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GroundWater balance simulation for open-pit mines in the semi-arid areas: A Case Study of the Gantour Deposit, morocco

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***Résumé* – A travers le monde entier, les zones arides et semi-arides sont particulièrement confrontées à une pression de plus en plus croissante en matière d'approvisionnement et de gestion des ressources en eau douce. Ces zones sont particulièrement vulnérables à la variabilité du climat et au changement climatique, avec des conséquences pouvant avoir des effets sociaux et environnementaux très graves. Il est plus difficile d'évaluer et de gérer avec précision les ressources en eau disponibles et renouvelables dans les régions semi-arides, par rapport aux pays riches en eau, car la base scientifique est limitée, les données sont rares et l'expérience des zones humides est inappropriée. En outre, de nombreuses régions arides sont au cœur de conflits potentiels liés à la rareté de l'eau, d'où la nécessité de développer des stratégies pour soutenir la paix et la sécurité. Une meilleure compréhension scientifique, la coopération et le partage des données sont autant de moyens permettant d'améliorer la gestion de l'eau et de soutenir la résolution des conflits.**

La simulation du bilan hydrique est un outil puissant pour (1) évaluer les risques liés au stress hydrique, (2) analyser des scénarios éventuels, (3) identifier les vulnérabilités liées aux incertitudes, et (4) proposer et tester des stratégies d'adaptation. L'évaluation de la sensibilité au changement doit tenir compte à la fois du climat et d'autres facteurs. Le modèle proposé fournit des estimations des taux de recharge et d'évaporation et des prélèvements d'eau souterraine grâce aux données météorologiques et à la paramétrisation hydrogéologique requise par les modèles d'écoulement des eaux souterraines. Une application du modèle à une région d'environ 4000 Km2 dans la partie centrale du Maroc est présentée ici, comme un exemple de calcul et d'analyse du bilan hydrique mensuel et annuel.

***Abstract* – Arid and semi-arid areas globally face the greatest pressures to deliver and manage freshwater resources. These areas are particularly vulnerable to climate variability or climate change, with consequences that may have very serious social and environmental effects. Accurately assessing and managing available and renewable water resources is more difficult in semi-arid regions, compared with water-rich countries, since the science base is limited, data are scarce and the humid zone experience is inappropriate. Moreover, many arid regions are the focus of potential conflicts over water scarcity, making it necessary to develop strategies to support peace and security. Improved scientific understanding, cooperation and data sharing all provide ways of bettering water management and of supporting conflict resolution.**

The water balance simulation is a tool that may be useful in terms of risk assessment and scenario analysis procedures, that can help us identify the vulnerabilities to change, predict risk, assess the significance of the risk relative to the im-pact and uncertainties, and to propose and test adaptation strategies. Both climate and other factors need to be consid-ered in assessing sensitivity to change. Such a framework would be useful to focus and guide global change research. Such events have huge global economic and social impacts, and a classification and prediction capacity are a prerequi-site for adaptive management. The model provides estimations of recharge and evaporation rates and groundwater with-drawals due to meteorological data and hydrogeological parameterization required by groundwater flow models. An application of the model to a region of about 4000 Km2 in the central part of Morocco is presented here, as an example of monthly and annual water balance calculation and analysis

***Mots clés* – Ressources en eau, Simulation de l'équilibre en eau, Empreinte en eau, Responsabilité sociale des entreprises, industrie minière.**

***Keywords* – Water Resources, Water Balance Simulation, Water Footprint, Corporate Social Responsibility, Mining Industry.**

1 INTRODUCTION

With the rapid development of economy and population growth, the water scarcity gradually becomes a severe obstacle of the whole world. With the globalization continues to develop, we not only care about in what situations we are but also show our concerns on how other's lives are. In a word, there are already some achievements on analyzing the different types of water scarcity in both the time and space dimensions. It is a hidden resource, and to manage water better, an improved understanding and quantification of water ecosystems is required. Water balances provide information on the quantities of the most significant inflows and outflows, which is important for assessing the sustainability of a water management regime. They are tools that can be used to help set priorities, give longer-term perspectives, and develop improved management practices.

The modelling approach adopted needs to be appropriate to the water system being modelled and the purpose of the modelling. It is also important that simplifications and assumptions that are introduced during modelling are well documented and are communicated to those using the model results. Similarly, communicating the likely accuracy of results is important.

