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A New Approach to Evaluate the Ecological Status of a River by Visual Assessment

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Abstract

Most water management methodologies require comprehensive studies and thus, entail voluminous data, time, and scientific expertise. Sensorial evaluation techniques were thus, considered as these represent methods with minimal cost and can involve the local communities. This study applied the Sarno River Visual Assessment Protocol (SRVAP), a modified version of the Stream Visual Assessment Protocol developed by the United States Department of Agriculture, to Sarno River, Italy and tested its reliability as a river assessment tool. SRVAP scores has a statistically significant positive correlation with Chemical Oxygen Demand (COD) and shows that local knowledge is important and increases the viability of incorporating public participation in the evaluation. Correlation between SRVAP and organic content greatly increased barring seasonal variability and a significant positive relationship was found between SRVAP score and Biochemical Oxygen Demand (BOD) and COD during spring, as well as during summer. The resulting regression equations may be used as rapid estimates of COD and BOD levels in Sarno River for the seasons of spring and summer.

Keywords: Ecological indicators; Environmental monitoring; Public participation; River water quality

Introduction

The degradation in the quality of surface waters has become a major environmental concern due to continued industrialization and the impact of rising population. As a necessary step in the protection of such resources, particularly of rivers, various methodologies have been developed to assess their conditions. In Europe, the evaluation of water sources is based on the European Water Framework Directive (WFD) [1]. This directive unifies the water management approaches in 32 countries in order to achieve the common goal of "good" water quality in all surfaces, underground and coastal waters [2-6]. In Italy, the surface water quality regulation based on WFD is defined by Legislative Decree No. 152/2006 [7]. For river systems, the law requires the determination of the environmental status of every homogenous reach based on the physical, biological, and chemical characteristics of the study area [8].

Nevertheless, the assessment methodologies available suffer from critical challenges primarily stemming from the use of numerous parameters that involve extensive data and require time and scientific expertise. This has led to the development of new strategies that allow the rapid assessment of water bodies at minimal cost owing to the use of fewer analytical procedures and the involvement of the local communities. One such strategy is the use of sensorial evaluation such as the Stream Visual Assessment Protocol (SVAP) developed by the United States Department of Agriculture [9]. This method uses visual indicators easily identifiable by the local population which can then provide preliminary assessment and a warning mechanism for intervention, should the need arise. However, due to the specific and unique conditions pertaining to the Sarno River in Italy, it becomes necessary to modify the SVAP. The end product is the Sarno River Visual Assessment Protocol (SRVAP). The assessment involves both technical and non-technical evaluations and the overall assessment score is used as basis for river quality classification. This study applied SRVAP in determining the ecological condition of the Sarno River in Italy using both technical and local knowledge in the assessment. The applicability of the protocol was tested by correlation of SRVAP scores and actual river organic content, a required parameter stipulated by Legislative Decree No. 152/2006 [7].

Materials and Methods

Study area and sampling stations

The area for the study is the Sarno River, considered as one of the most polluted rivers in Italy. With a length of 24 km, the river traverses three provinces in the Campania Region and affects between 750,000 and one million inhabitants. Degradation of the river results from the combination of high population and presence of highly-polluting industries in the area [10,11]. Water sampling was conducted at five monitoring stations labeled A, B, C, D, and E located at Ponte San Michele, Scafati, Cavalcavia Del Sarno, Castellamare di Stabia and Torre Annunziata, respectively (Figure 1). The stations form part of the monitoring network set up by The Italian National Environmental Protection Agency for Campania Region (Agenzia Regionale Protezione Ambient Campania or ARPAC).

