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Dealing with Cumulative Effects (Impacts) in Asian Multi-Functional Wetlands

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Abstract

The paper proposes a technique for evaluation of natural and anthropogenic impacts on multiple functions of natural wetlands performing, amongst numerous other services, a service of water pollution mitigation at large scale. It is based on data available from elicitation of expert opinion, rapid environmental assessment, participatory rural appraisal and statistical analysis. The technique may be useful if extensive environmental data sets are not available, that is frequently the case in the developing world. Important conclusions on impacts of water pollution and other driver (stressors) on multi-functional wetlands, otherwise impossible, may be made through its use in situations of complex driver interactions. Cumulative Effects Assessment, of which the technique may be an integral part, is to be incorporated into both Environmental Impact Assessment and Strategic Environmental Assessment to provide for a more sustainable use of the wetland services.

Keywords: Cumulative impacts; multiple functions; Strategic Environmental Assessment

1. Introduction

The concept of Cumulative Effect Assessment (CEA) as a vehicle for the quantitative assessment of cumulative effects (impacts) on natural multi-functional wetlands is further developed. It takes into account an inherent and chronic lack of environmental data sets in the vast majority of wetland ecosystems in the developing Asia. The CEA analysis involves identification of impact sources, selection of Valued Ecosystem Components and multi-functions affected, use of a set of the key indicators to examine cumulative effects arising from the aggregate of these effects. PRA, socio-economic valuation, ecological survey, bio-geochemical and Remote Sensing-Geographic Information System (RS-GIS) analyses need to be used to gather data and quantitatively evaluate the cumulative effects. Whereas an elicitation of expert opinion as a CEA method has been long recognized, a Participatory Rural Appraisal, PRA (Chambers, 1996), as an important method was largely overlooked despite its strong validity under the circumstances. Need to overcome the shortage of data sets is particularly important due to the fact that the developing world comprises most of the world's ecosystems, biodiversity and human population. Furthermore, Cumulative Effects Assessment represents a significant conceptual and methodological challenge for any environmental assessment. It requires more than simple "adding up" effects (impacts). Synergistic interaction of impacts is a phenomenon notoriously elusive to estimate. The CEA approach allows for a scientifically justified sustainable utilization and conservation of multi-functional wetlands both in Asia and elsewhere, ensuring their effective use for the adaptation to global climate change and disaster risk management. This necessitates an explicit attention to cumulative environmental effects. Regional wetlands, ranging from estuaries, mangroves, seagrass beds to paddy (rice) fields and freshwater marshlands, mainly natural but also ecologically engineered, play an increasingly multi-functional role. Multi-factorial analysis intrinsic to CEA is seen as a relevant approach to the multi-functionality of wetlands in which the function of pollution control (frequently inadvertent) is one of common denominators. The presented technique was developed during the assessment of multi-functional wetlands in the Hoi An river basin (Quang Nam province, Central Vietnam), Nam Ngum river basin (Central Laos) and the Sundarbans mangrove area

(Bangladesh-India). The areas were impacted by a range of environmental effects comprising those of pollution, land use change, tourism development, mismanagement in industrial, fishing/aquacultural activities, water quality changes due to hydropower, irrigation and mining projects, *etc*. The technique aimed to clarify complex interrelationships, overcome their mind-boggling complexity and glean important insights to be used in furthering wetlands' sustainable use and conservation.

2. Methodology

The relevant extensive sets of drivers (direct and indirect) for wetlands, Valuable Ecosystem Components (VEC) and their ecosystem services provided by wetland multi-functions were identified considering various environmental and socio-economic conditions, such as: water quality, sources of pollution in wetland ecosystem, wetland habitat, biodiversity, soil quality, climatic condition, socio-cultural condition, economic activities, infrastructure development, *etc* (MEA, 2005). Identification of drivers and VECs was done by Rapid Environmental Assessment, extensive review of available reports and evaluations made in different study areas through actual field visits and informal interview with the key informants.

