REPUBLIQUE ALGERIENNE DEMOCRATIQUE ET POPULAIRE

Ministère de l'Enseignement Supérieure et de la Recherche Scientifique

Ecole Nationale Polytechnique

المدرسة الوطنية المتعددة التقنيات
Ecole Nationale Polytechnique

LMGCE
LABORATOIRE MATERIAUX DE GENIE CIVIL ET ENVIRONNEMENT

Hydraulic Department

Civil Engineering Materials and Environment Laboratory

Final year's project thesis

To obtain the State Engineer Diploma in Hydraulic

Integrating remote sensing services for reservoirs' characterizing

Asma BRAZI

Under the supervision of Mr. Mohamed Amine BOUKHEMACHA, MCA at ENP

Defended on the 30th of September 2021

Before the jury composed of:

President	Mr. Omar BELHADJ,	MAA	ENP
Advisor	Mr. Mohamed Amine BOUKHEMACHA,	MCA	ENP
Examinator	Mr. Ali Yacine SAHNOUN,	MCB	ENP
Guest	Mrs. Nadjia REZKALLAH,	PHD Student	ENP

Ecole Nationale Polytechnique 10, Avenue Hassen Badi 16200 Alger

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Département Hydraulique

Laboratoire Materiaux de Genie Civil et Environement

Mémoire de projet de fin d'études

Pour l'obtention du diplôme d'ingénieur d'état en Hydraulique

Intégration de services de télédétection dans la caractérisation des réservoirs

Asma BRAZI

Sous la direction de Mr. Mohamed Amine BOUKHEMACHA, MCA at ENP

Présenté et soutenu publiquement le (30/09/2021)

Composition du Jury

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Dedication:

I dedicate, with sincere gratitude, this modest work to those whom I will never be able to express my sincere love.

To my little family: my dear sisters Salam, Amira, Itimade, my precious Rahil, and my loved brother Yasser. Above all to my dear parents for all their sacrifices, support, and their prayers all along the way.

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ملخص :

الجزائر من البلدان العديدة التي تواجه صعوبات في إدارة الموارد المائية ، ولا سيما السطحية منها. ولذلك ، يمكن أن يكون من العملي التركيز على تكنولوجيات الاستشعار عن بعد ، و التي تعتبر واحدة من افضل التقنيات الحديثة المعروفة بدقة المعلومات التي توفرها، بالاضافة الى وفرتها الظرفية. يهدف هذا المشروع إلى دمج استخدام منتجات الاستشعار عن بعد ، مثل صور رادار ذو فتحة اصطناعية ، في رصد التغيرات في مساحة وارتفاعات السطوح المائية في الخزانات. في هذه الدراسة ، يتم تطوير منهجية منطقة الدراسة الواقعة في الجزء الشمالي من البلاد والتي تغطي 13 سدا ومراقبة هذه التغيرات على مدى .واختبارها بنجاح على عامين

الكلمات المفتاحية: الاستشعار عن بعد، الخزانات، رصد الموارد المائية، صور رادار ذو فتحة اصطناعية

Résumé :

L'Algérie est l'un des nombreux pays qui rencontrent des difficultés dans la gestion des ressources en eau, en particulier les eaux de surface. Par conséquent, il peut être pratique de se focaliser sur les technologies de télédétection, reconnue comme une des meilleures techniques modernes pour fournir des données spatio-temporelles d'une précision remarquable. La présente étude vise à intégrer l'utilisation de produits de télédétection, tels que les images Radar d'Ouverture Synthétique (ROS), dans le suivi des variations des paramètres qui caractérisent les réservoirs (niveaux d'eau, surfaces et volumes stockés). Dans ce projet, une approche est développée et testée avec succès dans une zone d'étude située dans la partie nord du pays couvrant 13 réservoirs et surveillant ces paramètres sur une période de deux (02) ans.

Mots clés : télédétection, réservoirs, surveillance des ressources en eau, images ROS.

Abstract:

Algeria is one of the many countries that face difficulties in managing water resources, especially surface water resources. Therefore, it can be practical to focus on remote sensing technologies, which has been recognized as one of the best modern techniques to provide spatio-temporal data available with remarkable accuracy. The present project aims to integrate the use of remote sensing products, such as SAR images, in monitoring the variations of the parameters that characterize the reservoirs (water levels, areas, and stored volumes). In this study, an approach is developed and successfully tested on a study area located in the northern part of the country covering 13 dam reservoirs and monitoring these parameters over a period of two (02) years.

Key words: remote sensing, dam reservoirs, water resources monitoring, SAR images.

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List of abbreviations:

SAR :	Synthetic Aperture Radar
RS :	Remote Sensing
H:	Horizontal
V:	Vertical
ANBT :	Agence Nationale des Barrages et transfert
NASA:	National Aeronautics and Space Administration
OM:	Oued Mellouk
SMBT:	Sidi M'hamed Ben Taiba
ESA:	European Space Agency
GIS:	Geographic Information System
PBIAS:	Percent Bias
NSE:	Nash-Sutcliffe Efficiency

General introduction:

Water is the most valuable resource for life on earth, and it is essential to human daily life, irrigation, and drinking water. Over the past 40 years, the global demand has risen fourfold and now exceeds more than half of the total available resources(Moulahoum & Chaoui, 2019). The growing population and the increasing demand for water are risking this important resource which, at this rate, is expected to reach its full hydraulic potential by the year 2050(Moulahoum & Chaoui, 2019).

The water supply in Algeria relies on several water resources bodies including surface water and groundwater. These are used for various purposes such as domestic, water drinking, agriculture, industries, and for other environmental purposes. Although water is something of a rare commodity in Algeria (Hamiche, Stambouli, & Flazi, 2015), the availability of these water resources has been affected by irregular and uncontrolled water withdrawals from surface and groundwater bodies (Negm, Bouderbala, Chenchouni, & Barcelo, 2020). Recently, due to the rapid population and economic growth, urban land expansion, climate change conditions, and industrial activities, the water consumption in the country has increased. On top of that, the recent increase in agricultural activities and other domestic practices has caused the deterioration of the water bodies used for drinking water needs in the country(Negm, Bouderbala, Chenchouni, & Barcelo, 2020).

Water supply in the country is mainly from surface water distributed through and stored in reservoirs, and other transfer facilities(Moulahoum & Chaoui, 2019). The reservoirs are the most important rainwater reserve in Algeria. They constitute a reserve of about 5.5 billion cubic meters, distributed over the dams' population of the country(Progress, 2016). To better manage these water resources, it is important to understand and monitor the water bodies and watersheds. However, such data collection using traditional techniques requires the establishment of costly physical infrastructure (rain gauges, stations, etc.) as well as the use of expensive equipment (e.g., sounders) that need to be deployed over large areas and may require human intervention (for monitoring and control and maintenance, etc.); aspects leading generally to a reduction in the spatio-temporal resolution of the so acquired monitoring data. Alternatively, the use of remote sensing in such monitoring activities is gaining popularity as complementary and even as an alternative solution.

Remote sensing techniques have been in constant development over the last few years due to its diverse of application. It provides observations of changes in hydrologic conditions and variables over time and space(Ritchie & Rango, 1996).

The main objective of this study is to develop and implement a methodological and practical approach that uses remote sensing to generate geospatial data related to the hydrological characteristics of selected Algerian watersheds with the aim of supporting a rational management of water stored in dams. This study relied on a quantitative monitoring of the spatiotemporal variation in the area of the water surface, water level and stored volume in selected dam reservoirs located in North Algeria.

The present report is structured into four chapters.

The first chapter gives generalities about remote sensing, including definitions, concept, and the fields of application. The second chapter presents the study area used for this work. The choice of this area was made based on many criteria including the availability field data and remote sensing data, in order to contain the largest number of reservoirs of dams.

The third chapter presented the approach adopted in this work and the used data.

The fourth chapter summarizes and discusses the obtained results.

Introduction générale (version française) :

L'eau fait partie des ressources naturelles vitales pour toutes les formes de vie sur terre. Elle présente un élément essentiel dans la vie quotidienne de l'homme, notamment pour l'irrigation et la consommation d'eau potable. Au cours des 40 dernières années, la demande mondiale s'est multipliée par quatre et dépasse aujourd'hui plus de la moitié des ressources totales disponibles(Moulahoum & Chaoui, 2019). L'accroissement de la population et la demande en eau croissante menacent cette ressource importante qui, à ce rythme, devrait atteindre son plein rendement hydraulique d'ici 2050(Moulahoum & Chaoui, 2019).

En Algérie, le secteur de l'eau repose sur plusieurs sources en eau, notamment les eaux de surface et les eaux souterraines. Celles-ci sont utilisées à de nombreux usages, telles que pour les activités domestiques, l'agriculture, l'industrie et d'autres besoins environnementaux. Bien que l'eau soit une commodité plutôt rare en Algérie(Hamiche, Stambouli, & Flazi, 2015). La disponibilité de ces ressources en eau est affectée par des prélèvements d'eau irréguliers et incontrôlés dans les sources d'eau de surface et souterraines(Negm, Bouderbala, Chenchouni, & Barcelo, 2020). Récemment, en raison de la croissance démographique rapide, du développement économique, de l'expansion des zones urbaines, des changements climatiques et des activités industrielles, la consommation d'eau dans le pays a augmenté. De plus, l'augmentation récente des activités agricoles et d'autres pratiques domestiques ont entraîné la détérioration des masses d'eau utilisées pour les besoins en eau potable dans le pays(Negm, Bouderbala, Chenchouni, & Barcelo, 2020).

La production d'eau dans le pays provient principalement des eaux de surface distribuées et stockées dans des réservoirs et autres ouvrages de transfert(Moulahoum & Chaoui, 2019). Les barrages sont la plus importante réserve d'eau de pluie en Algérie. Ils constituent un stockage d'environ 5,5 milliards de mètres cubes, répartis sur la population des barrages du pays(Progress, 2016). Pour mieux gérer ces ressources hydriques, il est important de comprendre et de surveiller ces réservoirs d'eau. Cependant, une telle collecte de données à l'aide de techniques traditionnelles nécessite la mise en place d'infrastructures physiques coûteuses (pluviomètres, stations, etc.) ainsi que l'utilisation d'équipements onéreux (par exemple, des sondeurs) qui doivent être déployés sur de vastes zones et peuvent nécessiter une intervention humaine (pour le suivi, le contrôle et la maintenance, etc.), des aspects qui conduisent généralement à une réduction de la résolution spatio-temporelle des données de surveillance ainsi acquises. Par contre, l'utilisation de la télédétection dans ces activités de surveillance gagne en popularité en tant que solution complémentaire et même alternative.

Les techniques de télédétection ont été en constant développement au cours des dernières années en raison de la diversité de leurs applications. Elles permettent d'observer les changements des conditions et des variables hydrologiques dans le temps et l'espace(Ritchie & Rango, 1996).

Cette étude a pour objectif principal de développer et de mettre en œuvre une approche méthodologique et pratique qui utilise la télédétection pour générer des données géospatiales relatives aux caractéristiques hydrologiques des bassins versants algériens sélectionnés, dans le but de supporter une gestion rationnelle de l'eau stockée dans les barrages. Cette étude s'est appuyée sur un suivi quantitatif de la variation spatio-temporelle de la surface, niveau d'eau et du volume d’eau stocké dans des barrages situés dans le Nord de l'Algérie.

Le présent rapport est constitué de quatre chapitres.

Le premier chapitre donne des généralités sur la télédétection, y compris les définitions, le concept et les domaines d'application.

Le deuxième chapitre présente la zone d'étude choisie pour ce travail. Le choix de cette zone a été fait en fonction de nombreux critères dont la disponibilité des données de terrain et des données de télédétection, afin de contenir le plus grand nombre de réservoirs de barrages.

Le troisième chapitre présente l'approche adoptée dans ce travail et les données utilisées.

Le quatrième chapitre résume et discute les résultats obtenus.

Chapter 1:

Fundamentals of remote sensing

1 Chapter 1: Fundamentals of remote sensing

1.1 Introduction:

In the first chapter, we introduce the technology of remote sensing in general, its definition, components, concept and the different fields of application. In addition, we talk about radar, SAR images and satellite, with focusing on providing the necessary information needed in this study.

1.2 Definition

Remote sensing (RS) is gathering data about objects or areas on the earth's surface without being in direct contact with them. It monitors selected characteristics of these objects/areas by measuring their reflected and emitted radiation at a distance.

1.3 Components of Remote Sensing:

While there are many different methods of collecting, processing, and interpreting the resulting remote sensing data, the major components of imaging systems are the following(Ray, 2013): (1) energy source of illumination, (2) interaction with the target, (3) recording of energy by the sensor, (4) transmission, reception, and processing and (5) interpretation and analysis.

1.3.1 Energy Source or Illumination:

Having an energy source (see subsection 1.4) is the first requirement for Remote Sensing, it provides electromagnetic energy to the target of interest.

1.3.2 Interaction with the Target

When the energy moves from its source to the target, it interacts with the atmosphere it passes through. This interaction can occur a second time when the energy moves from the target to the sensor. After the energy passes through the atmosphere to the target, it interacts with the target depending on the radiation and the target's properties. A variety of interactions is possible when electromagnetic energy encounters any material, solid, liquid or gas(Ray, 2013).

1.3.3 Recording of Energy by the Sensor

Once the energy is scattered by or emitted from the target, a sensor is needed to collect and record the electromagnetic radiation. In order to take observations, sensors must be mounted on a platform. This platform can be land-based (e.g., handheld radiometers), airborne (e.g., NASA's AVIRIS sensor), or space borne, i.e., satellite-based. Operational remote sensing systems are generally space borne(Ray, 2013).

Resolution is a major sensor parameter affecting the optimal use of the data. There are four types of resolution.

- **Spatial Resolution:** Sensor's ability to image (record) closely spaced objects.
- **Spectral Resolution:** The spectral bandwidth in which the data is collected.
- **Radiometric Resolution:** The capability of the sensor to differentiate the smallest change in the spectral reflectance/emittance between various targets.
- **Temporal Resolution:** the capability to view the same target, under similar conditions, at regular intervals.

1.3.4 Transmission, Reception, and Processing:

In many cases, the energy captured by the sensor must be transmitted in electronic form to a receiving and processing station on the earth, where the data is processed and stored in digital form.

1.3.5 Interpretation and Analysis:

The processed data is visually and/or digitally interpreted to extract information about the target of interest. Special instruments/hardware and software are usually used for this purpose, and they are often called image processing tools. When applying the extracted information to solve specific problems, this is the final element of the remote sensing process(Ray, 2013).

1.4 Types of Remote Sensing

Remote sensing systems are categorized into the two following groups(Martensson, 2011):

- **Passive remote sensing systems:** measuring the existing radiation such as the reflected solar radiation from the earth's surface (e.g.: Photography, Digital photography, Scanning Mirror (MSS), and Push broom Scanner(Martensson, 2011)).
- **Active remote sensing systems:** emitting radiation on the study object and measuring the reflected amount of radiation (e.g. Radar, Sonar, Echo-sounder, and the more recently added Lidar which use laser technology to emit and then collect reflections from the surface of the earth(Martensson, 2011))..

For example, a simple camera is considered a passive remote sensing system because it uses existing light as input and then forms an image. However, if the camera is equipped with a flash, it then becomes an active remote sensing system because it provides the necessary radiation independently of the existing radiation sources (Martensson, 2011).

1.5 Remote Sensing Applications**:**

- Remote sensing applications have proven to be very useful in various fields, including agriculture, water resources, forests and ecosystems, disaster management, infrastructure development, atmospheric and marine sciences, etc.(Ray, 2013). Land resource mapping/monitoring;
- The restoration of biogeophysical parameters is used in the model to predict changes in the earth and the biosphere;
- Management/decision support, where remote sensing data is used to make decisions about the availability of land resources;

1.6 Remote Sensing Data Acquisition

The term "remote sensing" is commonly used with electromagnetic technology for data acquisition. It covers the entire electromagnetic spectrum in the low-frequency electromagnetic wave, microwave, sub-millimeter wave, far infrared, near-infrared, visible light, ultraviolet, X-ray, and gamma-ray regions. The development of satellites gives access to global and weather information about the different planets and their environment. Sensors on satellites orbiting the Earth provide information on global cloud patterns and dynamics, surface vegetation cover and its seasonal changes, surface morphology, ocean surface temperature, and near-surface wind (Van Zyl & Elachi, 2006)**.**

1.6.1 Properties of Electromagnetic waves used in Remote Sensing:

a) Definition

Electromagnetic energy is a means of transmitting information from an object to a sensor. The information can be captured in the frequency content, intensity or polarization of the electromagnetic wave. It travels at the speed of light through electromagnetic radiation, either directly from the source through free space, or indirectly through reflection, scattering and re-radiation to the sensor. The interaction of electromagnetic waves with natural surfaces and the atmosphere largely depends on the frequency of electromagnetic waves. Waves in different spectral bands often excite different interaction mechanisms, such as electronic, molecular or conductive mechanisms.(Van Zyl & Elachi, 2006).

b) Characteristics of Electromagnetic waves

a) Propagation speed:

Electromagnetic waves can propagate in the void as well as in the air at the speed of c = 3×10^8m/s. However, in other mediums, the speed is divided by n, n being the refractive index of the medium (Mevel, 2019).

Where the wave celerity c is given in [m.s-^{1}] and n [-].

b) Period, frequency:

The frequency of a phenomenon is the number of times it repeats itself per unit of time. The frequency unit in physics is the hertz (Hz), which represents the number of "peaks" of the wave passing at a given point in one second(Mevel, 2019). The period T of a wave is defined as the inverse of the frequency f:

$$T = 1/f \tag{1}$$

Where f is expressed in hertz [Hz].

c) Wavelength and intensity

For electromagnetic waves, we often replace the value of the frequency with the wavelength, which represents the distance the wave travels during a period T of oscillation (Mevel, 2019). For a progressive wave propagating with the speed c, the wavelength λ is then defined by the following equation:

$$\lambda = c\,.T = c\,/\,f \tag{2}$$

Where λ is expressed in [m], f in hertz [Hz], and c in [m.s-^{1}].

The electromagnetic intensity is the electromagnetic energy passing through a surface that directly depends on the energy of the electromagnetic wave (Mevel, 2019).

d) Electromagnetic spectrum

The electromagnetic spectrum is the classification of electromagnetic radiation according to their frequency and wavelength in the void, or the energy of photons. The electromagnetic spectrum extends from short to very long wavelengths through the ultraviolet, visible light and infrared. For historical and physical reasons, it is divided into several major classes in which the radiation is studied by particular ways (González, Ruiz, & Acosta, 2014).

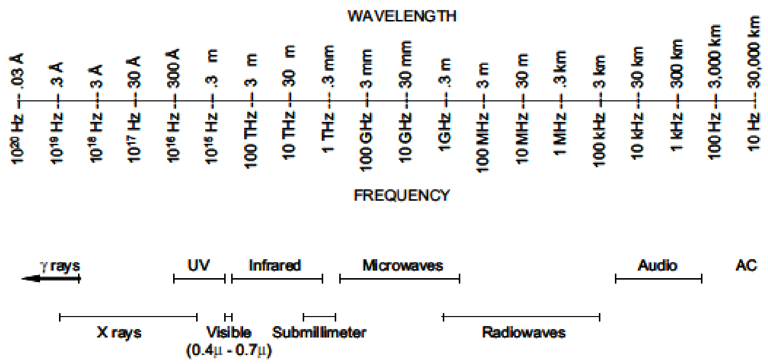


Figure 1-1 : Electromagnetic spectrum (Van Zyl & Elachi, 2006)

As it's shown in Figure 1-1, the electromagnetic spectrum represents a subdivision of frequency bands in which:

- The visible range: it corresponds to very low wavelengths (i.e. high frequencies) of the order of the micrometer (10^6 m), and its spectrum includes the colors that we know(Chevalier, 1999).
- The microwave frequency band: it covers nearby regions with wavelengths as low as 1 mm (i.e. frequency of 300 GHz). Most interactions in this region are controlled by molecular rotation, especially at the shortest wavelengths. This area is mainly used for spectrometers and radar systems.(Van Zyl & Elachi, 2006)

e) Wave polarization

The polarization of the wave is defined by the direction and trajectory of the electromagnetic fields during the propagation. There are two types of polarization for electromagnetic waves, a vertical polarization (V) and a second horizontal (H) (Chevalier, 1999).

f) Wave bands

A band is a set of wavelengths or radar frequency ranges. It is, therefore, difficult to separate the frequencies into intervals, each band has its symbol and frequency range, as well as an associated range of use(Chevalier, 1999). Table 1-1 shows the band division used by IEEE (Institute of Electrotechnical and Electrical Engineers)

Table 1-1: Frequency bands(Chevalier, 1999)

Designation	Frequency range (GHz)	Designation	Frequency range (GHz)
Band L	1-2	Band K	18-26.5
Band S	2-4	Band Ka	26.5-40
Band C	4-8	Band Q	33-50
Band X	8-12	Band U	40-60
Band Ku	12-18	Band V	50-75

1.6.2 Radar:

a) Definition

The term RADAR is derived from the initials of the term "Radio Detection And Ranging". Generally speaking, the radio energy emitted by a radar transmitter is reflected by objects in the path of the radar beam. The characteristics of the received echo are used to form an image or determine certain characteristics of the object that caused the echo(FRANCIS, BACON, & USN, 1965).