Water Sampling Protocol and Analytical Methods

Water sampling and visual assessment of the river were done simultaneously in May and August, 2013 to obtain data representing the spring and summer seasons, respectively. At each site, 5-L samples were collected midstream and analyzed within 24 h. BOD5 measurement was done using Oxitop® Manometric BOD Measuring Device while

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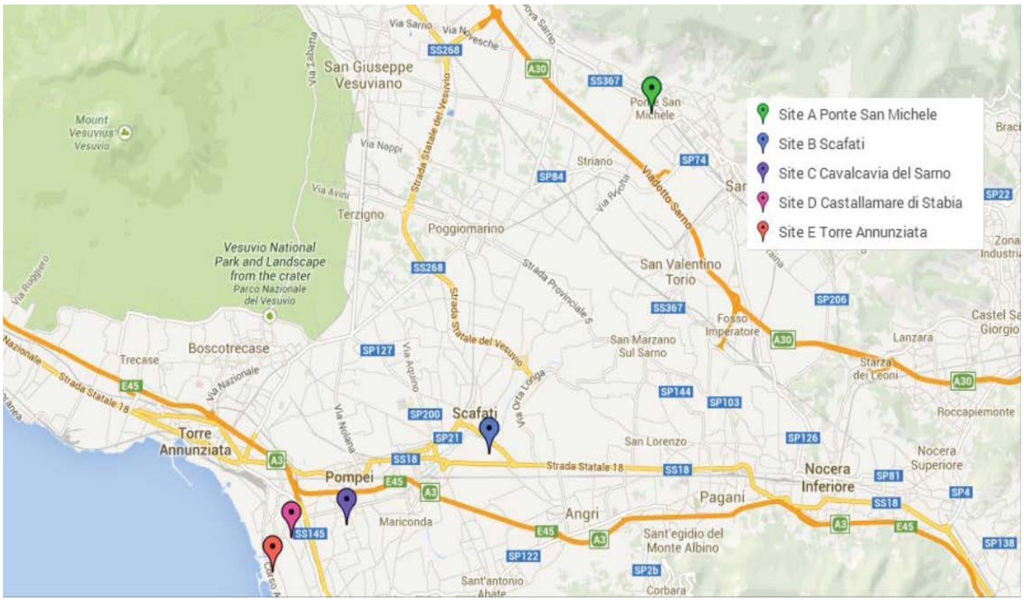

Figure 1: Geographic location of Sarno River and sampling sites1 75 1 Map Source: maps.google.com; geographic coordinates from ARPAC.

COD was determined using standard Open Reflux method specified by Standard Methods for the Examination of Water and Wastewater Section 5220B [12]. The focus on organic content was decided because Sarno River has consistently shown elevated levels ofthese parameters and also because BOD and COD allow analysis of pollutant load and identification of sources.

The sarno river visual assessment protocol (SRVAP)

The SRVAP involves both technical and non-technical evaluation. The technical evaluation is based on scientific knowledge of the environmental conditions and processes through instantaneous observations. On the other hand, the non-technical evaluation is based on temporal and experiential knowledge of the conditions of the river. The technical evaluation is composed of eleven (11) visual elements, namely, channel condition (ChC), hydrologic alteration (HA), riparian zone (RZ), bank stability (BS), water appearance (WA), nutrient enrichment (NE), barriers to fish movement (FB), in stream fish cover (IFC), invertebrate habitat (IH), canopy cover (CaC) and manure presence (MP). In consideration of the knowledge and availability of the local people, the non-technical evaluation was limited to six (6) elements, namely, ChC, HA, BS, W A, FB, and MP. The instrument used was a questionnaire composed of multiple choice questions, translated into the local knowledge. Pictures were also incorporated in order to facilitate ease and consistency of the answers. The scores for the visual elements were also used to determine the aspects of ecological condition, namely, energy sources (ES), chemical variables (CV), flow regime (FR) and habitat structure (HS). These are based on the factors that influence the integrity of streams defined by Karr [13] as cited by USDA [9] and USDA (2009).

Field evaluation of Sarno river visual assessment protocol

The two seasonal technical evaluations were undertaken by a panel of four experts. Meanwhile, the non-technical evaluation was done by respondents from the local population. For each site, 10 respondents were interviewed on three separate days (Tuesday, Wednesday, Thursday) for three weeks (1^{st},3^{rd},4^{th}) in July, 2013. Scores for the technical evaluation were assigned by the panel of experts. For the non-technical evaluation, the scores were based on the median scores of the respondents. A scale from 1 (Worst condition) to 10 (Best condition) was adopted in the evaluation of each measured element and the total assessment score was computed using the weighted-average scores for each element. Weights were pre-determined from Pair-comparison Analysis (PCA) Method [14-16]. The total assessment scores obtained is then used to classify the sites into 5 classes, specifically, bad, poor, fair, good and excellent condition.

