SUSTAINABLE DEVELOPMENT IN VULNERABLE COASTAL ZONES: THE CASE OF ABRUZZO

Cristina Montaldi, Gianni Di Pietro, Chiara Cattani, Francesco Zullo

Abstract: Coastal areas are pivotal in socio-economic and environmental contexts. They face heightened vulnerability due to their strategic significance and high population density, particularly evident in countries like Italy. The study areas are the 19 Abruzzo Region coastal municipalities, with a specific focus on the coastal belt of 1km. The main objective is to examine urban transformations and their causes driven by economic and demographic factors. For a strategic perspective on future territorial transformations the Planning Tool Mosaic (PTM) has been used. Municipal plans in Italy often overlook neighboring municipalities, resulting in disjointed management policies linked only by administrative borders. This study aims to provide a deep understanding of urban dynamics, identifying areas of high environmental value and assessing the economic and demographic energy of each municipality. By evaluating these aspects holistically, the study seeks to justify and adjust planning provisions to ensure sustainability, mitigating the loss of ecosystem services like crop production, water storage, and carbon sequestration. This comprehensive approach is crucial for fostering sustainable development in vulnerable coastal territories.

Keywords: Human and natural landscape, sustainability of coastal ecosystems, urban planning.

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Introduction

Coastal areas are extremely active in terms of urban transformations but at the same time they are extremely complex and fragile systems. These areas have a high level of environmental value [11] but they are subjected to strong anthropogenic pressures linked specifically to the high population density. Many scientific studies investigated the high fragility of the Mediterranean regions that are characterized by intense phenomena of land consumption [18]. Land use changes have impact on different ecosystem services. For example, they determine the variation in the surface water infiltration capacity [21,12], in soil carbon capture and storage [19] and in agricultural production [24].

In this paper, these three ecosystem services have been analyzed in reference to different scenarios. Specifically, two crono-section have been considered (2012 and 2021) for the measured variation in land use and forecast scenarios for future land use have been elaborated. For the last scenarios the Planning Tool Mosaic of the considered municipalities have been used (Figure 1c). Starting from the current settlement configuration, the work shows both what the future urban layout could be since the forecasts of urban plans and their possible effects on the above-mentioned ecosystem services.

The study area (Figure 1b) are the 19 Abruzzo Region coastal municipalities, with a specific focus on the coastal belt of 1km. The choice of this area is linked to the fact that this stretch is the one most affected by urban phenomena related to the economies of the sea, as also demonstrated by recent studies [3]. The importance of these areas for the regional demographic and economics dynamics becomes clear investigating what happened in the last 10 years. Between 2013 and 2023 the population of the Abruzzo region is decreased of about 40 000 people, instead of the coastal municipalities that increased their population of about 9 000 people. 14 municipalities of the 19 studied have a population higher than 10 000 people with 3 of them that surpassed the 40 000 inhabitants (Vasto, Montesilvano and Pescara).

The study area extends for 640 km^2 with a population of about 440 000 people for 2023. The population density (DA) of the area is 683 inhab./km^2, with the highest value for the municipality of Pescara (3479 inhab. /km^2). Values like that are very high if compared to the national (about 200 inhab. /km^2) and to the regional one (about 120 inhab. /km^2). Morphologically, the 130 km of Abruzzo coastline are rather uniform, with flat formations, low and sandy beaches and a flat or low hilly hinterland. This morphology has facilitated both the construction of infrastructures and productive-residential settlements. The presence of important infrastructure like highways and high-speed rail has allowed the growth and strengthening of urban centers. Coastal Abruzzo's settlement can be considered linear urban sprawl, growth mainly during the 60's and 70's.

From an economic point of view, coastal municipalities contribute more than a third of the regional taxable income (reference year 2021). Despite the strong anthropization, it is still possible to identify areas that preserve important natural traits, which, however, with less than a couple Special Areas of Conservation are subject to forms of protection that allow margins of transformability (e.g. Landscape Plan).