Thus, the challenge is to develop a predictive water balance model that characterize and simulate complex systems, easy to develop and use, and provide accurate results that are easy to communicate to non-scientists. No single modelling approach can claim to do all these well.

An overview of existing water balance models and their data requirements was carried out with an emphasis on matching existing data availability with input data requirements.

2 LITERATURE REVIEW

A water balance, also known as a water budget, quantifies the major inflows, outflows and changes in storage of a water system. A water balance can be spatially and/or temporally distributed or it can be reported as a lumped parameter.

The elements of water model development that build support in demonstrating that a model is capable of producing meaningful results are (Anderson and Woessner ,2002):

1. Establish the purpose of the model;
2. Develop a hypothesis, usually referred to as a conceptual model, for how the system operates;
3. Select the model method or software to be used;
4. Design the spatial and temporal discretization and determine initial parameter values for the site-specific model;
5. Calibrate the model by determining the parameter estimates that yield the results that best replicate field observations;
6. Verify model predictions against unused field data;
7. Generate model predictions;
8. Present the model design and results;
9. Update the model.

Due to high complexity of hydrological systems, a single general-purpose water balance model, which involves all processes, does not exist. Dividing the large hydrological system into a number of important constituent components facilitates the modeling process. In recent years, finding the most important components is becoming a new focus in water science (Khodayar Abdollahi and Al., 2019). Several water balance models have been developed in response to the given problems. Among them, and in order to extend a physically based stochastic model of soil moisture into a seasonal conte, a new model was developed by integrating the daily and seasonal variabilities (precipitation, evapotranspiration and mean leakage/run-off) consistently within a stochastic framework (Xue Feng and Al., 2015). Motivated by the desire to explore water balance variability at the catchment scale, another study explores the underlying climate and landscape interactions that cause differences in water balance between a number of temperate and semiarid benchmark catchments around Australia (D. Farmer and Al., 2003). Another dynamic water balance simulation relying on a watershed model and two climatic scenarios (Direct Precipitation, Runoff from the catchment, Evaporation, Drainage and Water Consumption) was made to analyze the water balance of the lake of Balaton (Hungary) (M. Honti and L. Somlyo´dy, 2009). An update of the water balance model of the small areal sea, located in the arid zone of Central Asia, was applied to ensure effective water resources planning and for better utilization of water, since there were only a few researchers that have investigated the water balance in the area. Data of evaporation, river runoff, and precipitation was collected from 1987 to 2014 and used as inputs to simulate the water balance variation (A. Massakbayeva and Al., 2020). In North China, ISAREG, which is a computer simulation water balance model designed to simulate, select and evaluate alternative irrigation schedules, and to support their application in the field practice, was used as a new approach to effectively represent the dynamics of water fluxes occurring in the cropped soils, and the relationships between upwards flux, water-table depth, soil water storage and crop evapotranspiration (Y. Liu, 2002). Considered as the main source of drinking water for those living in the catchment, and due to the rainfall decrease leading to serious droughts in the Western Sahel including Senegal, it was crucial to understand how this change affects groundwater recharge and determine the current proportions of groundwater recharge, runoff, subsurface runoff and evapotranspiration using a simulation approach (M. Idrissou and Al., 2014). Variations in climatic inputs (in particular, rainfall and potential evapotranspiration) have garnered considerable attention in recent years as controlling factors for mean annual soil water plant responses and adaptive strategies, regional vegetation distribution, carbon fluxes and primary productivity, with further implications for agriculture and land management, thus, CROPGRO-Drybeans a model for the prediction of soil water balance, as well as growth components and bean crop yield, was assessed using data (rainfall, solar radiation, maximum and minimum temperature) from two field experiments conducted at the State University of Maringá Irrigation Technical Center, Paraná – Brazil (R. Dallacort and Al., 2010). The SEAWAT-2000 numerical model was used as a tool to determine the water balance components (precipitation, evapotranspiration and groundwater recharge) in the low-lying area of Manukan Island to protect the island's ecological balance so that groundwater resources are not compromised. Different

