УДК 911.52(551.583.1+504.05):528.88

Remote sensing and geospatial analysis for monitoring the landscape dynamics inside the plain of Tafilalet (Morocco) under the impacts of climate change and human activities

Eddahby Lhou [1, 7], Jihane Tlemçani [2], Mikhail Popov [3*], Sergey Stankevich [3], Daoud Mezzane [4], Igor Lukyanchuk [5], Abdelkader Larabi [1], Ali Essahlaoui [6]

[1] *Laboratory LIMEN "Water Resources & Information Technology", Mohammadia School of Engineers, Rabat, Morocco*

[2] *Faculty of Sciences and Technology of Errachidia, My Ismaïl University, Meknes, Morocco*

[3] *Scientific Centre for Aerospace Research of the Earth, NAS of Ukraine, Kiev, Ukraine*

[4] *LMCN, Faculty of Sciences and Technologies, Cadi Ayyad University, Marrakech, Morocco*

[5] *LPMC, Picardie Jules Verne University, Amiens, France*

[6] *Research Group "Water Sciences and Environmental Engineering", Laboratory of Geo-Engineering and Environment, Faculty of Sciences, My Ismaïl University, Meknes, Morocco*

[7] *DTO/DDZO/ANDZOA, 417, Bd. Al Maghreb Arabi, Ouarzazate, Morocco*

In this study we are interested in the plain of Tafilalet to follow the dynamics of palms under constraints of climate change and human activities with the same approach. Climate changes are evaluated based on three methods: rainfall station of raft Erfoud, the deviation from the mean, the rainfall index and moving average 5 years. Identified and mapped the human actions are of three types: the discharge, liquid waste from cities and landfills and urban planning. Multispectral satellites images of Landsat TM (1984, 2009) and ETM+ (1999) are analyzed. Processing which takes account of both natural and human constraints allowed us to evaluate the dynamics palms of Tafilalet. The obtained results of this area were compared to the middle Ziz oasis.

Keywords: multispectral satellite imagery, land cover classification, climate change, human pressure, landscape dynamics, plain of Tafilalet (Morocco)

Introduction

Climate change caused urgent environmental problems in Morocco. Morocco has a great desert southern-east area; approximately 93% of the country is arid or semiarid [13]. Modern geoinformation technologies uses the remote sensing data to monitor environmental condition and socio-economic consequences inside wide area [11].

In Morocco, the scarcity and randomness of rainfall and desertification are increasingly worrying and threatening farmland and irrigation infrastructure. Tafilalet region, located in the southern Atlas of Morocco, is facing enormous difficulties combining scarcity and poor quality of water then long periods of severe drought that have affected recent decades and whose ecological consequences are considerable, as evidenced by the decline in the area irrigated under the action of desertification and rising saline soils [1, 7, 9].

In this study, we attempted, using the remote sensing and geospatial analysis, to evaluate the current status and oases landscape dynamics at the regional level inside the plain of Tafilalet (Morocco) [12]. Our previous work has been on the middle Ziz Oasis using the remote sensing and geoinformation technologies to determine the dynamics of soil occupancy rate in this area. This study showed the undeniable contribution of ground-based and remote sensing data for monitoring spatio-temporal covert plant oasis in an area very sensitive to the impact of climate change. The evaluation of chlorophyll activity was obtained by calculating the average NDVI of each scene (from 1972 to 2011) and validated by SAVI and MSAVI indices. In addition, we were able to calculate the vegetation area percentage within the study area [5].

The study area

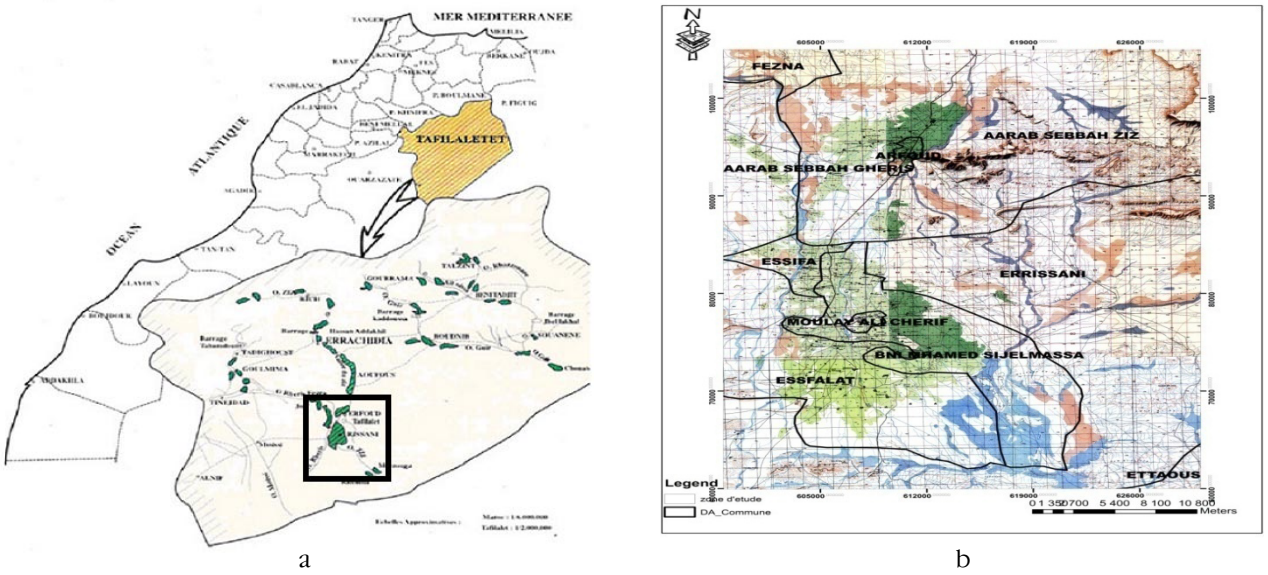
The Plain of Tafilalet is located south-east of Morocco, in the pre-Saharan zone, with a varying width 15 to 20 *km* and long 50 *km*. It lies between latitudes 31°30' and 31°10'. It was the subject of several geological and hydrogeological studies [1, 3, 4, 9]. Quaternary basin Tafilalet is essentially a vast erosion depression, clearing of the resulting secondary and tertiary coverage and epigenetic of Ziz, Ghriss, Oukhit valleys. In the primary substratum, forms of erosion are represented by extensive glazing on the edge of the basin. These are much smoothed surfaces or regs that connect peripherals to the plains reliefs (Kreb of Hamada). Reliefs of the study