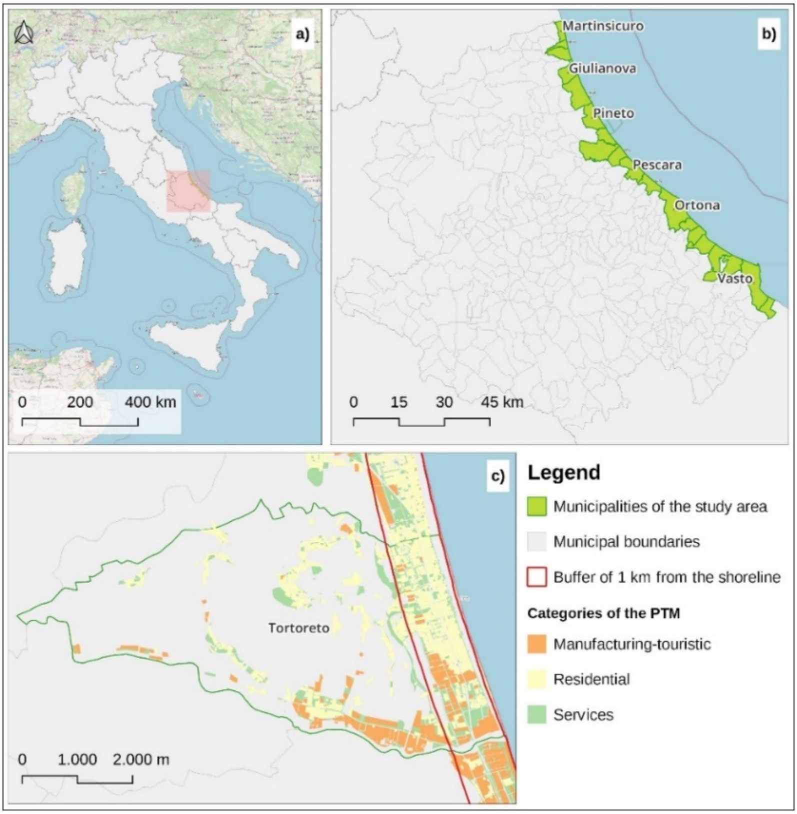

Figure 1 – Study area. a) position of the Abruzzo region in Italy, b) municipalities of the study area, c) example of PTM (Planning Tool Mosaic) for the municipality of Tortoreto, with the buffer of 1 km from the shoreline.

Materials and Methods

The elaborations contained in this work required the use of data of different nature from multiple sources. The reconstruction of the geography of the future urban settlement was carried out by reconstructing the framework of municipal urban planning instruments (PTM). The techniques for the construction of this tool are consolidated and used in several articles of the scientific literature [4,9,13,15,20,25,27]. The PTM required the retrieval of plans at the institutional portals of the individual municipalities, a pre-elaboration (georeferencing, digitization, elaboration of the union framework) and the reclassification according to the homogeneous territorial zones defined by Ministerial Decree 2 April 1968, No. 1444. This process involves a certain discretion in the zonal attribution; however, this is a reversible process because the original description of the area is always preserved in the database. The territorial zones are thus defined as:

A parts of the territory concerned by urban agglomerations that have a historical, artistic character and of particular environmental value or portions of them, including surrounding areas, which may be considered to be an integral part, for those characteristics, of the agglomerations themselves;

B parts of the territory that have been totally or partially built up, other than (A) zones: partially built up are those areas in which the covered area of existing buildings is not less than 12,5 % of the buildable area and in which the territorial density exceeds 1,5 m^3/m^2;

C parts of the territory intended for new settlement complexes, which are unbuilt or in which the pre-existing building does not reach the limits of surface area and density referred to in point (B);

D parts of the territory intended for new settlements for industrial installations or similar;

E parts of the territory intended for equipment and installation of general interest, public spaces, or spaces reserved for collective activities, public green, or parking, with the exclusion of spaces intended for road locations.

In this specific case, it has been decided to further simplify and the above zones. They have been reduced to three categories (Table 1) to make the reading of the phenomena more immediate.

Table 1 – Reorganization into categories of the zoning by D.M. 1444/68.