scenarios for different water balance were studied to outline factors affecting the water balance (overpumping, recharge rate, freshwater storage) (Sarva Mangala Praveena and Al., 2012). For the same purpose, a simple conceptual rainfall–runoff model is used for the estimation of groundwater balance components for a karst aquifer in Dalmatia (Croatia), the proposed parameter estimation procedure merges the soil-moisture balance and the groundwater balance approaches to obtain the complete groundwater budget. Data from nearby meteorological station includes daily average discharge, the amount of precipitation, the average temperature and the humidity from 1995 to 2010, was used as inputs to the model (Ivana Z'eljkovic and Ana Kadic, 2015).
The aim of this paper is to assess the water balance of a mining industry- OCP considered as the world leader in the phosphate industry- using a model based on the water balance equation as well as meteorological and hydrogeological data. The model also allows to evaluate the water footprint of all the activities conducted by the industry as an indicator of sustainability. GANTOUR region was selected as a field to carry out the model in hope that the results can provide some insights into feasibility of a large-scale planning for ecological restoration in the entire zone, and can effectively protect aquatic habitat and water quality under this semiarid climatic condition.

3 Study Area

The study area belongs to the Gantour deposit which occupies the central part of the country, it is part of an east-west oriented rectangle of 120 km long and 20 to 30 km wide.
The exploitation of the phosphate is carried out according to two grandiose zones: Youssoufia area (western part of the deposit) and Benguerir area (central part of the deposit).
The plain of Bahira, which constitutes the aim of this study, is divided into two major areas that are the plateau of Gantour in the north (with high altitudes reaching 531 m), and the plain of Bahira in the west (with low altitudes reaching 404 m). The plain of Bahira contains a loose water table and a deep captive water table, which is a determining factor for the socio-economic development of this region. In addition, the consecutive droughts that the area has suffered since the beginning of the 1980s have led to a growing mobilization of groundwater. The surface free water is subjected to intense exploitation to meet the growing needs, especially of drinking water supply and irrigation. The area is characterized by significant hydrogeological and mining potential.
The plain of Bahira is marked by a semi-arid climate, and the average annual rainfall is about 200 mm / year. The air temperature varies significantly between seasons; the minimum value recorded in winter is -3.6 ° C and the maximum summer temperature is 48 ° C. The Average annual evaporation measured using a Colorado bin is 2618.7 mm (Tensift Watershed Agency (ABHT)).

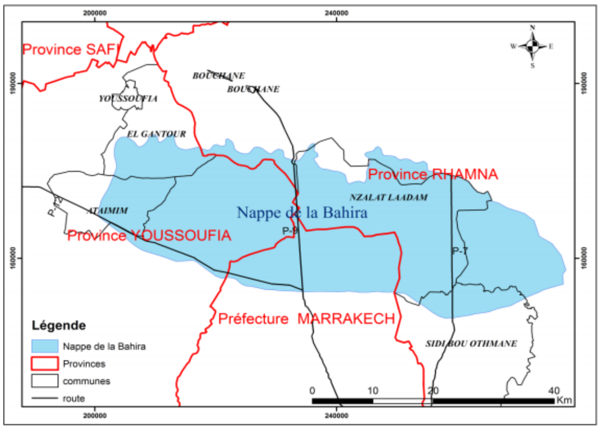

Figure 1: Map of the location of the Bahira aquifer

4 Materials and Methods

4.1 Data collection

We got the precipitation and temperature history from the site www.worldweatheronline.com, and we used the Turc formula to calculate the evapotranspiration:

$$ETR\ (mm/an) = P\ /\ (0{,}9 + P^2/L^2)^{1/2} \qquad (1)$$

Where $L = 0.05T3 + 25\,T + 300$

P is Precipitation in mm
T is Temperature in ° C

4.2 Methods

The lack of adequate links between the formulations of the water and mass balance models has always been considered as a major shortcoming in management plans aimed at assessing the quantity and quality of water in mining projects. This model has been written for government and industry stakeholders and consultants in the mining sector. It addresses various aspects of the "water resources" component of the mine planning process, seeking to ensure that mines are designed and operated with environmental concerns in mind. The life cycle of a mine includes the following phases: Exploration; Feasibility Study; Planning; Construction; Operation; Closure and Restoration.