Multiple interrelationships among the drivers were analyzed by digraph theory and matrix analysis (Wenger *et al*., 1999). The degree of connectedness among the drivers was analysed an approach by Roberts (1976). Spearman's Rank Correlation technique was used to quantify the degree of connectedness among the drivers and a 'weighing technique" was used (Bennui et al., 2007). The interrelationships of drivers and VECs (resources) depending on their cause-effects relationships were established using the expert opinion technique, Participatory Rural Appraisal results, Rapid environmental assessment with report survey. A relationship was considered to be an impact by a driver on a valued ecosystem component in different studied areas.

For vulnerability assessment of wetland VECs (resources), the cumulative effects from drivers were computed by Principal Components Analysis (PCA) technique (Ainong *et al.*, 2006) on the basis of previous output. From the computed cumulative effects, vulnerability of specific VEC was determined considering their quantified value. While computing cumulative effects (CE), covariance matrix (C_v) of drivers was calculated. An eigen value (λi) of matrix C_v and its corresponding eigenvectors (α_i) were computed. Principal Components (PC) were calculated for corresponding drivers by the following equation: $PC = Db$, where, PC = principal component, b = coefficient for principal components. CEs on the wetland VECs were defined as accumulation of weighted principal components (drivers-stressors) shown as below (Ainong *et al.*, 2006): $CE = \alpha_1 PC_1 + \alpha_2 PC_2 + ... + \alpha n PCn = \alpha_i PC_i$, where PCi = no. i principal component (i=1, 2, 3, …, n), α_i = corresponding eigen vectors considered as corresponding contributions of drivers to VEC. CE values for all VECs were calculated. To determine VEC vulnerabilities, quantified CE were evaluated on the basis of their values. In this study, higher vulnerability was determined by the higher value of CE.

3. Results and Discussion

Both direct and indirect drivers (stressors) were identified (data not shown). These were represented by an extensive list of 19 drivers comprising aquaculture, flooding, erosion, hydropower and water diversion development, industries, etc. Initially only 19 drivers out of a much greater number of interacting drivers (stressors) were selected for simplicity. Differentiation between direct and indirect drivers was not used for CEA in prior work by other researchers (e.g., Hegmann et al., 1999), which is not in line with an authoritative, comprehensive and global analysis done in the framework of the Millennium Ecosystem Assessment (1999-2005). This also makes understanding of the driver interrelationships incomplete and final CEA outcome deficient.

An inherent and chronic lack of environmental data sets in the vast majority of ecosystems in the developing Asia is a major stumbling block on the way of CEA, and at the same time it is a lesser problem for many developed world sites. An increased number of environmental indicators (parameters) used for the cumulative effect analysis in the developing world sites was found in the presented study to be a potentially useful way to overcome this disadvantage of CEA in the developing world. Such non-parametric approach to fill in the gaps due the lack of parametric data needs be further aligned and developed with a view to complementing CEA tool. Identified relevant sets of direct and indirect drivers (or stressors, exerting impacts/effects) demonstrated that despite substantial geographic and socio-economic differences between the studied areas drivers were nearly identical, albeit varying in magnitude. Identification of Valued Ecosystem Components (VEC) of physico-chemical, biological and socio-economic nature showed that VECs and performed services for the three geographic areas were substantially differing in terms of biological VECs (e.g. tiger, chital deer, Ganges river dolphin, unique sundari mangrove *Heritiera*, *etc* in the Sundarbans; saola, nipa palm forest in the Hoi An river basin), but similar in physico-chemical (e.g. surface water, *etc*) and socio-economic VECs (e.g. employment, *etc*) (data not shown).

Assessment of interrelationships between a multitude of relevant drivers (stressors) by matrix analysis, clustering and principle components analysis (PCA) showed that despite the near identical drivers for all three areas, the interrelationships varied significantly. It was obvious that out of 19 drivers identified in the Hoi An river basin only 13 drivers (e.g. organic water pollution, flooding, salinity intrusion/inorganic water pollution, deforestation, *etc*) were found to be strongly interconnected, while the upstream hydropower/water diversion development was not one of them (Figure 1). Hence the latter is unlikely to be involved in cumulative synergistic interrelationships with other impacts on the wetlands, as was widely anticipated (ADB, 2008). On the other hand, out of ten drivers identified in the Nam Ngum river basin, only 6 drivers (same as those in the Hoi An basin) were found to be strongly interconnected and hydropower/water diversion development was also not one of them (Figure 2, Table 1). Only eight out of 18 drivers identified in the Sundarbans were found to be strongly connected and the same conclusions could be drawn (data not shown). However, the hydropower dams and Farakka barrage were found to be the most influencing drivers in all cases (Table 2).