Category	Zoning (D.M. 1444/68)
Residential	B, C
Manufacturing-touristic	D
Services	F, S

The analysis for carbon sequestration was conducted through the open-source software InVEST (Integrated Assessment of Ecosystem Services and Tradeoffs) version: “InVEST 3.12.0 Workbench”, which is a suite of models, including that of Carbon Storage and Sequestration (CSS). The methodologies used for the evaluation of models follow the flowchart already tested in other geographical areas [4,28]. The *Istituto Superiore per la Protezione e la Ricerca Ambientale* (ISPRA) data on land use were used for the assessment of these ecosystem services. The data used can be found at the following link https://www.isprambiente.gov.it/it/banche-dati/banche-datifolder/suolo-e-territorio/uso-del-suolo (accessed on 10 April 2024). Two years were considered: 2012 and 2021. The most up-to-date data for 2022 was not used as it is affected by errors for the study area. The geometric resolution of the data is 10 m/pixel. This data has different categories of land uses identified with a unique code, the corresponding with the description is shown in Table 2.

Table 2 – Legend of ISPRA land uses for the study area.

CODE	Description
2	Forest use
3	Quarries and mines
4	Urban and similar areas
5	Water uses
11	Arable crops
12	Forage
13	Permanent crops
14	Agro-forestry areas
16	Other agricultural uses
61	Wetland areas
62	Other non-economic uses

The model (based on the IPCC guidelines [7]) requires four types of carbon pools:

- epigeal biomass (C above), which includes all living plant material above the soil (e.g., bark, trunks, branches, leaves);
- the hypogean biomass (C below), comprising the living root systems of the epigeal biomass;
- soil organic matter (C soil), which constitutes the largest terrestrial carbon pool;
- dead organic matter (C dead), which includes litter and dead wood (both ground and dead logs still standing).

These input data were derived from the SimulSoil database using the different sources [5,6] and adjusting the legend to the one in the ISPRA land cover data as reported in Table 3.

Table 3 – Values of the Carbon Pools for model Carbon Storage and Sequestration for land uses.

Land use code	C above	C below	C soil	C dead
2	40,67	21,63	77,77	14,02
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
11	5	0	97,01	0
12	0	0	142,47	0
13	10	0	92,8	0
14	10	0	44,8	0
16	0	0	93,79	0
61	0	0	0	0
62	0	0	0	0

The economic value of the seized carbon (expressed in EUR/ton) was derived from Trading Economics (carbon price from the ETS (Emission Trading Systems) market on 29 April 2024 https://tradingeconomics.com/commodity/carbon.

As regard the crop production and water storage InVEST has not been used for the lack of input data. For this reason, evaluations about crop production follow a methodology already tested [26]. Soils considered as agricultural are identified by the code 11,12,13 and 16 reported in Table 2. Values for agricultural yield come from the Abruzzo region website (reference year 2014) [16] and price value comes from *Istituto di Servizi per il Mercato Agricolo Alimentar*e (ISMEA) [10]. Yield values are expressed in 100 kg per hectare, prices in euros per 100 kg.

The land use legend does not provide information about the type of cultivation present on the ground, for this reason in this study has been considered the wheat as cultivation. The values of crop production are available by provinces, so for this study the mean value of three involved provinces has been considered. This value is equal to 6000 kg per hectares. The conducted analysis on crop is a purely economic estimate and does not correspond to the biophysical value of the service of agricultural production however conditioned by the uncertainty of yield and average price that have been considered. The economic assessment is provided as a support, to understand the size of the environmental impact expected from the implementation of the transformation forecasts of municipal urban plans [2].

The last considered ecosystem service is related to water storage. Specifically, it was estimated the variation of runoff linked to the land use variation. Reference was made to the rational method which is a method to evaluate the flow of water through a specific section of a basin [22]. This empirical method, based on Equation (1), has different conditions to be met for its correct application, especially relating to the calculation of the intensity of rain. However, this study is outside the scope of the water discharge calculation but focuses on the evaluation of the runoff coefficients.

$$Q = \varphi \, i \, A \tag{1}$$

where:
Q = water discarge [m^3/s];
i = rain average intensity [m/s];
A = catchment area [m^2];
φ = runoff coefficient [-]