The signal emitted by the radar does not propagate in all directions, however, it is concentrated in a spatial area and once the signal reaches the target (e.g. on the surface), it will be partially or completely reflected back to the radar receiver. This type of detection is proactive because the radar is both the transmitter and the receiver of the echo (Owe, Brubaker, Ritchie, & Albert, 2001).

b) Concept:

The transmitter sends out very short signals at regular intervals (e.g., every thousandth of a second), at a given frequency (corresponding to a wavelength that varies from few meters to few millimeters depending on the application). The signal is not emitted in all directions: the radar antenna acting as a projector concentrates the emission in a very narrow space area, or in a cone of small horizontal aperture (approximately 1 degree), or in a small vertical opening in the cone (also on the order of 1 degree). This is how targets located in the antenna field are illuminated, the weaker they are, and the further away they are from the antenna. These targets reflect the received signal, and the radar picks up the echo with an offset relative to the transmission. The greater the offset, the farther the target is(Hadj Sahraoui, 2005).

c) Radar Remote Sensing:

Currently, radar is used most frequently in various resource inventories. The use of radar remote sensing can be particularly useful in regions that are often thickly covered, due to the fact that radar waves penetrate clouds and even vegetation cover to a certain extent.(Martensson, 2011).Table 1-2 summarizes the advantages and disadvantages of radar images (Canada, Ressources naturelles Canada. Tutoriels sur la télédétection, 2019)

Table 1-2: advantages and disadvantages of radar images (Canada, Ressources naturelles Canada. Tutoriels sur la télédétection, 2019)

Advantages	**disadvantages**
· Detection capability during nearly all weather conditions; · Detection capability during day and night hours; · Penetration through vegetation cover; · Penetration through underground surfaces; · Minimum atmospheric effects; · Sensitivity to both materials' dielectric properties and structures (distinguishing between liquid and solid objects).	· Data is sometimes difficult to interpret, comparing to the optical image; · Noise effects in the images; · Topography effect on the imagery content.

d) Synthetic Aperture Radar (SAR)

a) Definition:

A radar antenna is a device responsible for detecting the echo from a target on the earth's surface. By increasing the length of the antenna, the resolution of satellite images (a finer resolution) can be improved. However, obtaining usable resolution is not possible by increasing the physical size of the antenna, but rather virtually. To do this, it is sufficient to combine all the echoes in phase during the antenna movement between two pulse emissions, thus building a very large virtual antenna (Hadj Sahraoui, 2005). This is the concept of a Synthetic Aperture Radar (SAR).

Thus, Synthetic Aperture Radar is an active remote sensing technology that can provide high-resolution that are independent of daylight and minimally affected by weather conditions (Soergel, 2010).

b) Polarization of SAR images

A radar system has antenna designed to transmit and receive waves with a defined polarization. It can have the following channels:

- VV: single co-polarization, vertical transmits/vertical receive.
- HH: single co-polarization, horizontal transmit/horizontal receive.
- VV + VH: dual-band cross-polarization, vertical transmit/horizontal receive.
- HH + HV: dual-band cross-polarization, horizontal transmit/vertical receive.

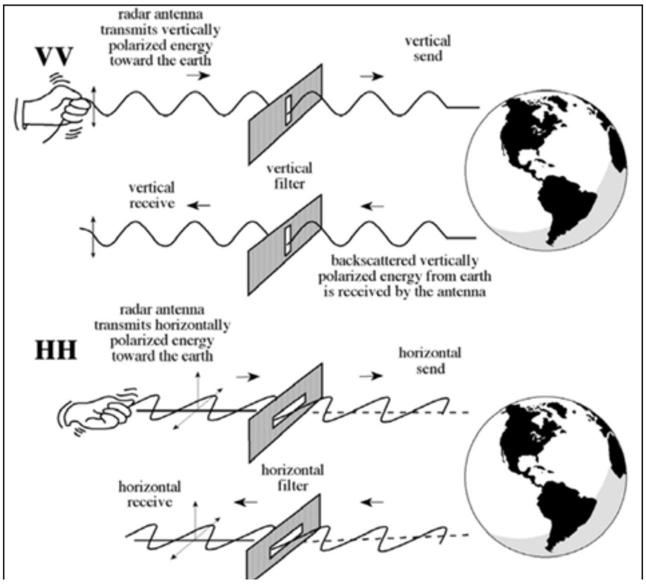


Figure 1-2: Transmission and reception modes of polarized waves in active radar systems(Podest & Mehta, 2018).

The first two of these polarization combinations are called similar polarizations because the transmit and receive polarizations are the same. The last two combinations are called cross polarization, because the transmit and receive polarizations are orthogonal to each other. A radar system can have different levels of polarization complexity (Canada, Educational ResourcesTutorial: Radar Polarimetry. Polarization in radar systems, 2014):

- single-polarized HH or VV or HV or VH ;
- dual-polarized HH and HV, VV and VH, or HH and VV ;
- Quad-polarized HH, VV, HV and VH.

c) SAR applications

Radar can penetrate clouds and can be obtained at any time, regardless of whether the availability of sunlight. SAR satellites' penetration characteristics allow soil moisture to be measured, which makes it a useful tool for land use and land cover studies, as well as land observation and monitoring (Owe, Brubaker, Ritchie, & Albert, 2001). SAR images can also be used for (Musa, Popescu, & Mynett, 2015):

- Monitoring ice areas and the polar environment;
- Mapping for aid in crisis situations;
- Monitoring marine environments;
- Monitoring the risks associated with earth surface movements;
- Mapping land surfaces: forest, water, soil, and agriculture.

d) Mission and satellites:

Several space agencies have launched numerous missions to use remote sensing products from space for hydrological and environmental research. In general, satellites have a very limited lifetime, which makes the launch of new missions vital to maintain continuity in monitoring and collecting data. Table 1-3 gives a comparison of several satellites used for surface water and land use change(O'Loughlin, Bruen, Bates, & Schumann, 2015):

Table 1-3: comparison of satellites used for surface water and land use change (O'Loughlin, Bruen, Bates, & Schumann, 2015).

Satellite Missions	Sensor	Ground Footprint (m)	Repeat Cycle (days)	Time Period
Landsat	Optical	15+	16	1972 - Present
MODIS	Optical	250+	1	1999 - Present
SPOT	Optical	1.5+	26	1986 - Present
JERS-1	Optical & SAR	18	44	1992 - 2001
ERS	SAR	30	35	1991 - 2003
RADARSAT	SAR	1-100	24	1995 - Present
Sentinal-1	SAR	5	12	2014 - Present
TerraSAR-X	SAR	1-16	11	2008 - Present

e) Future Satellites Missions in hydrology:

The Surface Water and Ocean Topography (SWOT) mission is a future satellite altimeter that aims to conduct the first global study of the Earth's surface waters and is a joint cooperation project (CNES) between NASA and the French Space Agency. Its launch is planned for

November 2022 at the 4E Space Launch Center at Vandenberg Air Force Base, California, using the SpaceX Falcon 9 rocket. The SWOT will consist of two SAR antennas, which are expected to exhibit centimeter level errors when sampled up to 1 square kilometer. It will estimate the water level of lakes larger than 250 x 250 m^2 twice every 21 days. SWOT is not intended to replace the existing emission measurement network, but as a supplementary source of additional information(O'Loughlin, Bruen, Bates, & Schumann, 2015) ((JPL), 2018).

Chapter 2:

The Study Zone

2 Chapter 2: The Study Zone:

2.1 Introduction

In this chapter, we present the study zone used to demonstrate the proposed approach, the dam reservoirs that are within this zone, their geographical location, climatic data and other related characteristics.

2.2 Reservoirs chosen for the study

Algeria is divided into five primary basins, having a total of 17 catchments, located mainly in the north. The estimated total renewable surface water resources are 11 billion cubic meters per year. Surface water bodies in the Sahara basin are low, totaling 0.5 billion cubic meter per year. However, the north relies primarily on surface water, with many medium and large dams capturing nearly 7 billion cubic meters per year. The runoff occurs during rapid and powerful floods, which recharge the dam reservoirs during the short rainy season, commonly from December through February (Moulahoum & Chaoui, 2019).

The study zone is located in North Algeria is where a large part of the reservoirs with greatest capacity in the country can be found. The selection of this zone was based on the following factors including:

- Reservoirs showing significant water level decrease;
- Availability of remote sensing data;
- The spatial density of the dam reservoirs;
- Availability of field data (mostly provided by ANBT).

Table 2-1: The dams treated in this study. lists the 13 dams reservoirs that were studied and key characteristics of their dams.

Table 2-1: The dams treated in this study.

DAM ID	Name	Wilaya	Dam Type	Crest height (m)	Normal water level (NGA) (m)
R1	Boukerdane	Tipaza	Embankment dam	75	119,5
R2	Bouroumi	Ain Defla	Earth made dam	98	323
R3	Derdeur	Ain Defla	Zoned embankment dam	56	605
R4	Gergar	Ghilizane	Zoned embankment dam	70	118
R5	Ghrib	Ain Defla	Rockfill dam	105	427,5

R6	Harreza	Ain Defla	Homogeneous earth made dam (clay)	41	313
R7	Kef Eddir	Chlef	Zoned embankment dam	95	111,25
R8	Koudiat Rosfa	Tissemssilt	Zoned embankment dam	57	642
R9	Oued Fodda	Chlef	Gravity dam	101	370,5
R10	Ouled Mellouk (OM)	Ain Defla	Zoned embankment dam	51	243
R11	Sidi M'hamed Ben Taiba (SMBT)	Ain Defla	Zoned embankment dam	58	317
R12	Sidi Yakoub	Chlef	Earth made dam	94	264
R13	Taksebt	Tizi-Ouzou	Embankment dam	76	165

2.3 Properties of the area

2.3.1 Geographical localization:

The 13 dam reservoirs selected for this study fall within a study zone intercepts the following Wilayas: Ain Defla, Chlef, Medea, Tissemsilet, Ghilizane, Tipaza, as well as Tizi-ouzou (Figure 2-1).

Figure 2-1: The study zone used for the studyThe spatial distribution of these dams (shown in Figure 2-2) is given as follows:

- Tipaza (***R7***: Kef eddir ; ***R1***: Boukerdane);
- Chlef (***R9***:Oued Fouda; ***R12***: Sidi Yakoub);
- Ain Defla (***R11***: SMBT; ***R10***:OM; ***R6***: Harezza; ***R5***: Ghrib; ***R3***: Deurdeur);
- Medea (***R2***: Bouroumi);
- Ghilizan (***R4***: Gergar);
- Tissemsilet (***R8***: Kodiat Rosfa);

- Tizi-ouzou (***R13***: Taksebt);

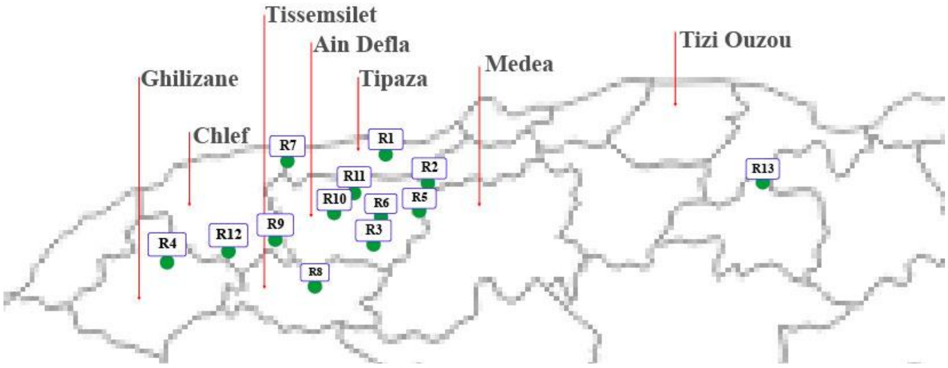


Figure 2-2 : Spatial distribution of the studied dams within the study zone

The choice of the selected region that includes the reservoirs R1-R12 was based on the large number of the dams that it contains and the reservoirs most affected by droughts. For R13, the choice of the region was because the water level in this dam was remarkably decreasing lately.

2.3.2 Climatic conditions:

The study zone presents areas with relatively different climatic conditions. In the northern basins, such as Boukerdane and Kef Eddir dams, the average temperature is between 18.6°C and 21.4°C, and annual precipitation is 631mm/year. While other dams located in the southern provinces of Ain Defla and Chlef have a warm and temperate climate with an average temperature of 14.6°C and more precipitation with an average of 756 mm/year. And for the basin located in the wilaya of tizi-ouzou, the climate is warm and mild and the temperatures varies between 9.9°C and 26.7°C(data, 2019).

Figure 2-3 gives a summary of key climatic parameters of the different cities included in the study area.

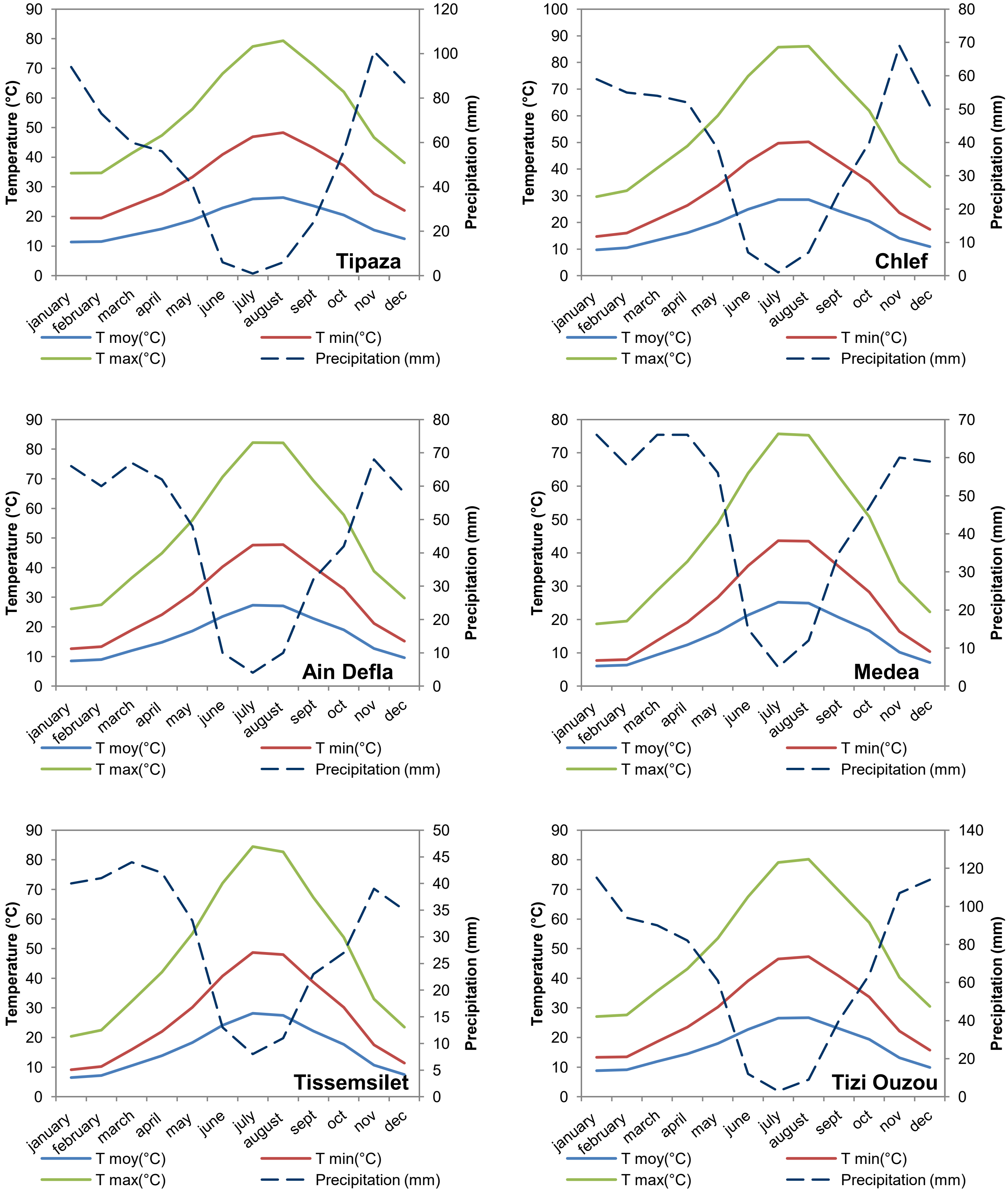


Figure 2-3: Summary of climatic parameters of the different cities included in the study area(data, 2019), (with:P: monthly precipitation; Tmin: minimum average temperature; Tmoy: average temperature; Tmax: maximum temperature)

2.3.3 Morphology, Geology:

From a morphological perspective, our study zone belongs to the Tellian domain, which represents the crossroads of the major structural geological units of north Algeria, and also of the external domain of the Alpine orogen of the Mediterranean area, which means that the Tellian chain is part of a vast mountain system, very well developed, called geosynclinal (Chanane, 2008). Figure 2-4 gives the Maghrebian geological structural setting.

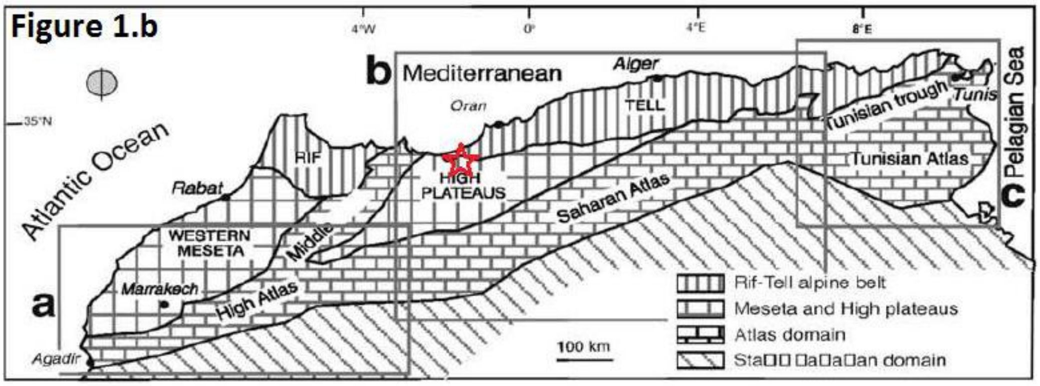


Figure 2-4: Maghrebian geological structural set(Chanane, 2008).

Chapter 3:

Data and Methods

3 Chapter 3: Data and Methods:

3.1 Introduction:

In this chapter, we explain the different stages of the approach followed for a radar (SAR) remote sensing-based quantitative monitoring of the studied surface water bodies.

3.2 Remote sensing data used in the study:

The SAR data collection was based on a detailed scan of all images related to our study area. In order to select a constant time span between images, the ESA (European Space Agency) Sentinel-1 mission data acquisition online platform (available at: https://scihub.copernicus.eu/dhus/#/home) was used to define an acquisition timetable.

The Sentinel-1 mission consists of two C-band SAR satellites ("Sentinel-1 A" and «Sentinel-1 B"), with a 12-day recurrence cycle and 175 orbits per cycle. The constellation of two satellites Sentinel-1A and Sentinel-1B offers an exact 6 days repeat cycle (ESA, 2021). With the aim of achieving a high temporal resolution monitoring of the studied elements, this six (06) days acquisition schedule was fully exploited (see APPENDIX 1 for more details).

3.3 Processing approach:

The approach adopted in the study is based on the use of SAR images to extract time series corresponding to changes in the water area of each dam reservoir within the study zone, and related changes in the water level and water volume.

The approach followed involves three processing stages: (1) RS processing; (2) GIS processing and (3) time series analysis. Each stage in the approach consists of several steps, as shown in Figure 3-1.

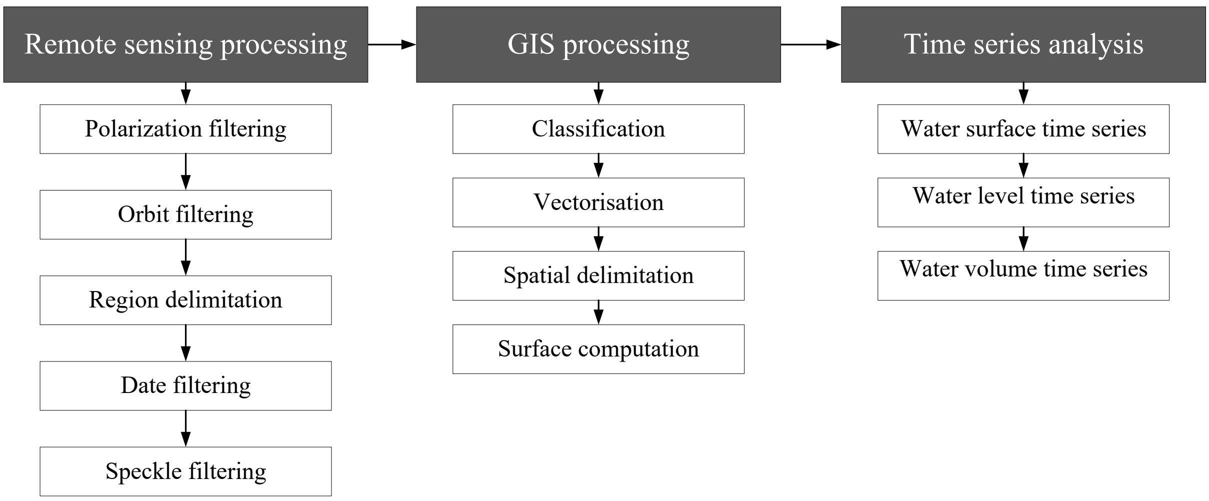


Figure 3-1: Processing approach used in the study.