* E-mail: mpopov@casre.kiev.ua

Online ISSN 2313-2132

area are mainly due to the limestone of Devonian sandstones and Ordovician. Altitude plain decreases from north to south from 850 *m* to 700 *m*. The plain has a markedly convex shape overall with an area of about 650 km^2. It is framed in the North and East by erosion ledges Hamada west and south by the olds massifs of the Anti-Atlas. The area of our study is shown in the Fig. 1a and 1b.

The climate of the region is arid or semi-desert with high continental influence. Rainfalls in the plain of Tafilalet are erratic in space and time. Fig. 2 shows a variation of annual rainfall between 10.7 *mm* observed for the period 1983–1984, and 185.2 *mm* observed in 2008–2009. The average annual rainfall is 65.66 *mm* for the period 1958-2009. The annual average evaporation is about 3 500 *mm*. This value is very high and leads to



a b

Fig.1. Plain of Tafilalet (Morocco) study area: a – location within state, b – topographic map

the characteristics of arid and Saharan climates. The maximum value of 521 *mm* is observed in July.

The drainage system in the plain of Tafilalet is composed by two wadis (river-beds): Ziz and Gheris. They arise from High Atlas. In times of drought they are dry except during floods. Mobilization of flood water in the area is done by a set of diversion dam.

Materials and methods

For the analysis we have used remote sensing satellite data and ground-based climate/topographic/statistical/census data over study area for the 1984 – 2009 period. Satellite data included Landsat TM (1984, 2009) and ETM+ (1999) medium resolution multispectral satellite images, as well as GeoEye-1 (2010, 2013) high-resolution multispectral satellite images. All satellite images were under radiometric/atmospheric correction and then were converted into land surface reflectance (0 ...1 range value in floating point format). Auxiliary data were submitted as topographic map 1:50 000 of study area (8 sheets), Tafilalet municipal plan, urban development plan of the Ziz Valley and other.

Evaluation the climate changes

The drought is defined as a period of time "abnormally" dry, prolonged enough to cause a water shortage lowering characterized by a significant water resource levels. There are a multitude of methods for the characterization of drought [15].

In this study we used three climate change indicators: rainfall index (ratio with the average rain of the reference station), deviation from the mean, and moving average 5 years rainfall [7] at the raft of Erfoud station (Fig. 2).

The calculation of the deviation from the mean rainfall at the raft of Erfoud station has identified the most humid and rainiest year is 2008/2009.

Rainfall index deviations analysis allows to detect some anomalies in the annual rains. Fig. 3 shows the rainfall indices from 1958 to 2009, for the period more than 50 years.

Analysis of the moving average over five years extracts the trend of precipitation in the Fig. 4. The rainfall in the region is characterized by great irregularity; witch is characterized over the years by successive episodes of abundance of rain and drought. There are three rainiest periods: 1964–1980,1987–1989 and 2006–2009.

Identifying and mapping the human actions

The degradation of groundwater quality that makes two way either by pollution which results from human activity or by natural degradation due to the geological nature of aquifers. Human groundwater contamination

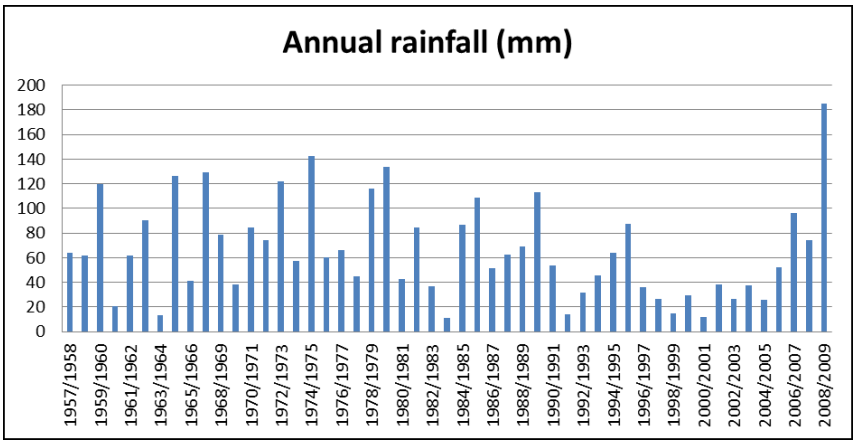


Fig. 2. Annual rainfall at the raft of Erfoud station (Source: ABH-GZR data)

