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Mapping flood impacts arising from land cover maps of Sidi Salem dam and Bousalem city, north western Tunisia

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Abstract

Automatic land cover classification from satellite images is an important topic in many remote sensing applications. In this study, the spatial distribution of the inundation hazards around Sidi Salem dam and Bousalem city was determined using land-cover maps derived from classification of Landsat images. This study modeled the spatiotemporal changes of Sidi Salem dam and its surroundings and Bousalem city during the rainy episode of February and March 2015 using the multi-temporal Landsat 8-OLI-TIRS images. Our findings revealed that the releases of 394.184 Mm3 from the dam during the month of March have had significant impacts on the region. They caused changes in the dam holding area in 18/03 which increased by a factor of 150% that of January requiring major evacuations leading flooding around the dam and the city of Bousalem where urban areas and entire roads (C60 and C75) were covered with mud spoofed by the wadi Medjerda. The results indicate an intense decreasing trend in Sidi Salem dam surface area in 03rd April, when it lost the majority of its surface area compared to the previous month. The results illustrate the effectiveness of the automatic land cover classification approach for surface water change detection, especially in detecting the changes between two and three different times, simultaneously.

Key Words: Floods, classification, Land cover map, Landsat Images, Tunisia.

Cartographie des impacts des inondations résultant des cartes d'ocupation de sol du barrage de Sidi Salem et de la ville de Bousalem, au nord-ouest de la Tunisie

Résumé

La classification automatique de l'occupation de sol à partir d'images satellites est un sujet important dans de nombreuses applications de télédétection. Dans cette étude, la distribution spatiale des risques d'inondation autour du barrage de Sidi Salem et de la ville de Bousalem a été déterminée à l'aide des cartes de couverture terrestre dérivées de la classification des images Landsat. Cette étude a modélisé les changements spatio-temporels du barrage de Sidi Salem et de ses environs et de la ville de Bousalem pendant l'épisode pluvieuse de février et mars 2015 en utilisant les images multi-temporelles Landsat 8-OLI-TIRS.Nos résultats ont révélé que les rejets de 394,184 Mm3 du barrage au cours du mois de mars ont eu des impacts importants sur la région. Entrainant des changements dans la zone de retenue du barrage en 18/03 avec une augmentation d'un facteur de 150% par rapport à janvier, nécessitant des évacuations majeures entraînant des inondations autour du barrage et de la ville de Bousalem où les zones urbaines et les routes entières (C60 et C75) étaient couverts de boue issue d'oued Medjerda. Les résultats indiquent une tendance à la baisse intense de la superficie du barrage de Sidi Salem au 03 avril, date à laquelle il a perdu la majorité de sa superficie par rapport au mois précédent. Les résultats illustrent l'efficacité de l'approche de classification automatique de la couverture terrestre pour la détection des changements des eaux de surface, en particulier pour détecter les changements entre deux et trois moments différents, simultanément.

Mots clés : Inondations, classification, carte de l'occupation du sol, images Landsat, Tunisie

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INTRODUCTION

Floods are the most devastating natural hazard affecting the social and economic aspects of population [1] and claiming more lives than any other natural phenomenon [2]. Flooding is normally severe in flood plains wich are regions of a valley floor located in either side of a river channel that is full of sediments deposited by the river that flows through the surface of land [2]

In Tunisia, the flooding phenomenon is ancient, throughout history we count by tens the number of times various regions were affected.The inventory of flooding which has produced material or human damage and reveals a marked worsening of the hydrological risk. Over the past five decades, they have caused nearly 800 deaths and material losses which figures on the amount to hundreds of millions of dinars [3] The brutal and intense rains befalling exceptionally Tunisia cause flooding suceptible to induce significant damage in different areas of the watershed of Mejerda North Western Tunisia mainly Ghardimaou near the border with Algeria, Bousalem tail of the dam Sidi Salem, Slouguia and Medjez El bab [4]. Among the most significant floods over the course of Mejerda; Flood December 1934 (2060 m3/s), September 1969 (1485 m3/s in Bousalem ,1440 m3/s in Mejez El bab), March 1973 (3360 m3/s in Bousalem) and February 2003 (1020 m3/s in Bousalem with 4 points from successive floods in a month having accumulated one million m3 contributed to Sidi Salem. the management of these floods was their lamination to prevent damage to downstream and then evacuate them in time [4].The flood in 1973 has had significant impacts on the entire Mejerda valley where the flooded area reached 473 square kilometers. The thickness of the deposits varies from a few millimeters to more than 2 meters (2.30 meters in Testour and Slouguia) [5].

