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Review Article

Campania as a Water Paradox Region: natural abundance, strategic vulnerability, and governance challenges in Mediterranean water security

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Abstract: Campania, traditionally perceived as a water-rich region, represents a significant example of the Mediterranean water paradox. Despite the presence of important natural resources, the region is affected by structural water insecurity driven by groundwater vulnerability, water quality degradation, infrastructural inefficiencies, and fragmented governance. This paper analyses water as a strategic asset, able to influence regional resilience and stability. The research integrates hydrological evidence, climate indicators, and policy analysis through key regional case studies, including aquifer vulnerability, recent drought conditions, degradation of the Sarno River Basin, residential water-use dynamics, and agricultural pressures on water resources. The results highlight systemic weaknesses that cannot be fully explained through traditional sectoral approaches. For this reason, the work proposes an integrated monitoring tool, aquifer protection, and coordinated governance, contributing to broader discussions on Mediterranean water security.

Keywords: Campania region, water security, climate-induced drought, Mediterranean water management, groundwater vulnerability, water governance.

1. Introduction

Water resources are recognized as a strategic component of environmental stability, economic development, and territorial resilience. In the Mediterranean region, the growing interaction between climate variability and infrastructure limitations has intensified concerns regarding long-term water security. Traditionally, water-rich territories are now experiencing forms of structural vulnerability that challenge the historical assumptions of resource abundance. Within this scenario, understanding how water systems evolve under the pressure of environ-

mental, climate, and institutional factors has become a central issue both for scientific research and for the planning of public policies. The Campania region is a significant case within the Mediterranean framework: historically characterized by important hydrological systems and groundwater reserves, the region has long been perceived as safe in terms of water availability. However, recent evidence has shown how this perception of abundance hides a very complicated reality. The interaction between aquifer vulnerability, progressive deterioration of water quality, infrastructural inefficiencies, and governance fragmentation has contributed to a growing condition of water insecurity. It is an apparent contradiction between natural availability and systemic vulnerability that can be described as a real paradox of water abundance. In Campania, some of the most productive aquifer systems are the main supply source for the population and economic activities, but at the same time, they are considered the most exposed to contamination and environmental degradation. Moreover, growing climate variability has increased the frequency and intensity of drought episodes, exposing structural weaknesses in distribution systems and water resources management. Processes of long-term environmental degradation, such as the Sarno River Basin, show how persistent pollution phenomena can transform a renewable resource into a structural issue for the territory.

After these considerations, this work aims to analyze water as a regional strategic asset, whose availability, quality, and governance structures directly influence the territorial resilience in the long-term. The analysis focuses on the Campania region, a representative case study of emerging challenges in managing water resources in the Mediterranean, to understand how structural vulnerabilities can develop even in contexts characterized by an apparent abundance of resources. To do so, this paper adopts an interdisciplinary approach that integrates hydrological evidence, climate indicators, and the analysis of public policies.

Moreover, this study proposes a conceptual model oriented towards an integrated management of regional water security, based on the strengthening of monitoring systems, evaluation of hydrological vulnerabilities, and the use of analytical tools based on scenarios and environmental stress tests. This approach allows overcoming a reactive logic while managing water crises, encouraging a preventive and anticipatory perspective.

By integrating these different analytical dimensions, the study aims to contribute to the broader debate on water governance in the Mediterranean. Specifically, it highlights how water security cannot be interpreted only in terms of the physical availability of resources but must be analyzed through a systemic perspective that considers environmental processes, infrastructure, and institutional structures that regulate its use. Eventually, it proposes an integrated framework for regional water management, founded on long-term planning, aquifer protection, and innovative monitoring tools, an approach relevant not only to the Campania context but also to other Mediterranean territories facing similar challenges in sustainable water resource management.

2. Literature Survey

The scientific and institutional literature on Campania highlights a progressive shift from the interpretation of water as an abundant resource to a more complex vision focused on structural vulnerabilities, resource quality

and governance capacity. Several consolidated hydrological studies show that the regional water system is based on carbonate and alluvial aquifers, historically considered reliable for domestic, agricultural, and industrial supply. However, a relevant part of the literature underlines that these systems are particularly exposed to phenomena of contamination and degradation, undermining their use as a strategic reserve.