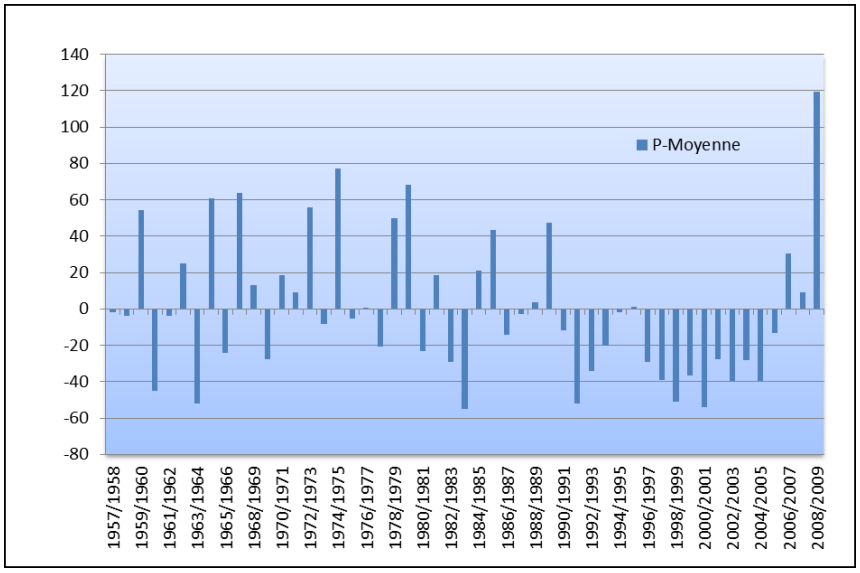


Fig.3. Variation in rainfall compared to the average to Erfoud station

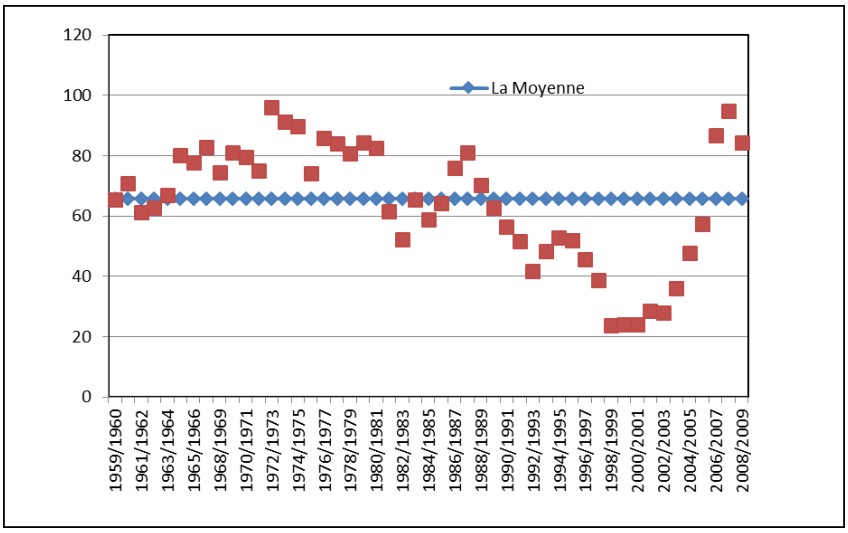


Fig. 4. Rainfall moving average over 5 years and compared with the average (1959–2009 period)

may be linked to the disposal of waste in a timely manner (uncontrolled dumps, septic tanks, discharge points of wastewater, livestock areas, mining areas residues and salt runoff and other chemicals on the roads) or diffusely (spreading manure, mineral fertilizers and other amendments to the land fertilization, pesticide use in the fight against unwanted organisms and acid rain).

In this study, landfills, liquid discharge points and the pollution caused by the industries are classified as point source of pollution of the groundwater in the plain of Tafilalet. Diffuse pollution is mainly related to agricultural activity. The palmary Tafilalet is divided into 21 sectors irrigation of different areas and which irrigation differs from one to another. It is done either by releases from dams Hassan Addakhil, pumped by river Ghr ss by flood river Ziz and/or resurgences by averaging one hand traditional and modern irrigation systems. The lack of statistics on the use of fertilizers in the plain of Tafilalet leads to the inability to assess the flow of diffuse pollution in this area. The Fig. 5 shows the main sources of pollution in the valley of Tafilalet.

The urbanization experienced significant changes at the oasis. Indeed, the habitat model NNNEI "Ksar" has several advantages: ecological habitat, ease of basic infrastructures installation: AEP, sanitation and electricity, and maintaining the solidarity of the population. However, the current habitat is in the "oil stain" around the Ksar: it introduced in a palm ecological disturbance factor of more threatening. A limited solely problem of sanitation is lacking completely in this type of habitat; we can measure the degree of danger to the waters of the aquifer under strain because of the widespread use of septic tanks in homes. In this work, we use the Remote Sensing and GIS to assess the impact of this phenomenal extension of urbanization in the plain of Tafilalet.

