EFFECTS OF LAND USE CHANGE ON THE RIPARIAN ZONES' QUALITY ALONG THE ZAT RIVER AND ITS TRIBUTARIES: HIGH ATLAS OF MOROCCO

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Abstract. This study was conducted to assess the quality of riparian zones of Zat basin of Morocco by using the QBR index, and to analyze land use changes over 30 years along the Zat River and its tributaries by using remote sensing and Geographic Information System. Five land use/land cover classes were identified: Forest, building area, water, bare soil, and agricultural land using Landsat images. Also, the QBR index was evaluated in 14 localities distributed along the Zat River and its tributaries from 2018-2019. For instance, the total forest area was reduced from 959.07 ha (15.35%) in 1990 to 890.41 ha (14.25%) and 713.25 ha (11.41%) in 2005 and 2020, respectively. Whereas agricultural land and building area classes increased with an estimated rate of change of 24.99% and 33.81% respectively over the last 30 years. Furthermore, our results indicate that 35.7% of the banks in the riparian zone are of very poor quality, 14.3% of poor quality, 28.6% of average quality and 21.4% of good quality. The finding demonstrates that the low QBR score obtained by some sampling localities especially downstream is the result of multiple anthropogenic interventions in riparian ecosystems, including forest plantations, land use for agriculture, and road infrastructures.
Keywords: *QBR index, LULC changes, riparian vegetation, remote sensing, Zat basin, Morocco*

Introduction

The riparian forest also called "riparian buffer" corresponds to the transition zone between the aquatic and terrestrial environments. It is composed of a group of trees, shrubs, and herbaceous plants and its main role is to maintain water quality (Naiman and Decamps, 1997; Bertoldi et al., 2011). Due to its filtration capacity, the riparian buffer strip performs many functions: it contributes to the reduction of non-point pollution of surface water by reducing the nutrient and sediment load of runoff from agricultural land, it serves as a refuge for biodiversity (fauna and flora), and it also provides protection against erosion and limits the rate of evaporation (Pusey and Arthington, 2003; Stevaux et al., 2012). In addition to its ecological, remediation, and protection functions, it also plays a very essential role in maintaining the integrity and aesthetics of the landscape (Naiman and Decamps, 1997). One of the characteristics of riparian strips is the edge vegetation (Ripisylves) which, in addition to its role in structuring landscapes, through its root system, serves to stabilize the banks and provide refuge areas for wildlife (Ater et al., 2008; Naiman and Decamps, 1997).

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However, changes in the use of land surrounding water bodies and pollution have had a deep impact on the functionality of riparian ecosystems (Jetz et al., 2007). These changes lead to modification in species richness, species composition, and species relative abundance (Pereira et al., 2012), and may also lead to the introduction of exotic plant species (Hood and Naiman, 2000; Richardson et al., 2007) which can cause the extinction of local plant species, which have severely degraded their structure and ecological function (Cushing et al., 1995; Nilsson and Berggren, 2000; Hughes and Rood, 2003).

Since it plays an essential role in maintaining the integrity of a hydro system, there is undoubtedly a need for methods to guide managers in maintaining and restoring these complex systems. The development of methods to quickly and effectively assess the ecological status of riparian ecosystems has received a great deal of attention in recent times, and it is on this basis that sampling techniques and methods have been developed by several researchers to assess the biological and ecological quality of riparian strips (Stella et al., 2013; Valero et al., 2014).

The QBR ("riparian forest quality") index, proposed by Munné et al. (2003), is currently the most widely used measure for riverbank analysis; it is used to describe the quality of in situ vegetation. The QBR index is useful for assessing riparian forest quality and the degree of bank alteration in four distinct components; three of these are based on the characteristics of riparian vegetation (cover, structure, and nature), while the fourth refers to changes in the river channel (Munné et al., 2003).

The QBR index has already been tested in Mediterranean streams (Gonzalez del Tanago and Anton, 1998; Prat et al., 1999; Carrascosa and Munné, 2000; Suarez and Vidal Abarca, 2000; Martinez and Lozano, 2004; Gonzalez del Tanago et al., 2006; Gonzalez del Tanago et al., 2010; Stella et al., 2013) with good results. In Morocco, the studies on riparian zones are those carried out by Ater et al. (2008), which focused on the structure and diversity of riparian zones and how they constitute a refuge for the avifauna in the Laou River. Another example is Ennabili (1999) who studied the ecology and context of hygrophilous vegetation and its role in wastewater treatment. Similarly, Ater et al. (2008) and Khamlichi et al. (2008) studied riparian or riverine vegetation in the Laou and Tahddart basins respectively to highlight the structure and diversity of riparian vegetation.