At the same time, many studies have brought to light the increasing contrast between the potential natural availability and the effective availability of usable water, underlining the role of infrastructural losses and higher costs of treatment. Within this framework, the attention has shifted from water quantity as the main determining factor of water security, especially in contexts affected by historical and persistent anthropogenic pressures.

A relevant part of the literature addresses environmental change and drought, which are considered cumulative stress rather than isolated events. Long-term analyses show an increase of rainfall variability and more frequent dry conditions in Campania, with direct effects on the surface and groundwater resources. Recent institutional reports confirm that the already observed conditions between 2023 and 2025 represent an acceleration of current trends, highlighting the limits of emergency management.

Further contributions have introduced a socio-economic and strategic vision of water resources. A body of literature shows how the apparent reduction in domestic consumption can mask an "illusory decoupling" linked to greater use of groundwater resources of uncertain quality. Meanwhile, policy analysis and institutional studies underline how degraded basins, such as the Sarno, represent emblematic examples of water resources turned into structural liabilities.

The literature survey highlights the need to overcome fragmented approaches and underscores the urgency of an integrated interpretative framework, in which water is considered not only an environmental resource or a public service but also a strategic asset for regional security.

3. Proposed Methodology: comparative analysis of existing solutions

The current contribution adopts a qualitative and comparative approach, aimed at critically evaluating the management strategies for water resource management, which are currently implemented or planned in Campania at present. The methodological goal is not limited to the description of the current strategies, but it consists of analyzing the systematic coherence compared with the regional water security framework, known as the ability of a territory to guarantee quantitative availability, environmental quality, infrastructural reliability, and institutional resilience. The methodological framework is based on the idea that the regional water problems do not arise from a single factor, but from the interaction among climate change, hydrological vulnerabilities, and fragmented governance structures. As a consequence, the proposed analysis integrates the physical and strategic dimensions, comparing the existing solutions in light of literature-identified structural threats.

3.1 Review of current water management strategies

The first phase of the methodology consists of a systematic review of water management strategies, currently adopted at a regional and sub-regional level. This revision includes:

- Infrastructural interventions (implementation of aquifer infrastructure and projects of network modernization): Campania region and water service managers have invested in modernization and enhancement interventions of water networks and in interconnection works between water systems. These interventions aim to ensure continuity of supply and reduce service interruptions, especially during periods of greater water stress. However, national and regional data highlight significant levels of water dispersion along the distribution network, with losses that affect water availability. For this reason, the infrastructural strategies are oriented toward improving the reliability of the existing system rather than a structural transformation of the management model.
- Efficiency measures and reduction of losses: this area concerns measures aimed at reducing demand and increasing efficiency. It includes:
  - Water loss reduction programs
  - Digital network monitoring systems
  - Water saving awareness campaigns
  - Tariff tools aimed at increasing user accountability

  Recent literature shows how the reduction in domestic consumption does not coincide with a lower overall pressure on water resources, in particular on groundwater. Indeed, a possible reallocation of withdrawals toward less controlled sources is observed, which makes it more difficult to evaluate the real effectiveness of these policies.

- Qualitative protection policies of groundwater and surface Basin: a third strategic category concerns the qualitative protection of water resources, in particular that of carbonate and alluvial aquifers, which constitute the main regional reservoirs. The measures include:
  - Delimitation of protected catchment areas
  - Controls on potentially polluting activities
  - Chemical and microbiological monitoring of water quality
  - Remediation interventions in the degraded Basin

  Scientific literature highlights that the main aquifers are vulnerable to contamination due to their hydrogeological features and anthropogenic pressure. Protection strategies must be compared with a framework of high structural risk, which requires coordinated and strong governance measures.

- Climate strategies and drought monitoring tools: In recent years, there has been a progressive strengthening of climate monitoring tools and drought indicators, including through national

initiatives and data integration programs. These tools offer a way to overcome emergency management challenges by incorporating planning elements based on historical series and forecasting models. However, climate indicators in management decisions are still limited.

- Regulatory mechanisms related to the allocation of civil, agricultural, and industrial uses: regional agriculture, characterized by high irrigation intensity in some areas, exerts significant pressure on surface and groundwater resources. Management strategies include tools for regulating withdrawals and incentives for irrigation efficiency, but coordination between agricultural planning and water management remains partial.