3.3.1 Stage 1: Remote sensing processing:

The remote sensing processing stage consists of applying several filters to provide our final SAR images that can be further treated to extract the parameters needed to monitor the water area changes of each dam for specific time frames. The objective of this stage is to develop a pre-processing chain that will produce spatial data (raster format) that can be further treated (during stage 2 to extract water features by classification).

The remote sensing processing can be done using different GIS tool as well as SNAP Software (SNAP: a common platform for all Sentinel products, called "Sentinel Application Platform", developed by the European Space Agency (ESA), allowing the processing and analysis of images from the different Sentinel missions.)

Figure 3-2 : Input and output of the remote sensing processing approach.

The steps followed in this part involved selecting the polarization, orbit, region, and date and finally apply a speckle filtering to reduce the noise in the images. Each of these steps is explained in detail as follows:

a) Polarization filtering:

For this study, the polarization selection (from VV and VH) was done on basis of the ease in distinguishing between land and water with least noise level possible. Both VV and VH were used here.

b) Orbit filtering:

In order to obtain a more detailed covering of the area of interest, the use of the two ascending-descending orbits was a highly efficient technique to fill in certain gaps caused by geometric deformations in the images captured and to increase the temporal resolution.

c) Date filtering:

The choice of the acquisition schedule frame was done to cover the largest possible number of images between the years 2019 and 2021 in order to obtain the most accurate representation of the water level evolution in the reservoirs studied.

d) Region filtering:

In this step, the spatial extent of the regions of different reservoir present in the study zone was delineated using rectangular polygons (having a larger extent then the largest water foot print each reservoir). The characteristics of the selected polygons are shown in Table 3-1.

Table 3-1 : Coordinates (longitude and latitude in decimal degrees) of the nodes of the polygons used in the region filtering.

Dam	Node 1		Node 2		Node 3		Node 4	
	X	Y	X	Y	X	Y	X	Y
Boukerdane	2,26888	36,50524	2,32931	36,50524	2,32931	36,53573	2,26888	36,53573
Bouroumi	2,53220	36,32316	2,59503	36,32316	2,59503	36,36989	2,53220	36,36989
Derdeur	2,17762	35,96289	2,26551	35,96289	2,26551	36,01123	2,17762	36,01123
Gergar	0,94324	35,85565	1,11353	35,85565	1,11353	35,96687	0,94324	35,96687
Ghrib	2,54883	36,09586	2,61337	36,09586	2,61337	36,16532	2,54883	36,16532
Harreza	2,08537	36,16416	2,11662	36,16416	2,11662	36,19589	2,08537	36,19589
Kef Eddir	1,61261	36,42616	1,66651	36,42616	1,66651	36,48719	1,61261	36,48719
Koudiat Rosfa	1,73418	35,81152	1,81109	35,81152	1,81109	35,85717	1,73418	35,85717
Oued Fodda	1,56623	35,98992	1,62357	35,98992	1,62357	36,04879	1,56623	36,04879
Ouled Mellouk	1,81748	36,16544	1,85902	36,16544	1,85902	36,21365	1,81748	36,21365
Sidi M'hamed Ben Taiba	1,99555	36,31060	2,06782	36,31060	2,06782	36,34144	1,99555	36,34144
Sidi Yakoub	1,28995	35,91385	1,37475	35,91385	1,37475	35,97945	1,28995	35,97945
Taksebt	4,09472	36,61506	4,16442	36,61506	4,16442	36,67773	4,09472	36,67773

e) Speckle filtering:

SAR images typically have speckle noise that degrades image quality and resolution. This noise is defined as tiny bright dots which cause difficulty in evaluating the information extracted from these images. In order to reduce this effect, several techniques were tested (such as the Refined Lee Sigma methods, or other methods based on the evaluation of statistical parameters of the image) and the final processing was done using a focal reducer filter. This filter looks at each pixel and its neighboring pixels and takes the median. The technique used provided the best noise reduction results for the targeted classification (in stage 2) as shown in Figure 4-1 (b).

3.3.2 Stage 2: GIS processing:

GIS (Geographic Information System) presents an efficient tool for compiling, classifying and storing the information captured from the SAR images (Figure 3-4). The purpose of this stage of the approach is to conduct spatial analysis on the preprocessed raster dataset (resulting from stage 1, consisting in realizing:

a) A feature classification:

The delimitation of the water area is done on the basis of a classification of the signal intensity of the Sigma0 backscatter in two classes (Sigma0: the reflection coefficient, which represents the classical measure of the intensity of reflected radar signals, usually expressed in dB(Podest & Mehta, 2018)), for which the two types of surfaces are perfectly distinct (Figure 4-1 (c)).

The analysis of the intensity histograms of the SAR images used in this study allowed us to observe that the threshold of separation between classes (water/ground) in terms of Sigma0-dB is generally between -23 dB and -13 dB (Figure 3-3).

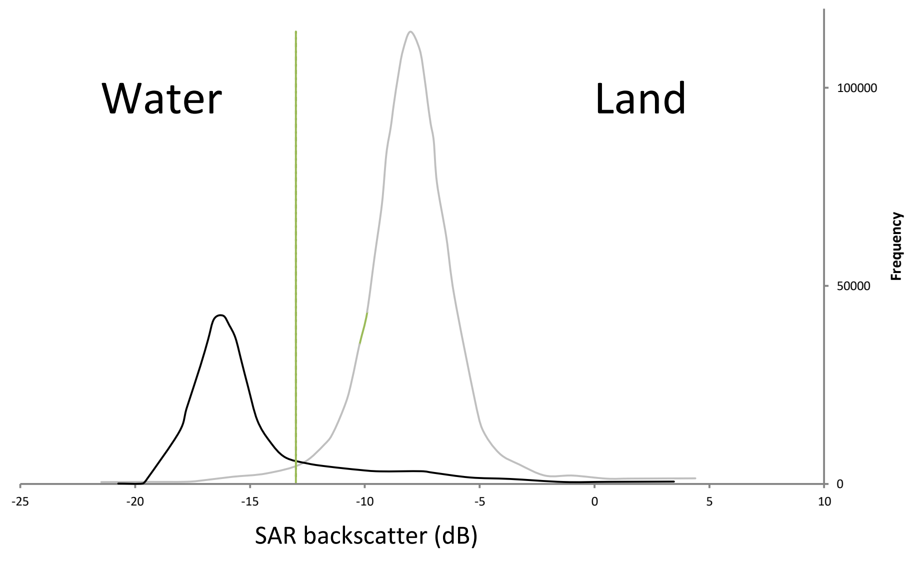


Figure 3-3 : Example histograms of SAR backscatter intensity, with vertical lines indicating thresholds. The dashed line represents a global threshold derived from the whole image (water shown in the black curve and land surfaces in gray)

b) A vectorisation of the classified raster images

After completing the classification, it is now possible to delineate water areas of the reservoirs from the different dates analyzed by creating polygon features from the raster classified images (Figure 4-1 (d)).

c) Spatial delineation of the water bodies.

d) Quantification of the area of these bodies.

Figure 3-4: Input and output of the GIS processing approach.

3.3.3 Stage 3: Time series analysis:

The last stage of the approach consists of post processing the output of the 2nd stage to convert the water area time series to water level and water volume (storage) time series.

This stage relied on reservoirs capacity curves (given in the form level vs. surface and volume vs. surface). The time series obtained resulted from extracting the water level and volumes based on the water area values obtained in stage 2.

Figure 3-5: Input and output of the time series analysis approach.

Chapter 4:

Results & Discussion

4 Chapter 4: Results & Discussion

4.1 Introduction

This chapter provides a presentation and discuses the obtained results, followed by a comparison of these results with the data available from the Algerian national agency for dams and transfers (ANBT) as a validation.

4.2 Validation data

The data used to validate the obtained results were provided by the ANBT. The agency provided us with:

- Monthly variations of water volumes stored in the studied dam reservoirs during the years 2019 to 2021;
- Reservoirs capacity curves (height-capacity-area curves) for 12 of the 13 studied reservoirs (see APPENDIX 2). However for R13 (Taksebt), the data regarding its capacity curves was not available.

4.3 Big Data used in the study:

Within the present study, we processed a large amount of data at each stage of our approach (Big Data-based approach). The remote sensing processing stage involved exporting over 20000 raster images representing 48 Gb of physical storage memory (considering all used orbits, polarizations, resolutions and acquisition dates) with a preprocessing time of 3-10min/raster, then testing these images and further processing them with GIS. Among the preprocessed images, over 10000 raster (representing 24 Gb) were retrieved and further processed in GIS to extract over 3209 polygons (representing 0.5 Gb) that represented the water area of each acquisition date in each of the reservoirs. The work done led us to extract the time series presented in the following sections.

4.4 Statistical parameters related to data validation:

To assess the level of performance of the developed RS-based monitoring approach, the following statistical parameters (given in Table 4-1) were used to compare the RS results against ANBT data:

- NSE (Nash-Sutcliffe efficiency);
- PBIAS (percentage bias);
- RSR (standard deviation ratio RMSE);

Table 4-1: The statistical parameters used(Moriasi, Arnold, Van Liew, Bingner, Harmel, & Veith, 2007)

Parameter	Expression	Level of performance			
		Very good	Good	Satisfactory	Unsatisfactory
NSE	$1 - \frac{\sum(Y_{obs} - Y_{sim})^2}{\sum(Y_{obs} - Y_{obs}^{moy})^2}$	$0{,}75 < NSE \leq 1$	$0{,}65 < NSE \leq 0{,}75$	$0{,}5 < NSE \leq 0{,}65$	$NSE \leq 0{,}5$
PBIAS	$100.\frac{\sum(Y_{obs} - Y_{sim})}{\sum(Y_{obs})}$	$PBIAS < \pm 10$	$\pm 10 \leq PBIAS < \pm 15$	$\pm 15 \leq PBIAS < \pm 25$	$PBIAS \geq \pm 25$
RSR	$\sqrt{\frac{\sum(Y_{obs} - Y_{sim})^2}{\sum(Y_{obs} - Y_{obs}^{moy})^2}}$	$0 \leq RSR \leq 0{,}5$	$0{,}5 < RSR \leq 0{,}6$	$0{,}6 < RSR \leq 0{,}7$	$RSR > 0{,}7$

Where: Y_{obs}: Observed results used for validation, Y_{sim}: Our simulated results and Y_{obs}^{moy}: Average of the observed results.

4.5 Image Processing Results

Figure 4-1 shows the image processing from original SAR images to water area polygon. The figure represents an original ascending image captured on the 02/04/2019 of R7 (Kef Eddir), which was then smoothed using the noise reduction filter and classified using GIS to extract the water area polygon by vectorizing the classified raster image.

a- Original image **b- Smoothed image** **c- Classified image** **d- Water area polygon**

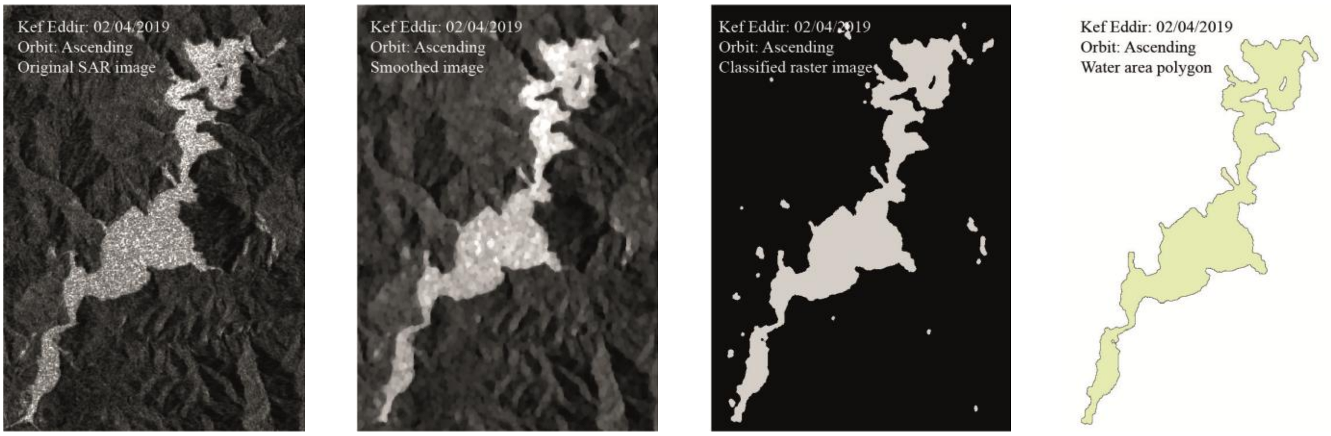


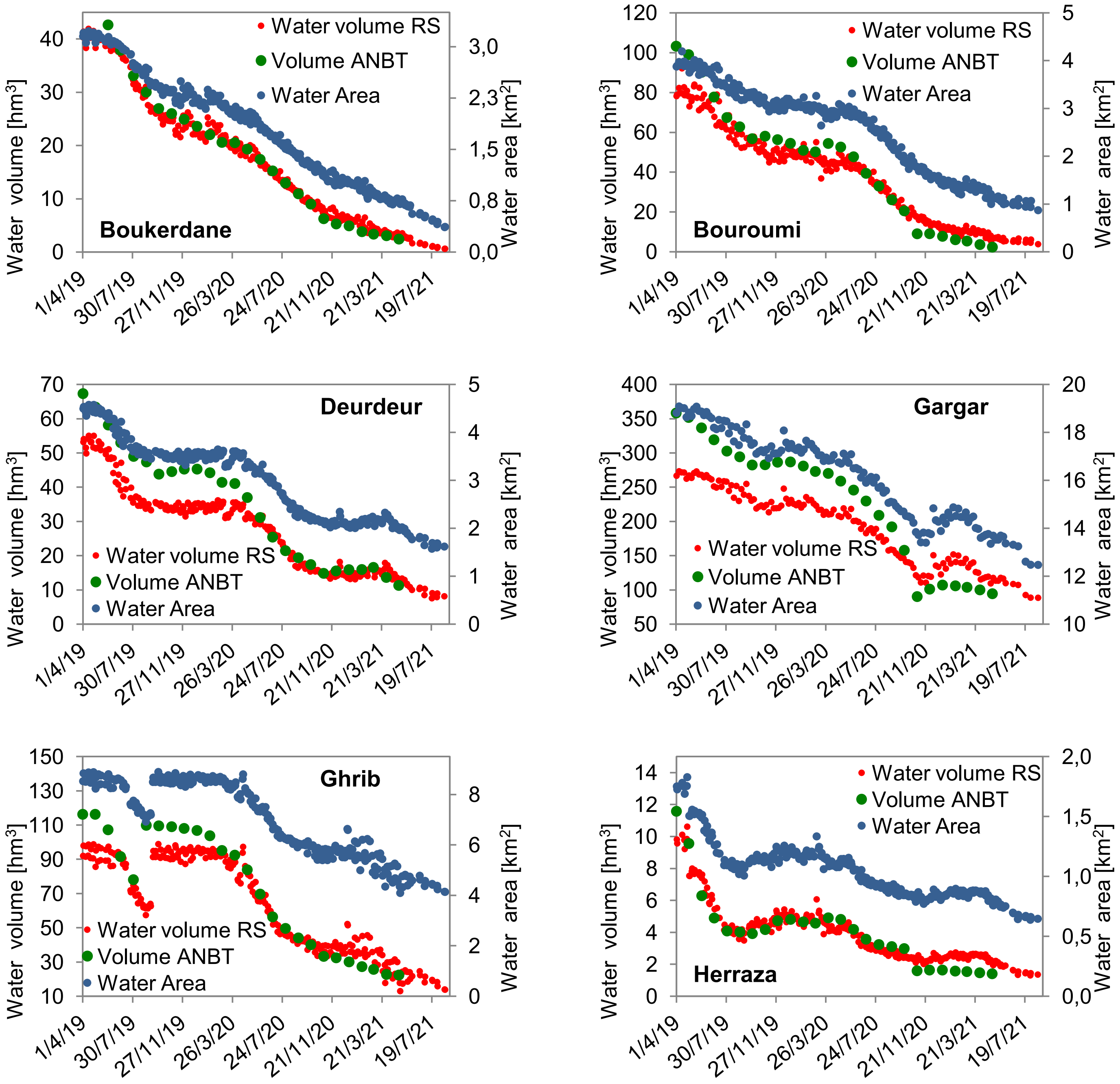
Figure 4-1 : Image processing during the different stages of the approach of R7 (Kef Eddir) on 02/04/2019

4.6 Obtained Time Series:

This section presents the obtained time series of the quantitative parameters (area of the water surface, water level and water volume in each dam reservoir). It should be noted that the results related to R13 (Taksebt) will be presented separately in the next sub-section since its capacity curve was missing in this study.

4.6.1 Water volume and area variation curves:

The temporal variations of water area and volume of the reservoir R1 to R12, estimated by the proposed RS-based approach and corresponding field data provide by ANBT are presented in Figure 4-2.



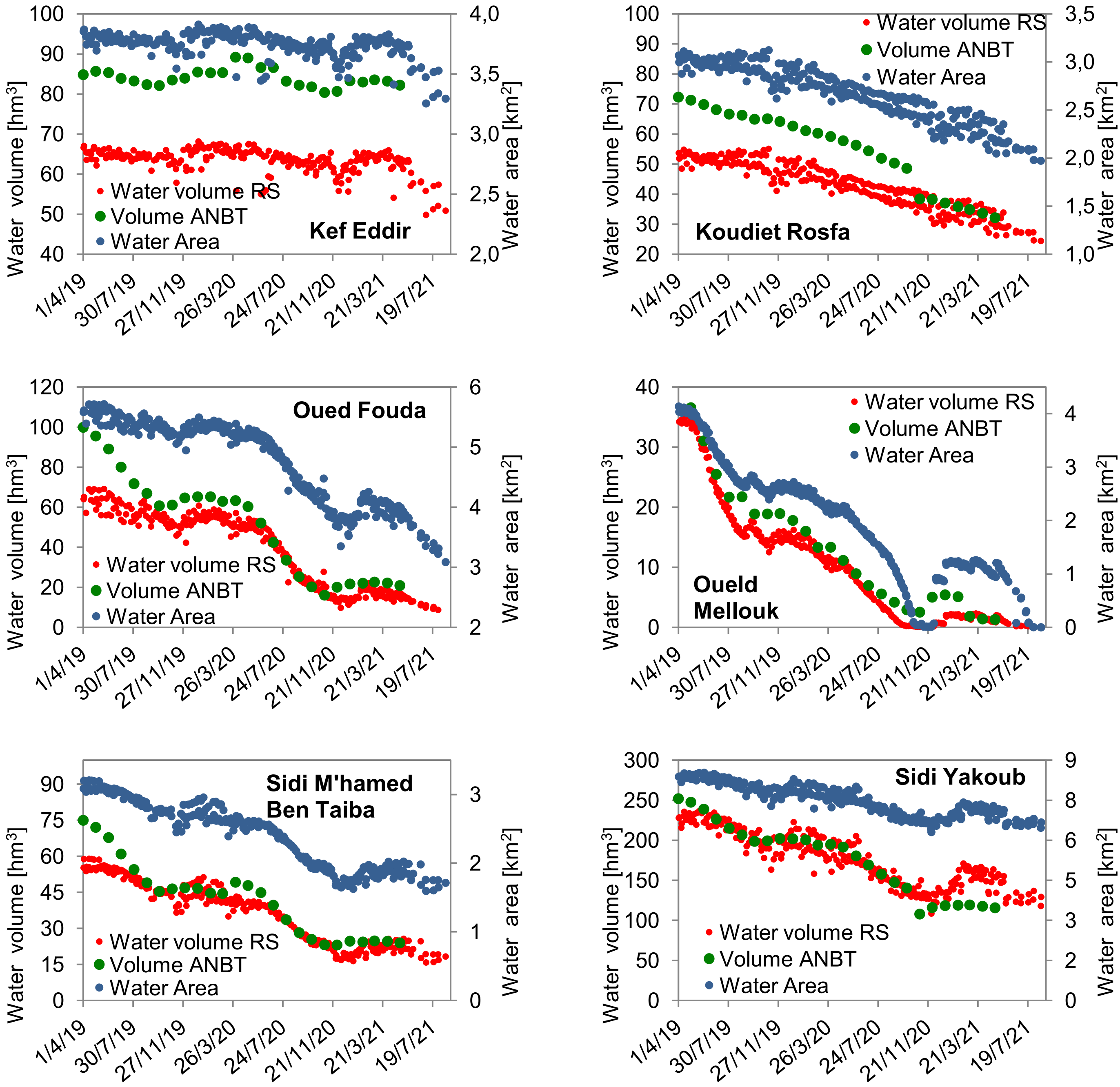


Figure 4-2: Time series of the water area and volume variation in the reservoirs R1 to R12 (where red and blue dots are the results of the RS-based approach, green dots are ANBT data)

It can be noticed that for all 12 reservoirs, both surface and volume time series (Figure 4-2) show similar decreasing trends with seasonal fluctuations. This was to be expected considering the direct proportionality relationship between these two parameters (since the values of water volume were computed from the water areas in the reservoirs using capacity curves). The general decreasing trend is in agreement with the draught observed during the studied period, and so are the seasonal fluctuations showing increased in the water surface and volume during raining seasons as well as the decreases outside these periods characterized by high water losses and low to no recharge.

