify the most suitable set of variables for the classification, among ET_a , SM, but also Leaf Area Index, Crop Stress Coefficient, Normalized Difference Vegetation Index and Land Surface Temperature. Results showed how combining ET_a and SM produced the best classification results in terms of accuracy of around 90 %, when used with ResNET. As a result, it was possible to create annual maps of irrigation systems for the considered study area, which showed a general trend towards modern irrigation systems such as drip and sprinkler.

Estimation and prediction of groundwater storage and depletion using downscaled GRACE data, SWAT model and ANN: Case of the phosphate basin of Meskala.

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Keywords: Groundwater storage, SWAT model, GRACE data, ANN, Phosphate basin.

Droughts cyclicity due to the climate change effect, population growth and the over pumping of groundwater for irrigation are major factors that affect water resources, especially in arid and semi-arid areas. The rational use of these resources requires the understanding of groundwater storage (GWS) and depletion variations at a high temporal and spatial resolution, which is a challenge in unmonitored watersheds like the Meskala phosphate basin. This work emphasizes the potential benefits of combining a calibrated Soil and Water Assessment Tool (SWAT) model, artificial neural network (ANN) and the data of Gravity Recovery and Climate Experiment (GRACE). The first SWAT model calibration results gave a coefficient of determination (R^2) and the Nash–Sutcliffe efficiency (NSE) equal to 0.52 and 0.5, respectively. The per cent bias (PBIAS) calculated for this model equal was $2.9\% < 10\%$, and a low value of the root mean square error (RMSE). The results can still be improved, especially because we intend to generate future forecasts. To solve this problem, we apply model forcing by GRACE data at a fine scale ($1 \text{ km} \times 1 \text{ km}$) by application of a mixed geographically weighted regression (MGWR) and the ANN results on a series of observed data (2000-2010) such as precipitation, temperatures, evapotranspiration, land use, soil texture, NDVI, and soil moisture. The used approach in this work will give the most reliable results for the spatiotemporal variation of GWS and groundwater depletion as well as their future predictions.

Influence of snowmelt and rainfall on the recharge processes within the Ourika sub-catchment, Morocco

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Dynamiques des agricultures irriguées de l'Oued Ghighaya au Maroc en amont de Marrakech : quels impacts sur l'évolution des ressources en eau ?

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Mots-clés : ressource en eau, changement climatique, conflits d'usages, systèmes de culture, irrigation

Au Maroc, le bassin versant de l'oued Tensift est alimenté par différents cours d'eau provenant du versant nord de l'Atlas, dont l'oued Ghighaya. Ce cours d'eau, alimenté par la fonte des neiges de l'Atlas, permet en amont l'irrigation de cultures de haute montagne puis de piémont puis de plaine, avant de finir en aval sa course dans l'oued Tensift, aux portes de Marrakech. L'analyse des débits moyens annuels de l'oued sur plusieurs décennies au niveau de la plaine montre une baisse relativement marquée au XXI^e siècle. Or les besoins en eau du territoire de Marrakech ne cessent d'augmenter, pour alimenter les populations urbaines et les terrains de golf qui se multiplient. L'agriculture irriguée de montagne est montrée du doigt comme étant la cause en amont de la diminution de la ressource en eau constatée en aval. Mais quelle est véritablement la part des prélèvements en eau de cette agriculture, et comment a-t-elle évolué au cours du temps ? Un travail de formation par la recherche mené en 2018 par des étudiants, des doctorants et professeurs des Universités d'Agadir, de Marrakech, de l'Institut Agro Montpellier en partenariat avec le LMI MediTer a répondu à cette question. Une analyse pluridisciplinaire et pluri-scalaire croisant agronomie, géographie, anthropologie, hydrologie et climatologie a été menée sur les trois territoires agricoles traversés par l'oued Ghighaya : le territoire d'Imlil, situé à une altitude entre 1500 à 2000m, caractérisé par une agriculture en terrasses d'arboriculture associée à des céréales ; le territoire d'Asni, situé à environ 1200m d'altitude, caractérisé par une arboriculture fruitière sur des surfaces plus étendues ; le territoire de Tahanaout, situé en zone de plaine à une altitude d'environ 500m, caractérisé par une agriculture d'oliveraies et de céréales en sec. Croisant enquêtes et mesures de terrain, modélisation hydrique et analyse diachronique d'images de télédétection, nous avons retracé pour chaque territoire agricole l'évolution sur quatre décennies des surfaces, des espèces cultivées, des pratiques de gestion sociale de l'eau et de conduite de l'irrigation. A partir de l'estimation des besoins en eau des systèmes de culture anciens et actuels, nous avons comparé les volumes d'eau prélevés à l'échelle des territoires entre les années 1980 et 2018. Nos résultats montrent que les droits d'eau et les volumes d'eau utilisés par l'agriculture (de l'ordre de 3,5 millions de m³ par an) ont peu évolué dans la partie amont sur les territoires d'Asni et d'Imlil, et ce malgré le développement d'une arboriculture fruitière diversifiée. Cette agriculture ne semble pas être responsable du manque d'eau préoccupant que nous constatons plus en aval sur le territoire de Tahanaout. En revanche, notre analyse de données hydro-climatiques sur la période 1988-2017 met en avant le rôle du changement climatique qui se traduit essentiellement par la hausse des températures et la réduction des précipitations sous forme de neige, d'où la baisse des débits de l'oued Ghighaya.

