Time-tracking of the natural and anthropogenic metals input into the Oualidia-Sidi Moussa lagoonal complex, Morocco

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Abstract: The present work aims to track the natural and anthropogenic metals input into the lagoonal complex of the Oualidia-Sidi Moussa and assess their sediment quality by applying the International sediment quality guidelines. We compared the concentrations of metals (Cu, Cr, As, Zn, Ni and Pb) measured in the sediment of the lagoonal complex of the Oualidia-Sidi Moussa between 1976 and 2017 with a range of sediments quality guidelines values. The comparison showed a decreasing trend of metals concentration in the last decade in the Oualidia lagoon except for As, Cr and Cd. Similarly, Cd and Cr displayed higher concentrations exceeding the threshold effect level values signifying possible toxic risk for marine biota living in the Sidi Moussa lagoon.

Keywords: Oualidia lagoon, Sidi Moussa lagoon, sediment, S.Q.G., pollution assessment.

1. Introduction

Coastal lagoons are vital and productive ecosystems which provide many services, goods and resources to human welfare. The biodiversity richness of these ecosystems plays an important role in local economies. Nevertheless, the growth of human activities in these ecosystems negatively impacts these ecosystems' environmental health.

Many studies on the coastal lagoon were carried out, which were mainly focused on their biology (MEJJAD et al., 2020a; MONIQUE et al., 2021), morphology (JAUBET et al., 2021; BRUNEAU et al., 2011, ZONTA et al., 2007), hydrology (BEHRENS et al., 2015; ELSHINNAWY et al., 2021) and ecological classification. Whereas, in the last two decades, almost all studies are focused on evaluating the pollution levels and the potential effect of human activities growth on such ecosystems environment (MEJJAD et al., 2020a; 2020b; 2018) and discussed the need for implementing management projects, policies and strategies allowing better governance and resilience for conserving and protecting these vital environments (EL MAHRAD et al., 2020).

Morocco houses five lagoons from the North to the South (Nador lagoon, Moulay Bousselham Lagoon, Oualidia lagoon, Sidi Moussa lagoon, and Khnifis lagoon). These lagoons present many services and goods to the population, especially aquaculture (in Oualidia, Khnifis), tourism, fishing, and agriculture. Moreover, the increase in human activities around such ecosystems has negatively influenced their environmental quality. The Oualidia-Sidi Moussa lagoon complex, located in the central part of the Moroccan Atlantic coast, has a valuable and rich landscape.

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Due to their ecological and cultural interest, the lagoonal complex was designed as a protected area by the Ramsar Convention (Ramsar site no. 1474). In addition, the site is classified as a Permanent Hunting Reserve and was recognized as a priority 1 S.I.B.E. (No. L24). The complex hosts' different habitats of international interest for birds' (DAKKI et al., 1998), especially limicolous birds or warders (JOUILLAMI, 2013). According to BirdLife International (BIRDLIFE INTERNATIONAL, 2021), the complex is an important wintering site and passage for Palearctic migrants, while about 80 species have been registered, including two of the Mediterranean North Africa biome. In general, in the spring and summer periods, the complex is almost deserted by waterbirds, but only a few species breed because of the significant levels of human disturbance.

In the late 50s, the Oualidia lagoon has known as the start of the first Oyster farming activities along its shores, and then it became the Oyster capital of Morocco as it presents 72% of the Moroccan aquaculture production (KADDIOUI et al., 2018). In 1970 approximatively, different activities were developed in/and around the lagoon, and the region has known a significant demographic growth (H.C.P.) (MAANAN et al., 2014). The increase in human activities in this lagoon was accompanied by increased natural resource exploitation for economic purposes, especially during the summer when many national and international visitors come to this lagoon to enjoy its landscape and taste its unique oyster.

Sidi Moussa lagoon is situated 30 km north of the Oualidia. It is one of the most important Moroccan wetlands as a stopover and wintering site for different waterbird species found in large expanses of mudflats of the Sidi Moussa lagoon, with adequate and favorable ecological conditions (EL HAMOUMI et al., 2000). In addition, it is worthily noting that the lagoon presents more services other than a habitat; many activities are practiced around and in the lagoon and have grown in recent years, including grazing on its edges, agricultural activities, fishing, shellfish harvesting, and salt exploitation (KHOUKHOUCHI et al., 2018).