Like other Moroccan river systems, the Zat basin has undergone several changes in time and space, including deforestation, the elimination of natural vegetation in favor of cultivated areas, overgrazing, and the occurrence of natural disasters; As a result, the water resources of the rivers of Zat and its tributaries are being depleted day after day (Mostakim et al., 2021; AHT Group, 2016; Ait Mlouk et al., 2015). The Zat basin has been the subject of several sectoral and/or localized studies (Mostakim et al., 2021; Mostakim et al., 2020; Ait Mlouk et al., 2015), however, little is known about the chronological trend of Land Use Land Cover (LULC) in the Zat basin and assessment of riparian zone quality using QBR index. Based on the landscape of this area, the LULC assessment is carried out on the following five categories, namely: Building (all land covered by infrastructure), Water Body (all surface water areas), Vegetation (area covered by deciduous or coniferous woody vegetation), Agricultural Land (land used for the production of agricultural products) and Bare Soil (non-forested, non-agricultural land). This study considered 1990 as the base year and examined LULC from 1990 to 2020 to assess the trend of change over the past 30 years.

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This paper attempts to improve thematic knowledge on changes in land use and landscape structures and to describe the ecological status of riparian zones in Zat basin, using the QBR index and to analyze how the quality of riparian vegetation and the species composition is related with altitude, species richness, and proportion of exotic species of the study area.

Materials and methods

Study area

The study was carried out in the Zat basin in High Atlas of Morocco (*Fig. 1*), it is part of the hydraulic system of the Tensift watershed, between 31° 17’ and 31° 32’ North and 07° 29’ and 07° 34’ West. It is drained by the Zat River with a length of 89 km, which has its source at the foot of Taska n’Zat (3905 m) on the right bank and Tougroudaden (3736 m) on the left bank and drains a catchment area of about 525 km². The surface area of the riparian zones is approximately 62.47 km² (*Fig. 1*).

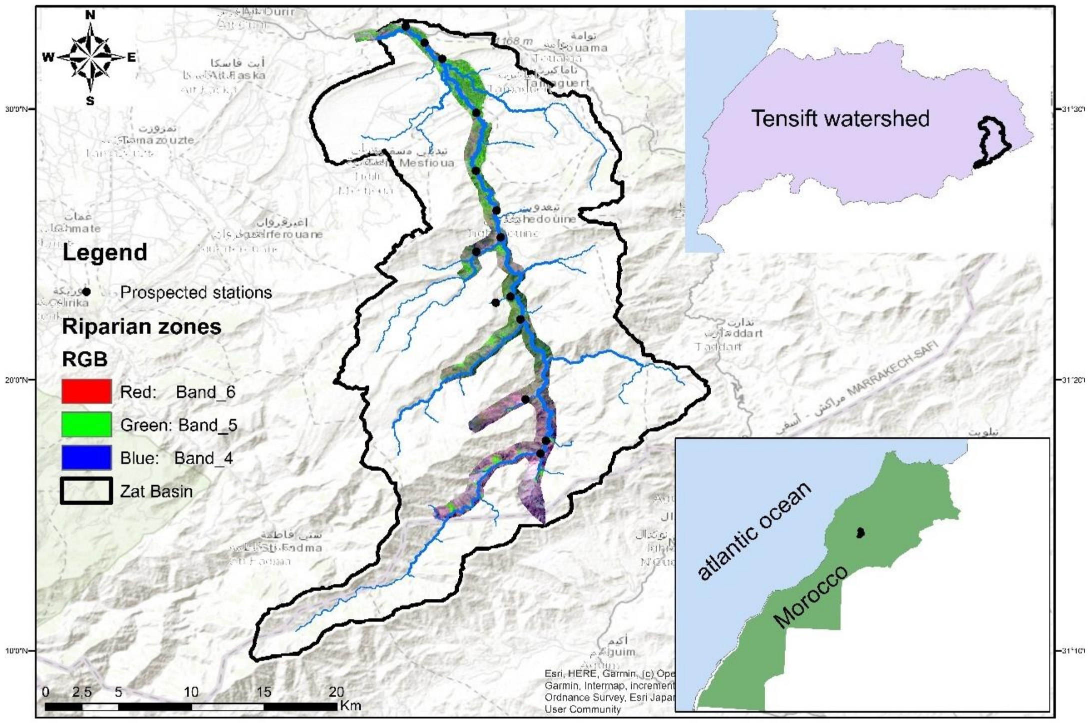

Figure 1. *Geographic location of sampling localities of riparian zones of Zat basin*

The Zat basin is bounded to the east by the Ghdat sub-Basin, to the south by the High Atlas Mountains, to the north by the Tensift watershed, and to the west by the Ourika sub-Basin (*Fig. 1*). It is characterized by an arid to semi-arid climate downstream and sub-humid in the high mountains (Ait Mlouk et al., 2015). The type of climate in this region is Mediterranean with a cold and rainy winter (average annual rainfall of 382 mm) from October to April and a hot and dry summer (5.2-37.1 °C) from May to September (Lovich et al., 2010; AHT Group, 2016). It is a perennial mountain stream, largely fed by snowmelt, with a pebble substrate. Clearwater supports dense accumulations of filamentous algae on the bedrock substrate (Lovich et al., 2010).