How fragile is it? A GIS-based multicriteria assessment to define management priorities for a Mediterranean terraced system (Tuscany, Italy)

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Mots-clés : Terraced landscape, Surface water management, Dry-stone walls, Anthropic impacts, Olive groves, Tuscany

Terraced systems shape the surface water and soil management of many agricultural areas around the Mediterranean coasts. These systems are anthropic modifications that permanently impact the geomorphological stability due to the intense reshaping of steep slopes. By design, they require continuous anthropic management to keep the system stable and the coordination between multiple actors to maintain the stability of the various parts that compose the system. Several studies and research projects have addressed terraced system management insofar, encompassing many geographic locations and several disciplinary or integrative approaches. However, there is still the call for providing simple tools to identify the correct management practices and coordinate their deployment among different actors. Partly abandoned or neglected because of their poor accessibility to machinery in the past several decades, some terraced systems shifted toward neo-rurality when located in peri-urban areas. There, newcomers purchased houses and land for settlement purposes, eventually restarting farming as a part-time or hobby activity with sporadic or incorrect terrace-management practices. Such a mix of full-time, part-time and hobby farmers suggests that the main challenge is capitalising on past knowledge, providing reliable support to the different land managers and developing new management strategies. This paper aims to present a method to help policy-makers and local land managers prioritise the management of terraced systems. To this end, we designed a GIS-based multicriteria decision analysis to assess the terrace system fragility, intended as the inverse of land suitability, as it measures the distance from natural constraints; the greater the distance, the greater the fragility. The study area covers 62 km² of the south-western hillside of Monte Pisano (43° 44' N - 10° 32' E, Tuscany, Italy), delimited by the administrative boundaries of the three municipalities participating in the research project. It counts 1,930,000 linear meters on 1,813 ha of total agricultural surface, with an average density of 1050m/ha; the highest value has been 2,000 m/ha. We assessed fragility on two main criteria: structural fragility, related to natural and permanent anthropic constraints, and overall fragility, which includes agricultural practices. Seven attributes were selected and elaborated, then aggregated to zone the study area into a set of ranked alternatives responding to the initial decision

problem. Finally, the validation in the field with a Kappa analysis provided stakeholders with a measure of the reliability of the fragility assessment process. The local administration adopted the results to enhance the coordination for the terraced system management through the design of a handbook of best management practices produced in cooperation with the local department of Civil Protection. In perspective, the proposed GIS-based assessment and the reliability evaluation procedure could support the integrative modelling of soil and water resource management in other Mediterranean agricultural systems at the watershed or landscape level.

Water management of mediterranean orchards analyzed from Remote Sensing data and surveys.

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Mots-clés : Cherry trees, Sentinel missions, agricultural practices, irrigation.