In recent decades, almost all studies in the Oualidia-Sidi Moussa lagoon complex focused on studying the changes in the environmental conditions, monitoring and evaluating the water quality and sediment quality. Other studies were focused on assessing the historical inputs of pollutants, including heavy metals (MAANAN et al., 2004; ZOURARAH et al., 2007; MEJjad et al., 2018; KHOUKHOUCHI et al., 2018; MEJjad et al., 2020b; BENHHamMEd et al., 2021a), rare earth elements (MEJjad et al., 2016, BENHHamMEd et al., 2021b, MEJjad et al., 2022), and radioactive elements (MEJjad et al., 2016; LAISSAOUI et al., 2018; BENHHamMEd et al., 2021a). Other authors have combined the history of human activities growth with the evolution of pollutants concentrations by establishing the relation age-depth to understand better the source of pollution (MEJjad et al., 2020b).

In the present research work, we review the studies carried out in the Oualidia lagoon and Sidi Moussa lagoon during the last 50 years to establish the historical evolution of heavy metal pollution lagoon ecosystems and define the common source of pollution in this complex. In this sense, the study seeks to understand the tendency of pollution accumulation in the lagoon's sediments and identify the possible source of pollution to suggest and provide better recommendations for the sustainable growth of these ecosystems.

2. Materiel and methods

2.1 Study Area description

The Oualidia Sidi Moussa lagoon complex, situated on Morocco's Atlantic coast (Fig.1), entails two main coastal lagoons and several wetlands separated from the sea by sandy dunes. While the site is protected by the Ramsar Convention (site no. 1474) as a biologically and
ecologically significant wetland and migratory bird protection area, it is subjected to significant environmental stresses mainly caused by anthropogenic activities such as agriculture, animal husbandry, oyster farming, saltworks, fishing, tourism and the growing industry with NORM as a by-product. The Oualidia lagoon is an area of high economic growth potential. The site is wealthy in natural resources and has a high diversity of fauna and flora in terms of wading birds, marine invertebrates, and seagrass beds. It also provides a habitat for many migrating birds and some species of turtles. Fishing and aquaculture, particularly oyster farming, have expanded since about 1970 and now support many local fishers, and the area offers several investment opportunities. In addition, agricultural production and livestock farming are carried out near the Oualidia lagoon and involve considerable amounts of phosphate fertilizer. The lagoon has been the subject of many multidisciplinary studies investigating its environmental status with respect to its chemistry, radiochemistry and biology (ZOURARAH et al., 2007; MAANAN et al., 2018; MEJJAD et al., 2016). The Sidi Moussa lagoon has an area of about 4 km², and it is separated from the Atlantic Ocean by consolidated dune ridges that protect the lagoon from strong waves and currents. It comprises the main channel linked to the Atlantic Ocean by a narrow and quiet channel and many secondary channels. The maximum depth is about 5 m and decreases gradually upstream of the lagoon. Several human activities are concentrated around the lagoon; one of the most important is the phosphate processing complex of Jorf Lasfar, located 15 km from the coastal ecosystem of Sidi Moussa, which started in 1986.

Figure 1: Geographical location of Moroccan lagoons, including Oualidia and Sidi Moussa lagoons.
Figure 2: Steps related to the evaluation of contaminants concentrations in sediments. In red are the monitoring steps studied in the present paper.

2.2 Bibliographical literature

The searches were mainly focused on all studies aimed at evaluating and analyzing the environmental quality of these lagoons sediments (Fig. 2). Others studies related to the management, strategies and related policies were reviewed as well.

2.3 Oualidia-Sidi Moussa complex lagoons sediments compared to a range of sediment quality guidelines values (S.Q.G.V.s)

The important role that sediment plays as a habitat for marine microorganisms implies their use to define pollution. Furthermore, the sediment acts as a sink for pollutants as it is the final receptor of all kinds of pollutants. Additionally, sediments are used to track the natural and anthropogenic sources of pollutants in marine ecosystems allowing a better understanding of pollutant evolution. In this order, the sediments have gained more importance among other classical samples used to monitor and assess marine environmental quality such as biota and water by defining numerous sediments quality guidelines (S.Q.G.s) deriving from chemical databases sediments considered as not contaminated.

Traditionally, sediment contamination level was determined by evaluating chemical concentrations and often comparing the sediment concentrations with reference values such as those of the upper continental crust (U.C.C). concentrations or the local background (MCLENNAN 2001). In the latest 40 years, S.Q.G.s have incorporated the biological effects, including sediment ecology and toxicity effects, to establish the relationship between toxic response-sediment contamination (BURTON, 2002). These S.Q.G. were defined to protect and predict adverse effects on marine biological resources, especially sediment serving as a habitat for marine organisms (BURTON, 2002; SCHAEFER, 2013).