Assessment of interrelationships between individual drivers and Valued Ecosystem Components (resources) by participatory rural appraisal and expert opinion showed that the nipa palm forest in Hoi An (Figure 3) and *Heritiera* mangrove forest in the Sundarbans were highly interconnected with a multitude of similar drivers, namely 9-10 drivers (e.g. water pollution, freshwater flow change, invasive species, aquaculture, over-exploitation, *etc*). Wetland multi-functions were to be seen in all their diversity reflected by a multitude of services performed by the functions. Similar to the assessment of interrelationships between drivers and VECs by Participatory Rural Appraisal and expert opinion, these interrelationships need to be further assessed in the framework of the proposed technique for the quantitative assessment of cumulative effects. Since the category of vulnerability is commonly defined as a degree to which environmental systems are likely to experience harm due to drivers (stressors), the conclusion of this study is that in cases of the three areas covered by the discussed research a cumulative impact of the most influencing drivers reflects vulnerability (susceptibility) of a particular VEC. Analysis revealed that different drivers in the studied wetlands caused effects of variable quantitative value (in relative percentages). For Hoi An river basin, it is noted from the Figure 3 that flooding had the highest impacts (16%) on the nipa palm mangrove where water pollution caused high impacts (14%) on the surface water quality. hydropower dam caused high impacts (15%) on population settlements, while land use change caused 10 % change in agricultural practice (Figure 3). There were higher impacts on the unique sundri mangrove trees (*Heritiera fomes*) due to reduced freshwater flow (17%), Farakka barrage (11%), over-exploitation (11%) and salinity intrusion (10%) compared to other drivers, while nipa mangrove (golpata) was highly affected due to over-exploitation (10%). Strongly connected drivers (freshwater flow and Farakka barrage) were confirmed to cause highest impacts on VECs in the Sundarbans.

It was demonstrated that in terms of the quantification (Table 3) of cumulative impacts by a multitude of drivers on VECs and their services, that the following Hoi An river basin VEC was the most vulnerable (susceptible): the *Nypa* palm forest, which vulnerability was calculated as the cumulative effect of all strongly connected and most influencing drivers and may be expressed as 96.7 % (0.97). It was found that for the Nam Ngum area the VEC was surface water, while the vulnerability index may be expressed as 85.2 %. It was 95.9 % for the unique *Heritiera* mangrove of the Sundarbans. Total cumulative impacts feature in Figure 4. Strongly connected and the most influencing drivers clearly dominate over other drivers determining vulnerability of VECs (Figure 5). Since, apart from the above-mentioned normalized indices, the vulnerability can also be measured by mapping on a categorical scale, it can be concluded that once actual data is mapped (in rare cases when extensive datasets are available) the use of RS-GIS technique can be most useful.

4. Conclusions

Identified relevant sets of direct and indirect drivers for the multifunctional wetlands demonstrate that despite substantial geographic and socio-economic differences between the studied areas in three different countries (Viet Nam, Laos and Bangladesh) drivers (stressors), though nearly identical, varied in magnitude. Identification of physico-chemical, biological and socio-economic Valued Ecosystem Components, VECs, showed that the ecosystem services performed by the wetlands in three geographic areas were substantially different in terms of biological VECs, but similar in physico-chemical and socio-economic VECs. Assessment of interrelationships between the drivers by matrix analysis, digraph clustering and Principal Component Analysis demonstrated significant variability of driver interrelationships. The approach allowed for differentiation of the interrelationships with regard to their potential to act in relative isolation or actively interact with other drivers (comprising organic and inorganic pollution, sedimentation and erosion among others). Such interaction may possibly occur in a synergistic way, hence leading to complex and highly significant impacts. These situations are important to predict and account for in an attempt to quantify cumulative impacts by a multitude of drivers on VECs and their multiple services. The approach could be valuable in a typical developing country situation of chronic lack of extensive environmental datasets.