Around the Mediterranean, water represents the major resource that limits growth and production of plants, and which tends to decrease because of increase of irrigated territories, and competition between various water users on a territorial scale. The water consumption of fruit orchards depends on various factors, among them the soil and climate characteristics which vary a lot spatially, and also the leaf development which vary temporally according to crop variety. The water management at the basin scale must therefore take into account the plant need and also the farmer practices. Remote sensing at high spatial and temporal resolution can provide useful information for monitoring water status of orchards. This study aims two main purposes: 1) assess the development of orchard from biophysical variables derived from Sentinel data and 2) better understand the variability of irrigation management from farm to territory level in order to propose suitable tools for optimizing water use. A typical mediterranean basin was chosen in Southeastern France, where various monitorings are conducted on orchards by the EMMAH and Kaust teams: the Ouvèze basin (centered 44° 13.050' N, 5° 8.579'E). The analysis was based on multiple sources of data: 1) surveys on the agricultural practices of 15 farmers covering more than 495 fields; 2) various ground observations including soil moisture measurements made on 5 cherry trees on both inter and intra row, hemispherical photos taken on 13 cherry trees having different inter-row managements and 3) multi-spectral Sentinel 1 and 2 images acquired between 2016 and 2021. The images were processed using the Snap software for Sentinel 1 data and R functions to extract the mean values for each field of different vegetation indices and biophysical variables obtained from the BVNET model. The temporal profiles of indices and radar signals have been compared to ground observations. The survey analysis has shown a large heterogeneity among the different irrigation practices, for cherry trees for example some farmers brought around 140mm/year and others more than 450mm for similar drip systems. Statistical analysis based on PCA and AHC allowed to propose six different classes of farmers on the area. The surveys revealed that most farmers start irrigation after the crop flowering. Temporal profiles of spectral indices obtained for several orchards with Sentinel 2 allowed to clearly identify the trees' phenology and the impact of the inter-row management. Thresholds can be defined to separate young and old orchards. First correlation analysis between soil moisture measurements of the 5 fields monitored with different water management and the VV polarization extracted from Sentinel 1 data showed that radar data allow to reproduce the main trend of soil moisture variations and a significant correlation is obtained at field scale ($r^2=0.57$ for the best score), but a lot of noise still remains to be deeper investigated. The different variables derived from Sentinel data are useful for future spatialized modeling approaches. For the next work phases, different models will be compared to quantify water requirements for each field of the basin, in order to identify the most suitable to provide useful indicators to improve irrigation management in mediterranean context.

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Groundwater quality over the Tensift basin (Morocco)

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Keywords: hydrochemistry, salinity, pollution, irrigation, quality standards.

The Tensift basin is located in central Morocco and lies over a surface of 22.000 km² under an arid to semiarid climate. It compasses several plains, the major one is the Haouz plain with intensive agricultural and industrial activities, making the water resources potentially exposed to pollution risks, especially agriculture chemical inputs and waste water. To have an overview on the groundwater quality, samples were taken in the dry season of 2020 from the study area and analyzed for cations, anions, nitrate, and trace elements. By using various statistics, diagrams, and quality indices, the objective was to better understand the origin of chemical elements and to analyze the groundwater quality and suitability for drinking and irrigation uses.

The results showed that the dominant hydrochemical facies are bicarbonate-calcium and chloride-sodium. The sampled groundwater in the Tensift basin was found globally to be of good to permissible quality for drinking purposes and irrigation. However, in some groundwaters the concentration of Na⁺, Cl⁻, and SO₄²⁻ was high. Nitrates sometime exceed the WHO standards, originating mainly from anthropogenic activities. In addition to quantitative overexploitation, indices of groundwater contamination do exist in Tensift basin and should be tackled for sustainable use of groundwater.

Cohérence et incohérence entre les versions Excel et Python de SAMIR

Chloé Ollivier

1 Versions de SAMIR

La comparaison des calculs se fait à partir des documents :

- version Excel : SAMIRv5_juin2015
- version python : mis à jour du 20.11.2020 du git : http://130.120.119.105/gitlab_cesbio/rivallandv/modspa.git

2 Fcover

Excel

On définit la période de Fcovmax, celle-ci répond aux 3 critères suivant :

- période à partir du jour où on observe le maximum du NDVI
- qui dure le temps du “plateau” ou “Durapla” (70 jours en général)
- sauf si pendant cette période le calcul $NDVI * a + b < Fcovermin$

Calcul Fcover :

- pendant la période de Fcovmax : $FCov = NDVI_{max} * a + b$
- hors période Fcovmax : $FCov = NDVI * a + b$ avec $0 < FCov < 1$

Python (lignes 64 à 83 de AlgoETPSAMIR)

On définit la période de Fcovmax comme la période entre le jour où NDVImax (dayNDVImax) est observé et jusqu’à dayNDVImax + Plateau.