Data analysis

Correlation among the parameters was analyzed by pair-wise linear regression analysis using JMP 10® [17].

Results and Discussion

Water quality of sarno river

The organic content of the river based on BOD and COD measurements is shown in (Figure 2). From the figure it can be seen that the organic loading of the river is lower in the upstream stations (Site A and Site B) than in the downstream stations (Site C, Site D and Site E). BOD values ranged from 0 mg/L to 42 mg/L while COD values ranged from 0 mg/L to 108.9 mg/L. The highest BOD and COD values were measured during the summer season at Site C and Site D, respectively. Both values indicate bad river quality based on Italian regulation for water quality DL 152/2006. A significant increase in organic content was seen in all stations during the summer season. This can be attributed to the increased agricultural activities as well as increased temperature during this season. Additionally, the highest COD value detected in Site D during summer may be due to sewage and other discharges from a highly-populated community near the sampling site. The highest BOD level in Site C is also attributed to urban discharges in the area.

Visual assessment of sarno river

The results of the SRVAP evaluation are shown in (Table 1). The total assessment scores ranged from 4.31 to 8.18, indicating poor to good river quality. Several physical infrastructures are present along

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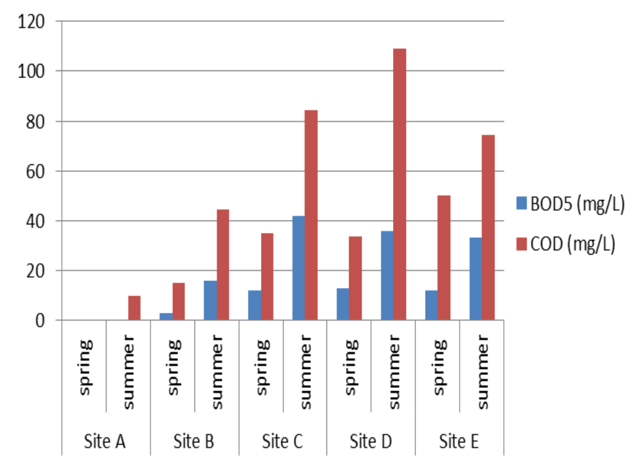

Figure 2: BOD and COD for the sampling stations of Sarno River.

Sarno River and these directly impacted the condition of the stream. In Sites A, C and E, the presence of dikes and pathways has affected the natural flow of the water while the drop structures in Site A has functioned as fish barriers and hindered biotic migration. Hydrologic alteration was observed during the summer season due to lowering of water level especially in Site A and Site C. As for the quality of the Riparian Zone in the river, it was observed that the highest quality was present in Site A and gradually deteriorated downstream. Bank Stability was high in Sites A, B and E and low in Sites C and D. However, bank stability improved in Site C during summer as more vegetation lined the banks of the stream. Canopy Cover was sufficient in the upstream stations (Sites A, B and C) and least in Site E where no shading was observed. Site D had poor cover although vegetation improved its score during summer. These observations showed that the conditions of the river were affected by seasonal variations.

Among the elements tested, Water Appearance and Nutrient Enrichment were worst as evidenced by the dark green coloration and turbidity along the stretch of the river, with the sole exception of the uppermost portion (Site A). Animal and human wastes were also observed throughout the river stretch. These factors affected the quality of the water and are reflected in the upward trend in the river's organic content.

The availability of space for Habitat for the biotic community in Sarno River decreased as the flow went downstream. Still, a decrease in availability was observed in Site A due to the lower water level (HA). At the same time, an increase in Site C was observed due to the increased vegetation in the riparian zone. These elements, together with Canopy Cover, define the energy sources and habitat structure in the river. They showed moderate variation with seasonal changes.