The analysis is based on scientific sources, institutional reports, technical documents, and official data, with particular attention to the coherence between declared goals and implemented operational tools, in order to verify whether the regional strategies respond effectively to the already identified issues or to evaluate the presence of possible discrepancies between intentions and concrete results. In this phase, the strategies are classified as:

i) Solutions aimed at increasing supply, which include infrastructural interventions to enhance aquifers and large hydraulic works. These measures are aimed at addressing temporary or seasonal water scarcity, but their long-term impact depends on the sustainability of the resources used and, on the ability, to integrate infrastructural planning with the protection of ecosystems and aquifers.

ii) Measures to reduce demand and inefficiency, which include programs of water loss reduction, digital network monitoring systems, public awareness campaigns on water conservation and tariff tools aimed at promoting responsible use of water resources. These strategies aim to improve system efficiency and limit waste and unnecessary withdrawals. However, recent literature highlights that the success of these interventions depends on effective monitoring capabilities and coordination among management bodies, as apparent reductions in domestic consumption may coexist with increased withdrawals from less controlled groundwater sources.

iii) Climate prevention and adaptation tools, which include the adoption of advanced drought indicators, forecast models for water stress scenarios, programs of adaptive management, and interventions aimed at the resilience of the water system to climate change effects. The goal is to move from emergency management to an anticipatory approach that can activate preventive measures before the crisis fully manifests.

The revision's main objective is to highlight the logic underlying the interventions: emergency, compensatory, or preventive, which permits understanding if the regional governance is moving towards an anticipatory model of water security or whether a reactive approach still prevails. As a consequence, the analysis does not limit itself to surveying existing strategies; it also allows us to understand Campania's strategic capacity to transform water resource management into a true regional security instrument, laying the foundation for the subsequent comparative evaluation of effectiveness and vulnerability.

3.2. Assessment of effectiveness and limitations of existing interventions

The evaluation of the effectiveness of the strategies currently adopted in Campania must be read in light of the water paradox that characterizes the region: a territory traditionally perceived as rich in water, but increasingly exposed to structural forms of insecurity. In this framework, the analysis not only measures the technical efficiency of the tools and measures but also assesses their contributions to regional resilience, socio-economic stability, and water protection as a strategic asset.

A. Effectiveness in addressing aquifer vulnerability

Monitoring policies and aquifer protection have contributed to improving the awareness of regional hydrological systems and to delimiting protection areas around the main water catchments. However, studies on aquifer vulnerability show how the most productive systems in Campania are also the most exposed to widespread contamination and qualitative degradation, a condition that implies that the existing interventions are not yet sufficient to eliminate a high structural risk.

B. Effectiveness in drought management and climatic variability

The introduction of climate monitoring tools and drought indicators represents a significant step towards a more informed management of the risk. However, recent dry conditions show that the operational implementation of these tools remains partial. Rationing and withdrawal restrictions continue to be implemented in response to already evident critical issues, rather than as a preventive measure. As a result, despite strengthened monitoring, the overall approach remains largely reactive, with limited integration between forecasting and structural planning.

C. Limits of strategies to combat qualitative degradation

The case of historical degradation in the Sarno basin shows how the loss of quality can turn the renewable resource into a structural liability. Controlling policies have produced limited improvements, but the extent and the duration of pollution highlight the limits of late and fragmented interventions. This case reveals that water security cannot be guaranteed just through maintaining available volumes, but it requires systemic protection of quality as a primary condition for usability.

D. Apparent reduction in consumption and hidden vulnerability

Demand containment policies have determined an apparent reduction of domestic consumption. However, the evidence of "decoupling" in residential consumption suggests that it can coexist with a rising use of groundwater resources of uncertain quality. This phenomenon underlines a methodological and strategic limit: water security cannot be measured only through the volumes supplied by the public service, but must consider the overall sustainability of the supply system.

E. Competition between uses and infrastructure performance

The pressures exerted by agriculture and the present of significant infrastructural losses show how competition for water represents a critical factor in regional stability. The existing strategies have improved some operational aspects, but they have not yet solved the misalignment among natural availability, effective demand, and management capacity, and, without an integrated coordination between agricultural planning, urban management, and environmental protection, the risk of inefficient or conflicting allocations is still high.