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Sampling

Data acquisition and image processing

The data used for the Zat basin consist of Landsat satellite images and GPS data collected during fieldwork, these Landsat images are an important tool in land use mapping and resource planning and management, they are descriptive and provide spatial and spectral information, much more important than other sources of information (Uddin and Gurung, 2010). Multi-date Landsat images from 1990, 2005 and 2020 (*Table 1*) captured by satellite and downloaded from the USGS (United States Geological Survey; (http://earthexplorer.usgs.gov/) website by selecting those with the least disturbance, including cloud cover. The period of time when the images were taken was also taken into account in order to be able to make an effective comparison between the different dates. Since the site is often swampy and flooded during the rainy season and dry in summer, priority was given to satellite images taken during the summer season (July and August) to visualize the different land uses. Image data were used to generate the LULC for the study period.

Table 1. *Satellite data specification*

Satellite	Sensor	Path/Row	Year of acquisition	Spectral bands	Resolution
Landsat-1	MSS	146/44	15/4/1990	G, R, NIR, 4,5,6,7	60 + m
Landsat-5	ETM +	136/44	26/4/2005	G, R, NIR, 2,3,4,	30 m
Landsat-8	OLI	136/44	02/5/2020	G, R, NIR, Panchromatic, 3,4,5,8	30 m (For Panchromatic 15)

Image processing and classification

For image processing and supervised classification of satellite images, we have performed radiometric calibration of the sensor and atmospheric corrections of our images. These operations were carried out by combining them in a single step to preserve radiometric integrity (Maimouni et al., 2011). Sensor calibration allows the conversion of the digital number (DN) to visible luminance to correct sensor-specific anomalies and to obtain accurate, reliable, and precise information (Uddin and Gurung, 2010). The calibration coefficients published in the metadata file were used for each image. This apparent luminance was then transformed into apparent reflectance by introducing the solar illuminance, the angle of incidence, and the "Sun-Earth" distance. In the latter case, we convert the apparent reflectance into ground reflectance using the parameters of the acquisition date, solar zenith angle, atmospheric model, aerosol model, and ground visibility (Uddin and Gurung, 2010; Chowdhury, 2018). Next, all satellite data were studied by assigning pixel signatures in ArcGis 10.2.2. The entire area of the Zat basin was differentiated into five classes: building area, forest, agriculture land, water body, and bare soil, which are described in *Table 2*.

Table 2*. Classes delineated based on supervised classification of Landsat image.*

Class name	Description
Building area	Areas designated as residential, commercial, industrial, scattered rural settlements with forests, roads and transportation
Water	Rivers, lakes, ponds and reservoirs, as well as wetlands in the wet season and dry areas in the dry season, perennial wetlands and riparian vegetation
Forest	Areas covered with natural and planted trees
Agriculture land	Cultivated fields and fallow land
Bare soil	Exposed soil and barren area

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Land use/cover changes

After classifying the images, the geographic extent in terms of hectares for the land use and land cover class was calculated for each period mentioned and the magnitude of the change in land use type during and between periods was compared. The change in the different land use and land cover classes was carried out using ArcGIS 10.2.2 software and finally, the following calculation was used to find out the rate of change in hectares/year and the percentage share of each class in the periods studied.

$$\Delta A(\%) = \frac{At2 - At1}{At1} \times 100 \quad \text{(Eq.1)}$$

where: ΔA(%) = percentage change in the area of land use and land cover class type between initial time At1 and period At2 At1 = area of land use and land cover type at initial time At 2 = area of LULC type at final time As stated by Abate (2011) the rate of change of LULC type was calculated by the following formula:

$$R\Delta(ha/year) = (Z - X)/W \quad \text{(Eq.2)}$$

where: RΔ = rate of change Z = recent area of LULC type in ha X = previous area of LULC type in ha W = time between Z and X in years.

QBR index

The QBR index (Munné et al., 1998a, b, 2003) was applied, without modification, to assess the condition and the quality of riparian vegetation in both streams of 14 localities distributed along the Zat River and its tributaries from 2018-2019. This index focuses on four fundamental aspects of riparian systems: (1) the degree of vegetation cover, (2) vegetation structure, (3) vegetation cover quality, and (4) the degree of naturalness of the river channel. Vegetation cover assesses the connectivity between the riparian zone and adjacent terrestrial ecosystems by considering the percentage of tree, shrub and helophyte cover, in conjunction with the connection to the adjacent terrestrial community. Vegetation structure assesses the structural complexity of the riparian ecosystem, considering that environmental heterogeneity can increase its biodiversity. To evaluate it, the percentage of presence of each functional group and the presence of plantations and isolated plots in the riparian zone were taken into account. The quality of the vegetation allows us to determine the naturalness of the plant formations present, which is assessed based on the number of native species in the sampling area and depends on the geomorphological type of the riparian zone. The determination of plant composition was carried out according to the European standard for the study of macrophytes in rivers (Känel et al., 2017).