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Table 1. Degree of relationships between selected strongly positively and negatively related (connected) drivers (stressors) of the Nam Ngum river basin wetlands, C. Laos. Spearman's rank correlation. Bold indicates significant correlation at level 0.1 (full set at Figure 2)

Drivers	Aquaculture	Agriculture	Water pollution	Land use change	Flooding	Drought
Aquaculture, K	1.000	.361	-.169	-.205	.292	-.183
Agriculture, L	**.361**	1.000	.534	-.209	.619	.281
Pollution, H, I	-.169	**.534**	1.000	-.354	.274	-.104
Land use change, R	-.205	-.209	**-.354**	1.000	-.082	.395
Flooding, B	.292	.619	.274	**-.082**	1.000	.500
Drought, E	-.183	.281	-.104	.395	**.500**	1.000

Table 2. List of the most influencing drivers for the studied areas (* - 1 to 5 = high to low)

Rank*	Most Influencing Drivers (stressors)		
	Hoi An river basin	Sundarbans	Nam Ngum river basin
1	Flooding	Freshwater flow change	Land use change
2	Land use change	Over-exploitation of resources	Hydropower dam
3	Water pollution	Farakka barrage	Overfishing
4	Hydropower dam	Land use change	Agriculture
5	Fishing	Salinity intrusion	Aquaculture

Table 3. List of the determined most vulnerable wetland Valued Ecosystem Components (resources) for the areas (% values of cumulative effects) as computed by PCA

Area	Valued Ecosystem Components (% of effects)		
Hoi An river basin (delta)	Nipa palm mangrove 96.7	Fisheries 90.8	Surface water 89.3
Sundarbans	*Heritiera fomes* 95.9	Mangroves 93.3	Fisheries 90.7
Nam Ngum river basin	Surface water 85.2	Aquatic resources 80.3	Socio-economic 69.5