Remote sensing (RS) and Geographic Information System (GIS) techniques provide effective tools for considering the land use and land cover dynamics of the area as well as for observing , mapping and management of natural assets [6]. These techniques present an effective means of lineating such areas at risk and for communicating this to decision-makers, emergency response teams and the general public [7]. Flood mapping is the vital component in flood moderation measures and land use planning Satellite based remote sensing images have been used to map the extent of flood inundation since the early 1970 [8]. Most of the early studies used optical remote sensors which cannot penetrate clouds such Landsat MSS and TM, so they have been mainly used to observe post flood inundation extent [9].

This paper attempts to track impacts of floods arising from land use maps around Sidi Salem dam and city of Bousalem. Three dated Landsat images were used to detect dynamics of land occupation before and after inundation. Supervised and unsupervised classifications of Landsat images are imperative to insure precise change-detection results.

Study area

The study area lies on latitudes 36° 28' N and 36° 48' N and longitudes 8° 50'E and 9° 40'E. It include the Dam of Sidi Salem and the Bousalem city and its surroundings located in the North West of Tunisia (Fig.1).

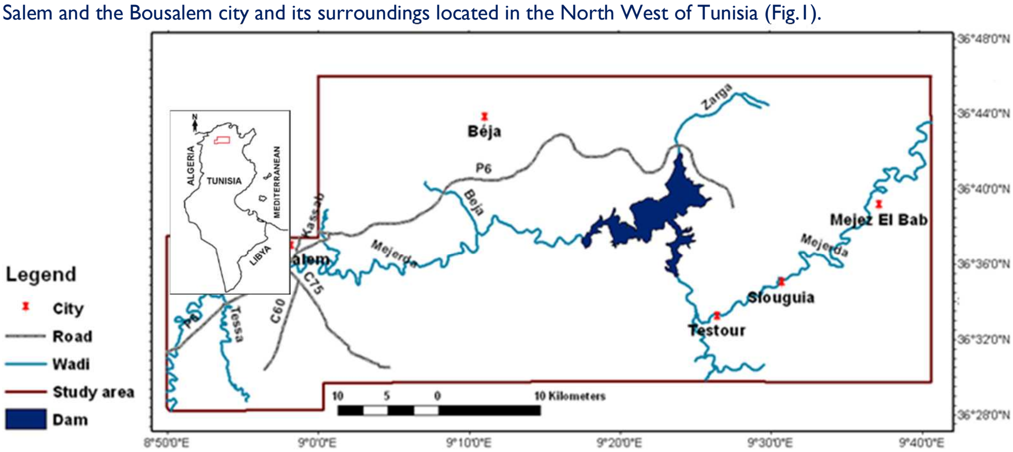

Fig1: Study Area.

The Sidi Salem dam is located 10 km south east of Beja city . It is an earth dam based on marl and sandstone of Miocene, high of 70 m, with 340 m long crest, having two large diversion tunnels with 8.20 m of diameter reused in bottom outlet (to 640 m3/s) and current floods spillway (free threshold in saturated wells 690 m3/s). It is provided with an overflow spillway with three large valves sector totaling 3 x 1400 = 4200 m^3 /s of flow capacity [10]. Its storage capacity to normal coast after the two successive enhancements in 1997 and 1999 is approximately 762 million m^3. It is built on the main course of the wadi Mejerda west of Mejez El Bab. Besides the drinking water supply, irrigation and hydropower generation, this dam is designed to protect the lower valley of Mejerda against floods, by making the rolling of peak flows, particularly

during the largest floods. In fact, the dam has divided the peak flow centennial flood by three. In Slouguia station, it increased from 3300 m3/s before the dam to 1100 m3/s after its entry into service [10].
The City of Bousalem is located 55.7 km west of the Sidi Salem dam on an area of 33649 ha. It is traversed by the main course of the Mejerda over a length of 53 km. Two tributaries; wadi Bouhertma at the left and wadi Tessa at the right bank power this section. The corresponding water system has a multitude of winding on flat relief where the variation of the slope is very low [11]. The climate is Mediterranean with a dry season coinciding with the hot season; the very capricious rainfall and temperature have a sensitive latitudinal gradient from the far north of the wet Mejerda basin with 750 to 1200 mm of rain and 17 ° C of annual average temperature [5].

MATÉRIELS ET MÉTHODES

The methodology includes two parts (see Figure2), The first is the treatment of dam data (Stock and Evacuated volume) (see Table 1) collected from DGBGTH in Excel software to get the histograms of the stock and the volume discharged from the dam during the two months of February and March 2015. The second part is a processing of Landsat 8-OLI-TIRS images downloaded from the USGS Global Visualization.
Generally the OLI requirements specified a sensor that collects image data for nine spectral bands with a spatial resolution of 30m over a 185km swath from the nominal 705 km LDCM spacecraft altitude [6]. Landsat 8 contains two sensors : Operational Land Imager (OLI) with 3 new bands (deep blue band for coastal, shortwave infrared band, and a quality assessment band) and thermal Infrared Sensor (TIRS) with 2 thermal bands. This mehod was implemented using the OLI-TIRS sensor and three scenes on three dates were found available for tracking changes in land use in the study zone following the rainfall episode in February-March 2015 (Table 2).