On the whole, the existing interventions have encouraged improvements and have strengthened the system capacity to face significant stress conditions. Nevertheless, their structural effectiveness seems limited by institutional fragmentation and the prevalence of a compensatory rather than preventive approach. It emerges that Campania suffers not so much from a shortage of water resources, but from insufficient strategic integration between quality protection, climate resilience and coordinated governance, that confirms this paper's central thesis: natural abundance can mask deep vulnerabilities and regional water security needs a shift from emergency management to long-term anticipatory planning.

4. Integrated System Model and Regional Stress Testing Framework

The analysis of regional water security requires overcoming of traditional and sectoral approaches, which tend to treat the quantitative availability, resource quality and infrastructural and governance efficiency as separate dimensions. In the Campania context, these dimensions are intertwined. Aquifer vulnerability affects actual availability, qualitative degradation reduces usable water, network inefficiencies amplify the effects of scarcity and decision-making fragmentation slows systemic responses. The paper tries to address this complexity by proposing an integrated model based on three complementary methodological components, which are System Dynamics, Scenario-Based Stress Testing and a Resilience Assessment Framework.

The first step of the model is the System Dynamics approach, which allows formalising the causal relationships and feedbacks between the main variables of the regional water system. From this perspective, availability of water resources is considered nothing but a dynamic result of the interaction between natural recharge, withdrawals, physicochemical quality and infrastructural performance, whose value lies in the ability to highlight the nonlinear effects and possible critical thresholds beyond which the system loses its self-regulation capacity.

The second step consists of the application of regional stress testing: once the dynamic structure is defined in the system, it is necessary to verify its robustness through the simulation of extreme but possible scenarios. Such scenarios can include prolonged periods of reduction in natural recharge, significant increases in agricultural or urban demand, progressive deterioration in the quality of groundwater or even a combination of these factors. The stress testing aims to evaluate whether the system is able to maintain its essential functions under pressure. In this way water security is measured not only in terms of average availability, but in terms of resilience to extreme conditions.

The third level is the Resilience Assessment Framework, which agrees to combine the results from dynamic simulations and stress tests with an overall evaluation of the regional stability. Such a framework distinguishes between structural vulnerabilities linked to the physical configuration of the territory, technical vulnerabilities connected to infrastructures, and institutional vulnerabilities linked to decision-making mechanisms. Integrating these dimensions allows to understand whether issues derive from natural factors or organizational and management limits, thus orienting intervention policies.

The innovative element of the proposed model lies in its ability to connect quantity, quality, and governance within a single analytical architecture. In a region historically characterized by a perception of water abundance, this integration makes the gap between natural potential and actual security visible. Therefore, water security is not defined as a simple balance between supply and demand, but rather as the regional system's ability to absorb shocks, adapt to climate change impacts, and preserve the quality of its resources over the long term. In this perspective, the integrated model represents a tool for anticipatory planning, aimed at transforming water management from an emergency approach to a structural governance based on the understanding of systemic dynamics.

5. Implementation steps of the proposed solution

The implementation of the proposed integrated model needs a structured operational sequence that allows the transformation of the analytic framework into a concrete support tool for regional water planning. The process aims to create a permanent monitoring platform, simulation, and decision-making support that enables long-term water governance.

The first step is the development of a unified platform to collect and integrate regional water data; currently, information on resource availability, water quality, and infrastructure conditions is distributed across different institutions and systems, which limits the ability to conduct systemic analyses and impedes rapid assessment of vulnerability. Therefore, the model's implementation requires a regionally integrated database to continuously aggregate data from different institutional sources, such as environmental agencies, Basin authorities, water service managers, and statistical institutes. The following data must be collected:

- Climate and rainfall data
- Piezometric levels of the major aquifers
- Quality indicators of surface and groundwater
- Infrastructural losses
- Domestic, agricultural and industrial water consumption

Such information base creation is a technical requirement for any dynamic analysis, and it allows overcoming the current fragmentation of the regional water system.

Once the database is established, the second step consists of the construction of a dynamic model of the regional hydric system, a phase in which the main components of the process are represented as intertwined subsystems (hydrogeological system, infrastructure system, water demand system, governance system).

Through System Dynamics, it is possible to discover the flows between these components and identify the main feedback mechanisms that influence the balance of the whole system. For instance, an increase in irrigation demand can lead to higher groundwater withdrawals, which can, in turn, affect piezometric levels and pollutant concentrations, thereby producing indirect effects on the availability of drinking water. At the same time, high losses in distribution networks can increase pressure on collection systems, thereby increasing overall vulnerability.