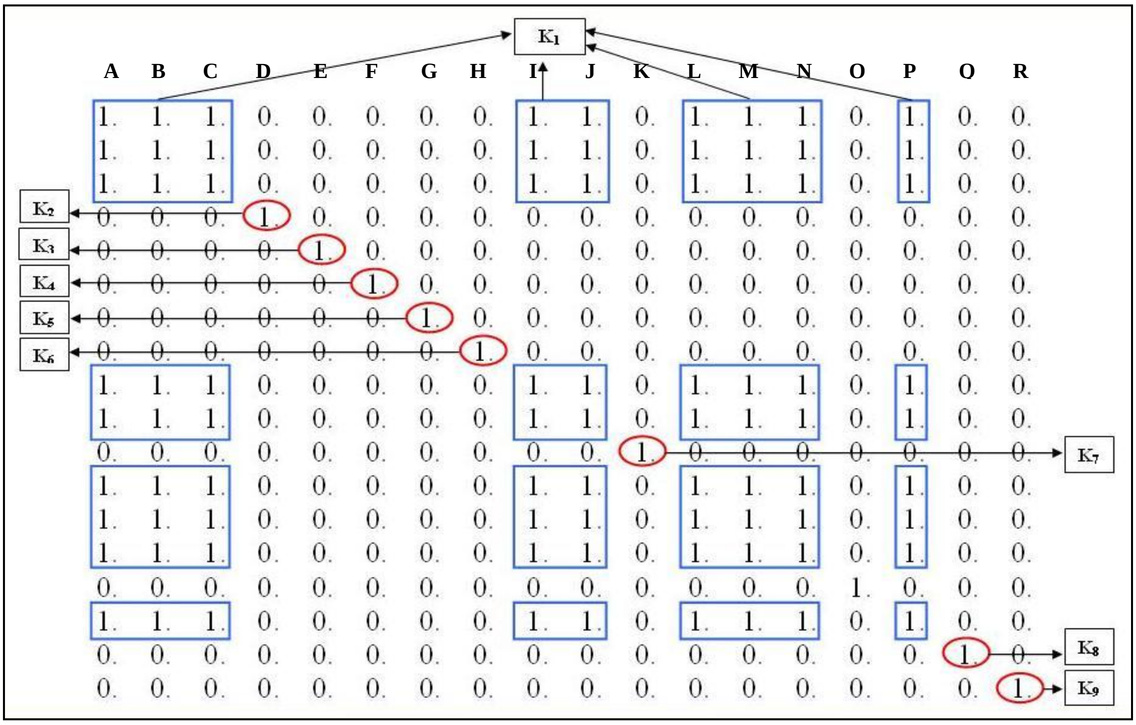

Figure 1. Matrix with identified clusters of closely related drivers (stressors) for the Hoi An river basin multi-functional wetlands, C. Vietnam. Digraph theory was used to analyze interrelationships of drivers, A-R (from A, erosion, through L, agriculture, to R, land use change), within an apparent complexity of the driver-driver relationships. Matrix analysis generated strong components (clusters of drivers, K_1-K_9) illustrating degree of connectedness of the drivers (Table 1).

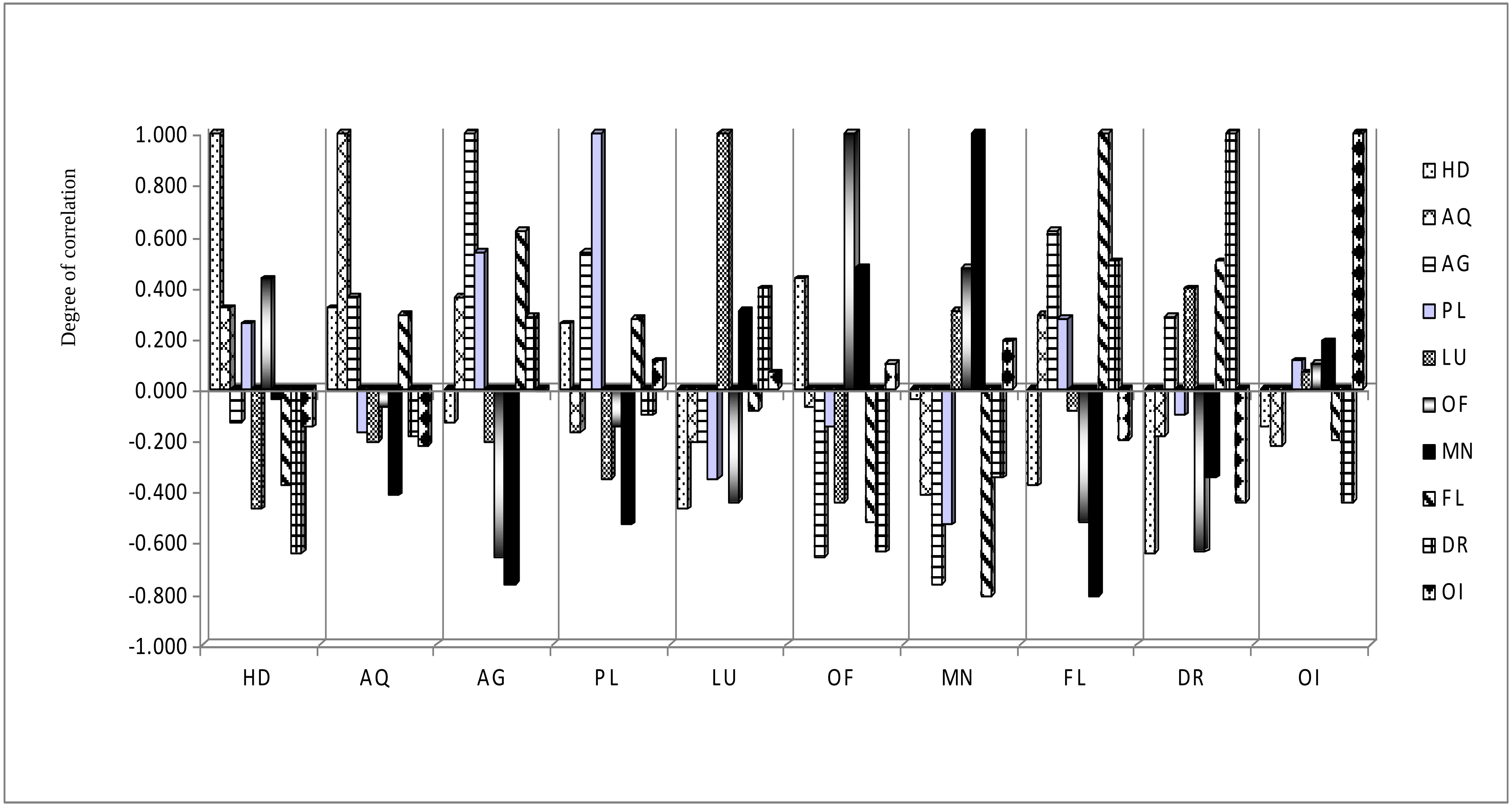

Figure 2. Degree of positive (negative) correlation among the full set of drivers of Nam Ngum river basin multifunctional wetlands, Laos.