Evaluation the land cover dynamics

In this step, it is necessary to fulfill land cover classification for each time stamp determined by Landsat satellite image date. The challenge is the fact that tradi-

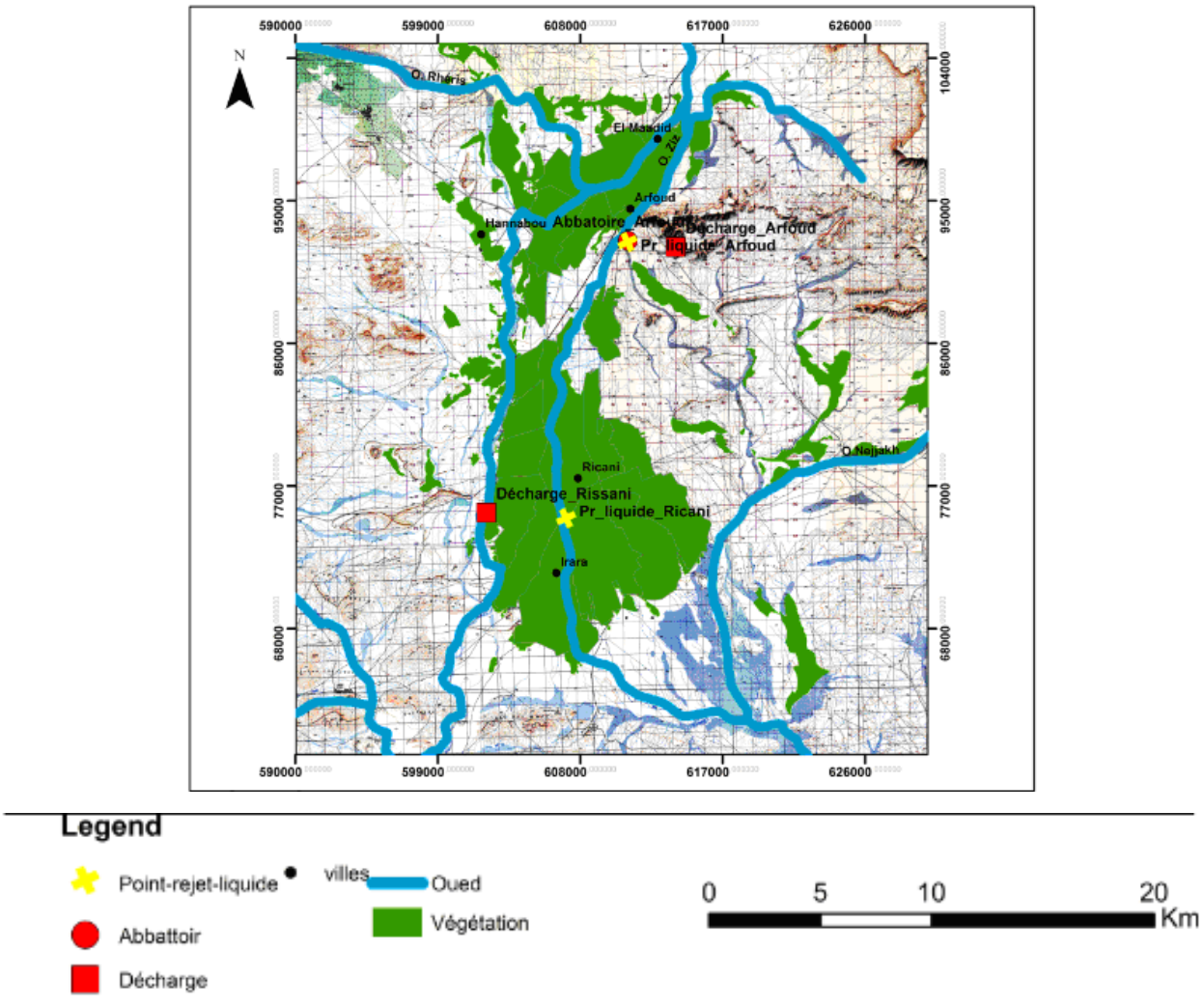


Fig. 5. Map inventory of pollution sources mapped on topographic base

tional pixel-based classification by Landsat's spectral bands is critically difficult for study area. This is especially true for detection of sparse vegetation and population settlements, because their spectral signatures are mixed significantly. Accordingly, more sophisticated classification technique rather than one based on simple spectral signature was applied. Both spectral and spatial (texture) features were used [8].

The normalized differential indices of Landsat imagery were selected as spectral features, such as the vegetative one (between the red and NIR bands), water (between green and SWIR bands) and desert soil (between blue and MWIR bands) ones. The normalized difference indices provide the complete or partial invariance of land cover features with undesirable additive and multiplicative distortions of registered optical signals. The remote sensing practice confirms high informativity of the indices set against raw spectral values [10].

The spatial features are very important for land cover classification under desert conditions. The settlement area within vegetated oasis differs from pure vegetation in texture. The same goes for the sparse vegetation on desert soil background. In this paper, the satellite image texture was characterized by variation (or more exact, by standard deviation) and by isotropic spatial contrast [6], which were calculated inside 5 × 5 sliding window averaging all 6 spectral bands.

Overall sequence of thematic processing of Landsat/TM/ETM+ multispectral satellite imagery for land cover classification is explained by Fig. 6 diagram.

Source multispectral images (a) of land surface reflectance are translated into the set of both spectral indices and texture parameters (b). These data layers are spatially consolidated in uniform multidimensional dataset, over which the statistical classification (c) already runs. Classification is done in two stages: 1) unsupervised pre-classification for the training samples determining within evident land cover classes and 2) final supervised classification to map selected land cover classes.