The next step is the definition of operational indicators, which enable continuous monitoring of the state of the system. These indicators must be selected in order to represent the main dimensions of the regional hydric security: quantitative availability, resource quality, infrastructural efficiency, and sustainability of consumption. The most relevant indicators include the average water table of strategic aquifers, the ratio of water demand to actual availability, the percentage of water leakage in distribution networks, and the frequency of exceedances of quality limits in groundwater and surface water. By defining these indicators, experts can identify alert thresholds beyond which the process becomes increasingly vulnerable. In this way, the model goes beyond simply describing the system and becomes an operational monitoring tool able to support management decisions.

After that, the dynamic model is used to simulate water-stress scenarios. This testing is crucial because it helps assess the system's ability to maintain its essential functions under stress. Such scenarios could include prolonged periods of drought, simultaneous increases in agricultural and urban demand, progressive deterioration in the quality of groundwater, or delays in infrastructure investments, but through these simulations, it is possible to observe how the system reacts to similar conditions and identify critical imbalances. This phase is significant because it detects the most evident and the most latent vulnerabilities that emerge only when multiple stress factors act simultaneously.

The results are then analyzed through a resilience evaluation framework, able to rank the identified vulnerabilities according to their nature and depth, distinguishing between problems related to the physical structure of water resources, problems linked to infrastructure, and problems tied to governance and management. The distinction is both useful and mandatory for defining effective intervention strategies. For example, if vulnerability is mainly infrastructural, policies must focus on the reduction of losses and network modernization. If the problem is instead related to groundwater quality, it will be necessary to reinforce the protection measures of aquifers and control of anthropogenic pressures. In this way, the analysis of resilience directs regional policies towards targeted, evidence-based interventions.

The very last step concerns integrating the model into the processes of planning and water resource management. For the proposed approach to yield concrete effects, the model must be used as a permanent decision-making support tool within regional institutions, which entails periodic database updates, revision of simulation scenarios

in response to new climatic and socio-economic conditions, and the use of operational indicators to guide investment and management decisions. In this way, water management can shift from a reactive approach, based on emergency interventions, to an anticipatory approach, grounded in predicting systemic vulnerabilities. Inside the Campania context, such a system would permit facing the main structural issues, transforming the scientific analysis into a concrete tool of governance and planning of regional water security.

6. Case study applications

The analysis is applied to a series of case studies, which show the main issues characterizing the entire water system in Campania. These examples are not treated as isolated episodes but as demonstrations of structural dynamics involving quantitative availability, resource quality, sectoral demand, and the institutional water governance structure. Through the application of the integrated model and stress testing approach, such phenomena can be analyzed like intertwined elements of a whole regional system, in which environmental and anthropogenic pressures act at the same time.

A. Aquifer Vulnerability in Campania

Regional aquifers are the cornerstone of the Campania water supply. Recent studies have highlighted how the most productive aquifer systems in the region, particularly carbonate aquifers, are also among the most susceptible to contamination and qualitative degradation. This vulnerability is linked to hydrological characteristics of high-permeability systems, which promote rapid recharge but also allow greater infiltration of contaminants coming from agricultural, industrial, and urban activities. Such a phenomenon shows a structural paradox: the most abundant and productive resources are also the weakest ones, from a qualitative point of view. In the proposed model, this dynamic is interpreted as a critical relationship between natural availability and resource resilience, in which the intensity of withdrawals and the anthropic pressure can quicken processes of progressive deterioration.

B. Recurrent Drought and Climate-Induced Water Stress

The increasing frequency of drought conditions has affected the region in recent years: climate analyses show how Campania region is experiencing an increased rainfall variability and a tendency towards longer periods of water deficit. In this context, drought no longer represents an isolated event but a recurring component of the regional climatic system. Through a stress-testing framework, such conditions can be analyzed by simulating scenarios of prolonged reduction of natural recharge and evaluating the effects on the availability of groundwater and surface resources. This approach allows highlighting how the combination between climatic variability and anthropic pressure can engender conditions of structural water stress, even in regions historically considered rich in resources.