Table 4-2 and

Table 4-3 summarize the minimum and maxim values recorded during the studied period of water area and volume in the reservoirs R1-R12 in absolute form and relative form (reported to the surface and volumes corresponding to the normal level of the reservoir).

Table 4-2 : Absolute and relative minimum and maximum values of water area in each dam during the years 2019 to 2021.

ID	Name	RS data		Data that corresponds to NNR		
		Absolute Water Area km^2		Water Area km^2	Relative Water Area [%]	
		Max	Min		Max	Min
R1	Boukerdane	3,22	0,36	4,64	69,4%	7,8%
R2	Bouroumi	4,19	0,87	5,90	71,1%	14,7%
R3	Deurdeur	4,57	1,57	5,42	84,4%	29,0%
R4	Gargar	19,08	12,47	20,33	93,9%	61,4%
R5	Ghrib	8,89	4,10	10,66	83,4%	38,4%
R6	Herraza	1,83	0,64	2,29	80,0%	27,9%
R8	Koudiet rosfa	3,12	1,97	3,67	85,1%	53,7%
R9	Oued foudda	5,71	3,09	6,49	88,0%	47,5%
R10	Oueld mellouk	4,14	0,00	5,24	78,9%	0,0%
R11	Sidi m'hamed ben taiba	3,21	1,60	3,53	90,9%	45,2%
R12	Sidi yakoub	8,53	6,31	8,78	97,1%	71,8%

Table 4-3: Absolute and relative minimum and maximum values of water volume in each dam during the years 2019 to 2021.

ID	Name	RS data		Data that corresponds to NNR		
		Absolute Water volume hm^3		Water volume hm^3	Relative Water volume [%]	
		Max	Min		Max	Min
R1	Boukerdane	41,90	0,60	68,06	61,6%	0,9%
R2	Bouroumi	92,11	3,77	179,88	51,2%	2,1%
R3	Deurdeur	55,01	7,56	94,01	58,5%	8,0%
R4	Gargar	273,21	88,47	347,15	78,7%	25,5%
R5	Ghrib	98,92	13,02	115,32	85,8%	11,3%
R6	Herraza	10,62	1,31	30,67	34,6%	4,3%
R7	Kef eddir	68,11	49,80	126,30	53,9%	39,4%
R8	Koudiet rosfa	55,05	24,40	65,71	83,8%	37,1%
R9	Oued foudda	69,08	7,75	102,85	67,2%	7,5%
R10	Oueld mellouk	35,80	0,00	51,76	69,2%	0,0%
R11	Sidi m'hamed ben taiba	58,98	15,84	70,22	84,0%	22,6%
R12	Sidi yakoub	236,95	108,60	252,58	93,8%	43,0%

- **Presentation of the results obtained for R13:**

Due to lack of capacity curve of this reservoir, its results are presented in terms of SR-based water area time series. Figure 4-3 shows the water area time series during the years 2019 to 2021. The change in the water surface area in this reservoir show a similar trend as above (general decrease indicating a draught during the period with seasonal fluctuations). Table 4-4 illustrates the absolute and relative minimum and maximum values of this parameter according to the NNR of the reservoir.

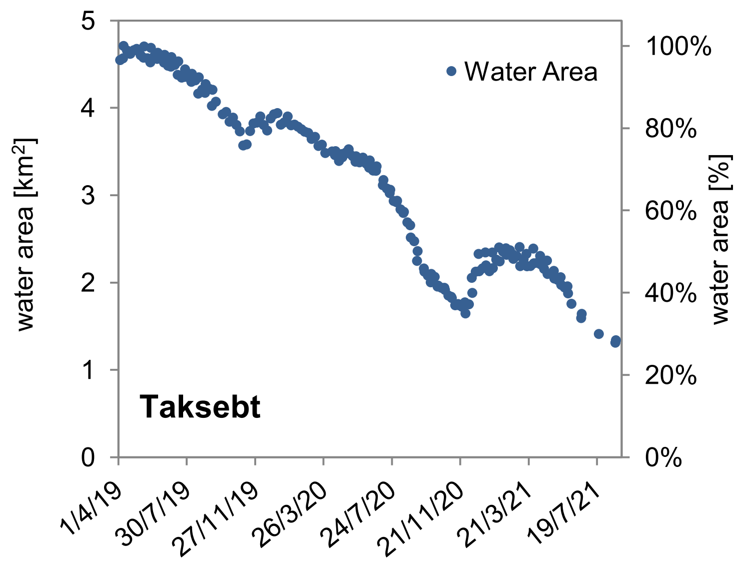


Figure 4-3: Time series of the water area variation in the reservoir R13 (where blue dots are the results of the RS-based approach)

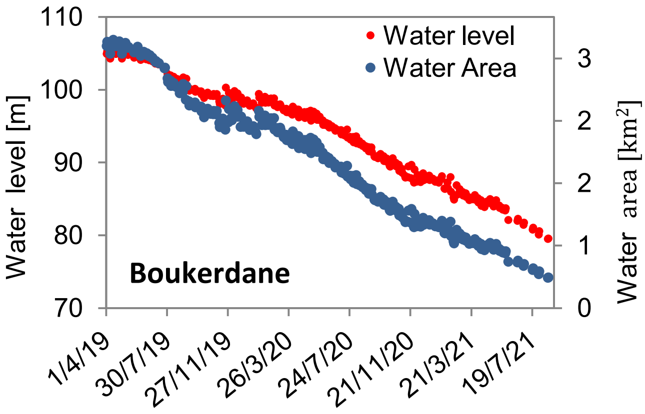
Table 4-4: Absolute and relative minimum and maximum values of water area in Taksebt during the years 2019 to 2021.

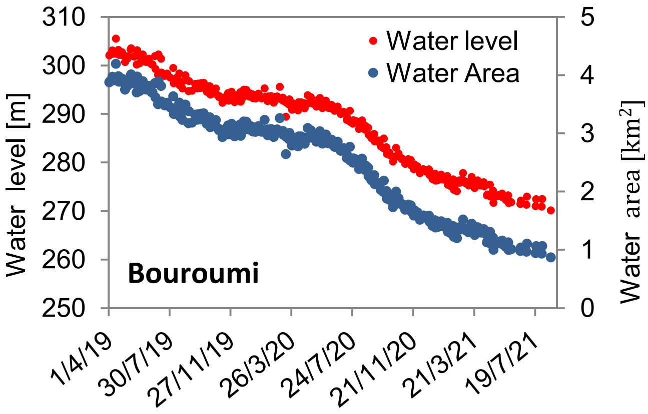
ID	Name	RS data		Data that corresponds to NNR		
		Absolute Water Area km^2		Water Area km^2	Relative Water Area [%]	
		Max	Min		Max	Min
R13	Taksebt	4,71	1,31	5,28	101,4%	24,8%

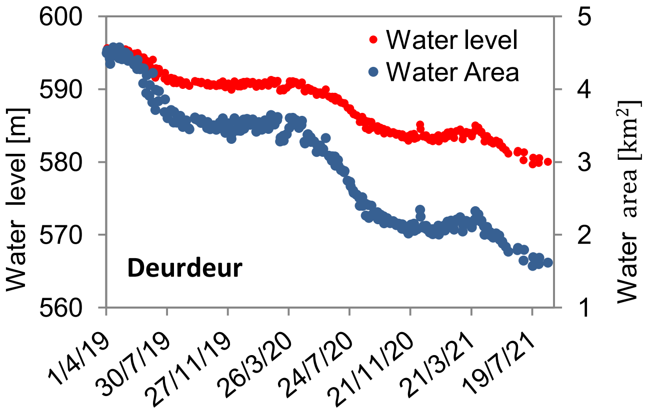
4.6.2 Water level and surface variation curves:

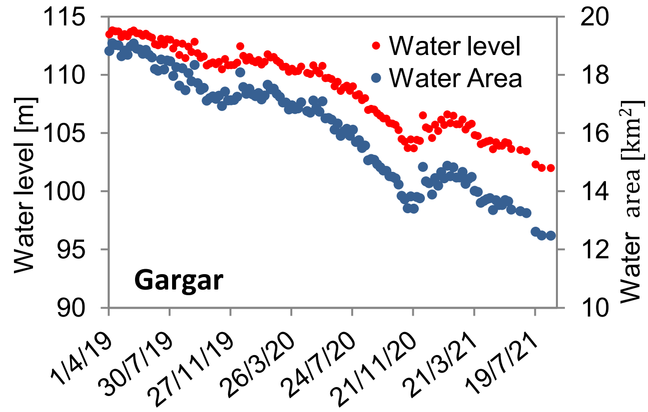
The temporal variations of water area and level of the reservoir R1 to R12, estimated by the proposed RS-based approach are presented in

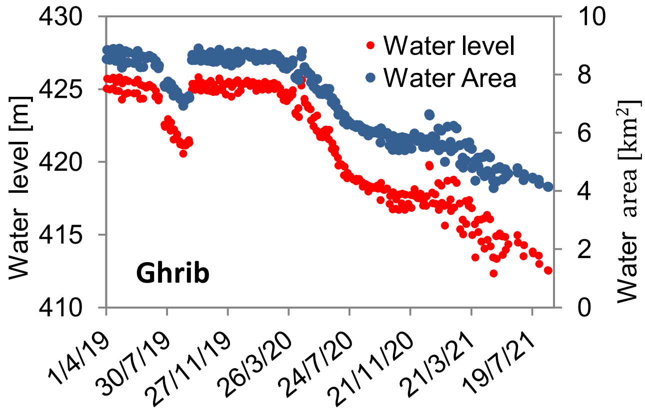
Figure 4-4.

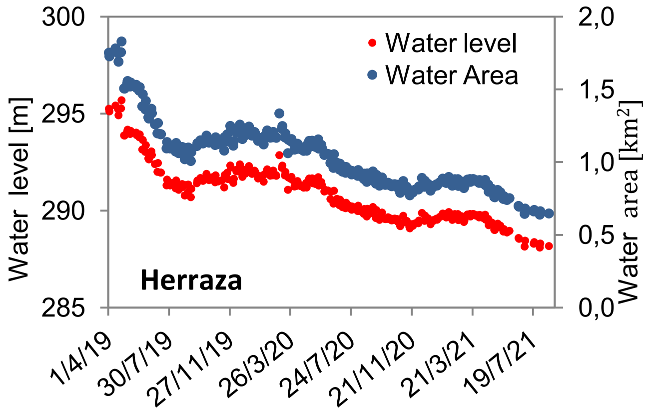

Boukerdane
Water level
Water Area
Water level [m]
Water area [km²]
110
100
90
80
70
3
2
1
0
1/4/19
30/7/19
27/11/19
26/3/20
24/7/20
21/11/20
21/3/21
19/7/21

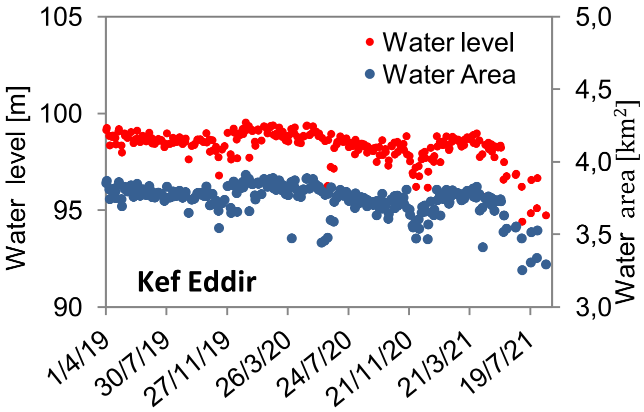

Bouroumi
Water level
Water Area
Water level [m]
Water area [km²]
310
300
290
280
270
260
250
5
4
3
2
1
0
1/4/19
30/7/19
27/11/19
26/3/20
24/7/20
21/11/20
21/3/21
19/7/21

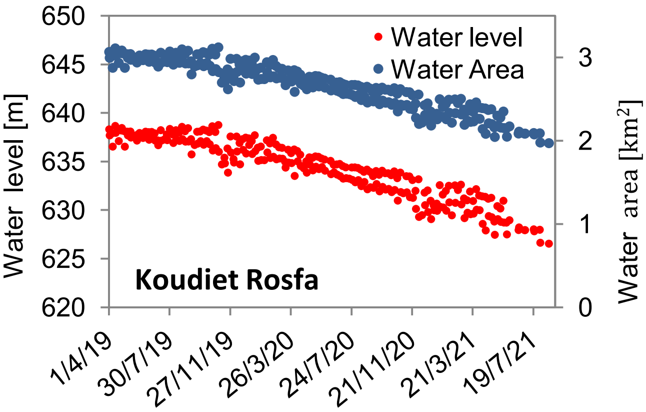

Deurdeur
Water level
Water Area
Water level [m]
Water area [km²]
600
590
580
570
560
5
4
3
2
1
1/4/19
30/7/19
27/11/19
26/3/20
24/7/20
21/11/20
21/3/21
19/7/21


Gargar
Water level
Water Area
Water level [m]
Water area [km²]
115
110
105
100
95
90
20
18
16
14
12
10
1/4/19
30/7/19
27/11/19
26/3/20
24/7/20
21/11/20
21/3/21
19/7/21


Ghrib
Water level
Water Area
Water level [m]
Water area [km²]
430
425
420
415
410
10
8
6
4
2
0
1/4/19
30/7/19
27/11/19
26/3/20
24/7/20
21/11/20
21/3/21
19/7/21


Herraza
Water level
Water Area
Water level [m]
Water area [km²]
300
295
290
285
2,0
1,5
1,0
0,5
0,0
1/4/19
30/7/19
27/11/19
26/3/20
24/7/20
21/11/20
21/3/21
19/7/21


Kef Eddir
Water level
Water Area
Water level [m]
Water area [km²]
105
100
95
90
5,0
4,5
4,0
3,5
3,0
1/4/19
30/7/19
27/11/19
26/3/20
24/7/20
21/11/20
21/3/21
19/7/21


Koudiet Rosfa
Water level
Water Area
Water level [m]
Water area [km²]
650
645
640
635
630
625
620
3
2
1
0
1/4/19
30/7/19
27/11/19
26/3/20
24/7/20
21/11/20
21/3/21
19/7/21

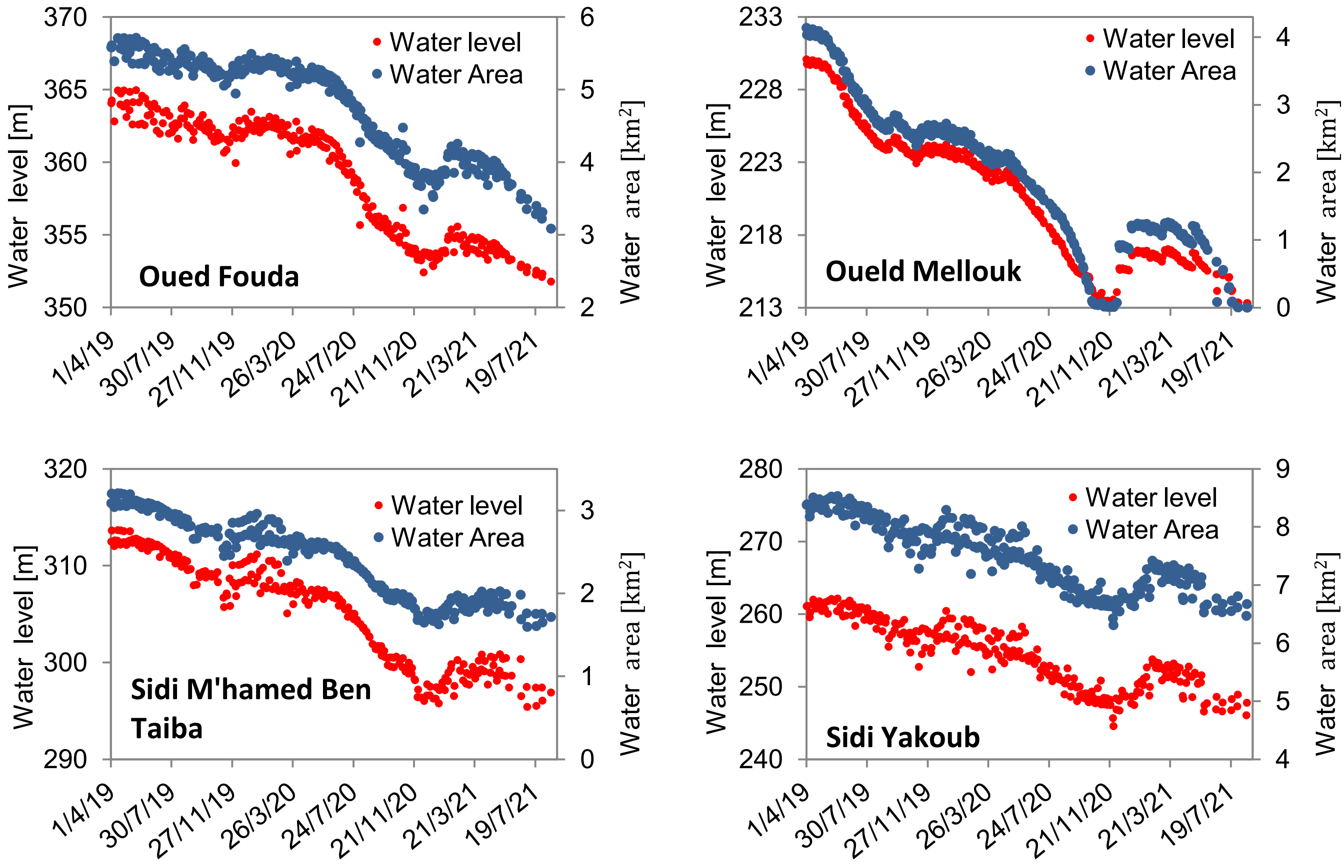


Figure 4-4: Time series of the water area and level variation in the reservoirs R1 to R12 (where red and blue dots are the results of the RS-based approach).

It can be noticed that for all 12 reservoirs, both water surface and water level time series (Figure 4-4) show similar decreasing trends with seasonal fluctuations. This was to be expected considering the direct proportionality relationship between these two parameters (since the values water level were computed from the water areas in the reservoirs using capacity curves). The general decreasing trend is in agreement with the draught observed during the studied period, and so are the seasonal fluctuations showing increased in the water surface and volume during raining seasons as well as the decreases outside these periods characterized by high water losses and low to no recharge.

Table 4-5 summarize the minimum and maxim values recorded during the studied period of water area and volume in the reservoirs R1-R12 in absolute form and relative form (reported to the surface and volumes corresponding to the normal level of the reservoir).

Table 4-5: Absolute and relative minimum and maximum values of water level in each dam during the years 2019 to 2021.

ID	Name	RS data		Data that corresponds to NNR		
		Water level m		Water level m	water level comparaison by percentage %	
		Max	Min		Max	Min
R1	Boukerdane	105,42	79,48	119,50	88,2%	66,5%
R2	Bouroumi	305,50	270,10	323,00	94,6%	83,6%
R3	Deurdeur	595,84	579,68	605,00	98,5%	95,8%
R4	Gargar	113,81	101,99	118,00	96,4%	86,4%
R5	Ghrib	425,81	412,33	427,50	99,6%	96,5%
R6	Herraza	295,69	288,09	313,00	94,5%	92,0%
R7	Kef eddir	99,53	94,41	111,25	89,5%	84,9%
R8	Koudiet rosfa	638,77	626,56	642,00	99,5%	97,6%
R9	Oued foudda	364,97	351,78	370,50	98,5%	94,9%
R10	Oueld mellouk	230,07	213,30	243,00	94,7%	87,8%
R11	Sidi m'hamed ben taiba	313,67	295,40	317,00	98,9%	93,2%
R12	Sidi yakoub	262,14	244,55	264,00	99,3%	92,6%

4.7 Discussion:

Based on the overall analysis of the time series, it can be noted that for all the reservoirs studied, and considering that the values of the water area, level and volume are connected, the resulting curves in a given reservoir have the same tendency.

During the studied time period, it is observed that the three (03) time series extracted, water area, level and volume tends to decrease from April 2019 until August 2021, following a linear pattern in general with exceptions that can be observed in some reservoirs.

In terms of the most affected reservoirs within the study zone:

- As the results indicated, **R10** (Oued Mellouk) was the most affected by drought, we first notice that from April 2019 to October 2020 the parameters studies were only decreasing reaching a zero value. During the next months till March 2021 these parameters increases and it can be explained by the seasonal variation mentioned before. However, all three monitoring parameters decrease again reaching 0% of its capacity during the period March 2021 to August 2021.
- **R1** (Boukerdane) and **R2** (Bouroumi) were also badly affected during this period, the water volume in these reservoirs reached 0,9% for R1 and 2,1% for R2 from their normal capacity.
- **R6** (Herraza), **R9** (Oued Fouda) and **R3** (Deurdeur) by August 2021 they reached 4,3%, 7,5% and 8% or their normal capacity respectively.