The degree of naturalness of the river channel has mainly taken into account anthropogenic modifications to the bed, those that modify, alter and disturb the riparian habitat. Each section was assessed independently at each sampling locality, with a score from 0 to 25, and the sum of the scores of the four sections fluctuated between 0 and 100, each aspect is initially scored with one of four values: 0, 5, 10 or 25; intermediate values cannot be scored.

The resulting quality values are divided into five ranges: very good quality, natural condition (QBR ≥ 90); good quality, slightly disturbed vegetation (QBR 75-90); intermediate quality, significant alteration (QBR 55-70); poor quality, significant

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alteration (QBR 30-50); and poor quality, extreme degradation (QBR ≤ 25). To calculate the QBR index, a 100 m long section (with an average separation of 1 km) was selected at each sampling station, and the full potential width of the forest and/or riparian vegetation was taken into account. It is the sum of four scores, based on four aspects of riparian quality (Munné et al., 2003).

Statistical analysis

All the sampled localities were ranked using the value of QBR index, considered as an indicator of the conservation status of riparian forests. We evaluated whether riparian forests with less exotic species, higher species richness, and higher altitudes had a more suitable conservation status. For this purpose, we performed Pearson correlations between QBR and plant species richness, percentage of exotic species, and altitude. This statistical analysis is to evaluate whether any of them have more influence or better explains the variations in the quality of the banks.

Results

Land use/cover change detection from the year 1990-2005

The dynamics of land use in the Zat basin between 1990 and 2005 show a strong anthropization of natural ecosystems. *Table 3* shows that the area of forest ecosystems has considerably decreased by -7.16%, from more than 959.07 ha in 1990 to less than 890.41 ha in 2005. An important part of these plant formations has been transformed into agricultural fields and building areas which respectively occupy an area of 1340.63 ha and 1898.56 ha of the riparian zones in 2005. On the other hand, the water class experienced a negative change with a rate of change of -44.76% and an average annual change of -27.35 ha/year (*Fig. 2)*.

Table 3. *Land use change assessment of Zat basin of Morocco over the last 30 years*

Classes of land use/land cover	**1990**		**2005**		**2020**	
	Area (ha)	**Coverage rate (%)**	**Area (ha)**	**Coverage rate (%)**	**Superficie (ha)**	**Coverage rate (%)**
Forest	959.07	15.3509	890.41	14.2520	713.25	11.4163
Agriculture lands	1030.96	16.5016	1340.63	21.4582	1561.63	24.9956
Build up area	1728.13	27.6606	1898.56	30.3885	2112.22	33.8083
Bare soil	1612.74	25.8136	1611.56	25.7947	1342.01	21.4803
Water	916.73	14.6732	506.36	8.1048	517.63	8.2852
Riparian zones	6247.63	100	6247.63	100	6247.63	100

Land use/cover change detection from the year 2005-2020

From 2005 to 2020, there is a significant decline in forest class with a rate of -19.90% (*Table 3*). The average annual evolution of the forest class is -11.81 ha/year, it has been mainly replaced by agriculture. During this period, the share of bare soil also decreased significantly, with an average annual change of -17.96 ha/year, i.e. a rate of change of -16.72% compared to the previous period, and was mainly converted to agriculture and urban construction, the latter two experiencing respectively an average

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annual change of 14.73 ha/year and 14.29 ha/year, i.e. a rate of change of 16.48% and 11.29%. The category that was mainly changed in 2005 is that of the forest. There was a decrease in the share of forest ecosystems from -7.16% to -19.90%, with an average of -11.81 ha/year (*Fig. 2*).