As observed, the major elements that contributed to the poor ecological condition of the river were water appearance, nutrient enrichment, manure presence, bank stability and riparian zones. While the first three elements are affected by land-use activities in the area such as agricultural run-off and municipal waste discharges, the last two elements can be related to management practices in the river. Therefore, anthropogenic activities near the river are the major causes of the deterioration in the ecological condition of the Sarno River. Based on the scores of the different aspects, Site A consistently exhibited good conditions. Site B had good condition as far as Flow Regime (FR) and Habitat Structure (HS) were concerned but had an overall fair evaluation due to low scores in Energy Sources (ES) and Chemical Variables (CV). The downstream stations (Sites C, D, and E) all had poor classification owing to low scores in ES and CV and fair conditions for FR and HS. The primary contributing factor for low water quality was identified as water appearance, indicating that people tended to judge the quality of the river in terms of visual cue. From the foregoing observations, it can be seen that the determination and analysis of the various visual elements and aspects are useful in obtaining more accurate information on the processes and interactions in the river. The consideration of factors such as the different pollution acceptor sources (water and soil) and energy flow in the evaluation are advantageous as this gives a holistic view of the condition of the river [18,19].

	Spring (May 8, 2013)					Summer (August 8, 2013)				
	Site A	Site B	Site C	Site D	Site E	Site A	Site B	Site C	Site D	Site E
Elements										
Channel Condition	4.75	10	4	8.5	4.75	4.75	10	4	8.5	4.75
Hydrologic Alteration	8.25	8	8.63	8	8.5	3	8	6.38	8	8.5
Fish Barriers	5.75	9.5	9.25	8.75	9.25	5.75	9.5	9.25	8.75	9.25
Bank Stability	8.5	8.5	4	3	6.5	8.5	8.5	4	7.5	6.5
Water Appearance	10	2.5	2.5	1	1	10	2.5	2.5	1	1
Manure Presence	6.13	5.25	4.75	5.25	4.75	6.13	5.25	4.75	5.25	4.75
Nutrient Enrichment	10	1	1	1	1	10	1	1	1	1
Canopy Cover	10	10	10	10	1	10	10	10	10	1
Riparian Zone	10	6.5	3	1	2	10	6.5	3	1	2
Instream Fish Cover	5	5	5	5	3	5	5	5	5	3
Invertebrate Habitat	10	7	7	7	7	10	7	7	7	7
Aspects										
Energy Sources score	8.71	3.92	3.75	3.92	2.25	8.71	3.92	3.75	3.92	2.25
Chemical Variable score	8.06	3.38	3.13	3.13	2.88	8.06	3.38	3.13	3.13	2.88
Flow Regime Score	7.58	8.35	5.25	6.25	5.88	5.48	8.35	4.75	6.7	5.88
Habitat Structure Score	8.49	7.21	5.45	5.33	5.44	7.7	7.21	6.21	6.3	5.44
Total score										
Weighted SRVAP Score	8.18	5.77	4.43	4.45	4.31	7.48	5.77	4.59	5.03	4.31
Classification	Good	Fair	Poor	Poor	Poor	Good	Fair	Poor	Fair	Poor

Table 1: Results of SRVAP Evaluation.

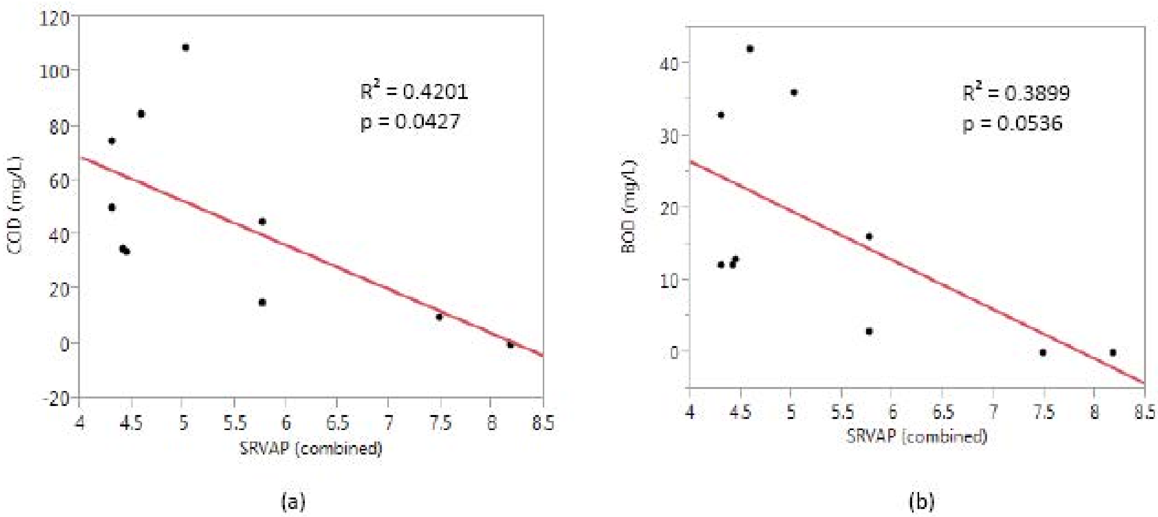

Figure 3: Correlation of SRVAP with (a) COD and (b) BOD.