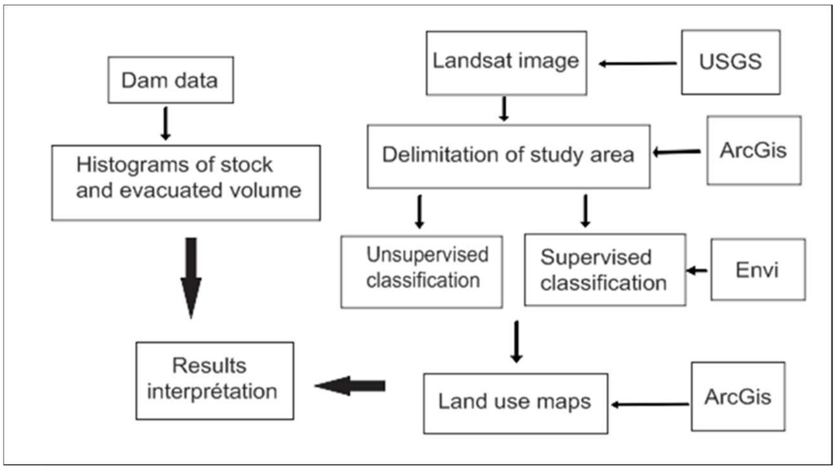

Fig.2: Flow chart for presented method

Table 2 : available Landsat scenes covering study area

Date	Cloud cover	Quality	Sensor
13rd January 2015	.19	9	OLI-TIRS
18th March 2015	.04	9	OLI-TIRS
03rd April 2015	.42	9	OLI-TIRS

The development of land cover maps was made through the classification of satellite images under the Envi software.The classification is developing a process map interpretation from remote sensing images. There are two general approaches to image classification: supervised and unsupervised. They differ in the manner in which the classification is performed.
In the case of unsupervised classification , the goal is to classify all pixels in an image from a sample of drive zones. Each land use class has a spectral signature of its own. The Envi software defines specific types of soil occupation based on a statistical characterization data drawn from examples in the image (training sites). K-means defined by McQueen [12]. is one of the simplest automatic data classification algorithms. The main idea is to randomly select a set of a priori fixed centers and searching iteratively the optimum partition [13] Equation (1)':

$$\sum_{i=1}^{k} \sum_{xj \in Ci} d(xj, Ci) \qquad (1)$$

Set of 'n' data denoted 'x', Desired number of groups written 'k', A partition of 'k 'groups (C1, C2, ... Ck) [13].
We will conduct an unsupervised classification of the previously created image using the K-means algorithm and the Classification Module< Unsupervised> K-means. The method of K-means is a method of geometric classification well adapted to the vector spaces of large dimension. It is also regularly used to perform unsupervised classification of multispectral images [14]. The K-means algorithm tries to find the most representative centroid data space since iteratively group pixels in the nearest class with a minimum of technique. Each iteration recalculates the average new classes and reclassifies pixels from these new means. This process continues until the number of pixels in each class varies from less the selected shift threshold or the maximum number of iterations is reached [14]. (Figure3).

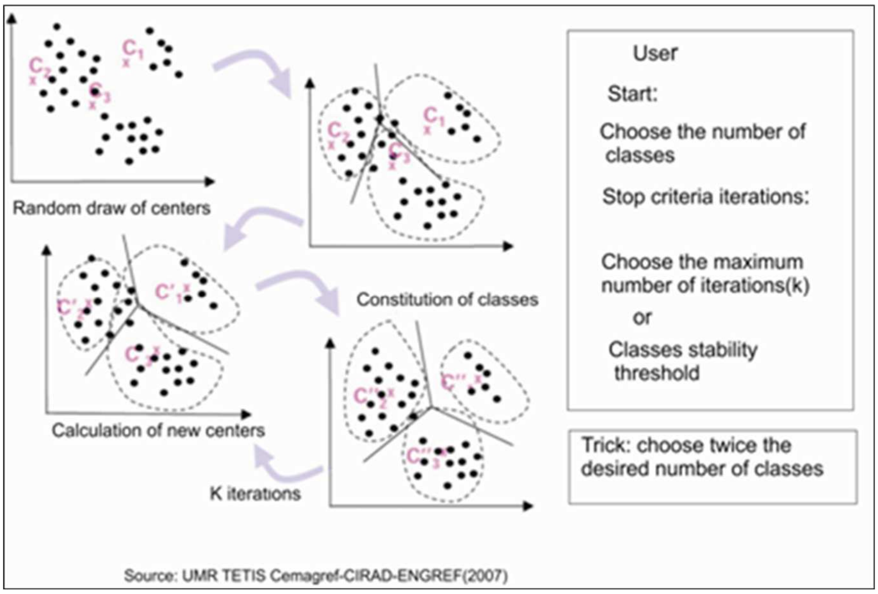

Fig.3: Principle of K-means

In the case of supervised classification, the user will guide the software by providing thematic or spatial order information. This type of classification therefore requires a minimum of knowledge about the study area. The thematic parameters entered by the user can be, for example, radiometric intervals that were identified in the study area (eg between 0 and 25 = pure water in the infrared). The spatial parameters are for example polygons drawn on the image (a wheat field, a coniferous parcel, an urban area, ...) that will serve as the standard of software.