In this case, it was considered that, with the same intensity of precipitation (i) and area of basin (A), the parameter which varies, depending on the change in land use, is the runoff coefficient φ. The water discharge infiltrated varies proportionally to the degree of waterproofing and, for this reason depending on the variation of the ground cover. For example, soil with 50% of sealing determines a runoff rate five times higher if compared to natural soil. The runoff coefficient φ (variable from 0 for fully permeable surfaces, to 1 for impermeable surfaces) is the parameter that determines the transformation of rainfall-runoff. This coefficient is equal to the ratio between the volume flown through an assigned section and the meteoric volume. In this study, the evaluation of φ values was made considering the permeability characteristics of the draining basin cover and it comes from scientific literature [8]. The used values are reported in Table 4. As a precaution, the runoff coefficients are considered constant throughout the weather event.

Table 4 – Values of the Runoff Coefficient.

Code	Description	φ
2	Forest use	0,2
3	Quarries and mines	1
4	Urban and similar areas	0,74
5	Water uses	0
11	Arable crops	0,7
12	Forage	0,4
13	Permanent crops	0,6
14	Agro-forestry areas	0,6
16	Other agricultural uses	0,6
61	Wetland areas	0
62	Other non-economic uses	0,7

Results

The carbon capture and storage examination has been done using InVEST model. Specifically, the analysis regard all the municipalities of the Abruzzo coast with a deepening for the area of 1km from the shoreline. From the output data of the model, it is possible to define perspective scenarios both whole study area and for each municipality. Particularly, the first result regards the land use change registered between 2012 and 2021. It results that in the study area natural land are decreased for an amount of 177 hectares for the increase of urban land. The municipality with the highest change is San Salvo that loss about 27 hectares of natural areas. For this changes in land use there is a change in carbon capture and storage capacity of the soil. Specifically, in this period, the study area loss about 13 000 tonnes of carbon (tC) about 1480 tC per year. The municipality with the highest loss is Roseto degli Abruzzi (-2710 tC). There are also 4 municipalities (Ortona, Francavilla al Mare, Martinsicuro and San Vito Chietino) that register a total increase in carbon storage capacity of 3000 tC. These variations correspond to a total economic loss of about 900 000 €, the value for each municipality is reported in Figure 2 by the dark green bars. It results that the highest loss is the one of Roseto degli Abruzzi equal to 180 000 € (about 20 000 €/y). On the other hand, Ortona earns about 8300 €/y due to the increase in natural land use soil.

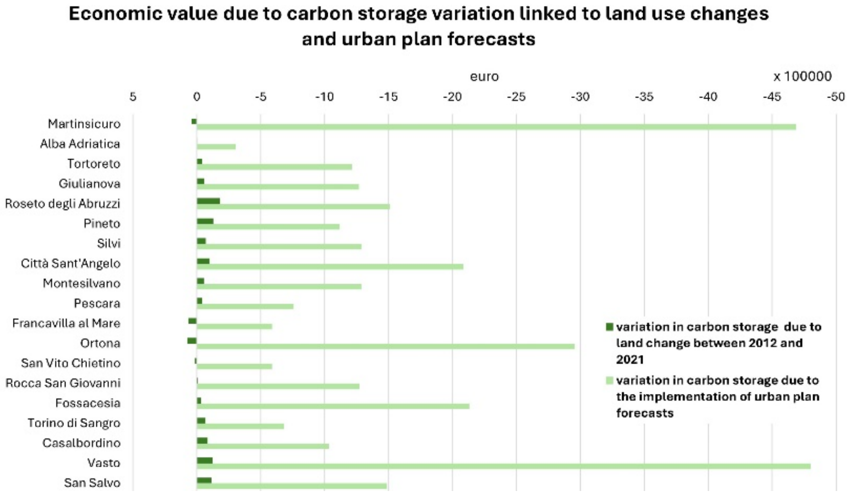

Figure 2 – Economic value due to carbon storage variation linked to land use changes and urban plans forecasts. The data are reported for each municipality ordered from the north to the south.