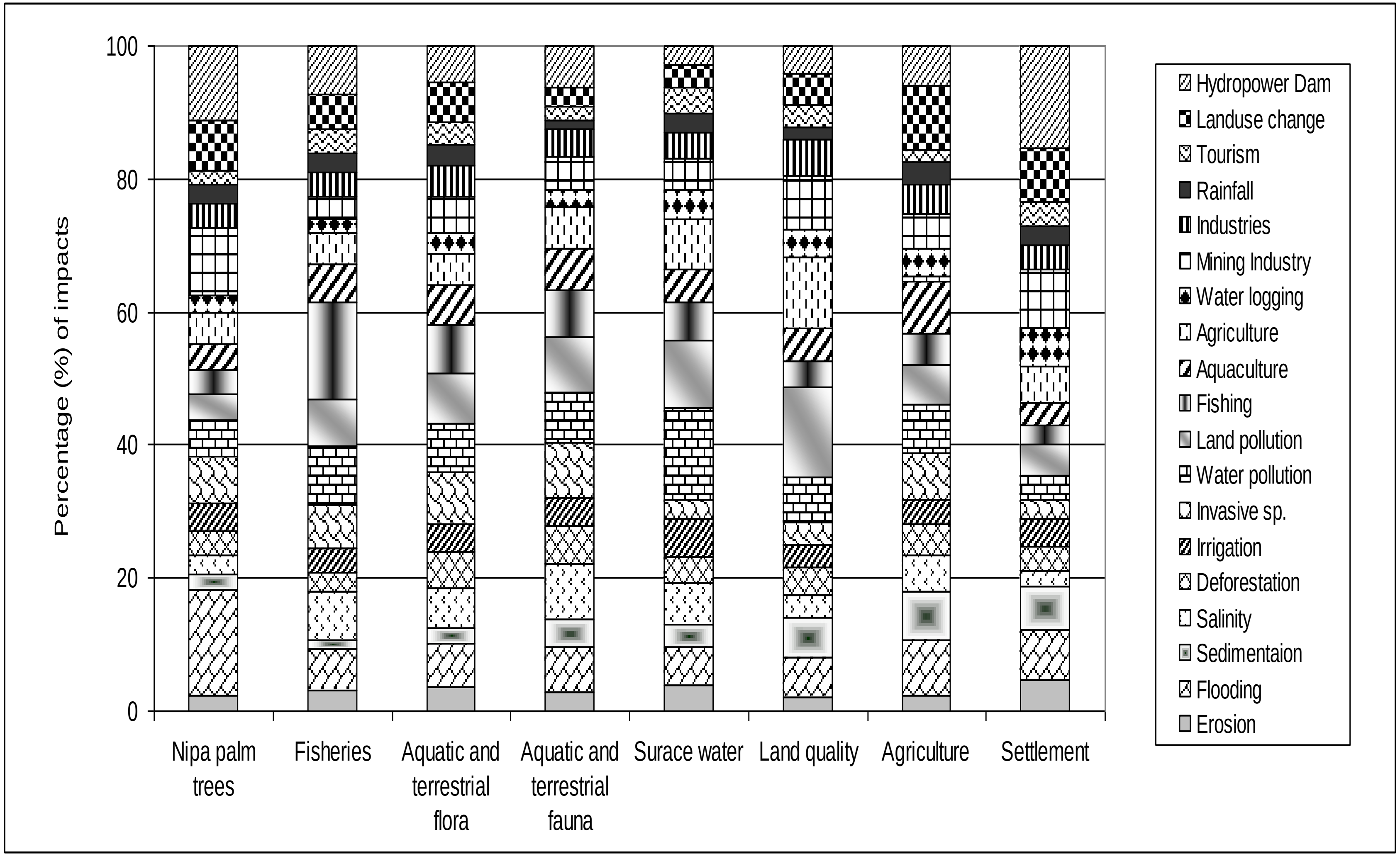

Figure 3. Impacts (effects) of different drivers (%) on the Valuable Ecosystem Components in the Hoi An river wetlands (Viet Nam).