RÉSULTATS ET DISCUSSION

Histograms of stock and evacuated volume evolution in Sidi Salem dam

the histogram of the water stock evolution at Sidi Salem dam (Figure 4) during the month of February 2015 shows a general trend towards increasing :

- From 01st to 08th February, we have an increase in the stock at the dam to reach 537.662 million m3.
- From 08th to 24th February, the stock at the dam remain almost constant.
- On 25th February, the stock rise again to reach the last day of the month 666.506 million m3 corresponding to the most important water volume during the month of February.

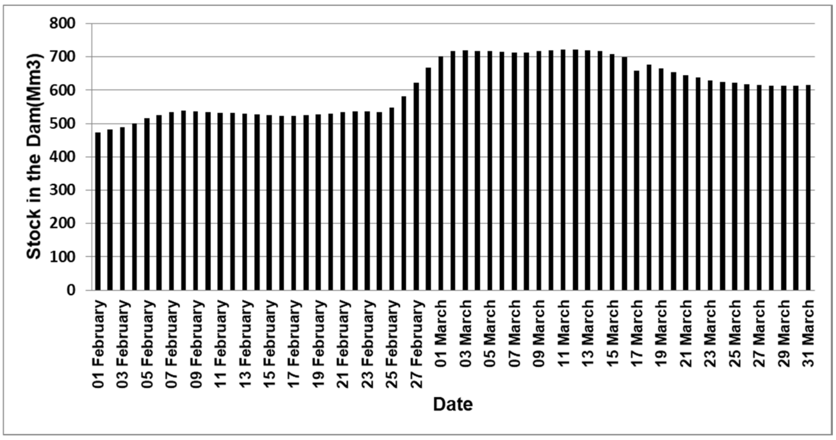

Fig. 4: Histogram of Stock in the Sidi Salem dam during February- March 2015

Major releases have been made during February taking into account the water level in the Sidi Salem Dam and its storage capacity. These releases were recorded on 02nd, 10th and 24th February but the larger was at the end of the month with 13.22 million m3 on February 28th (Figure 5).

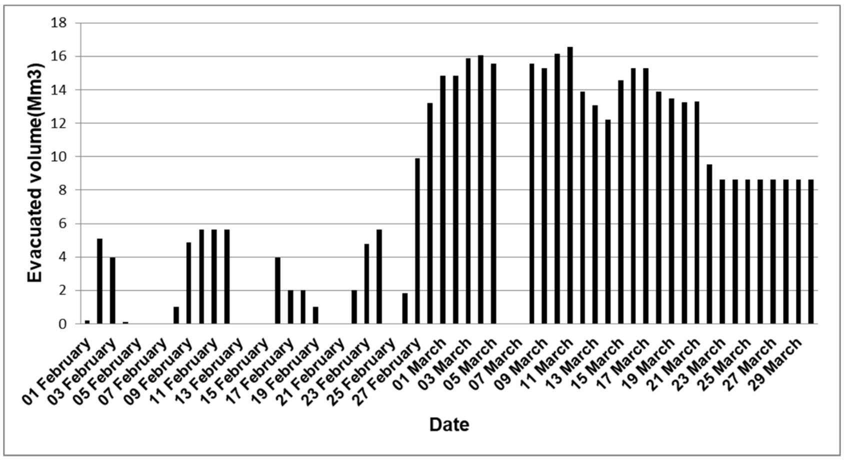

Fig. 5 : Histogram of the evacuated volume from Sidi Salem dam during February- March 2015.

The water level in the 1st March was 116 mGTL with a stock of 700.797 million m^3, until March 14th they remain almost constant. After they start to decline towards the end of the month to reach 114.51 million m^3 and 615.915 mGTL respectively. It's noteworthy that in March the most important releases were made at the dam Sidi Salem with water volumes of 6.318 to 16.56 million m^3 .

During the two months of February and March, the stock in the dam rose to142.464 million m^3 and the water level of 2.91 mGTL.