Month	Average Temperature (° C)	Average Rain (mm)	ETR (mm)
October	24	100,8	14,33
November	18	72,7	18,70
December	20	1,1	21,86
January	15	2,6	16,98
February	19	20,1	15,60
March	21	93,8	12,66
April	20	46,5	10,28
May	29	6,3	5,17
June	26	0,3	0,72
July	29	4	0,17
August	32	10,1	0,61
September	28	55,3	2,39

Table 1: Average Rainfall, Temperature and Evapotranspiration in the area (2018-2019)

There are deterministic and probabilistic formulations of water and mass balance models. Deterministic models use fixed parameters to predict an average quantity and quality of water and to assess specific scenarios (i.e., extreme cases, climate change and sensitivity analyzes). Probabilistic models involve random variables in the form of probability distributions to explicitly represent the uncertainty and / or variability associated with the modeled system. The output is also expressed in the form of probability distributions and indicates the probability of a result occurring.
Two types of modeling that stand out:

1. A model for the quantity and quality of water for each period chosen during a year, and for several different climatic scenarios: these are usually

average climatic conditions and representative values of humid and arid climatic conditions, generally implemented during a hydrological year, usually starts on October 1 and ends on September 30, according to local hydrological conditions;

2. A model for the quantity and quality of water over a longer simulation time (e.g. 50 years), using the mine plan and water management infrastructure in place for the period chosen, for the entire simulation time, and requires long time series of model input data;

The spatial domain defined in the models must include all construction and operating areas and restored areas planned for the life of the mine.

Models must be developed to yield results (i.e., flows, quantity and quality of water, water footprint) at selected locations in the receiving environment.

The current model is designed to help mine operators manage the water at their mine site during the operating phase with deterministic inputs for one year, for the different components of water management infrastructure.

4.2.1 Input data

Mining and dewatering processes: It is necessary to know the production characteristics of the ore processing plant. This data may include: Processing capacity;

Minimal fresh water requirement; Recovered water and / or recycled water requirements; Residue production rate and residue content in sludge; Water entering the ore processing plant and water leaving the plant with the prepared ore; Pumping and storage capacities; Dust removal, fire extinguisher water requirements and potable water; The dewatering of mining sites (surface or underground).

Climate data: The climatic data to be entered into the model must be established from meteorological data applicable to the region of the mining project. The main climatic variables are temperature, precipitation (rain and snowfall), snow on the ground and evapotranspiration. We can also think of other climatic variables, notably humidity, radiation, wind speed and direction, and the characteristics of snow (depth, density and water equivalent). Climate data are usually expressed as time series.

Hydrological and hydrogeological data: They are used to determine the maximum flow coefficients on the lands of the mine development area and the surrounding area, as well as the potential inflows to surface mines and underground mines. Hydrological and hydrogeological data will include: Water levels, areas, bathymetry and volumes of water tables likely to be affected by the mining project; The flow regime of local and regional watercourses likely to be affected by the mining project; Observed groundwater exfiltration from valley walls and in open-pit mines; The groundwater flow observed to underground mine sites.

4.2.2 Output data

The model will have as output data ranges of flows, volumes or water levels. Depending on the parameter presented and the range of results of the model, the summary tables of results can be divided into representative seasons. In addition, the results for water quantity can be presented in the form of graphs illustrating the summary tables.

4.2.3 Presentation and description of matrices**,** climatic data

It is the responsibility of the user to verify the validity of the model for the proposed mine and to make the necessary changes to the structure and equations of the model to meet the needs of his project.

Sheet 1 is the cover sheet of the model. The user must enter basic project data (e.g. mine name, owner, location, mined ore, modeled mining year, etc.).

Sheet 2 shows the commonly used units, symbols and abbreviations. The user must modify this sheet, if necessary, to enter the units and symbols important for his mining project.

Sheet 3 presents the logical diagram of the water balance and the related list of flows. Any model must include a conceptual diagram of the water balance and a list of flows, elements that will facilitate its development and examination. The user must update sheet 3 according to the conditions and parameters specific to the project.

Sheet 4 summarizes the precipitation, temperature, runoff, and evaporation data used in the model. This sheet should be updated based on site specific precipitation, flow and evaporation conditions. The user must also choose an annual evaporation volume (usually corresponding to a normal, wet or dry year) which will be distributed monthly. A conversion factor from evaporation-tank to evaporation-lake must be indicated, if applicable.

Sheet 5 presents the operational data and flows associated with ore processing.