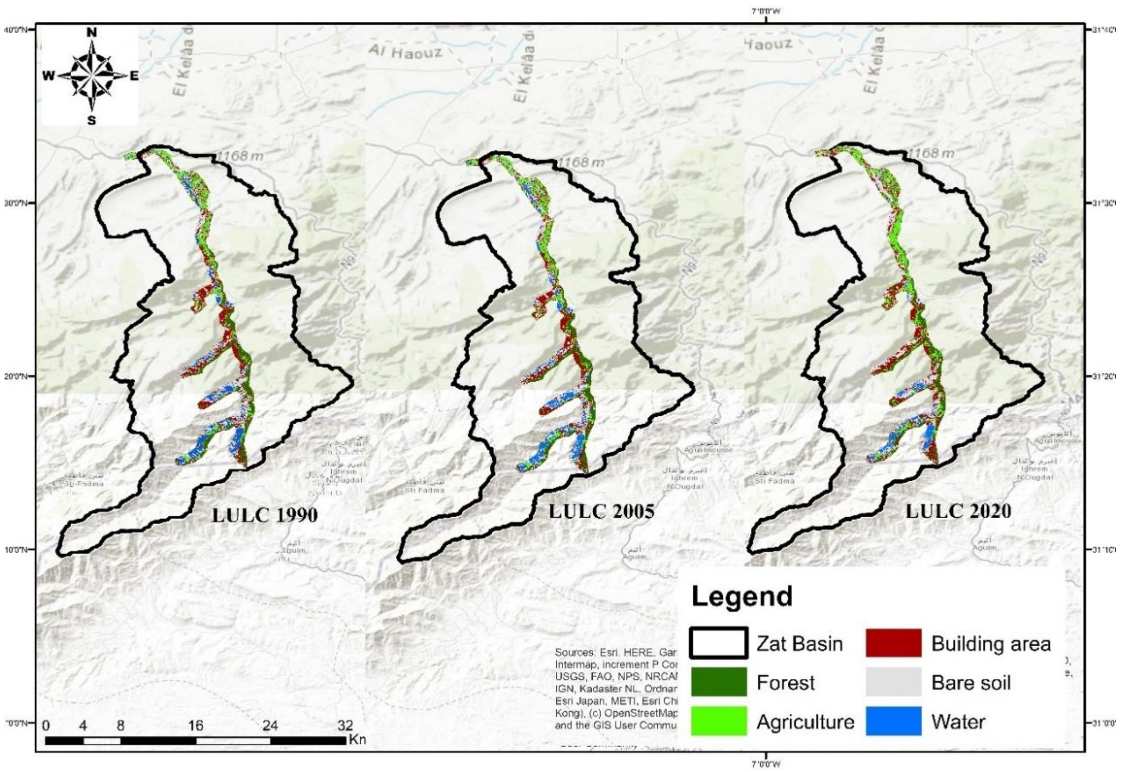

Figure 2. *Relative changes in Land use/Land cover of riparian zones in Zat basin of Morocco between 1990 and 2020*

Land use/cover change detection from the year 1990-2020

An overall comparison of each LULC class from 1990 and 2020 shows that there has been a considerable change over the past 30 years. Over this period, the forest and bare soil class in the riparian zones have decreased by -25.63% and -16.78% respectively (*Fig. 2*), with an average annual change of -8.19 ha and -9.02 ha. While the agricultural and urban land class have increased significantly over the last 30 years with an estimated rate of change of 51.47% and 22.26% respectively, equivalent to an average annual change of 17.69 ha and 12.82 ha (*Fig. 3*).

QBR index

The results obtained indicate that the QBR value of the Zat River and its tributaries ranged from 15 to 85 (*Table 4*). Approximately 35.7% (5 localities) of the all the sampled localities are with extreme degradation and worst Quality (including QBR index ≤ 25), 14.3% (2 localities) with strong alteration, and poor quality. However, 28.6% (4) of the study areas are of “Fair Quality” and almost 21.4% (3 localities) stations are of “Good Quality” (75 < QBR Index ≤ 90) (*Fig. 4*). It should be noted that there is no locality with natural habitat characteristics, i.e., with a QBR index ≥ 95.

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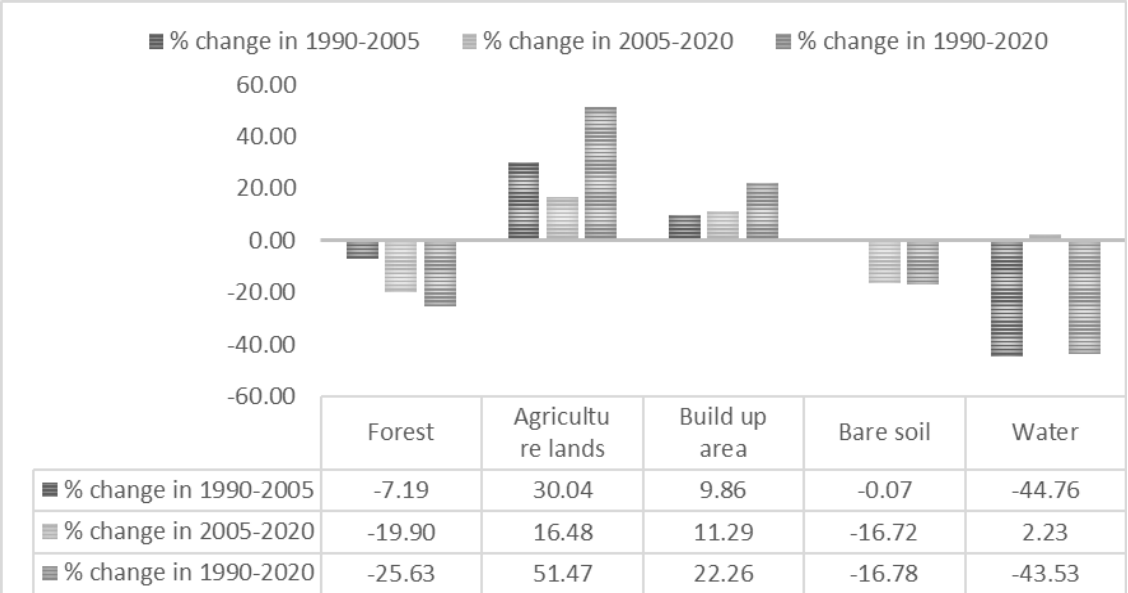