Since the 1980s, many S.Q.G.s have been developed, including specific factors, criteria, and approaches that consider the diverse condition of sediment contamination occurrence and deposit. Generally, these approaches could be defined as (WENNING, 2005):
(i) Empirical relationships are based on determining the sediment contamination level at which a toxic response could occur.

(ii) Theoretical relationships (equilibrium partitioning, EqP) (DI TORO, 1991) allow describing the bioavailability of the contaminant. Generally, S.Q.G.s outline two concentration thresholds: Threshold Effect Limit (T.E.L) and Probable Effect Limit (P.E.L). However, we can find in literature diverse empirical S.Q.G.s that have been established to derive numerical standard values for chemical elements in marine sediments (Table 1).

<table>
<thead>
<tr>
<th>Empirically derived sediment quality guidelines</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effects range–low (E.R.L.) and effects range–median (ERM).</td>
<td>LONG &amp; MORGAN 1991; MACDONALD,1992; LONG et al., 1995</td>
</tr>
<tr>
<td>Threshold effects level (TEL) and probable effects level (P.E.L.).</td>
<td>MACDONALD et al.,1996</td>
</tr>
<tr>
<td>The Threshold Effect Level (TEL) and the Toxic Effect Threshold (TET).</td>
<td>BABUT et al., 2003</td>
</tr>
<tr>
<td>Screening level concentrations (S.L.C.).</td>
<td>NEFF et al., 1987</td>
</tr>
<tr>
<td>Summed PAH model (R.P.A.H.), and negligible concentration (NC) and maximum permissible concentration (M.P.C.).</td>
<td>VAN VLAARDINGEN et al, 2005</td>
</tr>
</tbody>
</table>

As there are not yet guideline values for Moroccan sediments, in the present analytical study, we used different S.Q.G.s values defined by agencies worldwide and the local background of both lagoons sediments. Using the guideline values will help better understand the metals concentrations values, local background values, and S.Q.G.V.s.

3. Results and discussion

3.1 Metallic contamination of the Oualidia lagoon sediment

The measured concentrations of metals determined in sediments samples retrieved from the Oualidia lagoon between 1976 to 2014 are listed in Table 2. The concentrations of metals display an increasing tendency, especially for Cr, Zn, and Cd, as shown in the sediment retrieved from the lagoon in 1998. On the other hand, for the studied sediments by IDARDARE et al., 2008, the concentrations of metals are relatively low compared to those found by ZOURARAH et al., 2007. The sampling period of these sediments coincides with the opening of a breach in 2005 in the downstream dyke constructed in the lagoon in 1945. Thus, this may explain the observed decrease in metal concentrations. This breach was created to purify the lagoon from fine sediments and protect it from the confinement phenomena; thus, this abrupt change in metal concentration is linked to the opening of this breach. Besides, the vertical distribution of metal content shows a decreasing tendency in the layers dated between 2005 and 2008, according to IDARDARE et al. (2008). The concentrations continue to decrease except for Pb, Cd, Cu and Zn, as reported in MAANAN et al., 2014. This enrichment was explained by the human activities pressures on the lagoon, especially the lagoon has an economic, ecological and cultural interest and the region, in general, is among the most attractive touristic destination in Morocco, especially during the summer. It should be noted that other activities practiced in and near the lagoon, such as animal
grazing and agricultural activities, were reported as the possible primary origin of metals such as Cd, Cr, and As. The use of fertilizer and pesticides to increase yield productivity and quality may raise these metal concentrations.

The latest study carried out in the lagoon sediments showed that the concentration of almost all metals reported higher in MAANAN et al. (2014), and ZOURARAH et al., (2007), such as Pb, Cu, and Zn have decreased while Cd and Cr exhibit higher concentrations. Arsenic was measured for the first time in MEJJAD et al. (2018); thus, there are no previous values to compare and assess the As concentration evolution with time. The recorded concentrations showed higher values than upper continental crust values and other similar ecosystems’ measured concentrations (e.g., Moulay Bouselham lagoon ALAOUI et al., 2010).