Sheet 6 presents an estimate of the freshwater supply requirements of the ore processing plant, and of the losses by evaporation and by discharge into the plant;

Sheet 7 presents the summary of the water balance of the ore processing plant and the flows associated with the processing of the ore.

Sheet 8 calculates infiltration rates from daily estimates entered by the user.

Sheet 9 shows evaporative losses.

Sheet 10 calculates other flows, such as water for dust removal, potable water, and treated wastewater.

Sheet 11 presents a summary of modeled flows / losses by month.

Sheet 12 presents a summary of the main input data used in the water balance model.

5 RESULTS AND DISCUSSION

5.1 RESULTS

In this section, we will present the results of the model, and then we will evaluate the Water Balance model by comparing these results to the water extraction rates in the area. This will allow us to assess sustainability through the water footprint accounting. The collection of meteorological data allowed us to estimate the water recharge, and compared it to water extraction to assess the overall water balance of the area.

In what follows (Table 2), the different weighted flows for all the months of the year, where the weighted flow is the rainfall amount multiplied by the flow coefficient estimated here at 0,4.

We will in the following, estimate the runoff flows. To do this, we will need the surface of the watershed studied (40 Mm^2).

It now remains to estimate the amount of water evaporated, which is the evapotranspiration multiplied by the evaporation coefficient considered here as 0,7.

Month	O	N	D	J	F	M	A	M	J	J	A	S
Rainfall	25,8	33,7	39,4	30,6	28,1	22,8	18,5	9,3	1,3	0,3	1,1	4,3

Table 2: Weighted flows in mm

Month	O	N	D	J	F	M	A	M	J	J	A	S
Volume	1032	1348	1576	1224	1124	912	740	372	52	12	44	172

Table 3: Runoff flows in Mm^3

Month	O	N	D	J	F	M	A	M	J	J	A	S
Volume	573	748	875	679	624	506	411	207	29	7	24	96

Table 4: Evaporation flows in Mm^3

5.2 Discussion

Rainfall infiltration and runoff, estimated at 34 Mm^{3}per year, constitute the main component of the natural recharge of the western and central aquifers of Bahira; the outlets consist of pumps distributed at a rate of 9 Mm^3 for drinking water and sanitation, 0,3 Mm^3 for industrial needs (Table 5), and 28 Mm^3 for irrigation.
The destocking, of the order of - 4 Mm^3 in medium configuration, is accentuated in a deficit hydro-climatological year with the combined effects of a reduction in the infiltration of rainwater and an increase in agricultural withdrawals. Through the water balance equation (2), the water footprint of the area is negative (-3,3 Mm^3), therefore we can conclude that the area is already considered in shortage of water.

$$\text{Infiltration} = \text{Groundwater Abstraction} - \text{Destocking} \quad (2)$$

Month	O	N	D	J	F	M	A	M	J	J	A	S
Volume	23	25	22	24	25	26	25	25	24	23	24	23

Table 5: Water Consumption in 10^3 m^3

Also, climate change disrupts the water cycle and precipitation. According to scientists from the Intergovernmental Panel on Climate Change (IPCC), the impacts of climate change – including changes in temperature, precipitation and sea level rise – are expected to have varying consequences for the availability of freshwater around the world. An increase in the rate of evaporation will also affect water supply and contribute to the salinization of irrigated agricultural lands, and such effects are the increased likelihood of more intense droughts and precipitation events. This may lead to decreased water supplies and increased water demand.
It is at the national level that the most important decisions need to be made, and adaptation strategies developed.
Even where precipitation might increase, there is no guarantee that it would occur at the time of year when it would be useful. There is also a likelihood of increased flooding.

6 Conclusion

Due to high complexity of hydrological systems, many environmental problems are linked to the hydrologic cycle, and the water balance approach may be used to better understand and face all these challenges. It is considered as a tool that helps tracking the balance between input and output water flows of any hydrological system. In semi-arid regions groundwater balance is strictly connected with surface water balance, which in turn is directly governed by climate, and in particular, precipitation, temperature and evaporative energy.
For more accuracy, future studies should include hydrological models in order to determine the different inflows and outflows of the basin, and therefore estimate the real volumes of water resources available in the area, crop data, other meteorological data such as soil moisture, surface runoff, actual flow coefficients (transmissivity and hydraulic conductivity), return flow from irrigation (Irrigation Recharge), etc.

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