Results and Discussion

Frequency analysis of occurrence of dry years contributions in surface water in the study area are characterized by high variability. They can usually be 1 to 25 times the annual average. During droughts long periods, surface flows stop. However, these contributions to seasonal and inter-annual fluctuations as shown in Fig. 7.

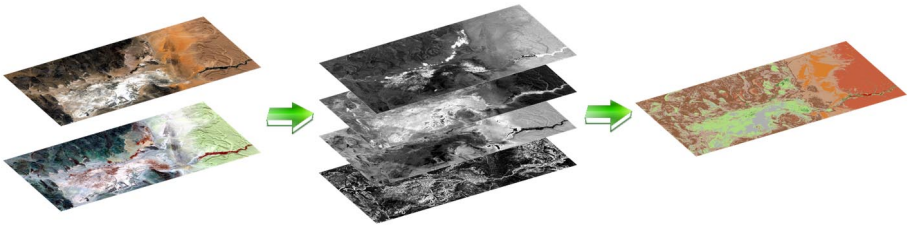


Fig. 6. Landsat satellite imagery thematic processing dataflow

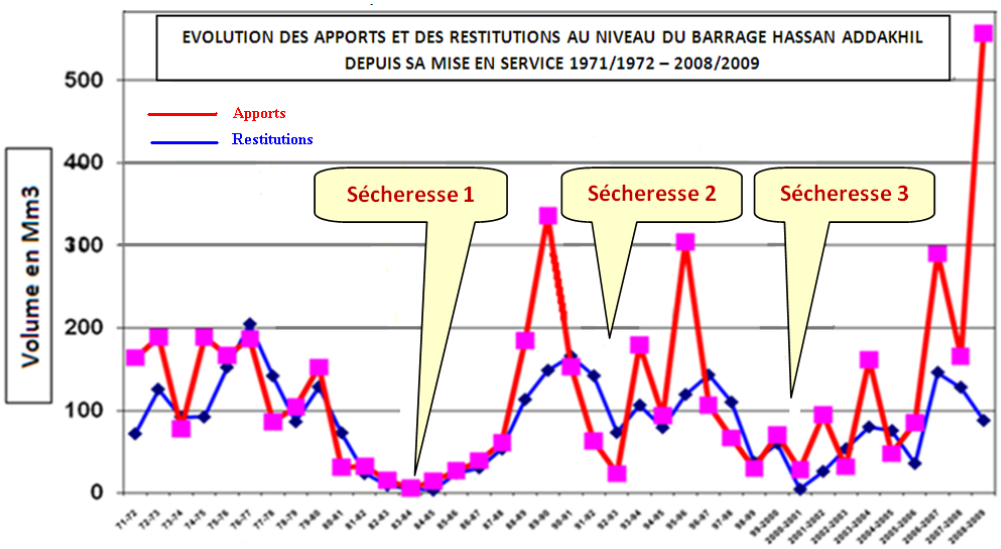


Fig. 7. Evolution of inputs and institutions of the dam Hassan Addakhil since its commissioning 1971/1971 to 2008/2009 (cycle recurrent droughts)

Online ISSN 2313-2132

Table 1. Frequency analysis of occurrence of successive dry years (1959/2009)

Period type	Number of dry years	Frequency of occurrence of a dry year
1 Year insulated dry	8	8
2 consecutive dry years	1	2
3 consecutive dry years		
4 consecutive dry years	1	4
5 consecutive dry years		
6 consecutive dry years		
7 consecutive dry years		
8 consecutive dry years		
9 consecutive dry years		
10 consecutive dry years	1	10
Total dry years		24
Total years observed		51

Table 2. Comparison with the rainfall and dam releases

Year	Volumes of releases Hassan Addakhil dam, Mm^3	Annual rainfall, *mm*
1983	0	10.7
1984	1984	86.7
...	...	...
1999		
2000	0	11.7
2001	0	38.2
...	...	...
2008	85.26	60.7
2009	39.32	185.2

Frequency analysis of occurrence of successive dry years was conducted over the period 1959/2009 by considering as dry all year where rainfall is less than 90 % of the average inter-station over the period studied. This analysis was performed on data from the raft Erfoud station.

The succession of periods of moderate drought (under three years) or severe (over four years) has an impact on the supply of groundwater resource. The resulting water problems of the effects of climate change depend on water deficit in the aquifer for severe drought farmers resort to pump groundwater to meet the needs of the palm. The Fig. 8 shows the evolution of the groundwater level in the aquifer in the center of the study area.

The Fig. 8 trend confirms the aridization in region, and most likely due to climate change.

Also the close correlation between rainfall precipitation and Hassan Addakhil dam releases is observed.

The year 1984 was characterized by lack of releases from the Hassan Addakhil dam and rainfall was very low. However, for the year 2009, the rainfall exceeds the annual average in most of the releases from the dam about 40 Mm^3.

The results of the land cover classification for multi-temporal Landsat satellite imaging (30 *m* spatial resolution) are shown in Fig. 9. The area occupied by settlements, normal (dense) vegetation and sparse vegetation was measured by multi-temporal maps of land cover classification which in Fig. 9. Percentage of said land cover classes within the images of study area are summarized in Table 3.