### Table 2: Metals concentrations measured in the Oualidia lagoon sediments between 1976 and 2014.

<table>
<thead>
<tr>
<th>Study References</th>
<th>Sampling date</th>
<th>Cu</th>
<th>Cr</th>
<th>As</th>
<th>Pb</th>
<th>Zn</th>
<th>Cd</th>
<th>Ni</th>
<th>Main events</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEJJAD et al., 2018</td>
<td>2014</td>
<td>17.72</td>
<td><strong>102.2</strong></td>
<td>10.99</td>
<td>10.99</td>
<td>75.86</td>
<td><strong>0.66</strong></td>
<td>19</td>
<td>Usual activities including Tourism, Aquaculture, Agriculture...</td>
</tr>
<tr>
<td>MEJJAD et al., 2016</td>
<td>2012</td>
<td>-</td>
<td>55.93</td>
<td>11.58</td>
<td>9</td>
<td>78.15</td>
<td>0.58</td>
<td>-</td>
<td>2012: Creation of wastewater treatment plant</td>
</tr>
<tr>
<td>MAANAN et al., 2014</td>
<td>2008</td>
<td>58</td>
<td>64</td>
<td>-</td>
<td><strong>73.6</strong></td>
<td><strong>229</strong></td>
<td>0.3</td>
<td>20.6</td>
<td>Usual activities including Tourism, Aquaculture, Agriculture...</td>
</tr>
<tr>
<td>IDARRADE et al., 2008-2006</td>
<td>2004-2006</td>
<td>17</td>
<td>68</td>
<td>-</td>
<td>6.8</td>
<td>104</td>
<td>0.58</td>
<td>28</td>
<td>2005: The opening of a breach</td>
</tr>
<tr>
<td>ZOURARAH et al., 2007</td>
<td>1998</td>
<td>36.4</td>
<td>52.4</td>
<td>-</td>
<td>54.4</td>
<td>227</td>
<td>0.2</td>
<td>-</td>
<td>Usual activities including Tourism, Aquaculture, Agriculture...</td>
</tr>
<tr>
<td>MEJJAD et al., 2018</td>
<td>LBV</td>
<td>5.27</td>
<td>43.47</td>
<td>11.89</td>
<td>0.71</td>
<td>23.57</td>
<td>0.12</td>
<td>7</td>
<td>19</td>
</tr>
<tr>
<td>MAANAN et al., 2013</td>
<td>LBV</td>
<td>26.6</td>
<td>38.4</td>
<td>nd</td>
<td>24</td>
<td>142.3</td>
<td>0.15</td>
<td>20.6</td>
<td>Before the human activities increase in the study area</td>
</tr>
</tbody>
</table>

#### 3.2. Metallic contamination of the Sidi Moussa lagoon sediment

Compared to the Oualidia lagoon, the Sidi Moussa lagoon received relatively little attention. Few studies have investigated the sediment level contamination by metals (MAANAN et al., 2004; BENHMAMMED et al., 2021A; BENHMAMMED et al., 2021B; CHEGGOUR et al., 1999). Almost all studies were focused on biological investigations as it presents an interesting role as a habitat for many types of migratory birds. Table 3 investigates the studies carried out between 2001 and 2021 for samples collected in the last three decades. The metal concentrations determined for top layers of sediments (4cm) are comparable to the Oualidia lagoon's (Table 2), and an apparent decrease in concentrations of metals during the last decades. However, the latest study exhibited a high concentration of Cr, As, and Cd higher than the local background values, while the Cd values exceed the values found in the Oualidia lagoon sediment. The location of the Sidi Moussa lagoon near the phosphate processing plants in Jorf Lasfar is the possible source of the higher values of Cd recorded in this lagoon sediment, as reported in CHEGGOUR et al. (1999). Another source of marine origin could also contribute to the
enrichment by Cd, which is the upwelling phenomena that characterize the Moroccan Atlantic coast (BRULAND et al., 1983), as this phenomenon is permanent along the coast between El Jadida and Safi regions, including the Sidi Moussa lagoon (ORBI et al., 1997). MAANAN et al. (2004) have reported that the increase in human activities, including the intensification of the traffic skirting in the Sidi Moussa lagoon, agricultural activities, growth and development of fishing boats equipped with motors (CHEGGOUR et al., 1999) are the main sources of heavy metals such as Zn, Cu, and Pb.