Figure 3. *Relative changes in Land use/Land cover of Za basin of Morocco over the last 30 years between 1990 and 2020*

Table 4. *Coordinate system, Elevation, percentage of native and exotic species collected, and QBR index score of each sampled localities of Zat basin of Morocco*

N° of station	Name	Coordinate system (X-Y)		Elevation (m)	% of native species	% of exotic species	Specific richness	QBR score
		Latitude (Y)	Longitude (X)					
1	Tafriat	31°32’38.81”N	7°35’53.51”W	733	20	80	11	15
2	Talbanine	31°32’54.18”N	7°35’1.20”W	746	24	76	13	20
3	Imin tghrist	31°31’51.2” N	7°33’43.8” W	819	60	40	18	35
4	Timzilite	31°29’51.68”N	7°32’27.98”W	850	40	60	12	20
5	Tassourte	31°27’43.33”N	7°32’28.73”W	965	35	65	13	20
6	Igherm Melloulne	31°26’14.9” N	7°31’42.6” W	1043	86	14	23	35
7	Tighadouine	31°25’15.7” N	7°31’33.5” W	1038	73	27	25	20
8	Tamal	31°24’43.7” N	7°32’27.9” W	1149	100	0	19	60
9	Ait slimane	31°22’13.98”N	7°30’49.80”W	1245	89	11	17	55
10	Yagour 1	31°23’4.54”N	7°31’11.90”W	1953	90	10	15	75
11	Yagour 2	31°22’51.01”N	7°31’44.52”W	2120	100	0	18	85
12	Ikkis	31°19’7.07”N	7°30’49.14”O	1456	96	4	23	80
13	Tizart	31°17’44.97”N	7°29’53.08”W	1520	80	20	19	55
14	Wansa	31°17’16.7”N	7°30’5.00” W	1430	78	22	17	55

Stations of “very poor quality” (QBR < 25) (1, 2, 4, 5 and 7) are mostly characterized by low vegetation cover on both the right and left sides of the shoreline, and poor connectivity between the riparian zone and adjacent terrestrial ecosystems, these localities also showed the poor quality of structure and cover, indeed these localities were marked by the non-negligible presence of exotic plant species such as *Nicotiana glauca* L. *Ricinus communis* L. *Fraxinus angustifolia* L. and *Dittrichia viscosa* L.).

Also, the localities with poor QBR quality (3 and 6) are marked by low tree cover on both banks of the creek with slight connectivity between the different strata, and poor

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quality of cover structure due to the presence of human and agricultural activities, as well as the localities with the lowest quality, we evaluated in these two stations the presence of exotic plants such as *Fraxinus angustifolia* and *Phragmite australis*, which affect the quality of the creek cover.