Calcul Fcover :

- pendant la période de Fcovmax : $FCov = NDVI_{max} * a + b$
- hors période Fcovmax : $FCov = NDVI * a + b$ avec $FCov_{min} < FCov < FCov_{max}$

Modifications Python :

- Ajouter un règle sur le calcul du NDVI4Fcov, pour prendre en compte l’arrêt du plateau si FCov théorique inférieur à FCov min, i.e si $NDVI < NDVImin$ (non ?)
- changer les bornes du calcul de FCov en 0 et 1

3 Kcb

Excel

- $Kcb = NDVI * a + b$ avec $0 < Kcb < Kcb_{max}$

Python (lignes 40 à 45)

— $Kcb = NDVI * a + b$ avec $Kcb_{min} < Kcb < Kcb_{max}$

Modifications Python :

— changer la borne inférieure en 0 à la place de Kcb_{min}

4 Zr

Excel

Avant dayNDVImax :

$$Zr = Zr_{min} + \frac{FCov_{max,cal}}{\max(FCov_{max,cal}, FCov_{max,th})} * (Zr_{max} - Zr_{min}) \quad (1)$$

Après dayNDVImax :

$$Zr = Zr_{min} + \frac{FCov}{\max(FCov_{max,cal}, FCov_{max,th})} * (Zr_{max} - Zr_{min}) \quad (2)$$

Avec $Ze + 0.001 < Zr < Zr_{max}$

Python (lignes 100 à 115)

On définit $FCov4Zr = FCov_{max}$, sauf après dayNDVImax, $FCov4Zr = FCov$

$$Zr = Zr_{min} + (Zr_{max} - Zr_{min}) * FCov4Zr / FCov_{max} \quad (3)$$

Avec $Ze + 0.001 < Zr < Zr_{max}$

Les versions sont équivalentes... au détails près que sous Excel il y a deux valeurs max possibles pour FCov (i.e. $FCov_{max,cal}$, $FCov_{max,th}$) avec $FCov_{max,cal}$, la valeur max calculée avec la relation $FCov = NDVI * a + b$ et $FCov_{max,th}$ la valeur max déterminée par l'opérateur. Sauf, que vu précédemment, le calcul de FCov est borné entre 0 et 1, donc dans le test $\max(FCov_{max,cal}, FCov_{max,th})$ est toujours égal à 1 (non ?) Si oui, les calculs sont équivalents... Sauf si l'opérateur détermine un $FCov_{max} > 1$

Potential of the modified water cloud model to retrieve soil moisture within a drip irrigation context in pepper fields using ALOS-2 and Sentinel-1 data

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Keywords : soil moisture, drip irrigation, radar, Sentinel-1, ALOS-2, modified Water Cloud Model

The water demand of agricultural sector has increased to meet the needs of a population that grows daily. To better manage water resources, the soil moisture estimation is a primordial component to optimize irrigation scheduling and precision irrigation. Over the last decades, the use of microwave remote sensing data has revealed a high potential to retrieve soil moisture at an agricultural scale. Several efforts were devoted to estimate surface soil water content mainly in X and C bands and some works in L band due to the lack of data in this frequency. The majority of the proposed approaches were developed in homogeneous spatial repartition of soil moisture without considering the inter-pixel heterogeneities of soil moisture. In the present work, we compare the potential of Synthetic Aperture Radar (SAR) data in L band acquired by Advanced Land Observing Satellite-2 (ALOS-2) and C band acquired by Sentinel-1 sensor to simulate radar behavior in heterogenous row crop fields locally irrigated with drips in semi-arid area in the center of Tunisia.

During SAR data acquisitions, in-situ data gathering campaigns were conducted in drip-irrigated pepper fields including soil surface properties (roughness and soil moisture) and vegetation parameters such as Leaf Area Index (LAI), cover fraction (Fc) and pepper height (H). For each reference field, an average soil moisture value is calculated as the sum of bare soil moisture weighted by α and the pepper row soil moisture weighted by $1-\alpha$. According to the ground truth observations, α is taken equal to 85%.

To simulate the co-polarized radar signals using L-band data in Horizontal- Horizontal polarization (L-HH) and C-band data in Vertical-Vertical polarization (C-VV) scattered by pepper-covered fields, we used a modified version of Water cloud Model (WCM). In the context of inter-pixel heterogenous soil water content, the total backscattering is modelled as the sum of bare soil part contribution weighted by the proportion of bare soil ($1-Fc$) and the contribution of vegetation row backscattering

weighted by F_c . The contribution of pepper row is calculated as the sum of vegetation contribution and the underlying soil attenuated by the vegetation. The underlying soil backscattering is the total response of two bare soil parts: drip irrigated part and non-irrigated part. The bare soil contributions are calculated using the modified Integral Equation Model (IEM-B). The calibration and validation of the proposed model is performed through three-fold cross validation method.