Spring evaluation	SRVAP Score
BOD (mg/L)	0.8642 (p=0.0222)
	BOD=26.48 - 3.40*SRVAP
COD (mg/L)	0.8542 (p=0.0247)
	COD=85.74 - 10.88*SRVAP
Summer evaluation	
BOD (mg/L)	0.8843 (p=0.0173)
	BOD=94.56 - 12.72*SRVAP
COD (mg/L)	0.7156 (p=0.0709)
	COD=202.71-25.45*SRVAP

Table 2: Regression coefficients and equations of water quality parameters and SRVAP score.

Data analysis

Correlation of river water quality with SRVAP: Linear regression was used to determine possible relationships between SRVAP scores and BOD and COD values. Plots for the linear regression are shown in (Figure 3). SRVAP scores has a statistically significant positive correlation with COD (R^2=0.4201; p=0.0427) while no significant correlation was observed with BOD. In terms of monitoring, visual assessment can act as a rapid estimation for the organic content of the Sarno River. Based on the results of regression, an equation that can be used is COD=133.76 -16.24*SRVAPscore. This suggests that incorporating non-technical evaluation can be identified as a plausible predictor of COD in the river. This shows that local knowledge is important and increases the viability of the evaluation. This also shows the feasibility of adding public participation as a tool for evaluation of the river which is consistent with the recommendation of Silvano [20]. Public Participation is a key element in the implementation of the WFD [3] and this assessment method can be an innovative way of involving local people in watershed management.

In order to identify possible factors for the low correlation, analysis was also done to study seasonal trends. The results are shown in (Table 2). It was observed that correlation greatly increased between SRVAP scores and organic content (in terms of BOD and COD) during spring and SRVAP scores with BOD during summer. This shows that the seasonal variability affected negatively the regression and thus, the derived linear regression equations were deemed more suitable for seasonal evaluation. Regression for COD during summer is not significant because COD values exhibited a very high increase during this time which indicates the contribution of agricultural activities such as tomato canning to the river.

Correlation of river water quality with SRVAP aspects/elements: Pair-wise linear regression analysis were also done for all SRVAP aspects and elements. Riparian zone was also found to be significantly and positively correlated with BOD (R^2=0.4051; p=0.0479) and COD (R^2=0.4833; p=0.0256). This suggests that riparian zone is the most influential element in determining water quality in Sarno River. This is highly relevant in terms of prioritization of river management plans because this signifies that changes in the riparian zone of Sarno River will bring a great impact on its ecological condition. A statistically significant relationship was also seen between chemical variables and COD, having an R^2 value of 0.4067 (p=0.0473) and this element may also be considered as one driving force in determining river condition. Furthermore, water appearance was related to COD (R^2=0.4383; p=0.0370) and this can be a possible indicator that local people can utilize as an early warning mechanism suggesting the need for management interventions in the river.

Conclusions

The modified SRVAP procedure using weighted-average technical evaluation proved to be representative of the general condition of Sarno River, with classification of good to poor for the five (5) sampling sites. The condition of the river was found to be deteriorating from the upstream to downstream stations. The results show that public knowledge should be incorporated in the evaluation. A statistically significant relationship was found for SRVAP and COD and this can be used as a basis for using SRVAP as alternative indicator of COD content in the river. Important elements to consider are riparian zone and water appearance which should be prioritized in management programs. High correlation between SRVAP and organic content was ascertained when seasonal variation is considered and linear regression equations which were generated may be used as rapid estimates of COD and BOD levels in Sarno River. However, it is recommended that additional validation studies are done to check the accuracy of the equations.

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