It is interesting to compare these findings to the one from the implementation of the urban plans. In general, the plans forecast for the study area attribute 43 % of the plan forecasts to the residential sector, 31 % to the manufacturing-touristic sector and 21 % to the services. The future implementation of these forecasts inevitably caused a reduction in soil carbon storage, specifically the following results represent what will happened with the total implementation of these forecasts. It results that the municipality that could loss the highest capacity in carbon storage is the one of Vasto (- 71 000 tC). InVEST model has also the output for the economic value linked to soil variation, as shown in Figure 2, since in all municipalities the carbon storage decreases with the implementation of the plans, the economic value is negative. Specifically, the municipalities of Martinsicuro and Vasto recorded the highest lost (higher than 4,5 million euro per year since the total implementation of the urban plans). The interesting things is that the economic loss due to the full implementation of all the urban forecasts is 34 times higher than the one recorded for land use changes registered between 2012 and 2021.

As declared in the introduction the study is also referred about the first kilometer from the shoreline. Specifically, it is interesting to understand the weight of this area in the variation of this ecosystem service recorded in each municipality.

As shown in Figure 3 the municipality of Martinsicuro has 45 % of its surface in the first km from the coast, and this area represents the 50 % of the loss in carbon storage detected for this municipality in the period 2012 – 2021. The plans forecasts located in this buffer if totally implemented will represent about the 30 % of the carbon storage loss due to plans forecasts for this municipality. In most municipalities, the coastal strip in the period 2012 - 2021 records the loss of carbon storage with a peak for the municipality of Francavilla.

From these results it is clear that the new urbanization areas are strongly responsible of probable future changes in carbon storage, specifically the expected losses are many times higher than the one measured by the model for the 9 years from 2012 to 2021.

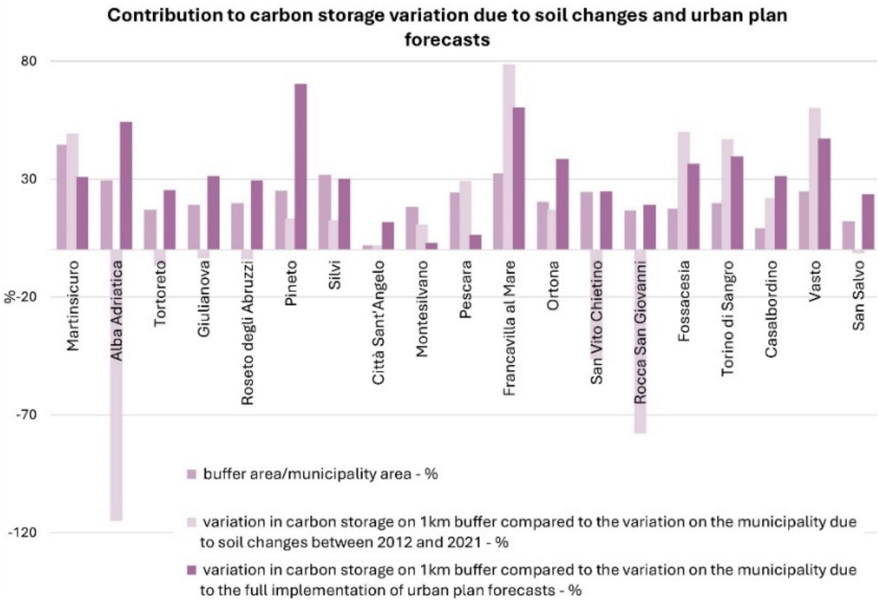

Figure 3 – Contribution to carbon storage variation due to soil changes and urban plan forecasts in 1 km buffer from the shoreline.

The second considered ecosystem service is the one of agricultural loss. Also, in this case the study is carried out both for the 19 municipalities and for their buffer of 1 km from the shoreline. The agricultural surface from 2012 to 2021 decreased and will continue to decrease if urban plans will be implemented. Specifically, the crop production that in 2012 is 234 million kg decreases to 233 million kg in 2021 and it will decrease to 211 million kg with the full implementation of urban plans. The last one will generate an economic loss of 4,5 million €/year that is 40 times higher than the one recorded between 2012 and 2021 (about 100 000 €), with the coastal belt that determine about 30 % of the total economic loss. The plans categories determine about the same contribution to that finding (33 % of the total for each one). This kind of analysis has been done for each municipality too. Figure 4 shows that in all the municipalities the crop production decreases from 2012 to 2021 and will continue to decrease with the full implementation of the plans and this is true also for the 1 km buffer. Some municipalities have low or not economic loss due the fact that not a lot of agricultural areas are in the coastal belt (i.e. Città Sant'Angelo, Montesilvano and Pescara) since these areas has been urbanized during the years particularly during the 60's and 80's [17].