**Table 3:** Metals concentrations measured in the Sidi Moussa lagoon sediments between 1999 and 2017.

<table>
<thead>
<tr>
<th>Study Reference</th>
<th>Sampling date</th>
<th>Cu</th>
<th>Cr</th>
<th>As</th>
<th>Pb</th>
<th>Zn</th>
<th>Cd</th>
<th>Ni</th>
<th>Main events</th>
</tr>
</thead>
<tbody>
<tr>
<td>BENHMAMMED et al., 2021a</td>
<td>2017</td>
<td>16.69</td>
<td>102.2</td>
<td>6.82</td>
<td>27.7</td>
<td>61.3</td>
<td>1.68</td>
<td>28.2</td>
<td>Coastal road traffic, tourism, fishing activities and agriculture</td>
</tr>
<tr>
<td>JOULAMI et al., 2013</td>
<td>2011</td>
<td>11.70</td>
<td>90.2</td>
<td>31.87</td>
<td>17.3</td>
<td>102</td>
<td>2.05</td>
<td>nd</td>
<td>Coastal road traffic, tourism, fishing activities and agriculture</td>
</tr>
<tr>
<td>MAANAN et al., 2004</td>
<td>2001</td>
<td>30.4</td>
<td>96.9</td>
<td>nd</td>
<td>22.7</td>
<td>49.8</td>
<td>nd</td>
<td>29.1</td>
<td>Coastal road traffic, tourism, fishing activities and agriculture</td>
</tr>
<tr>
<td>CHEGGOUR et al., 1999</td>
<td>1992-95</td>
<td>36.9</td>
<td>nd</td>
<td>nd</td>
<td>33</td>
<td>144</td>
<td>3.67</td>
<td>nd</td>
<td>Coastal road traffic, tourism, fishing activities and agriculture</td>
</tr>
<tr>
<td>BENHMAMMED et al., 2021a</td>
<td>LBV</td>
<td>5.89</td>
<td>34.5</td>
<td>3.92</td>
<td>11.6</td>
<td>19.1</td>
<td>0.23</td>
<td>11.9</td>
<td>Before the acceleration of human activities in the study area</td>
</tr>
<tr>
<td>MAANAN et al., 2004</td>
<td>LBV</td>
<td>25</td>
<td>38</td>
<td>nd</td>
<td>nd</td>
<td>24</td>
<td>nd</td>
<td>25</td>
<td>Before the acceleration of human activities in the study area</td>
</tr>
</tbody>
</table>

3.3 Oualidia and Sidi Moussa lagoons sediment quality and biological effects

The values recorded in the studies carried out for sediment of the Oualidia and Sidi Moussa lagoons were retrieved in 2014 (MEJJAD et al., 2018) and 2017 (BENHMAMMED et al., 2021a), respectively, were compared to a range of S.Q.G.V.s reported in table 4. Therefore, in the Oualidia lagoon, only Cr and As that show values slightly superior to the Threshold Effect Level (TEL), indicating a probable effect on the marine organism. The chromium concentration exceeds even the probable effect level (P.E.L.) (90 mg/kg) defined by MACDONALD et al. (1996), highlighting the need to investigate further this metal concentration and its origin in the Oualidia lagoon. The other elements exhibited values lesser than TEL, effects range low (E.R.L.), lowest effect level (L.E.L.); minimal effect threshold (M.E.T.), signifying that Cu, Pb, Ni, and Zn did not pose a toxicity risk for the lagoon organisms. It is worthy noting that Zn's recorded concentrations in 1998 and 2008, as reported in previous studies, were 227 and 229 mg/kg, respectively, higher than TEL values suggesting probable effects on marine organisms living. However, the decreasing trends of the Zn values could be related to the management projects carried out in the lagoon between 2008 and 2012.

Concerning the Sidi Moussa lagoon, the values of Ni, As, Cd, and Cr show higher values exceeding those of TEL, suggesting a potential toxicity risk for marine biota. In contrast, the Zn, Pb, and Cu have shown lesser values indicating no potential effects on marine organisms. Except for Ni, the three metals, As, Cd, and Cr, present higher concentrations in both lagoons suggesting probably a similar origin (the use of fertilizer, upwelling activities along the El-Jadida-Safi coast). The present investigation highlights the need to consider the ecological, cultural, and economic interest that this lagoonal complex presents for the whole country and the local population.
Table 4: range of S.Q.G.V.s.