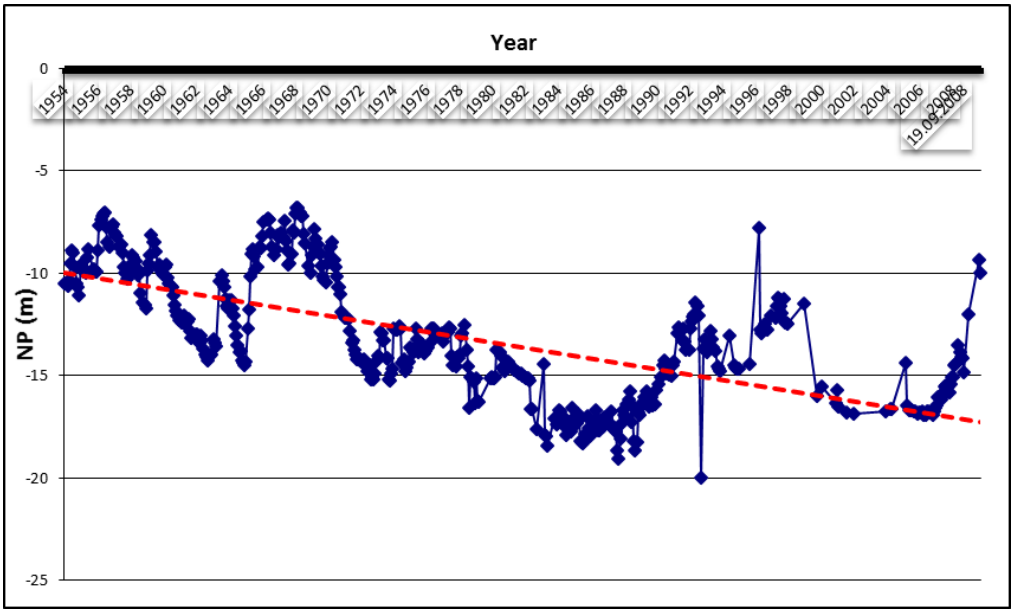
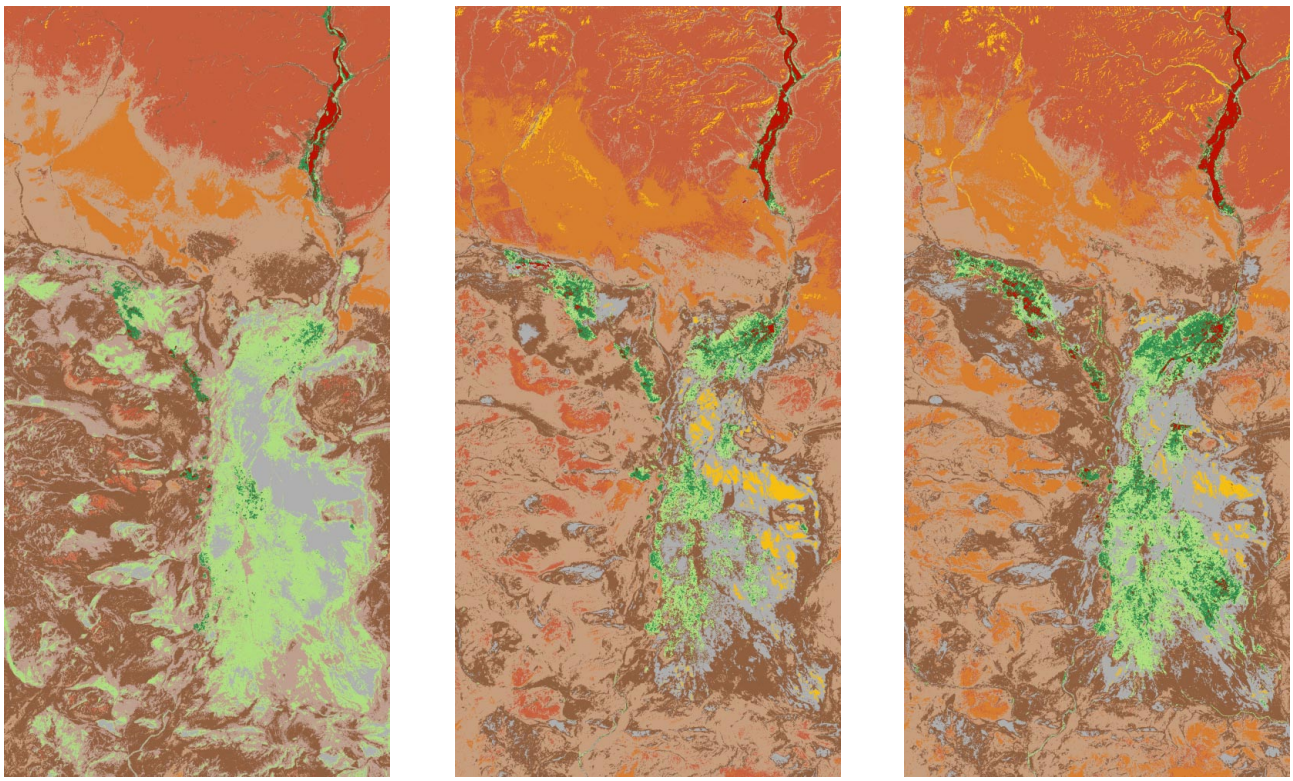


Fig. 8. Level change piezometric INE No. 446/57 of the quaternary table cloth ErfoudFigure 8 – Level change piezometric INE No. 446/57 of the quaternary table cloth Erfoud



a b c

Fig. 9. Land cover maps by Landsat multispectral satellite imagery: a – August 1984, b – August 1999, c – July 2009

Normal vegetation is concentrated in oases, in conjunction with human settlements; it is artificially cultivated, and its area increasing coupled with the growth of the settlement area. The sparse vegetation is mostly natural and it is under the anthropogenic pressure. Its area is shrinking rapidly in context of urban planning.