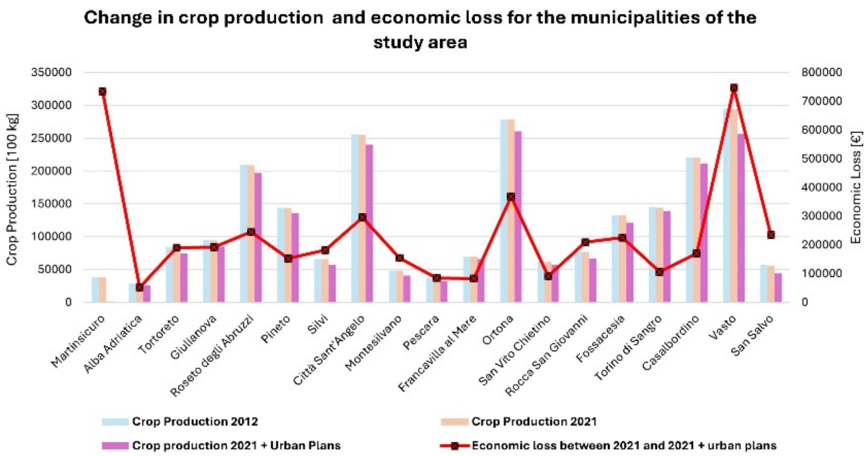

Figure 4 – Variation in crop production and in economic value for the municipalities of the study area. In light blue there is the crop production for 2012, in pink the one for 2021, in dark pink the expected crop production after the full implementation of urban plans forecast. The red line is the economic loss due to the changes in land use between 2021 and the implementation of the plans (2021 + urban plans).

The last ecosystem services considered is the water storage of soil. As declared in the methodology the water retention capacity of the soil change with the soil land cover and use. The higher is the impermeabilization rate the lower is the capacity of the soil to retain water. Specifically, as shown in Table 5, for this study the equivalent runoff coefficient (φ eq) has been calculated, and it result that in 2012 it is equal to 62,3 %, 62,4 % in 2021 and will become 63,5 % with the total implementation of urban plans forecasts. Value like that means that about the 60 % of the water become runoff and will not be retained by soil. The situation is more serious for the coastal belt in which the coefficient reached the 66,5 % with the total implementation of plans.

Table 5 – Equivalent runoff coefficient (φ eq).

Reference year	**φ eq all the municipality surface**	**φ eq for 1 km buffer**
2012	62,3 %	64,05 %
2021	62,4 %	64,07 %
Urban plans implementation	63,5 %	66,5 %

The study of each municipality shows that the value of φ_{eq} between 2012 and 2021 is similar, they differ only in few cases and the difference is very low (about some decimal). The absolute values of φ_{eq} can be read in Figure 5. It results that for 2021 each value is higher than 50 % this means that for all the municipalities at least 50 % of water becomes runoff and need adequate sewages to be managed.

The higher value is recorded for Pescara (about 70 %). After the plans implementation the situation changes. As shown in Figure 5 the cases in which φ_{eq} is the highest are Martinsicuro (>70 % both in the municipality and in the coastal belt) and Montesilvano. The cases of Torino di Sangro and San Vito Chietino are particular. They are the only municipalities in which the φ_{eq} on the coastal belt after the plans implementation is lower than the whole municipalities. In fact, generally, the coastal belts are more sealed than the other areas and consequently the water retention capacity is lower.