<table>
<thead>
<tr>
<th>No effect</th>
<th>Type</th>
<th>References</th>
<th>Cu</th>
<th>Cr</th>
<th>As</th>
<th>Pb</th>
<th>Zn</th>
<th>Cd</th>
<th>Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANZECC ISQG-low</td>
<td>ED</td>
<td>BABUT et al., 2003</td>
<td>65</td>
<td>80</td>
<td>20</td>
<td>50</td>
<td>200</td>
<td>1.50</td>
<td>21</td>
</tr>
<tr>
<td>TEL</td>
<td>ED</td>
<td>MACDONALD et al., 2000</td>
<td>35.7</td>
<td>37.3</td>
<td>5.9</td>
<td>35</td>
<td>123</td>
<td>0.6</td>
<td>18</td>
</tr>
<tr>
<td>TEL</td>
<td>ED</td>
<td>BUCHMAN, 1999</td>
<td>18.70</td>
<td>52.30</td>
<td>7.24</td>
<td>30.24</td>
<td>124</td>
<td>0.68</td>
<td>15.90</td>
</tr>
<tr>
<td>ERL</td>
<td>ED</td>
<td>MACDONALD et al., 2000</td>
<td>70</td>
<td>80</td>
<td>33</td>
<td>35</td>
<td>120</td>
<td>5</td>
<td>30</td>
</tr>
<tr>
<td>ERL</td>
<td>ED</td>
<td>BUCHMAN, 1999</td>
<td>34</td>
<td>81</td>
<td>8.20</td>
<td>46.70</td>
<td>150</td>
<td>1.20</td>
<td>20.90</td>
</tr>
<tr>
<td>LEL</td>
<td>ED</td>
<td>MACDONALD et al., 2000</td>
<td>16</td>
<td>26</td>
<td>6</td>
<td>31</td>
<td>120</td>
<td>0.6</td>
<td>16</td>
</tr>
<tr>
<td>MET</td>
<td>ED</td>
<td>MACDONALD et al., 2000</td>
<td>28</td>
<td>55</td>
<td>7</td>
<td>42</td>
<td>120</td>
<td>0.9</td>
<td>35</td>
</tr>
<tr>
<td>TEC (I)</td>
<td>CB</td>
<td>APITZ &amp; WHITE 2003</td>
<td>38.18</td>
<td>78.33</td>
<td>16.11</td>
<td>52.99</td>
<td>153.5</td>
<td>1.04</td>
<td>23.20</td>
</tr>
</tbody>
</table>

**Probable Effects**

| ANZECC ISQG-high | ED   | BABUT et al., 2003 | 270 | 370 | 70  | 220 | 410 | 10  | 52  |
| ERM               | ED   | MACDONALD et al., 2000 | 390 | 145 | 85  | 110 | 270 | 9   | 50  |
| ERM               | ED   | BUCHMAN, 1999    | 270 | 370 | 70  | 218 | 410 | 9.6 | 51.6 |
| PEL               | ED   | MACDONALD et al., 2000 | 197 | 90  | 17  | 91.3 | 315 | 3.53 | 36  |
| PEL               | ED   | BUCHMAN, 1999    | 108.2 | 160.4 | 41.60 | 112.2 | 271 | 4.21 | 42.80 |
| AET               | ED   | BUCHMAN, 1999    | 390 | 62  | 35  | 400 | 410 | 3   | 110 |
| TEC (I)           | CB   | APITZ & WHITE 2003 | 214.6 | 268.4 | 54.32 | 396 | 369.2 | 5.76 | 58.28 |

**Extreme effect**

| E.E.C. (I)         | CB   | APITZ & WHITE 2003 | 1,076 | 1,038 | 227 | 1,056 | 1,645 | 29.21 | 298.4 |


### 4. Conclusion

Preserving and conserving a country's culture and resources is mandatory. Therefore, valuing and assessing the environmental quality of such marine ecosystems is an urgent need for social, economic, and cultural sustainability.

The increase of human activities and overexploitation of natural resources, specifically marine resources, for meeting and satisfying human needs and wants cause biodiversity losses and indirectly affect the next generation’s well-being.

The study highlights the need for further evaluation of biological samples for a more accurate and precise definition of the environmental quality of those precious lagoons. Increasing the awareness among the local population about the importance of conserving and protecting these ecosystems is required. In addition, creating new plans and strategies for sustainable use of marine resources for touristic purposes in the region is necessary.

However, our investigation exhibits an evident deterioration of the environmental quality of the lagoonal complex of the Oualidia-Sidi Moussa. This complex is one example of numerous ecosystems in Morocco and worldwide suffering from the human activities pressure and overconsumption of their resources. Thus, this existing unbalance between human activities-resources exploitation, and the environment requires further investigation and practical management projects.
References


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