We analyze the behavior of the backscattering coefficients as function of the soil moisture under large conditions of vegetation parameters and bare soil content values under constant roughness parameters. The examination of the proposed model sensitivities to soil moisture highlights that model sensitivity decreases as function of the increase of pepper heights and the vegetation cover fraction. The modified WCM sensitivity using C-VV data decreases more rapidly than in L-HH case as function the vegetation parameters. The aforementioned results reveal the potential of the modified WCM to simulate radar signal over heterogenous soil moisture contexts using co-polarized data in L- and C-bands.

Evaluation du risque non cancérigène lié à la consommation des eaux

souterraines du Massif de Bokoya (Maroc)

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Mots clés : Eaux souterraines ; Risque non cancérigène ; Rif, Bokoya ; Maroc.

Au cours des dernières années, la forte augmentation de la concentration des nitrates dans les aquifères est devenue un problème important en terme sanitaire à l'échelle mondiale, et l'utilisation de cette ressource non contrôlée peut causer des problèmes potentiellement dangereux pour la santé humaine. L'objectif de la présente étude est d'évaluer le degré de la pollution nitratée des eaux souterraines dans le massif de Bokoya et de quantifier les risques non cancérigènes lié à leur consommation.

La zone d'étude est située dans le rif marocain, dans un contexte de climat semi-aride (P inférieure à 400 mm) et constitué d'un système géologiquement complexe formé en grande partie par des massifs calcaires fracturés et karstiques et donc susceptibles d'avoir une forte vulnérabilité à la contamination anthropique environnementale, notamment nitratée, issue d'une activité agricole importante, où une pollution diffuse existe à partir de l'emploi des engrais naturels et chimiques, et issue de zones fortement urbanisées où les moyens de traitement des eaux usées en général sont inexistants à l'exception du centre urbain d'Al Hoceima.

Deux séries de prélèvements ont été réalisés durant le mois d'avril et septembre 2018, qui ont permis de collecter 96 et 73 échantillons distribués entre puits et sources couvrant toute la zone d'étude d'une superficie de 277 Km². L'évaluation du risque non cancérigène par l'exposition aux nitrates par voie orale, a montré qu'environ 47 %, 45 % et 43 % des échantillons pendant la période humide et 47 %, 46% et 43% pendant la période sèche, constituent respectivement un risque non cancérigène pour la santé des enfants, des femmes adultes et des hommes adultes. Les enfants sont légèrement plus exposés aux risques non cancérigènes.

Dans une situation marquée à la fois par la rareté de l'eau potable et l'absence d'information auprès de la population de la zone d'étude sur les risques encourus, les résultats de cette étude vont

permettre d'orienter les décideurs et les services de gestion des ressources en eau vers une politique de limitation des sources de nitrates se retrouvant dans les aquifères afin de limiter les effets potentiellement nocifs pour la santé humaine.

Choix de procédés adéquat pour la réutilisation des eaux usées de la ville SEFROU en irrigation

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Mots-clés : eaux usées domestique sefrou, oued Aggay, AHP, choix multicritères de procédés de traitement

Une étude sur le système d'épuration le plus adapté aux eaux usées domestique de la ville de Sefrou en effectuant une analyse multicritères (économique, technique et environnemental) entre différents procédés du traitement. Pour cela j'ai choisi la méthode AHP (analytic hierarchy process) pour la pondération des critères de choix du type de traitement d'épuration à adopter. Ce système d'épuration doit répondre aux normes des eaux épurées destinées à l'irrigation afin d'offrir un environnement plus propre à la ville notamment le long d'Oued Aggay, sans oublier de répondre aux besoins en eau d'irrigation pour l'agriculture locale.

A deep learning-based approach for reference evapotranspiration estimation in the Haouz semi-arid region of Morocco

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Keywords: Evapotranspiration, deep learning, smart agriculture, FAO-56 Penman-Monteith, Hargreaves, ERA5-Land reanalysis data.