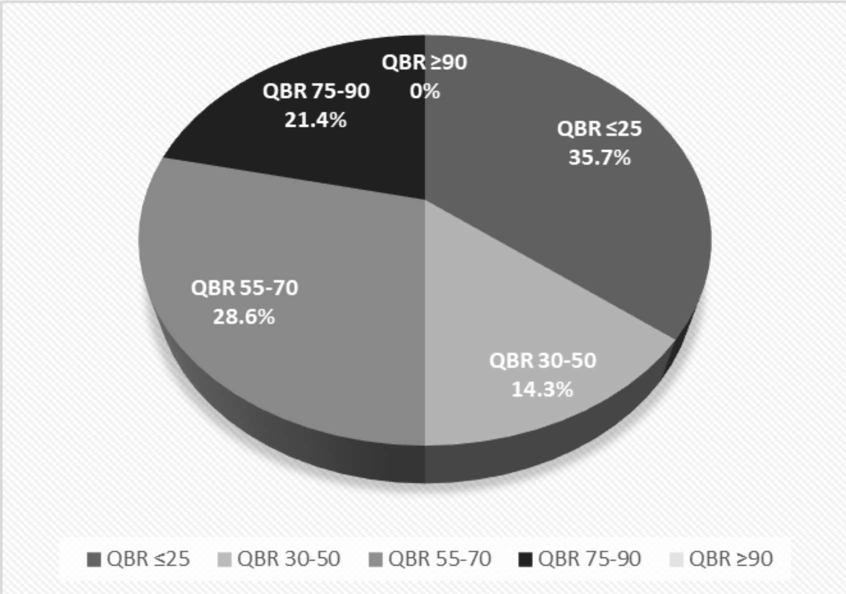

Figure 4. *Percentage of sampling localities over the total number sampled in each quality class according to the QBR index*

Then, the localities (8,9,13, and 14) with average QBR quality, (50 < QBR-index < 70) are characterized by an average vegetation cover and show alterations in the river (and its surroundings) such as the presence of roads, retaining walls for flood protection, and are marked by the presence of arboriculture and planted crops (*Ficus carica* L. and *Juglans regia* L.) in the riverside vegetation as well as dwellings on the river terraces.

Finally, the localities with a QBR value > 75 (10, 11, and 12), are the best in terms of the quality index (good quality) and have good vegetation cover in terms of quality, structure, and unmodified river channels on the left and right sides of the bank. They are located upstream of the river (higher altitudes). This area is an important reservoir of native riparian vegetation, acting as a buffer against increasing anthropogenic threats.

Significant alterations were identified in the quality of riparian vegetation using the QBR index, species richness, and the rate of exotic plants. Our results indicated that there is a significant correlation between the QBR index and altitude ($r = 0.72$, $N = 14$, $p = 0.01$) (*Table 5*), and the percentage of exotic plants ($r = -0.71$, $N = 14$, $p = 0.001$). We also obtained a non-significant correlation between the QBR index and the species richness of aquatic plants ($r = 0.40$, $N = 14$, $p = 0.01$).

Discussion

The results of this study investigate the effect of land use/land cover changes on the quality of riparian zones, particularly in the Zat basin in Morocco. This change has a negative impact on water resources throughout the watershed. The surrounding land

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cover change had a significant impact on both suspended solid and nitrate nitrogen loadings (Chu et al., 2013; Ding et al., 2015). Furthermore, Schilling et al. (2010) and Adusumilli et al. (2011) showed that agricultural activities have an important impact on the quality of the water more than climate change. So, the increasing of agricultural activities and settlements within Zat basin is a matter of great concern.

Table 5. *Pearson correlation coefficients matrix between the QBR index and variables "Elevation; % of native and exotic species, and specific richness" of study area*

	Elevation (m)	% of native species	% of exotic species	Specific richness	QBR score
Elevation (m)	1				
% of native species	0.71549	1			
% of exotic species	-0.71549	-1	1		
Specific richness	0.20028	0.66771	-0.66771	1	
QBR score	0.88206	0.81404	-0.81404	0.25068	1

Moreover, our results indicated that there is a significant correlation between the QBR index and altitude, and the percentage of exotic plants. This result is in agreement with other studies (Carrascosa Gómez and Munné, 2000; Suárez and Vidal-Abarca, 2000; Sirombra and Mesa, 2012) showing the increase in bank quality in high altitude sites due to the greater distance from urban areas and the inaccessibility of these places. In addition, this relationship was not as strong as we had expected, and this was related to the lower QBR value at higher altitude sites in Zat basin such as Tizart and wansa. The distance of these sites from urban areas explains the lower quality of the riparian strips at these stations.

In addition, the low QBR score obtained by some sampling localities located downstream of the Zat basin is the result of multiple anthropogenic interventions in riparian ecosystems, including land use for agriculture, road infrastructure and the abundance of invasive alien species such as (e.g. *Nicotiana glauca* L., *Ricinus communis* L., *Fraxinus angustiolia* and *Dittrichia viscosa* L.). The results published by Tüzün and Albaryrak (2005) and Valero et al. (2014) indicate that the areas classified as lower QBR correspond to those closest to human settlements and road infrastructure, which is consistent with the situation observed in this study, since the proximity of riparian ecosystems to population, productive land uses and corresponding road infrastructure leads to the modification and fragmentation of riparian habitats, resulting in low QBR scores.