For the rest of the reservoirs, as it is shown in the Table 4-2,

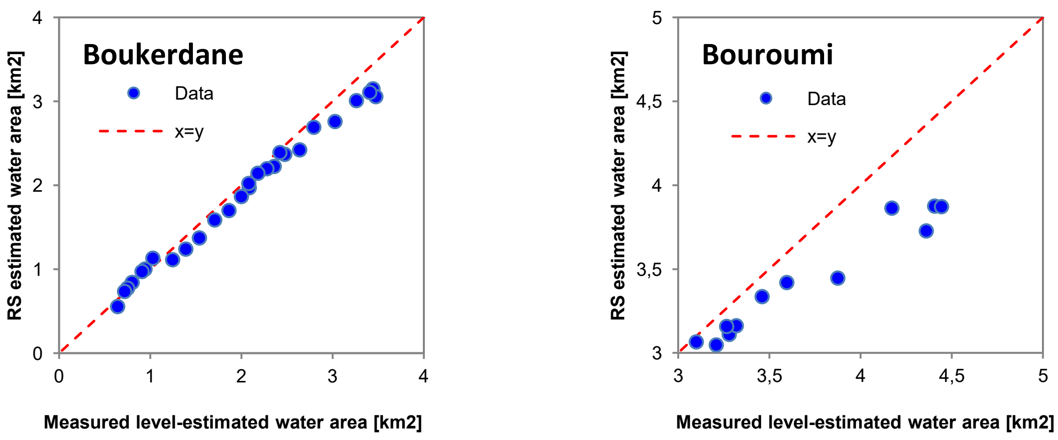
- Table 4-3, Table 4-5, their capacity by August 2021 reached values ranging from 10 % to almost 50% of their normal capacity.
- As for **R13** (Taksebt), according to the results we obtained, it's shown that it reached 24,8% of its normal capacity.

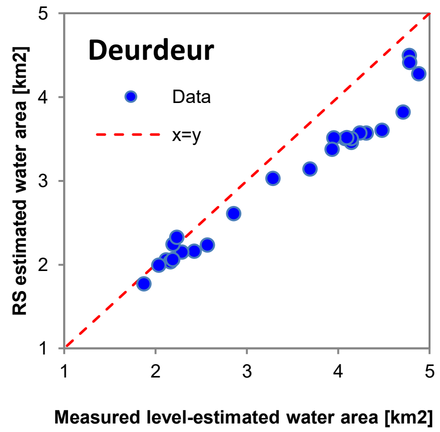
In terms of the noise in the times series, it should be noted that form date to date, there was the used of images with different acquisition orbits (ascending and descending). This is well known to produced different shadow areas within the images which magnitude will depend on the orientation of the shadow-causing features (topography); affecting therefore the computed water areas and associated water levels and volumes. This effect is particularly visible for **R8** (Koudiat Rosfa) presenting an almost complete separation between the ascending and descending times series (Figure 4-2 and

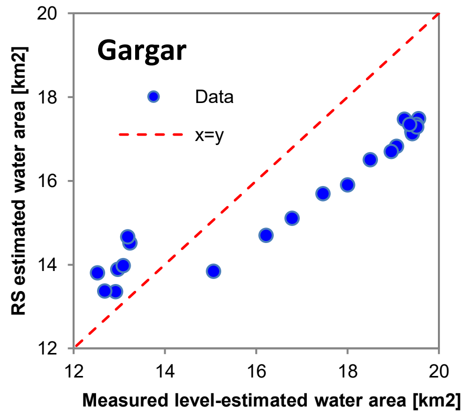
Figure 4-4)

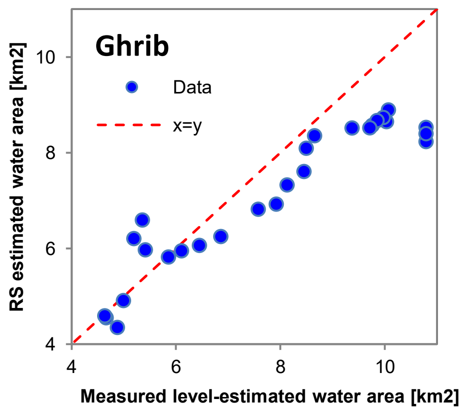
4.8 Results' validation:

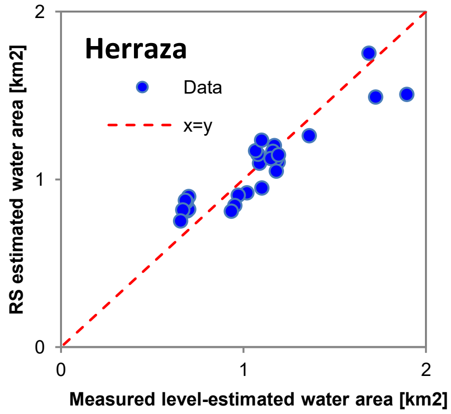
To validate our results, a comparison in terms of water area variations was made between the data estimated by the developed RS-based approach and those provided by the ANBT. The Q-Q curves resulting from this comparison are given Figure 4-5. Here it can be seen that for most reservoir, the RS estimates are in a good agreement with the ANBT data with some exceptions.

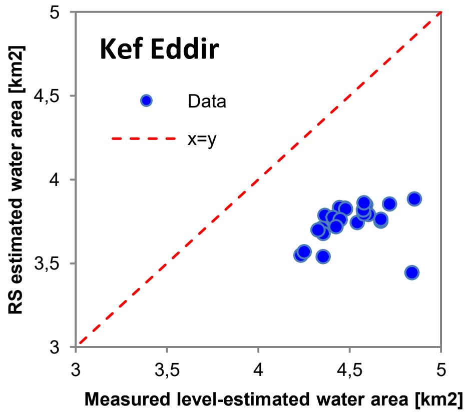


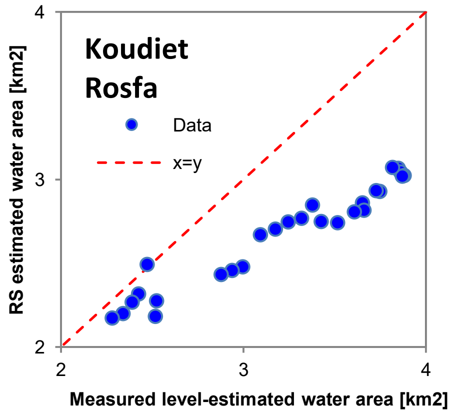

Deurdeur
Data
x=y
RS estimated water area [km2]
Measured level-estimated water area [km2]


Gargar
Data
x=y
RS estimated water area [km2]
Measured level-estimated water area [km2]


Ghrib
Data
x=y
RS estimated water area [km2]
Measured level-estimated water area [km2]


Herraza
Data
x=y
RS estimated water area [km2]
Measured level-estimated water area [km2]


Kef Eddir
Data
x=y
RS estimated water area [km2]
Measured level-estimated water area [km2]


Koudiet
Rosfa
Data
x=y
RS estimated water area [km2]
Measured level-estimated water area [km2]

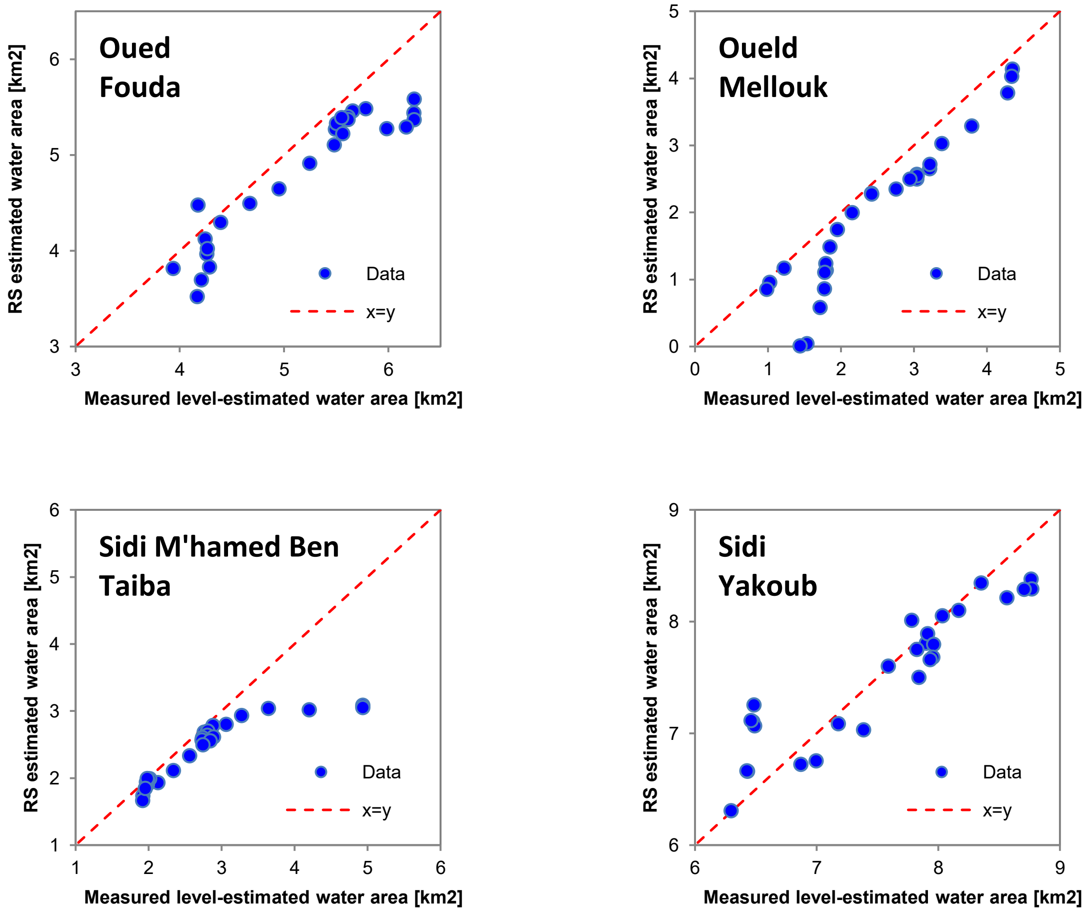


Figure 4-5: Comparison between the water area estimated from the approach followed and the data provided by the ANBT.

For a more quantifiable assessment of this above comparison, the statistical parameters for validating our results by those provided by the ANBT are presented in Table 4-6.

Table 4-6: Statistical parameters for the validation of our results.

ID	Reservoir	Statistical parameters		
		NSE	PBIAS	RSR
R1	Boukerdane	0,965	5,690	0,186
R2	Bouroumi	0,924	4,213	0,276
R3	Deurdeur	0,781	11,483	0,468
R4	Gargar	0,113	-92,819	0,942
R5	Ghrib	0,721	8,841	0,529
R6	Herraza	0,811	0,558	0,435
R7	Kef Eddir	-22,972	16,763	4,896

R8	Koudiet Rosfa	-0,222	16,769	1,105
R9	Oued Fouda	0,668	6,725	0,576
R10	Oueld Mellouk	0,606	20,025	0,628
R11	Simi M'Ahmed Ben Taiba	0,483	12,206	0,719
R12	Sidi Yakoub	0,819	0,212	0,426

Very good Good Satisfactory Unsatisfactory

Based on the above statistical parameters calculated for each reservoir, we note that the water area results obtained from the approach we followed show mostly a good correlation with those of the ANBT for eight (08) of the reservoirs, with small differences in accuracy. However we notice that the four (04) reservoirs left (R4, R7, R8, and R11) has a lower level of performance than the rest of the dams. It is suspected that there are differences related the used capacity curves as well as the water area estimated by ANBT and the way these areas were estimated (the monthly). It must be noted that the RS-based approach provide data that are not always in sync with the last date of the moth (but for a well known date) and differences in the monitoring date around the end of a given month (that are not precisely specified in ANBT data) can explain the observed differences.

We also suggest that the results obtained indicate that this difference between our values and those of ANBT is due to the fact that we do not have enough information on how the data collection process was carried out by the agency, or what factors were taken into consideration, for instance we are unaware of the rate of siltation in the reservoirs. All of these elements make it difficult to reach a final conclusion on the state of the reservoirs and the accuracy of the data used to validate our results.

However, it should be kept in mind that the RS-based water surface area data are direct observations presenting a given spatial resolution and are to be viewed as reliable indicators of temporal variations. Moreover, the RS data present a much higher temporal resolution than the available ANBT data (5 times higher). An aspect that further render this approach a more attractive complementary not to say an alternative data source.

4.9 Water area variation from 2016 to 2021:

Figure 4-6 represents the time series of the water area variation in the most affected reservoirs R10, R1, R6, R9, R3 and R12 from 07/12/2016 to 20/08/2021. The data comes for fussing the results of the current project with the results of a previous project (Benantar & Kharoubi, 2019)The previous work was conducted with a similar RS -based approach with a lower temporal resolution of 30 days (against a 6 days temporal resolution). In terms of trends, it can be noted that the period Dec. 2016 -Apr. 2019 shows mainly seasonal fluctuation around a mostly horizontal base line. While the period Apr. 2019- Aug. 2021 shows a clear decreasing trend indicating an important draught. Aspect clearly felt within the region especially during this summer where the water supply regime to the population needed to be reviewed to economize the water resources.

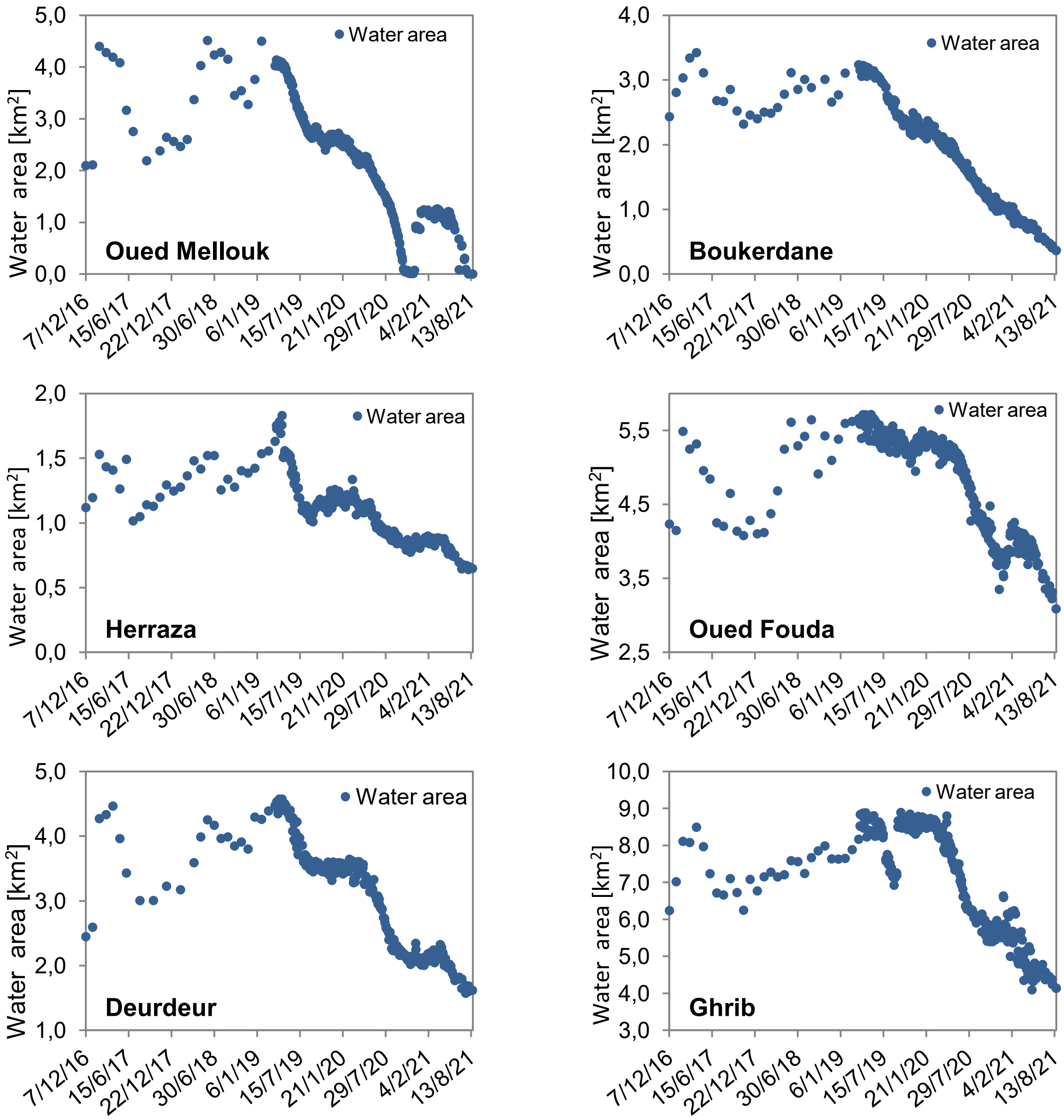


Figure 4-6: Time series of the water area variation in the reservoirs R10, R1, R6, R9,R3 and R12 (where red and blue dots are the water areas in the reservoirs from 2016 to 2021).

4.10 Conclusion:

The proposed approach allowed us to produce high quality quantitative assessment of the behavior of the calculated parameters (the change in water area, level and volume), which in turn supports our assumptions to identify the different problems of water resource management.

5 General conclusion:

Monitoring surface water variation in reservoirs is an undeniable necessity in order to reach and assure a good water resources management. Algeria, being one of the many countries encountering water stress, in many regions, makes it is necessary to quantitatively assess the most influential parameters on the changes occurring on this resource.

The present study aimed to develop and test an approach based on the use of remote sensing data to realize a large-scale monitoring of several large reservoirs. Here, the monitoring was done by analyzing the following parameters: water area, water level, and the variation of the volume of water stored in selected dam reservoirs, based on the information extracted from the SAR images. The obtained RS-based results were compared with filed data for validation.

The results of our study allowed us to understand and reliably quantify the evolution of the studied parameters during a period of two (02) years, which enables us to have an idea evolution of the available surface water resources within the studied zone (as for all 12 reservoirs R1-R12 the water storage went from 1043,53 hm^3 in Apr. 2019 to 346,81 hm^3 by Aug. 2021 representing a 67% decrease) and support the management of these dams, and the problems that occurred in them, such as the problems of siltation, or siltification, change in the topography of the land, which were highlighted as possible consequences of the great variation in the water volume variations within the different reservoirs.

This study has demonstrated the reliability and utility of remote sensing in the integrated surface water resources management. This technique has allowed us to realize a monitoring on a large scale, with minimal expenses.