Water scarcity is a reality, and water resources are under pressure due to the combined effects of population growth, economic development, and climate change. Agricultural practices, the main consumer of water resources, need to be optimized to address these challenges. This can be achieved by the accurate estimation of the water needs of crops, which in turn requires the estimation of the Evapotranspiration. In this context, this study proposes an approach to estimate the reference evapotranspiration (ET_0) from multi-source and multi-scale satellite images. A deep learning architecture based on a Long Short-Term Memory (LSTM) was adopted to forecast the reference evapotranspiration (ET_0) estimated by the Penman-Monteith and Hargreaves models of FAO (Food and Agriculture Organization). The proposed approach succeeds in this task either by using the relevant meteorological parameters collected by the local weather station or using historical ET_0 data. The results showed significant performance compared to state-of-the-art, with 0.88 and 0.4 for the first method (meteorological parameters), and 0.9 and 0.004 for the second method for the coefficient of determination (R^2) and the mean square error (MSE) respectively. When using reanalysis data, the proposed approach showed 0.91 and 0.4 for relevant parameters, and 0.89 and 0.4 for historical data in terms of R^2 and MSE, respectively. Additionally, a comparative study with several machine learning methods was performed. The results showed that the XGboost regression model performs well using the same data sources and physical models (0.94 and 0.93). These promising results make this proposed approach a real help in assisting farmers in their irrigation management.

Evaluation of snow cover product for monthly streamflow simulation in semi-arid region using Deep Learning Techniques: case study Oum Er-Rbia basin (Morocco)

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Keywords: SCA, Monthly Streamflow prediction, Deep learning, LSTM. (Calibri 11)

This study discusses the reliability of snow cover products in water resources management using deep learning techniques to simulate monthly streamflow in poorly gauged basins with 10 years of MODIS satellite snow cover data and hydroclimatic data. In this work, a powerful deep learning tool, Long-short time memory (LSTM) has been adopted to simulate streamflow on a monthly scale due to its flexible structure and solid results in the hydrology process. In order to avoid our model from overfitting, we split the dataset into training and validation; the training set was to fit the LSTM model, while the validation set was used during training to verify how strong the model is generalizing. The model was evaluated using three main criteria: Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and correlation coefficient (R^2) during the validation period. As first results, considering one feature, rainfall, the model was quite able to simulate streamflow with respective MAE, RMSE, and R^2 values of 4.99 (m³/s), 7.45 (m³/s), and 0.44, but when we add SCA, the performance of the model increases, and we get MAE = 4.291 (m³/s), RMSE = 6.859 (m³/s), and $R^2=0.62$. In order to improve the achievement of the LSTM model, we take into consideration baseline data. The outcome of one day of streamflow with one day of SCA as lagged inputs performs better than 1-day lag SCA without baseline with MAE = 2.87/4.42 (m³/s), RMSE = 4.32/6.28 (m³/s) and $R^2=0.82/0.70$ (m³/s) respectively. The current work concluded that the deep learning model LSTM improves its ability to produce a reasonable result, showing the effect of SCA on the behavior of the output that plays an important role in streamflow modeling. However, in this study, monthly streamflow prediction with the LSTM in a semi-arid region could be improved by the fusion of remotely sensed snow cover data and hydroclimatic data.

"Hydrogeochemical and isotopic study and assessment of groundwater quality of the aquifers in Djefara Medenine (Southeastern-Tunisia)"

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Abstract

The objective of this study is to identify the hydrogeochemical and isotopic characteristics and groundwater quality aptitude for irrigation and drinking water uses in arid and semi-arid areas. The study area is the Djefara of Medenine, in southeastern Tunisia. This region is facing increasing drinking water needs due to a rapidly growing population, increased urbanization and touristic activities. Fresh groundwater is the main source of water supply.

The methodology used a hydrogeological survey as well as periodic sampling campaigns and interpretation of geochemical and isotopic groundwater data in the study area.

Results demonstrated that the mineralization increase from upstream to downstream and its origins is the dissolution of sulphated salts (gypsum, anhydrite, epsomite, burkeite, thenardite and mirabilite) and chloride (halite and magnesium chloride) associated with the crust. Results approve hydrogeological communication between Zeuss Koutine (ZK) and Sahel El Ababsa Triassic sandstone (TSE) aquifers and the rainwater direct recharge of the two aquifers of the Djefara groundwater system. Furthermore, the groundwater quality map shows three water types: suitable, moderate and unsuitable water for irrigation purposes. While, results for drinking purposes demonstrate that the ZK aquifer is more favorable for drinking than Triassic SE aquifer. Which 86 percent of resources really used for drinking water by the National Company of Drinking Water Supply (SONEDE) and rural water supply by Regional Commissary for Agricultural Development (CRDA) (Sahal 2020).

Keywords: Hydrogeochemical, Origin, Groundwater system, Communication, Djefara.

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