From the table of ribs and reference volumes published by DGBGTH (Table 3), the water in the Sidi Salem dam was under the level of operations during the period from 01st to 26th February 2015. On 27th February it reached 114.84 mGTL to increase until 116.36 mGTL the 11/03 with a stock of 722.255 million m3. This required evacuation of a volume of 16.56 Mm3 the same day to stabilize the water level in the dam to a volume of operations on 31/03, the total volume evacuated in February and March 2015 was 501.273 million m^3.

Table3: Ribs and volumes of reference (DGBGTH)

Ribs (m GTL)	Description	Volume (Mm3)	Security
122	upper level of the dam	_	_
118,5	Highest Waters	900	Spillage of the tulip,, bottom outlet and tower outlet
114	operating level	500	150 Mm3 safety mattress before the operation of the tulip
113	Uncontrolled spill	840	Spillage of the tulip
			flood spillway.
112,5	exceptional level	1100	

Shape of Sidi Salem dam

The unsupervised classification shows a change of the area occupied by water from the Sidi Salem dam (Figures 6,7 and 8). On 18th March, the flooded area is multiplied by a factor of 150% it goes from 3.900.150 m² on 13rd January to 6.133.050 m² (Table 4). On April 03rd, the area of the water reservoir of the dam decreases strongly following the releases made at the end of March and reaches 530,019 m².