Field surveys have shown that the number of date-palm feet in the study area has been declining. This is the disease of Bayoud and the lack of good technical conduct of the spinneret: in fact, the soils have low organic matter content and available phosphorus content and low exchangeable potassium from North to South of the palm. Indeed, the number of date palm feet at the plain of Tafilalet (Erfoud CMV 703, Rissani and Merzouga CMV CM 705 716) in 2009 was 506 750 plants. However in 1984 it was approximately 560 000 plants. The change in NDVI shows its limitations in assessing the percentage degradation of the palm.

The plain of Tafilalet is characterized by a pre-urban urbanization that is experiencing a significant gap between urban growth and lack of basic infrastructures. This is due to the lack of land control and disrespect of texts relating to urban planning and environmental protection cause various nuisances: regression of agricultural land, development of housing and infrastructure on sites inappropriate at risk, recourse to preemptive rights [2, 14]. This urbanization affects the palm (destroying of plants palms and pollution of the water resource), the degradation of the living environment and on controlling infrastructure costs.

Conclusions

Today humanity is under the cumulative impact of both climate change and increasing anthropogenic pressure. The negative effect of these drivers is filled primarily in countries with hot and dry climate, and Morocco is one of them.

The aim of this research was to evaluate the landscape dynamics inside the plain of Tafilalet under the impacts of climate change and human activities. Climate changes were evaluated by the amount of rainfall percipitation; requested data have been received from local meteorological stations. Anthropogenic activity was assessed by classifying and geoinformation analysis of multitemporal multispectral satellite imagery. The satellite imagery thematic processing dataflow for change detection was proposed.

By a joint analysis of satellite and ground meteorological data quantitative estimates of landscape dynamics within the region of interest were obtained. These estimates may be useful in the planning of economic activity and decision-making in the region.

A clear trend was detected on significant growth of human settlement area and associated vegetation, while natural sparse vegetation area reducing. This trend most likely is the result of intense urbanization within the fragile ecosystems of desert oases, but the situation has been worsen by long-term aridization in region.

Future works should be aimed to models develop-

ing of climate change taking place on the south-eastern Morocco territory, medium-term forecasts provisioning and science-based recommendations establishing to mitigate negative consequences in socio-economic conditions.

References

1. Amharref M. Contribution to the hydrological study of the valley of the Ziz (Province of Errachidia in the south east of Morocco). The respective effects of drought and the Hassan Addakhil dam on the down-stream water resources / M. Amharref / Doctoral Thesis University of Besançon.– Besançon: University of Franche-Comté, 1991.— 232 p.
2. Ben Attou M. The new demographic aspects toward the development in the Moroccan Pre-Sahara: The case of Draa-Tafilalt / M. Ben Attou // Revue AFN Maroc, 2014.— Vol.14. — No.12.— P. 50–81.
3. Boudad L. The sedimentary formations of Pleistocene and Holocene of Tafilalet (southeastern Morocco). Géochronologie, Stratigraphie and palaeoenvironment / L. Boudad / Doctorat d'Etat en Géologie (option sédimentologie, Géologie du Quaternaire). — Meknès : Universit Moulay Ismaïl, 2004. — 270 p.
4. El Ouali A. and al. Food deep aquifers of sedimentary basins piedmont drylands their borders reliefs: Case Cretaceous aquifers basin of Errachidia (Morocco) / A. El Ouali, J. Mudry, P. Chauve, J. Mania, A. Essahlaoui, M. Marzouk, L. Eddahby // Africa Geosciences Review, 2000. — Vol.7— No.4. — P. 371–381.
5. Essahlaoui A. Integration of remote sensing and GIS in studying land cover trends and conditions in the Middle Ziz Oasis, Morocco / A. Essahlaoui, A. Mohamed, E. Lhou, F. Mohamed, L. Abdelkader // International Journal of Geosciences, 2013. — Vol.4. — No.7. — P. 1018–1023.
6. Kiema J.B.K. Texture analysis and data fusion in the extraction of topographic objects from satellite imagery / J. B. K. Kiema // International Journal of Remote Sensing, 2002.— Vol.23. — No.4. — P. 767–776.
7. Lhou E. Agriculture and salinity in the plain of Tafilalet: Evaluation of the impact of irrigation and methodological approach to water control / E. Lhou // Proceedings of the closing seminar of the development study of rural communities in semi-arid areas of Southeast Atlasic through rehabilitation khettaras in the Kingdom of Morocco. — Errachidia: JICA, ORMVA / Tf, 2005. — P. 102–25.
8. Liu D. Data field modeling and spectral-spatial feature fusion for hyperspectral data classification / D. Liu, J. Li // Sensors, 2016. — Vol. 16. — No.12. — P. 2146.
9. Margat J. Hydrogelocal stady of the quaternary basen Tafilalet / J. Margat // Water Resources in Morocco. — Rabat: Geological Survey of Morocco, 1977. — T. 3. — P. 310–380.
10. Popov M. A. Multispectral imagery normalized band-difference indexes for land cover classification / M. A. Popov, S. A. Stankevich, A. I. Sakhatsky, A. A. Kozlova // Proceedings of Digital Earth Summit on Geoinformatics 2008: Tools for Global Change Research. — Potsdam: Wichmann Verlag, 2008. — P. 333–338.
11. Popov M. A. Satellite monitoring for desertification forecasting and prevention / M. A. Popov, S. A. Stankevich, A. A. Kozlova, I. Luk'yanchuk, D. Mezzane, M. O. El Bah // Stimulus for Human and Societal Dynamics in the Prevention of Catastrophes / Ed. by A. Avagyan, D.L. Barry, W.G. Coldewey, D.W.G. Reimer.— Amsterdam: IOS Press, 2011.— P. 219–223.
12. Popov M. A. Satellite monitoring of desert oases dynamics caused by climate change / M. A. Popov, S. A. Stankevich, I. Luk'yanchuk, D. Mezzane, E. Lhou // Abstracts of 16th Ukrainian Conference on Space Research. — Odessa: Odessa Regional Institute for Public Administration, 2016. — P. 178.
13. Popov M. A. Socio-economic benefits from the prevention of desertification in Morocco and Mauritania using satellite monitoring / M. A. Popov, S. A. Stankevich, A. A. Kozlova, I. Luk'yanchuk, D. Mezzane, M. O. El Bah // Correlation between Human Factors and the Prevention of Disasters / Ed. by D. L. Barry, W. G. Coldewey, D. W. G. Reimer, D.V. Rudakov. — Amsterdam: IOS Press, 2012. — P. 3–14.
14. Study of regional layout of land the region Meknes-Tafilalet / 03 Reports. — Meknes: Regional Inspectorate of Spatial Planning, 2006. — 39, 334 and 137 p.
15. Yahyaoui M. Drought in the basin Guir Gheris and Ziz / M. Yahyaoui // Review of Water and Development, 1998. — Vol.3. — No. 5. — P. 6.