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APPENDIX 1
SAR images acquisition schedule

Acquisition dates and captured images							
DATE	R1,R2,R3,R5,R6,R7,R7,R8,R9,R10,R11,R12		R4		DATE	R13	
	Ascending	descending	Ascending	descending		Ascending	descending
02/04/2019	X		X	X	03/04/2019		
03/04/2019		X			04/04/2019	X	X
08/04/2019	X		X	X	09/04/2019	X	
09/04/2019		X			10/04/2019		X
14/04/2019	X		X	X	15/04/2019		
15/04/2019		X			16/04/2019	X	X
20/04/2019	X		X	X	21/04/2019	X	
21/04/2019		X			22/04/2019		X
26/04/2019	X		X	X	27/04/2019		
27/04/2019		X			28/04/2019	X	X
02/05/2019	X		X	X	03/05/2019	X	
03/05/2019		X			04/05/2019		X
08/05/2019	X		X	X	09/05/2019		
09/05/2019		X			10/05/2019	X	X
14/05/2019	X		X	X	15/05/2019	X	
15/05/2019		X			16/05/2019		X
20/05/2019	X		X	X	21/05/2019		
21/05/2019		X			22/05/2019	X	X
26/05/2019	X		X	X	27/05/2019	X	
27/05/2019		X			28/05/2019		X
01/06/2019	X		X	X	02/06/2019		
02/06/2019		X			03/06/2019	X	X
07/06/2019	X		X	X	08/06/2019	X	
08/06/2019		X			09/06/2019		X
13/06/2019	X		X	X	14/06/2019		
14/06/2019		X			15/06/2019	X	X
19/06/2019	X		X	X	20/06/2019	X	
20/06/2019		X			21/06/2019		X
25/06/2019	X		X	X	26/06/2019		
26/06/2019		X			27/06/2019	X	X

01/07/2019	X		X	X	02/07/2019	X	
02/07/2019		X			03/07/2019		X
07/07/2019	X		X	X	08/07/2019		
08/07/2019		X			09/07/2019	X	X
13/07/2019	X		X	X	14/07/2019	X	
14/07/2019		X			15/07/2019		X
19/07/2019	X		X	X	20/07/2019		
20/07/2019		X			21/07/2019	X	X
25/07/2019	X		X	X	26/07/2019	X	
26/07/2019		X			27/07/2019		X
31/07/2019	X		X	X	01/08/2019		
01/08/2019		X			02/08/2019	X	X
06/08/2019	X		X	X	07/08/2019	X	
07/08/2019		X			08/08/2019		X
12/08/2019	X		X	X	13/08/2019		
13/08/2019		X			14/08/2019	X	X
18/08/2019	X		X	X	19/08/2019	X	
19/08/2019		X			20/08/2019		X
24/08/2019	X		X	X	25/08/2019		
25/08/2019		X			26/08/2019	X	X
30/08/2019	X		X	X	31/08/2019	X	
31/08/2019		X			01/09/2019		X
05/09/2019	X		X	X	06/09/2019		
06/09/2019		X			07/09/2019	X	X
11/09/2019	X		X	X	12/09/2019	X	
12/09/2019		X			13/09/2019		X
17/09/2019	X		X	X	18/09/2019		
18/09/2019		X			19/09/2019	X	X
23/09/2019	X		X	X	24/09/2019	X	
24/09/2019		X			25/09/2019		X
29/09/2019	X		X	X	30/09/2019		
30/09/2019		X			01/10/2019	X	X
05/10/2019	X		X	X	06/10/2019	X	

06/10/2019		X			07/10/2019		X
11/10/2019	X		X	X	12/10/2019		
12/10/2019		X			13/10/2019	X	X
17/10/2019	X		X	X	18/10/2019	X	
18/10/2019		X			19/10/2019		X
23/10/2019	X		X	X	24/10/2019		
24/10/2019		X			25/10/2019	X	X
29/10/2019	X		X	X	30/10/2019	X	
30/10/2019		X			31/10/2019		X
04/11/2019	X		X	X	05/11/2019		
05/11/2019		X			06/11/2019	X	X
10/11/2019	X		X	X	11/11/2019	X	
11/11/2019		X			12/11/2019		X
16/11/2019	X		X	X	17/11/2019		
17/11/2019		X			18/11/2019	X	X
22/11/2019	X		X	X	23/11/2019	X	
23/11/2019		X			24/11/2019		X
28/11/2019	X		X	X	29/11/2019		
29/11/2019		X			30/11/2019	X	X
04/12/2019	X		X	X	05/12/2019	X	
05/12/2019		X			06/12/2019		X
10/12/2019	X		X	X	11/12/2019		
11/12/2019		X			12/12/2019	X	X
16/12/2019	X		X	X	17/12/2019	X	
17/12/2019		X			18/12/2019		X
22/12/2019	X		X	X	23/12/2019		
23/12/2019		X			24/12/2019	X	X
28/12/2019	X		X	X	29/12/2019	X	
29/12/2019		X			30/12/2019		X
03/01/2020	X		X	X	04/01/2020		
04/01/2020		X			05/01/2020	X	X
09/01/2020	X		X	X	10/01/2020	X	
10/01/2020		X			11/01/2020		X

15/01/2020	X		X	X	16/01/2020		
16/01/2020		X			17/01/2020	X	X
21/01/2020	X		X	X	22/01/2020	X	
22/01/2020		X			23/01/2020		X
27/01/2020	X		X	X	28/01/2020		
28/01/2020		X			29/01/2020	X	X
02/02/2020	X		X	X	03/02/2020	X	
03/02/2020		X			04/02/2020		X
08/02/2020	X		X	X	09/02/2020		
09/02/2020		X			10/02/2020	X	X
14/02/2020	X		X	X	15/02/2020	X	
15/02/2020		X			16/02/2020		X
20/02/2020	X		X	X	21/02/2020		
21/02/2020		X			22/02/2020	X	X
26/02/2020	X		X	X	27/02/2020	X	
27/02/2020		X			28/02/2020		X
03/03/2020	X		X	X	04/03/2020		
04/03/2020		X			05/03/2020	X	X
09/03/2020	X		X	X	10/03/2020	X	
10/03/2020		X			11/03/2020		X
15/03/2020	X		X	X	16/03/2020		
16/03/2020		X			17/03/2020	X	X
21/03/2020	X		X	X	22/03/2020	X	
22/03/2020		X			23/03/2020		X
27/03/2020	X		X	X	28/03/2020		
28/03/2020		X			29/03/2020	X	X
02/04/2020	X		X	X	03/04/2020	X	
03/04/2020		X			04/04/2020		X
08/04/2020	X		X	X	09/04/2020		
09/04/2020		X			10/04/2020	X	X
14/04/2020	X		X	X	15/04/2020	X	
15/04/2020		X			16/04/2020		X
20/04/2020	X		X	X	21/04/2020		

21/04/2020		X			22/04/2020	X	X
26/04/2020	X		X	X	27/04/2020	X	
27/04/2020		X			28/04/2020		X
02/05/2020	X		X	X	03/05/2020		
03/05/2020		X			04/05/2020	X	X
08/05/2020	X		X	X	09/05/2020	X	
09/05/2020		X			10/05/2020		X
14/05/2020	X		X	X	15/05/2020		
15/05/2020		X			16/05/2020	X	X
20/05/2020	X		X	X	21/05/2020	X	
21/05/2020		X			22/05/2020		X
26/05/2020	X		X	X	27/05/2020		
27/05/2020		X			28/05/2020	X	X
01/06/2020	X		X	X	02/06/2020	X	
02/06/2020		X			03/06/2020		X
07/06/2020	X		X	X	08/06/2020		
08/06/2020		X			09/06/2020	X	X
13/06/2020	X		X	X	14/06/2020	X	
14/06/2020		X			15/06/2020		X
19/06/2020	X		X	X	20/06/2020		
20/06/2020		X			21/06/2020	X	X
25/06/2020	X		X	X	26/06/2020	X	
26/06/2020		X			27/06/2020		X
01/07/2020	X		X	X	02/07/2020		
02/07/2020		X			03/07/2020	X	X
07/07/2020	X		X	X	08/07/2020	X	
08/07/2020		X			09/07/2020		X
13/07/2020	X		X	X	14/07/2020		
14/07/2020		X			15/07/2020	X	X
19/07/2020	X		X	X	20/07/2020	X	
20/07/2020		X			21/07/2020		X
25/07/2020	X		X	X	26/07/2020		
26/07/2020		X			27/07/2020	X	X

31/07/2020	X		X	X	01/08/2020	X	
01/08/2020		X			02/08/2020		X
06/08/2020	X		X	X	07/08/2020		
07/08/2020		X			08/08/2020	X	X
12/08/2020	X		X	X	13/08/2020	X	
13/08/2020		X			14/08/2020		X
18/08/2020	X		X	X	19/08/2020		
19/08/2020		X			20/08/2020	X	X
24/08/2020	X		X	X	25/08/2020	X	
25/08/2020		X			26/08/2020		X
30/08/2020	X		X	X	31/08/2020		
31/08/2020		X			01/09/2020	X	X
05/09/2020	X		X	X	06/09/2020	X	
06/09/2020		X			07/09/2020		X
11/09/2020	X		X	X	12/09/2020		
12/09/2020		X			13/09/2020	X	X
17/09/2020	X		X	X	18/09/2020	X	
18/09/2020		X			19/09/2020		X
23/09/2020	X		X	X	24/09/2020		
24/09/2020		X			25/09/2020	X	X
29/09/2020	X		X	X	30/09/2020	X	
30/09/2020		X			01/10/2020		X
05/10/2020	X		X	X	06/10/2020		
06/10/2020		X			07/10/2020	X	X
11/10/2020	X		X	X	12/10/2020	X	
12/10/2020		X			13/10/2020		X
17/10/2020	X		X	X	18/10/2020		
18/10/2020		X			19/10/2020	X	X
23/10/2020	X		X	X	24/10/2020	X	
24/10/2020		X			25/10/2020		X
29/10/2020	X		X	X	30/10/2020		
30/10/2020		X			31/10/2020	X	X
04/11/2020	X		X	X	05/11/2020	X	

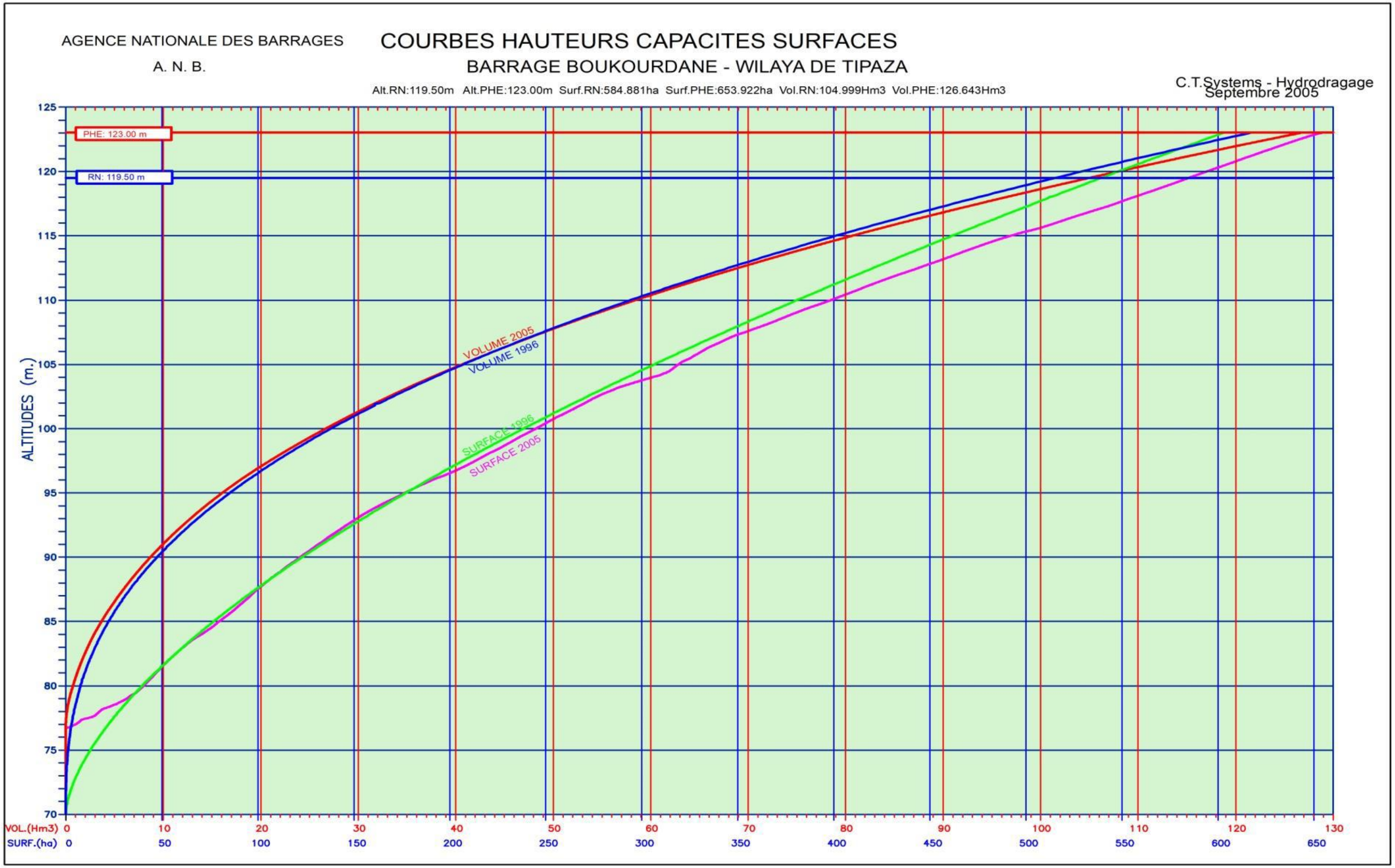
05/11/2020		X			06/11/2020		X
10/11/2020	X		X	X	11/11/2020		
11/11/2020		X			12/11/2020	X	X
16/11/2020	X		X	X	17/11/2020	X	
17/11/2020		X			18/11/2020		X
22/11/2020	X		X	X	23/11/2020		
23/11/2020		X			24/11/2020	X	X
28/11/2020	X		X	X	29/11/2020	X	
29/11/2020		X			30/11/2020		X
04/12/2020	X		X	X	05/12/2020		
05/12/2020		X			06/12/2020	X	X
10/12/2020	X		X	X	11/12/2020	X	
11/12/2020		X			12/12/2020		X
16/12/2020	X		X	X	17/12/2020		
17/12/2020		X			18/12/2020	X	X
22/12/2020	X		X	X	23/12/2020	X	
23/12/2020		X			24/12/2020		X
28/12/2020	X		X	X	29/12/2020		
29/12/2020		X			30/12/2020	X	X
03/01/2021	X		X	X	04/01/2021	X	
04/01/2021		X			05/01/2021		X
09/01/2021	X		X	X	10/01/2021		
10/01/2021		X			11/01/2021	X	X
15/01/2021	X		X	X	16/01/2021	X	
16/01/2021		X			17/01/2021		X
21/01/2021	X		X	X	22/01/2021		
22/01/2021		X			23/01/2021	X	X
27/01/2021	X		X	X	28/01/2021	X	
28/01/2021		X			29/01/2021		X
02/02/2021	X		X	X	03/02/2021		
03/02/2021		X			04/02/2021	X	X
08/02/2021	X		X	X	09/02/2021	X	
09/02/2021		X			10/02/2021		X

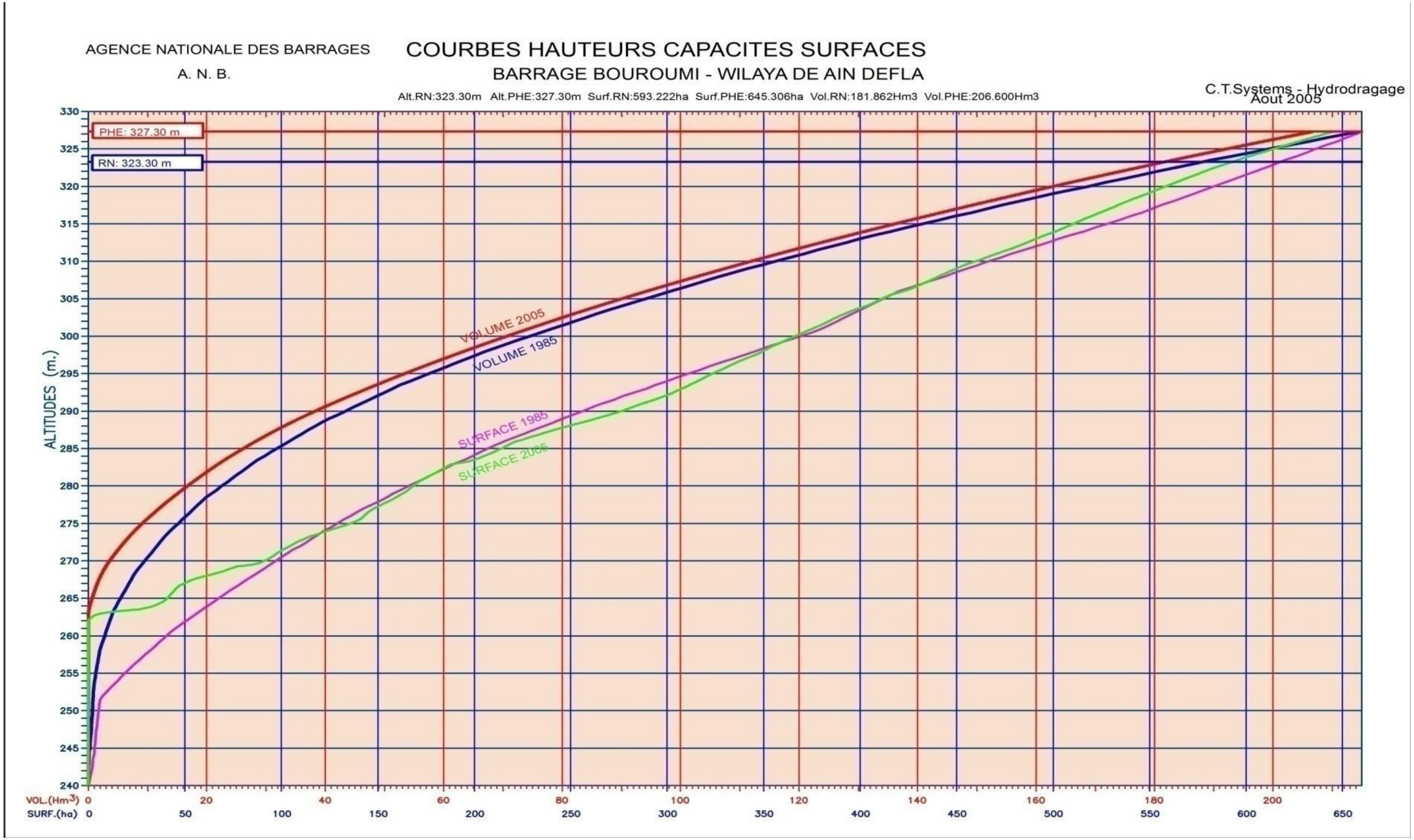
14/02/2021	X		X	X	15/02/2021		
15/02/2021		X			16/02/2021	X	X
20/02/2021	X		X	X	21/02/2021	X	
21/02/2021		X			22/02/2021		X
26/02/2021	X		X	X	27/02/2021		
27/02/2021		X			28/02/2021	X	X
04/03/2021	X		X	X	05/03/2021	X	
05/03/2021		X			06/03/2021		X
10/03/2021	X		X	X	11/03/2021		
11/03/2021		X			12/03/2021	X	X
16/03/2021	X		X	X	17/03/2021	X	
17/03/2021		X			18/03/2021		X
22/03/2021	X		X	X	23/03/2021		
23/03/2021		X			24/03/2021	X	X
28/03/2021	X		X	X	29/03/2021	X	
29/03/2021		X			30/03/2021		X
03/04/2021	X		X	X	04/04/2021		
04/04/2021		X			05/04/2021	X	X
09/04/2021	X		X	X	10/04/2021	X	
10/04/2021		X			11/04/2021		X
15/04/2021	X		X	X	16/04/2021		
16/04/2021		X			17/04/2021	X	X
21/04/2021	X		X	X	22/04/2021	X	
22/04/2021		X			23/04/2021		X
27/04/2021	X		X	X	28/04/2021		
28/04/2021		X			29/04/2021	X	X
03/05/2021	X		X	X	04/05/2021	X	
04/05/2021		X			05/05/2021		X
09/05/2021	X		X	X	10/05/2021		
10/05/2021		X			11/05/2021	X	X
15/05/2021	X		X	X	16/05/2021	X	
16/05/2021		X			17/05/2021		X
21/05/2021	X		X	X	22/05/2021		

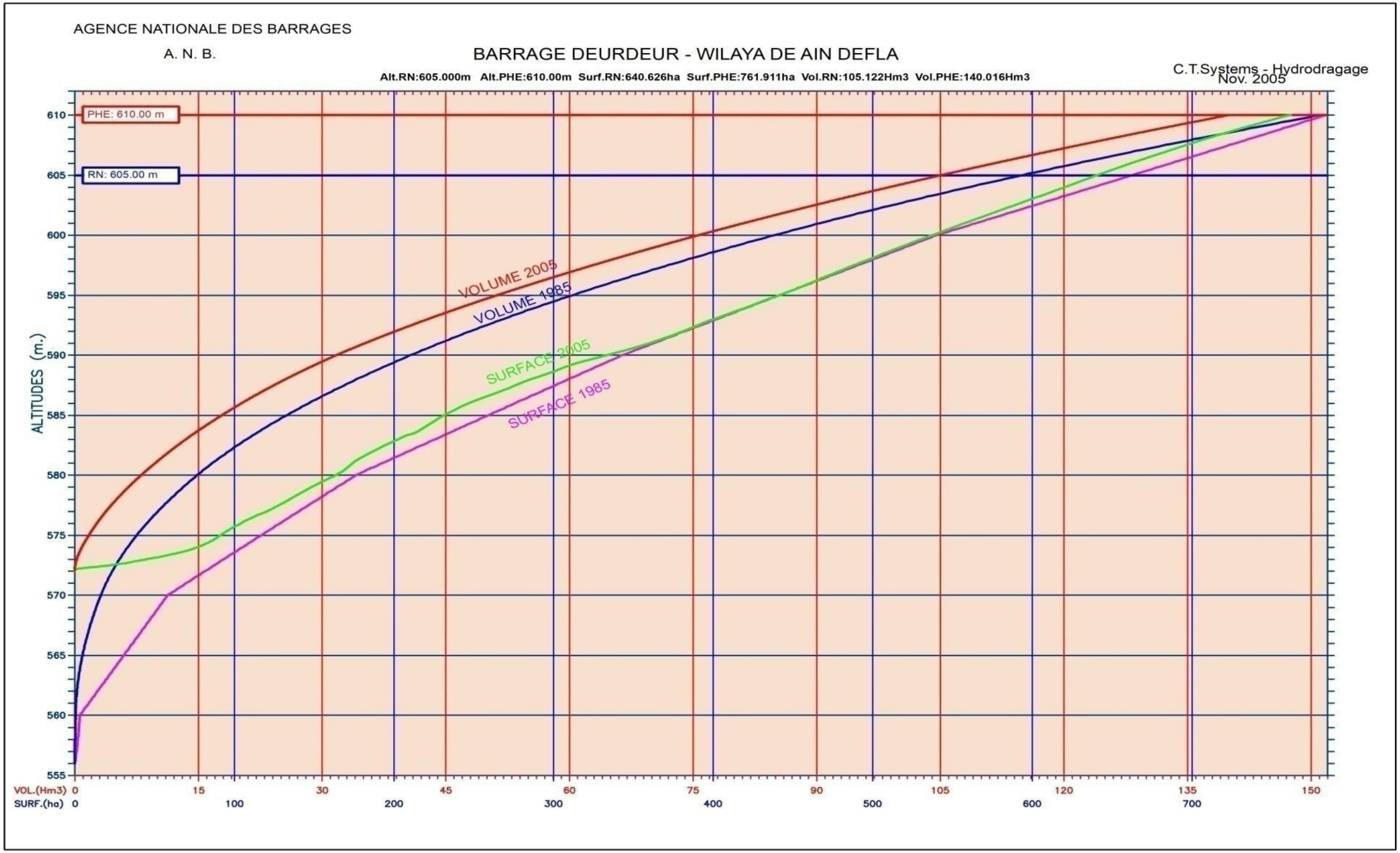
22/05/2021		X			23/05/2021	X	X
27/05/2021	X		X	X	28/05/2021	X	
28/05/2021		X			29/05/2021		X
02/06/2021	X		X	X	03/06/2021		
03/06/2021		X			04/06/2021	X	X
20/06/2021	X		X	X	21/06/2021	X	
21/06/2021		X			22/06/2021		X
02/07/2021	X		X	X	03/07/2021		
03/07/2021		X			04/07/2021	X	X
20/07/2021	X		X	X	21/07/2021	X	
21/07/2021		X			22/07/2021		X
01/08/2021	X		X	X	02/08/2021		
02/08/2021		X			03/08/2021	X	X
19/08/2021	X		X	X	20/08/2021	X	
20/08/2021		X			21/08/2021		X