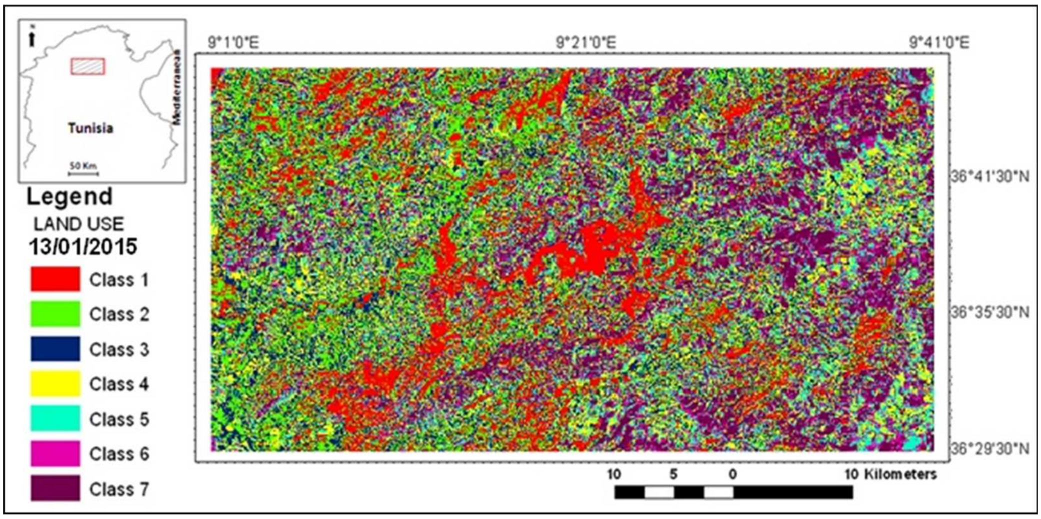

Fig. 6 : Unsupervised classification of Sidi Salem dam on 13/01/2015

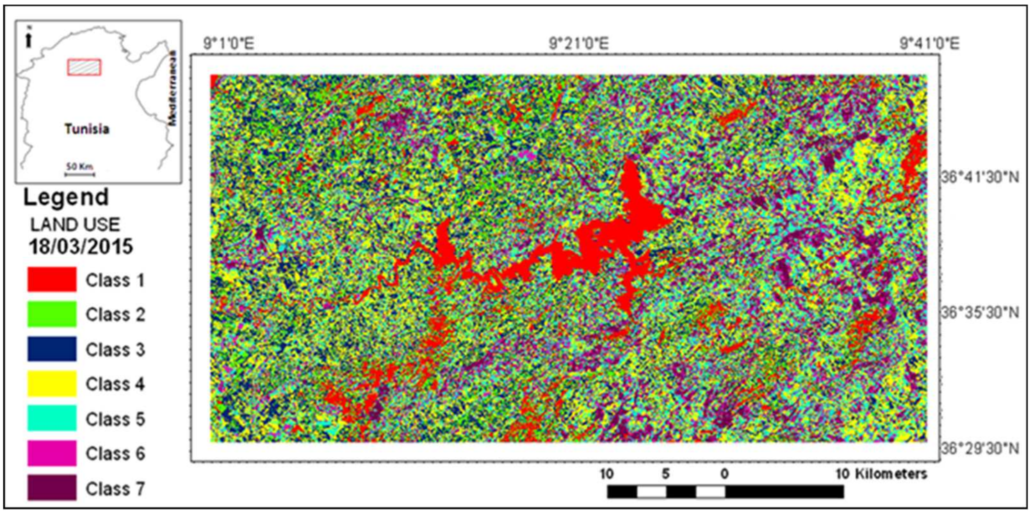

Fig. 7 : Unsupervised classification of Sidi Salem dam on 18/03/2015

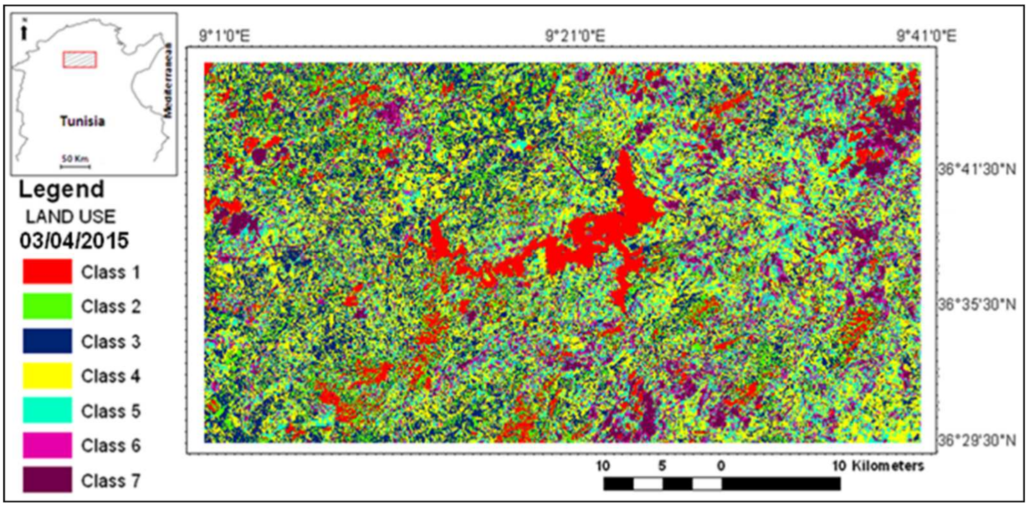

Fig. 8 :Unsupervised classification of Sidi Salem dam on 03/04/2015

Supervised classification at the Sidi Salem dam in the three dates, 13rd January, 18th March and 03rd April, shows (Figures 9,10 and 11):

On January18th, the water level in the dam was lower than in March, at its periphery, we observe the rockfill that behave like urban areas (same spectral signature), they appear in red on the land use map. These stones are covered with water on March 18th following the increase of the water level in the dam and they have the same color as the wadi on the land use map (cyan) where the depth of water is lower than in the center of the dam.

The overflow of Wadi Mejerda in the northeast of Mejez El bab city is clear on the land use map of March 18th and it disappears in April 3rd.

In April 3rd, the area occupied by bare land rises above the towers of Sidi Salem dam which could be associated with the releases that were performed from 19 to 31st March of almost 70 million m3 of water. The emergence of new urban areas in March and April is due to the cloud cover which has the same spectral signature of the urban area.