ДИСТАНЦІЙНЕ ЗОНДУВАННЯ ТА ГЕОПРОСТОРОВИЙ АНАЛІЗ ДЛЯ МОНІТОРИНГУ ДИНАМІКИ ЛАНДШАФТІВ РІВНИНИ ТАФІЛАЛЕТ (МАРОККО) ПІД ВПЛИВОМ КЛІМАТИЧНИХ ЗМІН І ДІЯЛЬНОСТІ ЛЮДИНИ

Еддабі Лоу, Тлємсані Джихан, Михайло Попов, Сергій Станкевич, Дауд Мезан, Ігор Лук'янчук, Ларабі Абделькадер, Ессалау Алі

В даному дослідженні в рамках єдиного підходу розглядається динаміка ландшафтів рівнини Тафилалет під впливом кліматичних змін і діяльності людини. Кліматичні зміни оцінюються середньорічними значеннями та середньоквадратичними відхиленнями кількості опадів на метеостанції району Ерфуд, а також ковзаючим середнім в 5-річному інтервалі. Факторами людської діяльності виступають водні стоки місць, а також міська забудова. Проаналізовано багатоспектральні космічні знімки Landsat TM (1984, 2009) та ETM+ (1999). Їх аналіз дозволив виявити динаміку ландшафтів Тафілалет під впливом як природних, так і антропогенних чинників. Одержані результати порівняно із ситуацією в оазисі Зіз.

Ключові слова: багатоспектральні космічні знімки, класифікація земних покриттів, зміни клімату, вплив людини, динаміка ландшафтів, рівнина Тафілалет (Марокко)

ДИСТАНЦИОННОЕ ЗОНДИРОВАНИЕ И ГЕОПРОСТРАНСТВЕННЫЙ АНАЛИЗ ДЛЯ МОНИТОРИНГА ДИНАМИКИ ЛАНДШАФТОВ РАВНИНЫ ТАФИЛАЛЕТ (МАРОККО) ПОД ВОЗДЕЙСТВИЕМ КЛИМАТИЧЕСКИХ ИЗМЕНЕНИЙ И ДЕЯТЕЛЬНОСТИ ЧЕЛОВЕКА

Эддаби Лоу, Тлемсани Джихан, Михаил Попов, Сергей Станкевич, Дауд Мезан, Игорь Лукьянчук, Лараби Абделькадер, Эссалау Али

В данном исследовании в рамках единого подхода рассматривается динамика ландшафтов равнины Тафилалет под воздействием климатических изменений и деятельности человека. Климатические изменения оцениваются среднегодовыми значениями и среднеквадратическими отклонениями количества осадков на метеостанции района Эрфуд, а также скользящим средним в 5-летнем интервале. Факторами человеческой деятельности выступают водные стоки городов, а также городское строительство. Проанализированы многоспектральные космические снимки Landsat TM (1984, 2009) и ETM+ (1999). Их анализ позволил выявить динамику ландшафтов Тафилалет под воздействием как природных, так и антропогенных причин. Полученные результаты сравнивались с ситуацией в оазисе Зиз.

Ключевые слова: многоспектральные космические снимки, классификация земных покрытий, изменения климата, воздействие человека, динамика ландшафтов, равнина Тафилалет (Марокко)