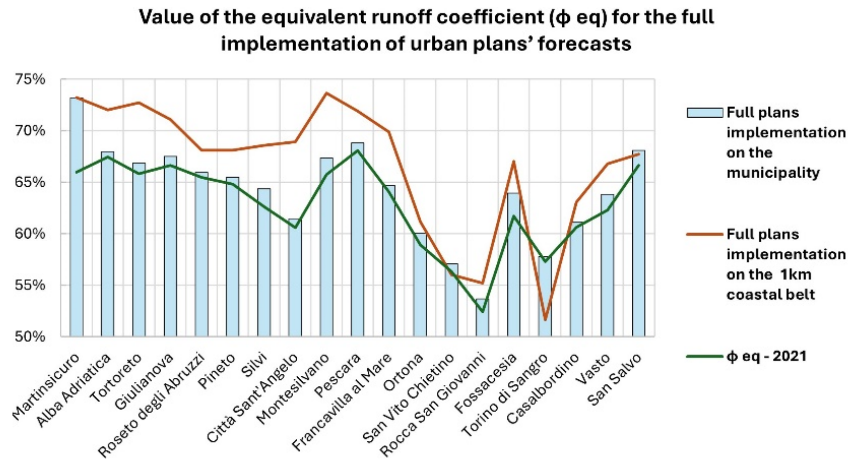

Figure 5 – Value of the equivalent runoff coefficient (φ_{eq}) for the full implementation of urban plans' forecasts calculated both for the whole territory of each municipality (in light blue) and for the buffer of 1 km (orange line). The green line represents the equivalent runoff coefficient for 2021 for the whole municipalities surface.

Discussion and Conclusion

The Adriatic coast certainly represents one of the most urbanized coastal areas in the Mediterranean basin. Today, the presence of important ecological values and ecosystem services clash with an ever-increasing anthropogenic pressure that, being seasonally adjusted, manifests its tangible effects over narrow time spans. Yet, this is an area, as seen for Abruzzo, that still has high ecological values of primary importance. The knowledge of which landscapes are the richest in carbon would help, for example, local governments in defining effective target incentives for landowners in exchange for forest conservation. Assessing ecosystem services is necessary to develop spatial planning scenarios and ex-ante evaluation of policies. Furthermore, in this way it is possible to consider the level of well-being of society and provide policymakers with tools to monitor and improve well-being. [1]. Decision-makers must equip themselves with cognitive and managerial tools capable of considering in spatial planning tools the ecosystem service and distinguishing the different areas of interest and relevance and knowing the interrelations at different spatial-temporal scales. Decision makers and the population should become more aware of the economic value of ecosystem goods and services, which, once destroyed, are sometimes impossible to restore or often are, but only at very high costs [23]. Increasingly, however, the initiatives that take place from year to year are aimed at ensuring the presence of the sandy shore (beach nourishment, coastal defense structures) to safeguard the economic spin-off generated by seaside tourism that represents one of the main sources of the local economy. As repeatedly observed, the absence of a strategic vision for the management and protection of these areas leads municipalities to increase urban loads in the territories involved and in the first kilometer from the shoreline. As mentioned, however, insufficient attention is paid to the influence such transformations could generate on coastal dynamics and fragile existing residual ecosystems [14].

The analyses on the transformative forecasts of municipal urban plans es made it possible to estimate the amount of potentially usable land for urban purposes, and to quantify, albeit with simplifying but effective assumptions, the impacts produced in terms of loss of agricultural production, carbon capture and storage and water retention. The knowledge of the transformative forecasts of urban plans is crucial for the identification of possible critical issues, for planning targeted corrective actions, and for the achievement of the important goals of Agenda 2030 [4]. As is often the case, the economic interest associated with urbanization is greater than that associated with other types of use. In general, urbanizing agricultural land is less costly than intervening in degraded areas or disused infrastructure [2].

Finally, it must be noted that the techniques and tools available make it possible to draw up highly detailed urban planning frameworks, but political measures often do not go beyond the borders of the administrative municipality unit. In addition to the already existing coastal protection plans that, it should be remembered, involve the territory of a single region, it might be advisable to start thinking about strategic plans that cover the entire physiographic unit and that can actively influence the location of new urban forecasts not only because of the possible physical risk but also because of the effect on sediment transport and erosion dynamics.

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