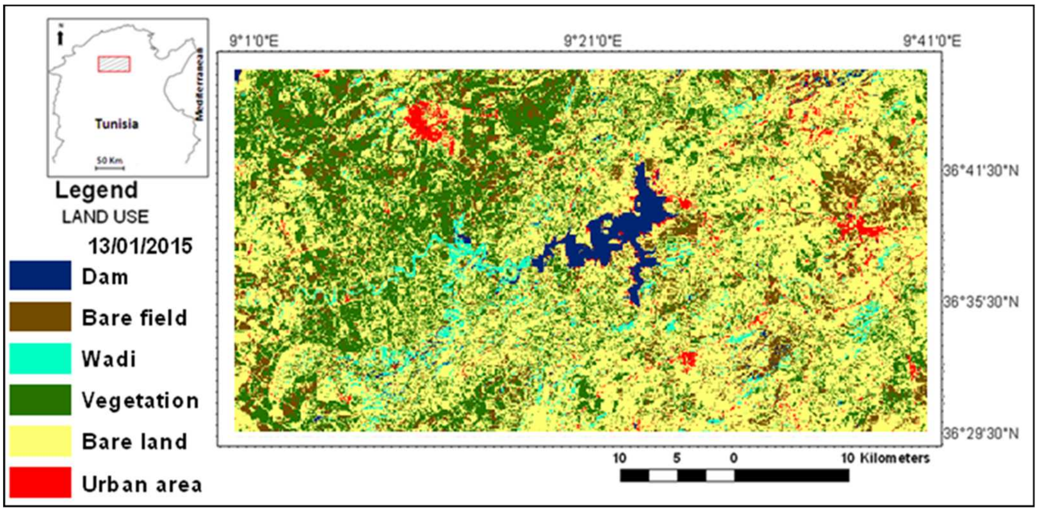

Fig. 9 : Land cover map of Sidi Salem dam on 13/01/2015

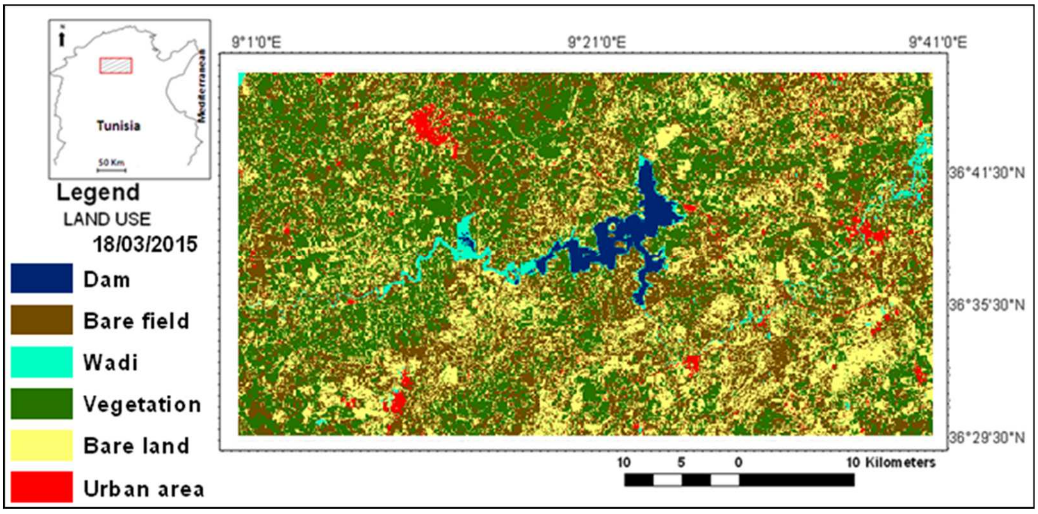

Fig. 10 : Land cover map of Sidi Salem dam on 18/03/2015

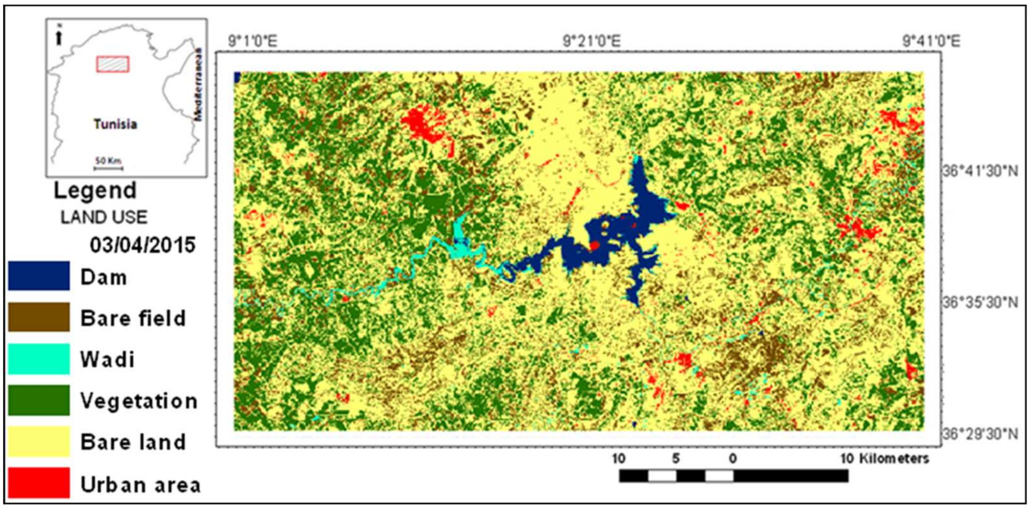

Fig.11: Land cover map of Sidi Salem dam on 03/04/2015

Bousalem region

The land use maps of Bousalem region and its surroundings (Figures 12, 13 and 14) show changes of land use after the rainy period from February 21st to March 16th 2015 :

In January 13rd, dense vegetation occupies the banks of wadis Mejerda, Tessa and Bouhertma. In March 18th, the vegetation is degraded due to flooding and overflow of the banks of wadis and surrounding lands are invaded by mud and behave as bare land on land use maps. Entire roads and few urban areas north of Bousalem city disappeared. The roads south of the city C60 and C75 are destroyed and they are covered by sediments carried by the flood during the rainy period from February 21st to March 16th 2015.