During the study, agriculture was found to be the predominant activity observed in the riparian zone of the surveyed localities. According to the latest censuses by the Department of Agriculture of Morocco (2013) (AHT Group, 2016), the surface area of the Zat basin (512 km²), covers approximately 186 km² of agricultural area, which represents 35% of the total surface area. In addition, the riparian cover in the study area was subject of high degradation due to different varieties of crops that have been cultivated on both banks of the rivers. This leads to the introduction of exotic plants, which displace native species, altering their capacity for regeneration and dispersal. We have identified in this study, 54 species, represented by 51 genera and 31 families. 75.93% of the identified species were native (*Table A1* in the *Appendix*), while 24.07% of the species were non-native (Taleb et Bouhache, 2006). As well as influencing the wildlife living in these ecological corridors. The same finding was made for Chandni

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Nalla by Chaurasia et al. (2015) and the Bhahner River by Bahsir et al. (2015). The predominance of agricultural practices on both banks of Chandni Nalla was also reported by War et al. (2014). It is responsible of soil erosion and the ecological degradation of the river.

Conclusion and recommendation

The study was carried out on the quality of the riparian zones of the Zat River and its tributaries using the QBR index in order to know the current state of the riparian vegetation and to identify the different areas that are most affected and that deserve special attention. Although the study was not carried out on all sections of the sub-Basin, due to the limited accessibility in some sections of the rivers, in these cases we suggested that the QBR index be complemented by spatial analysis tools, namely geographic information systems (GIS) and remote sensing, which make it possible to deduce the ecological characteristics of riparian areas. The results of this study showed that at some stations where the QBR index was low, there was a high abundance of infrastructure and crop fields, rock removal for building construction, and an abundance of exotic plants. Therefore, proper attention should be given to the restoration and management of the riparian area of the studied river. However, these assessment tools should be used in conjunction with biological and physico-chemical assessments to ensure a clear understanding of the status of riparian ecosystems. The development of a multi-metric index capable of assessing the entire ecosystem in a single value would be of great interest for future research.

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APPENDIX

Table A1. *List of identified taxa, indicating origin of Arboreal, shrub and herbaceous species present in the riparian zones of Zat River and its tributaries*

Taxa	Origin (Taleb and Bouhache 2006)	Taxa	Origin (Taleb and Bouhache 2006)
Pistacia lentiscus L.	Native	*Cistus salviifolius* L.	Native
Nerium oleander L.	Native	*Euphorbia hirsuta* L.	Native
Ricinus communis L.	Non-Native	*Astragalus caprinus* L.	Native
Retama monosperma L.	Native	*Mentha longifolia* (L.) Hudson.	Native
Quercus ilex L.	Native	*Mentha retondifolia* L.	Native
Juglans regia L.	Native	*Mentha pulegium* L.	Native
Ficus carica L.	Native	*Lavendula multifida* L.	Native
Fraxinus angustifolia Vahl.	Non-Native	*Marrubium vulgare* L.	Non-Native
Olea europea. L.	Native	*Scrophulaira auriculata* L.	Native
Ziziphus lotus L.	Native	*Hyoscyamus albus* L.	Non-Native
Rubus ulmifolius Schott.	Native	*Ononis repens* L.	Native
Rosa sempervirens L.	Non-Native	*Convolvulus althaeoides* L.	Native
Populus alba L.	Native	*Frankenia laevis* L.	Native
Populus nigra L.	Native	*Potentilla reptans* L.	Native
Salix purpurea L.	Non-Native	*Juniperus oxycedrus* L.	Native
Salix pedicellata L.	Native	*Oppentium ficus-indica* L.	Non Native
Tamarix africana L.	Native	*Juncus acutus* L.	Native
Nicotiana glauca L.	Non-Native	*Phragmites australis* L.	Non-Native
Phoenicum vulgare L.	Native	*Typha angustifolia* L.	Native
Asphodilus microcarpus L.	Native	*Launea arborescens* L.	Native
Asparagus horridus L.	Native	*Phoenicum vulgare* L.	Native
Dittrichia viscosa L.	Non-Native	*Verbascum sinuatum* L.	Non-Native
Atriplex halimus L.	Native	*Astragalus caprinus* L.	Native
Onopordum arenarium	Non-Native	*Arundo donax* L.	Native
Cistus monosplensis L.	Native	*Polygala balansa* Cosson	Native
Euphorbia hursita L.	Native	*Scolymus hispanicus* L.	Non-Native
Ononis natrix L.	Native	*Thymus satureioides* Cosson	Native

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Figure A1. *Riparian zone in Downstream of Zat River (S4) showed the implantation of buildup and agriculture land*

Figure A2. *Talbanine station (S2) located in downstream of Zat River showed the presence de agriculture land*

Figure A3. *Tafriat station (S1) located in downstream of Zat basin*

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Figure A4. *Tighadouine station (S7) present the implantation of building area in riparian zone*

Figure A5. *Igherm melloulne station (S6) located in upstream of Zat basin*

Figure A6. *Ait Slimane station (S9) located in upstream of Zat basin*

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Figure A7. *Tizart station (S13) located in upstream of Zat basin*

Figure A8. *Ikkis station (S12) located in upstream of Zat basin*

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