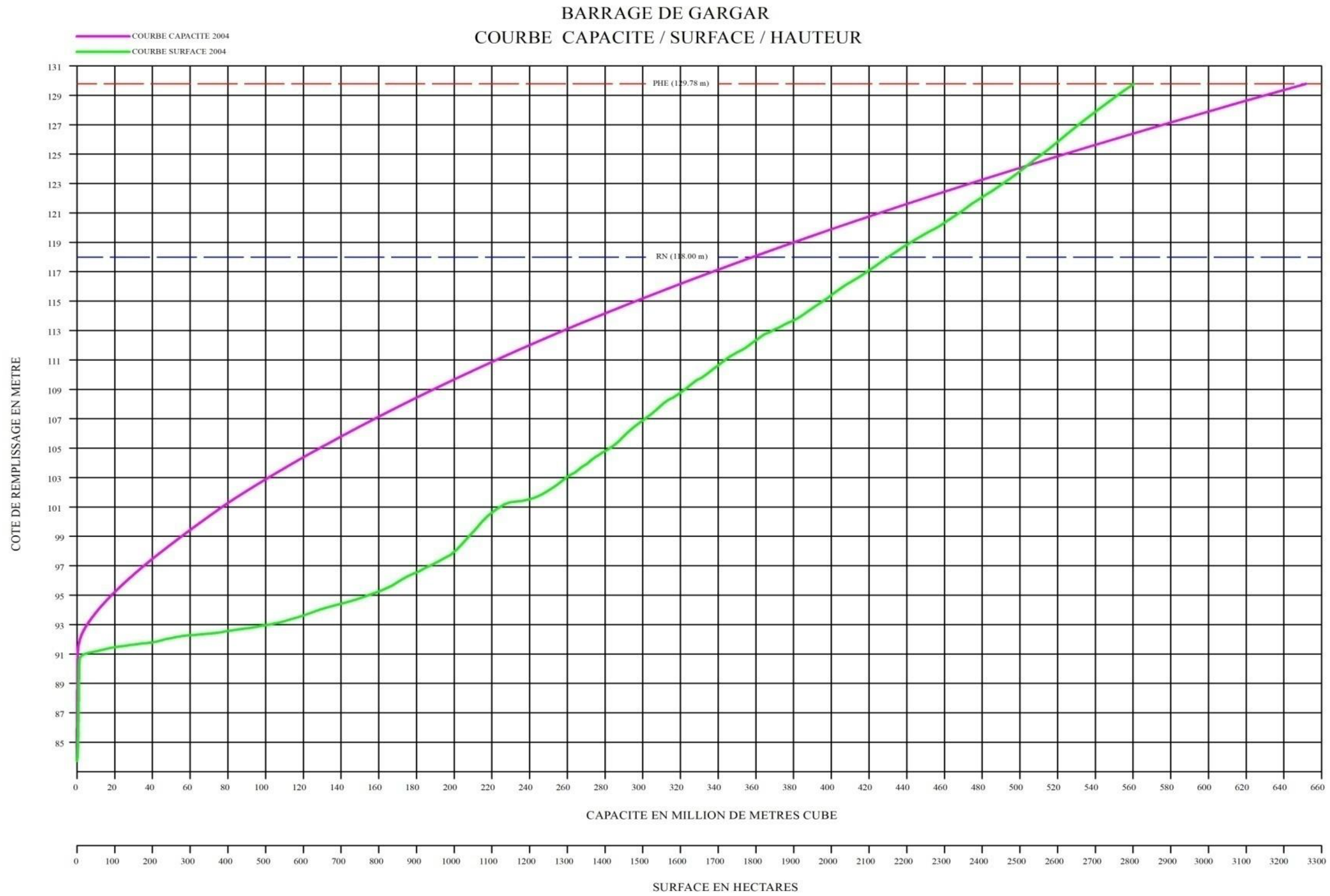
APPENDIX 2

Reservoirs capacity curves

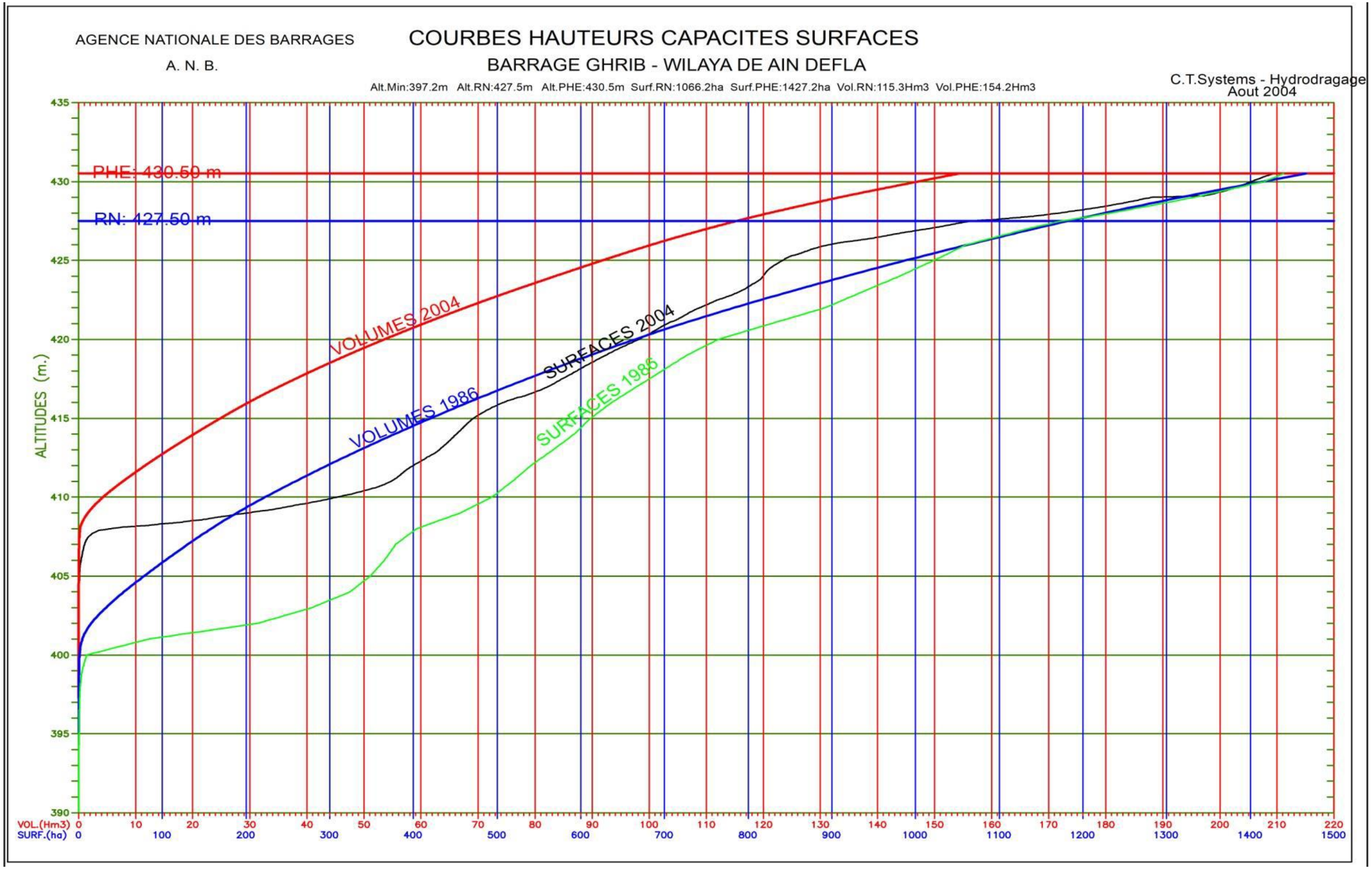

AGENCE NATIONALE DES BARRAGES
A. N. B.
COURBES HAUTEURS CAPACITES SURFACES
BARRAGE BOUKOURDANE - WILAYA DE TIPAZA
Alt.RN:119.50m Alt.PHE:123.00m Surf.RN:584.881ha Surf.PHE:653.922ha Vol.RN:104.999Hm3 Vol.PHE:126.643Hm3
C.T.Systems - Hydrodragage
Septembre 2005
PHE: 123.00 m
RN: 119.50 m
VOLUME 2005
VOLUME 1996
SURFACE 1996
SURFACE 2005
ALTITUDES (m.)
VOL.(Hm3)
SURF.(ha)

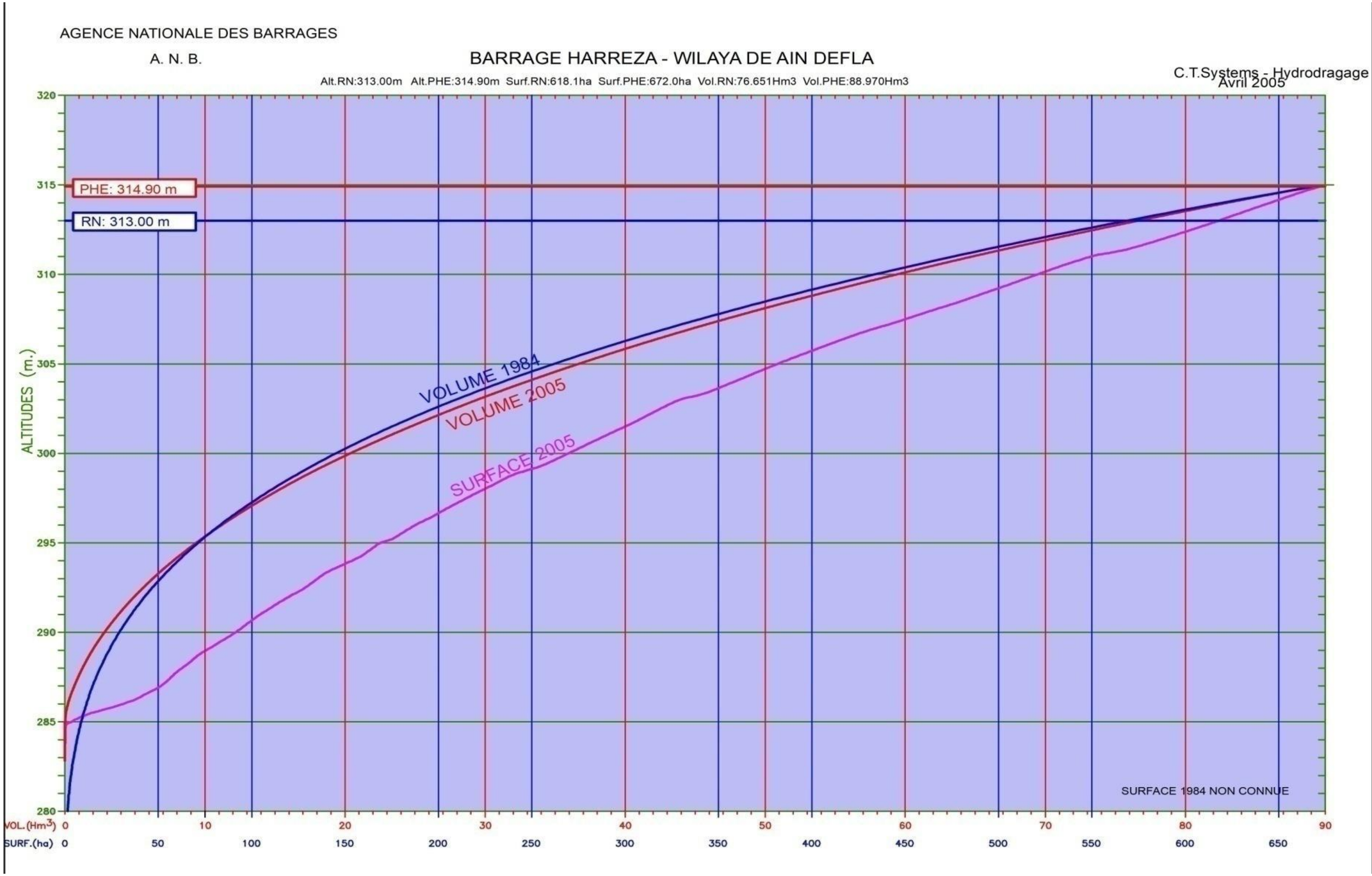

AGENCE NATIONALE DES BARRAGES
A. N. B.
COURBES HAUTEURS CAPACITES SURFACES
BARRAGE BOUROUMI - WILAYA DE AIN DEFLA
Alt.RN:323.30m Alt.PHE:327.30m Surf.RN:593.222ha Surf.PHE:645.306ha Vol.RN:181.862Hm3 Vol.PHE:206.600Hm3
C.T.Systems - Hydrodragage
Aout 2005
PHE: 327.30 m
RN: 323.30 m
VOLUME 2005
VOLUME 1985
SURFACE 1985
SURFACE 2005
ALTITUDES (m.)
VOL.(Hm3)
SURF.(ha)

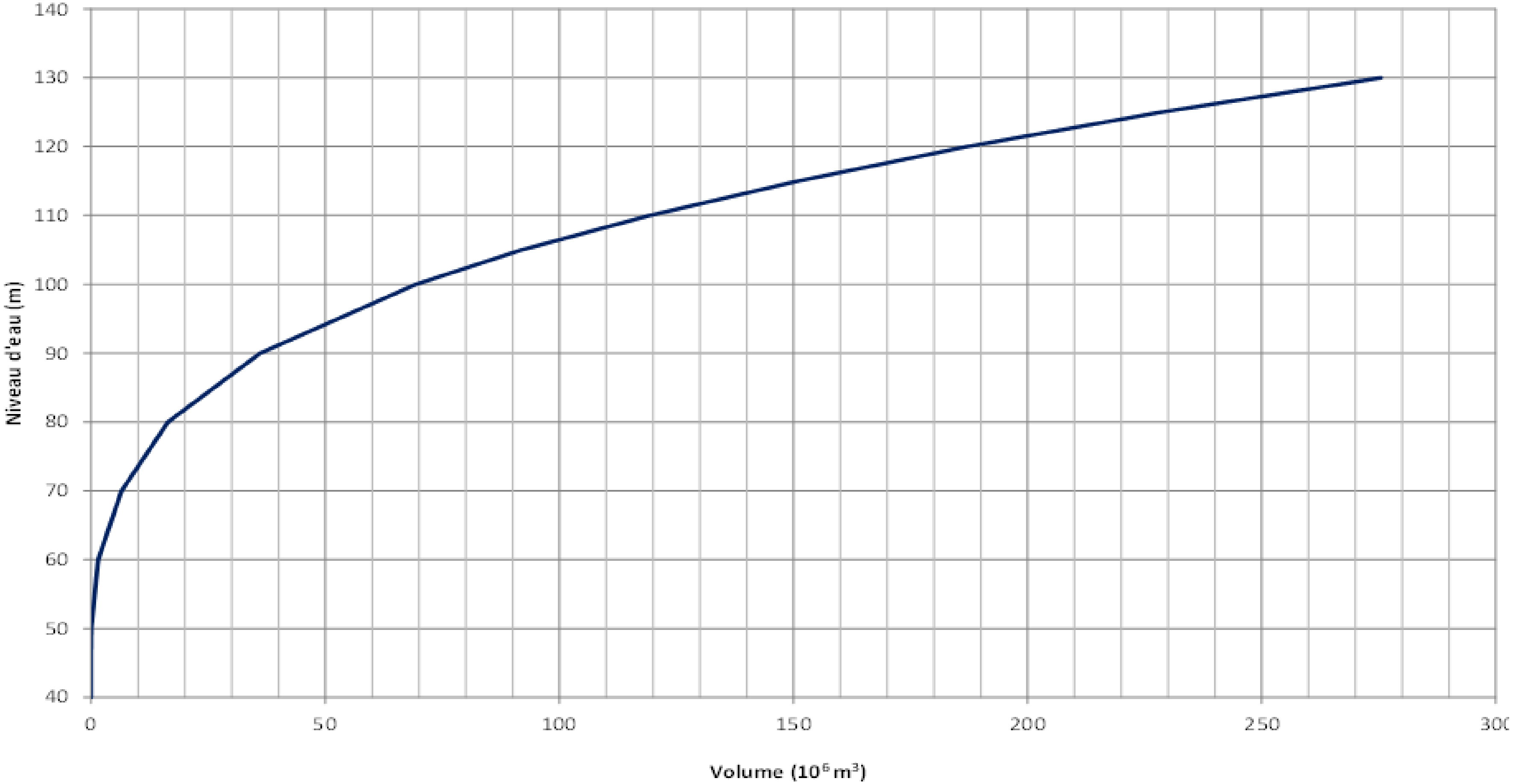

AGENCE NATIONALE DES BARRAGES
A. N. B.
BARRAGE DEURDEUR - WILAYA DE AIN DEFLA
Alt.RN:605.000m Alt.PHE:610.00m Surf.RN:640.626ha Surf.PHE:761.911ha Vol.RN:105.122Hm3 Vol.PHE:140.016Hm3
C.T.Systems - Hydrodragage
Nov. 2005
PHE: 610.00 m
RN: 605.00 m
VOLUME 2005
VOLUME 1985
SURFACE 2005
SURFACE 1985
ALTITUDES (m.)
VOL.(Hm3)
SURF.(ha)



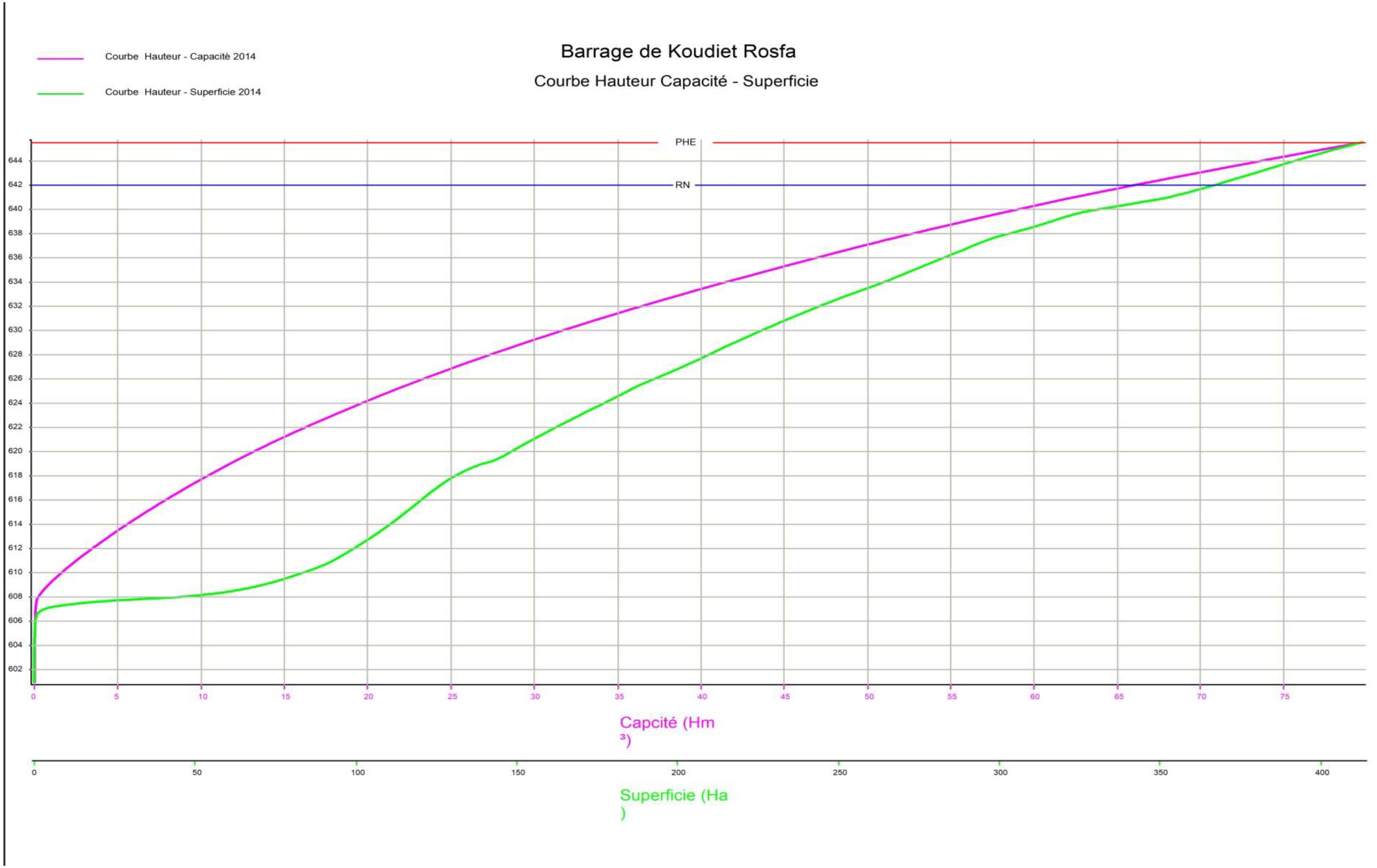
BARRAGE DE GARGAR
COURBE CAPACITE / SURFACE / HAUTEUR
COURBE CAPACITE 2004
COURBE SURFACE 2004
PHE (129.78 m)
RN (118.00 m)
COTE DE REMPLISSAGE EN METRE
CAPACITE EN MILLION DE METRES CUBE
SURFACE EN HECTARES