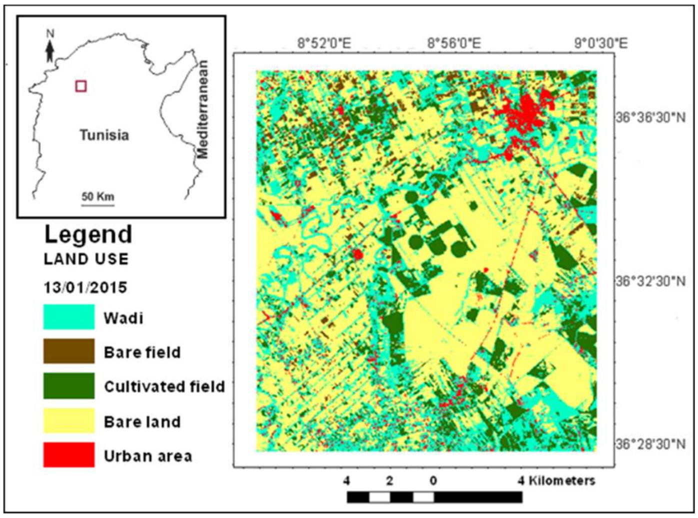

Fig.12 :Land cover map of Bousalem city on13/01/2015

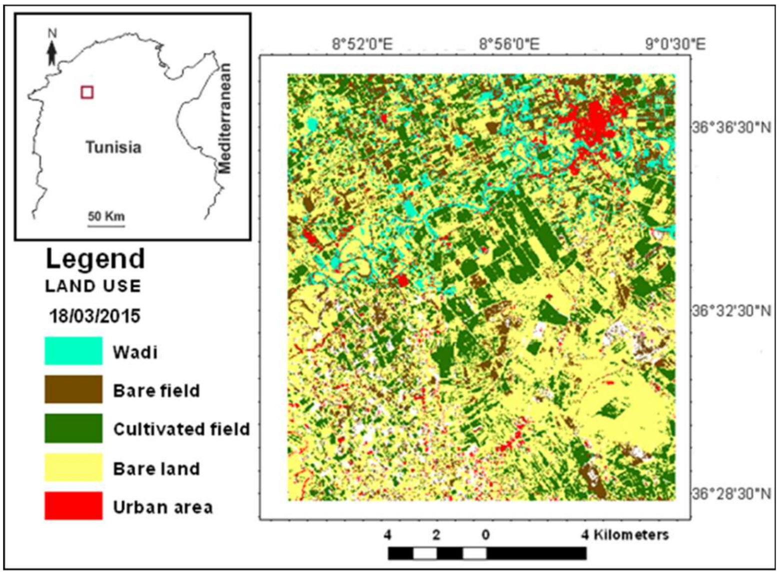

Fig.13 : Land cover map of Bousalem city on18/03/2015

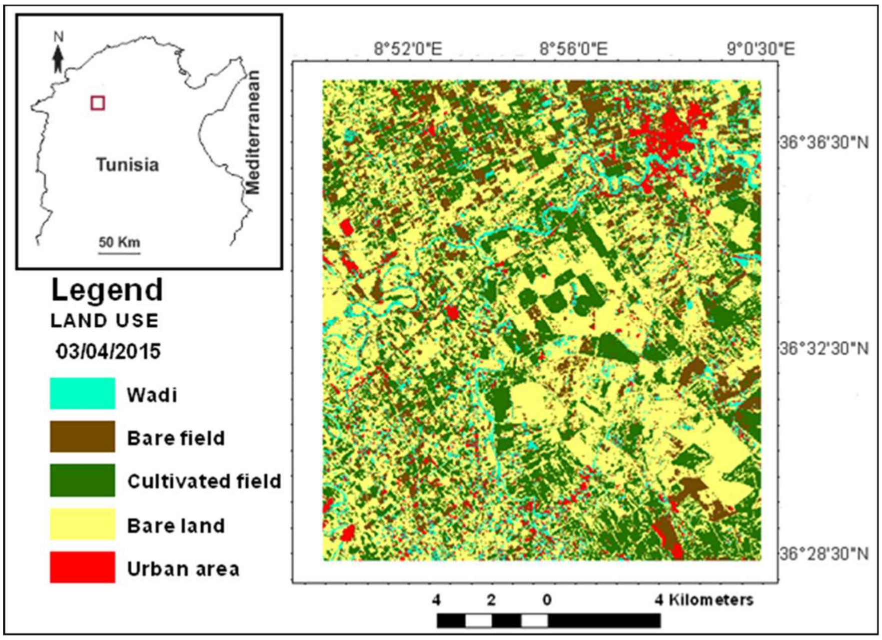

Fig.14 : Land cover map of Bousalem city on 03/04/2015

CONCLUSION

Flooding of Wadi Medjerda during February and March 2015 have largely affected the vicinity of Sidi Salem Dam and Bousalem city.
The land use maps obtained by the two types of classification; supervised and unsupervised show that the releases from the dam during the month of March with a volume of 394,184 million m3 had significant impacts on the region. On March 18th the area occupied by water in the dam has increased by a foctor of 150% their in January 13rd and requiring successive evacuations, caused flooding around the dam where land were covered by sediments carried by the river and in the city of Bousalem including urban areas and roads (C60 and C75) were buried under mud due to overflows of tributaries Tessa and Bouhertma.

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