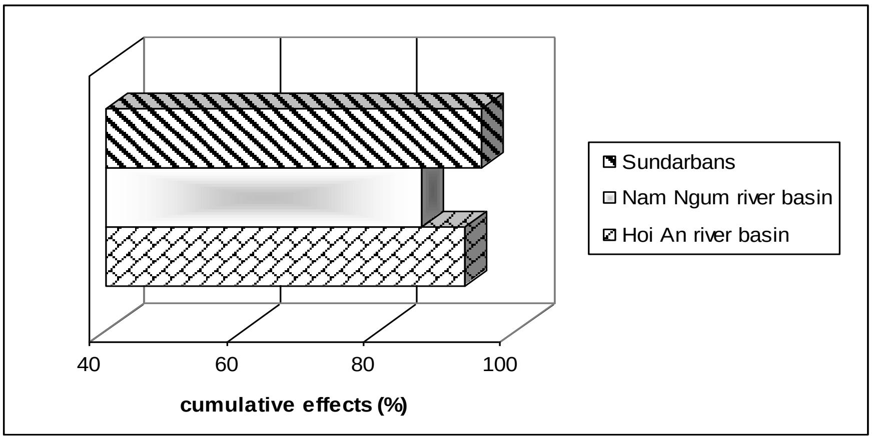

Figure 4. Cumulative effects (%) on the multi-functional wetlands of the studied areas.

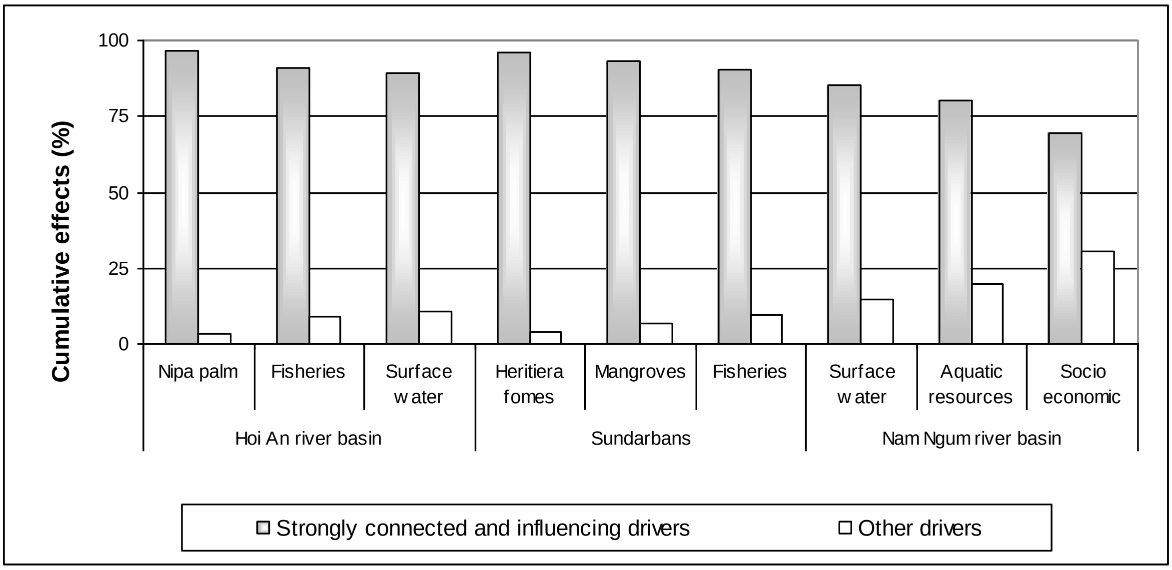

Figure 5. Cumulative effects or impacts (%) on individual Valued Ecosystem Components of the studied multi-functional wetlands.