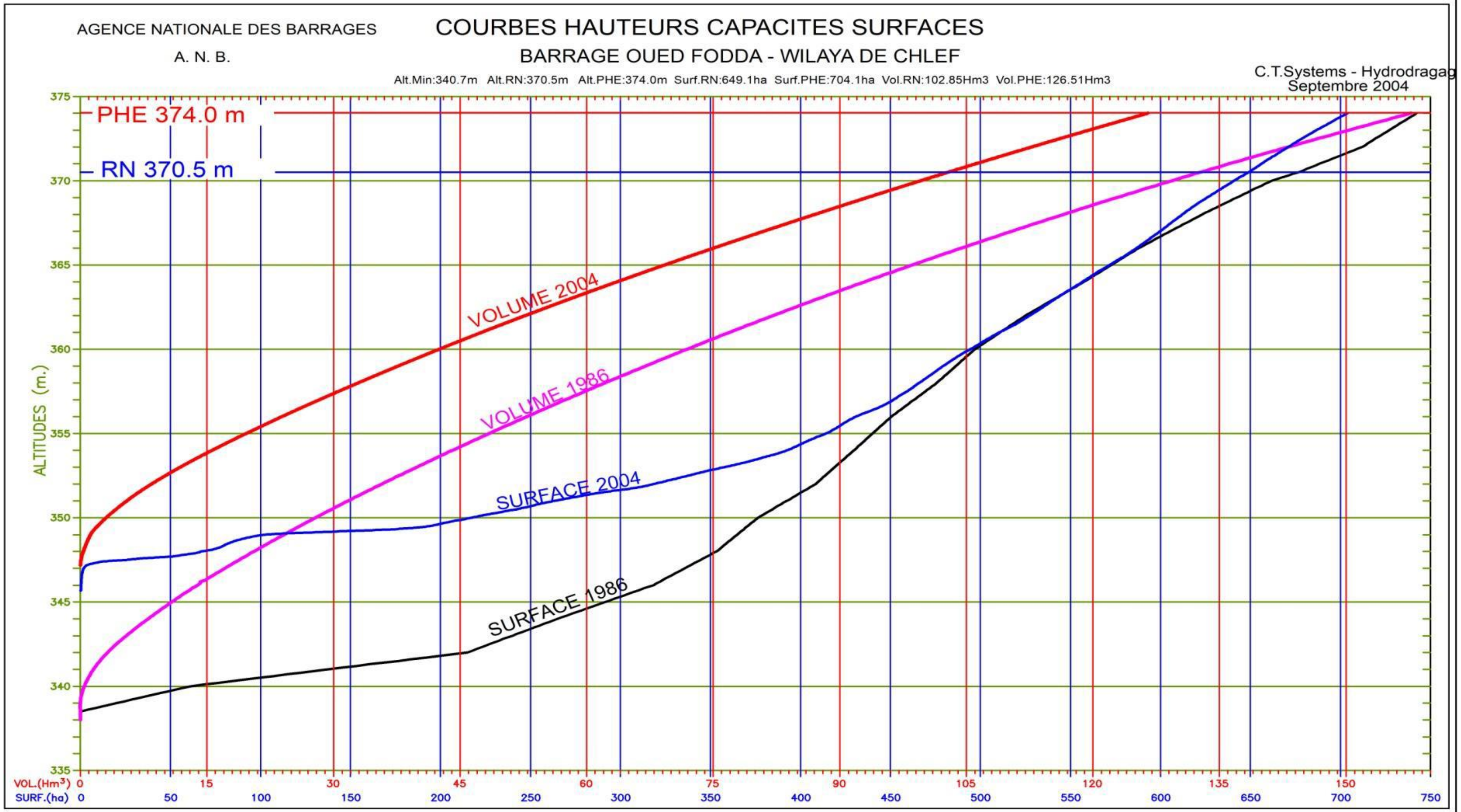

AGENCE NATIONALE DES BARRAGES
A. N. B.
COURBES HAUTEURS CAPACITES SURFACES
BARRAGE GHRIB - WILAYA DE AIN DEFLA
Alt.Min:397.2m Alt.RN:427.5m Alt.PHE:430.5m Surf.RN:1066.2ha Surf.PHE:1427.2ha Vol.RN:115.3Hm3 Vol.PHE:154.2Hm3
C.T.Systems - Hydrodragage
Aout 2004
PHE: 430.50 m
RN: 427.50 m
VOLUMES 2004
VOLUMES 1986
SURFACES 2004
SURFACES 1986
ALTITUDES (m.)
VOL.(Hm3)
SURF.(ha)


AGENCE NATIONALE DES BARRAGES
A. N. B.
BARRAGE HARREZA - WILAYA DE AIN DEFLA
C.T.Systems - Hydrodragage
Avril 2005
Alt.RN:313.00m Alt.PHE:314.90m Surf.RN:618.1ha Surf.PHE:672.0ha Vol.RN:76.651Hm3 Vol.PHE:88.970Hm3
PHE: 314.90 m
RN: 313.00 m
ALTITUDES (m.)
VOLUME 1984
VOLUME 2005
SURFACE 2005
SURFACE 1984 NON CONNUE
VOL.(Hm3)
SURF.(ha)

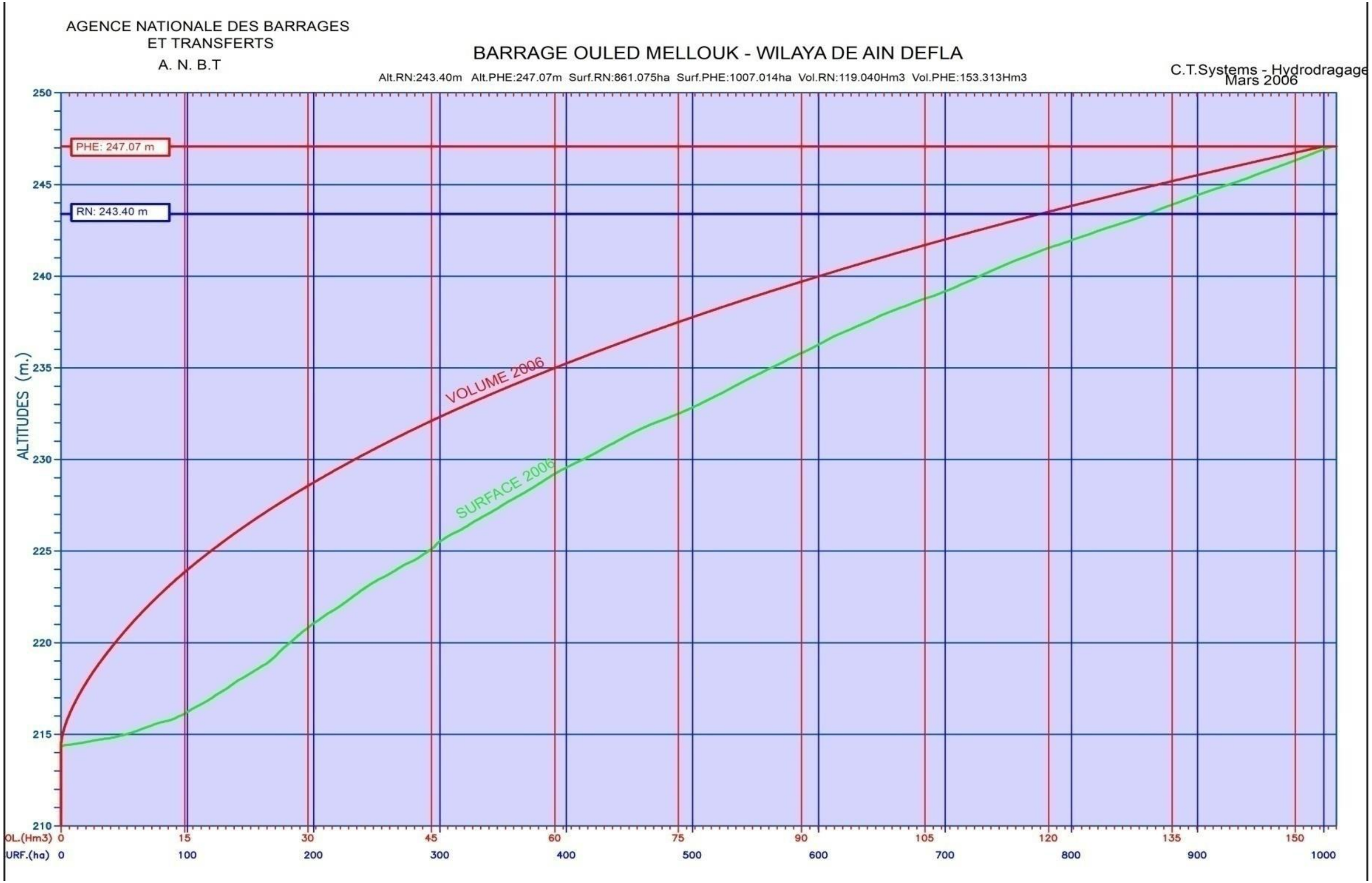


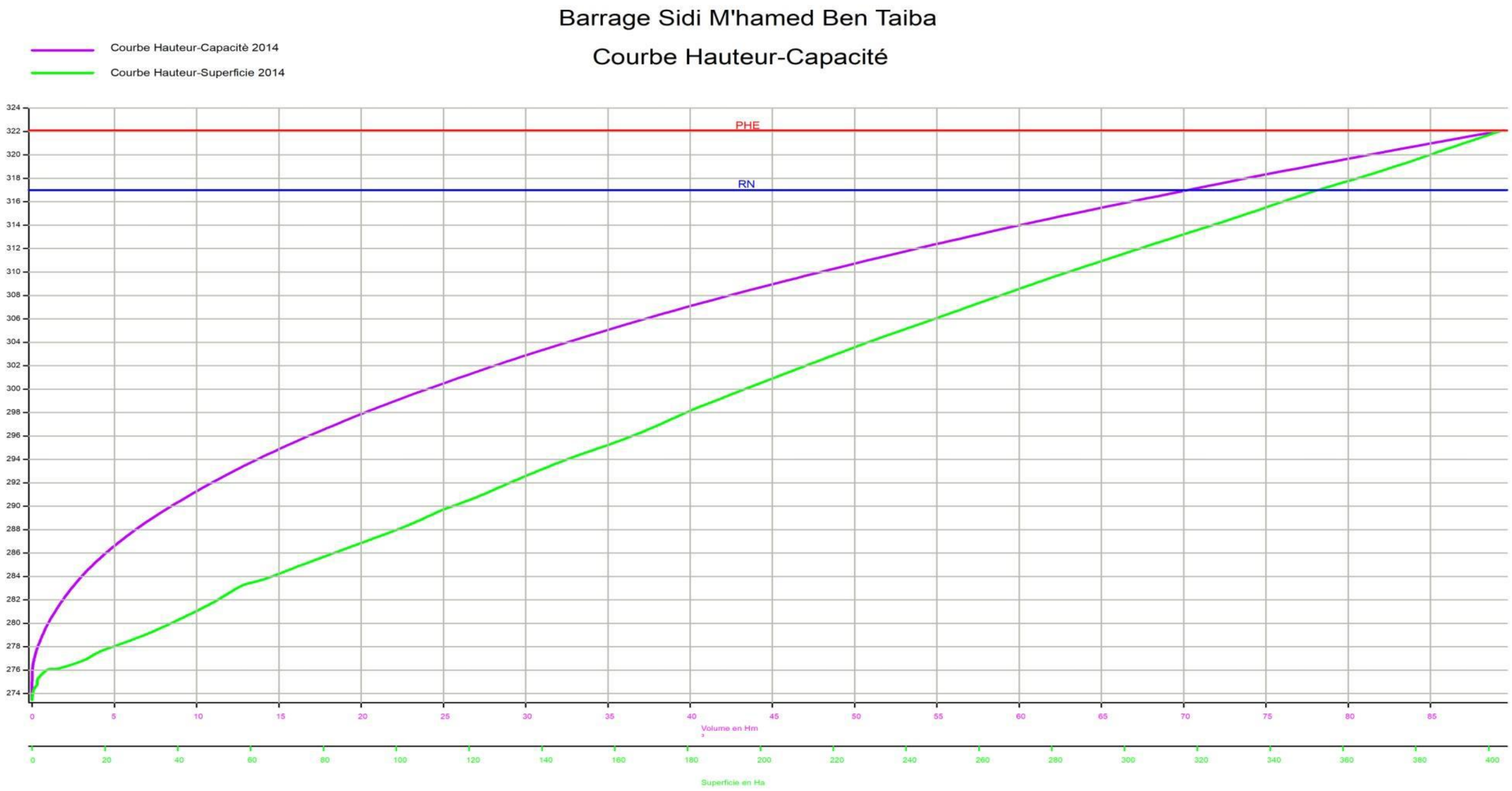
140
130
120
110
100
90
80
70
60
50
40
Niveau d'eau (m)
0
50
100
150
200
250
300
Volume (10^6 m^3)


Courbe Hauteur - Capacitè 2014
Courbe Hauteur - Superficie 2014
Barrage de Koudiet Rosfa
Courbe Hauteur Capacité - Superficie
PHE
RN
644
642
640
638
636
634
632
630
628
626
624
622
620
618
616
614
612
610
608
606
604
602
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
Capcité (Hm ³)
0 50 100 150 200 250 300 350 400
Superficie (Ha)

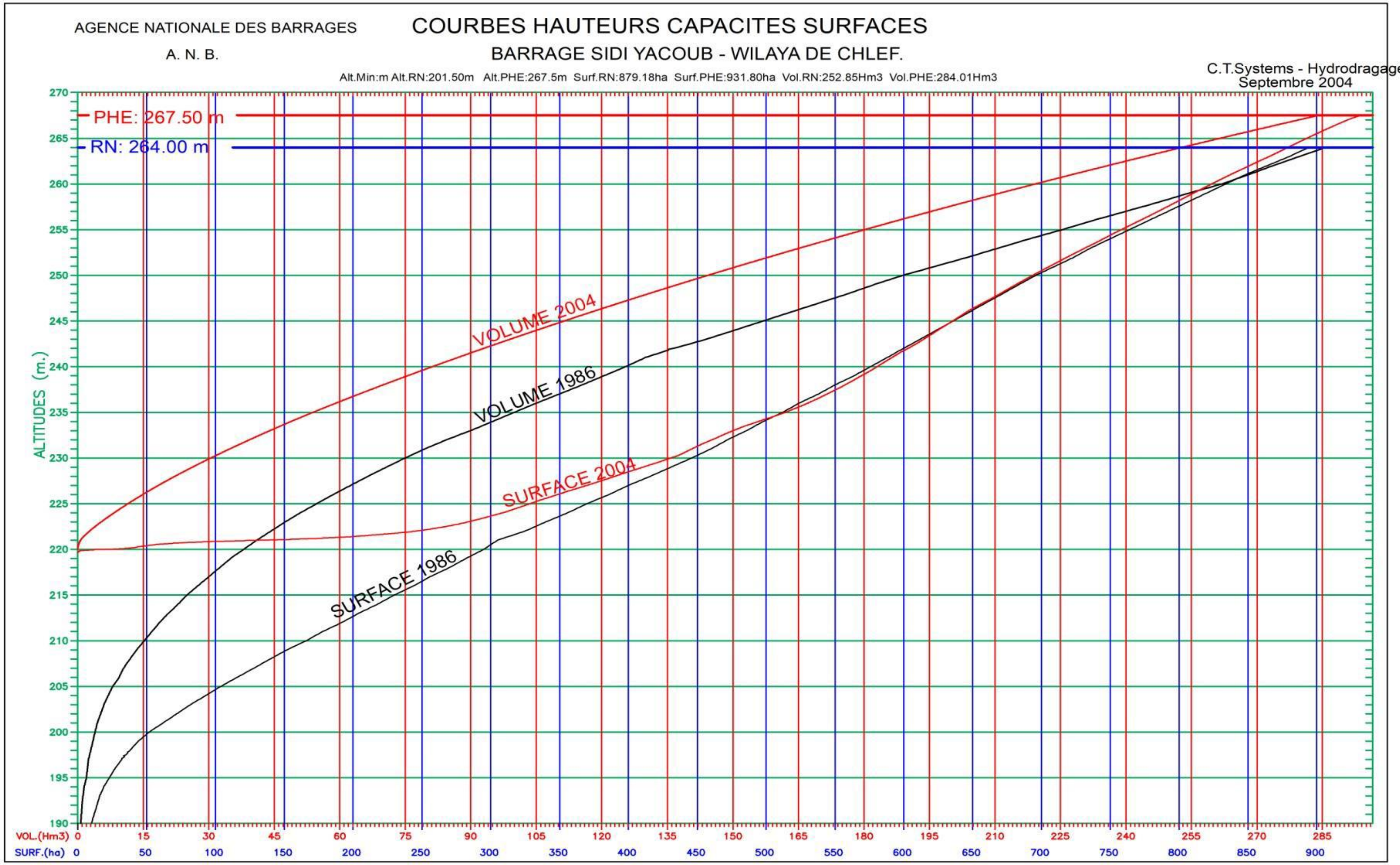


AGENCE NATIONALE DES BARRAGES
A. N. B.
COURBES HAUTEURS CAPACITES SURFACES
BARRAGE OUED FODDA - WILAYA DE CHLEF
Alt.Min:340.7m Alt.RN:370.5m Alt.PHE:374.0m Surf.RN:649.1ha Surf.PHE:704.1ha Vol.RN:102.85Hm3 Vol.PHE:126.51Hm3
C.T.Systems - Hydrodragag
Septembre 2004
PHE 374.0 m
RN 370.5 m
VOLUME 2004
VOLUME 1986
SURFACE 2004
SURFACE 1986
ALTITUDES (m.)
375
370
365
360
355
350
345
340
335
VOL.(Hm³) 0 15 30 45 60 75 90 105 120 135 150
SURF.(ha) 0 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750


AGENCE NATIONALE DES BARRAGES
ET TRANSFERTS
A. N. B.T
BARRAGE OULED MELLOUK - WILAYA DE AIN DEFLA
Alt.RN:243.40m Alt.PHE:247.07m Surf.RN:861.075ha Surf.PHE:1007.014ha Vol.RN:119.040Hm3 Vol.PHE:153.313Hm3
C.T.Systems - Hydrodragage
Mars 2006
PHE: 247.07 m
RN: 243.40 m
VOLUME 2006
SURFACE 2006
ALTITUDES (m.)
250
245
240
235
230
225
220
215
210
OL.(Hm3) 0 15 30 45 60 75 90 105 120 135 150
URF.(ha) 0 100 200 300 400 500 600 700 800 900 1000



Barrage Sidi M'hamed Ben Taiba
Courbe Hauteur-Capacité
Courbe Hauteur-Capacitè 2014
Courbe Hauteur-Superficie 2014
PHE
RN
324
322
320
318
316
314
312
310
308
306
304
302
300
298
296
294
292
290
288
286
284
282
280
278
276
274
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85
Volume en Hm3
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360 380 400
Superficie en Ha



AGENCE NATIONALE DES BARRAGES
A. N. B.
COURBES HAUTEURS CAPACITES SURFACES
BARRAGE SIDI YACOUB - WILAYA DE CHLEF.
Alt.Min:m Alt.RN:201.50m Alt.PHE:267.5m Surf.RN:879.18ha Surf.PHE:931.80ha Vol.RN:252.85Hm3 Vol.PHE:284.01Hm3
C.T.Systems - Hydrodragage
Septembre 2004
PHE: 267.50 m
RN: 264.00 m
VOLUME 2004
VOLUME 1986
SURFACE 2004
SURFACE 1986
ALTITUDES (m.)
VOL.(Hm3)
SURF.(ha)