C. The Sarno River Basin: From Resource to Structural Liability

The Sarno River Basin is one of the most significant examples of environmental degradation in the Italian water context. Over the years, the presence of industrial, agricultural and urban activities has implied a progressive deterioration of the water quality, turning the potentially strategic rainfall system into a heavily compromised resource. This case shows how persistent pollution can transform a renewable resource into a structural liability for the territory. from the perspective of the integrated model, the qualitative degradation of the Sarno represents an example of a loss of functionality of the surface water system, which can generate indirect effects on other components of the process, such as increased dependence on groundwater or increased treatment costs for civil and industrial uses.

D. Decoupling in Residential Water Consumption

Several recent analyses have shown an apparent reduction in per capita consumption in the urban areas of Campania. However, this decrease does not always correspond to a real reduction in the overall pressure on the water system. In some contexts, the reduction of volumes distributed among public networks can coexist with a deterioration of aquifers quality or with an increase of withdrawals from alternative sources. This phenomenon emphasizes the limits of indicators based only on volumes of consumption and underlines the necessity of more integrated analyses. In the proposed framework, these dynamics are interpreted as signals of a hidden vulnerability, which emerge only when consumption data are related to quantitative conditions and quantitative groundwater resources.

E. Agricultural Water Demand and Infrastructure Efficiency

The last presented case study concerns the pressure exerted by agriculture on the regional water system and the role of infrastructures on resource management. Campania region presents a high productive agricultural sector, characterized by crops of significant value but also with crucial water criteria. During the most climate variability, the irrigation demand tends to increase when the natural availability of resource availability decreases, generating a rising competition among agricultural, domestic and industrial uses; this dynamic is integrated with a problem related to the infrastructural efficiency, because significant losses in distribution networks can widely amplify the imbalance between demand and supply. This case study highlights how water security depends not only on the physical availability of the resource, but also on the institutional capacity to manage its allocation among several sectors.

7.Analysis and experimental results

The application of the proposed methodological framework to the Campania water system allowed for an integrated analysis of the main dynamics that influence regional water security. By combining systemic modeling, indicator analysis and stress scenario simulation, it was possible to observe how independent factors (hydrogeological vulnerability, climate variability, anthropogenic pressure, infrastructural inefficiency) jointly contribute to the formation of conditions of structural vulnerability. The results of the analysis show that water security in Campania cannot be considered in terms of natural availability of the resource. Despite the presence of important

aquifer systems and an major hydraulic infrastructure, the interaction between qualitative degradation, increased demand and management inefficiencies produces a progressive gap between theoretical availability and actual availability.

The analysis of data related to regional aquifers has highlighted how more productive aquifer systems often meet those featured by higher levels of vulnerability to contamination. This condition is particularly evident in highly permeable carbonate systems, in which rapid recharge processes favor both the replenishment of aquifers and the infiltration of contaminants from the surface. From the perspective of the dynamic model, this configuration generates a state of structural fragility. The same feature, that ensures high water productivity, increases the system's sensitivity to anthropogenic impacts. Therefore, the results show that regional water security depends consistently on the ability to preserve groundwater quality, as qualitative degradation can rapidly reduce the amount of usable water.

The analysis of recent climate conditions has made evident an increase of frequency of drought episodes and a major variability of rainfalls. The application of stress testing has allowed to simulate scenarios characterized by a prolonged reduction of natural recharge and to observe the effects of such conditions on the water system's balance. The results suggest that brief periods of rainfall deficit can produce amplified effects when they are combined with high levels of aquifers' withdrawals and inefficiencies in the distribution of the resource. In these cases, not only does a reduction of the natural recharge determine a decrease of piezometric levels, but it also increases the competition between the several uses of the resource, generating conditions of water stress which can persist even after the return to normal climatic conditions.

A further significant result concerns the impact of the qualitative degradation of regional river systems: the analysis of Sarno River Basin shows how persistent pollution can compromise permanently the functionality of surface water resources. In the presence of high levels of contamination, theoretical water availability does not translate into actual usability, as treatment costs or environmental risks make the water unusable for many purposes. In the integrated model, such situation produces an effect of compensation: the loss of functionalities of surface waters increases the pressure on groundwater resources, accelerating processes of overexploitation and increasing the risk of qualitative deterioration of the aquifers.

Analysis of urban consumption data has pointed out apparent reductions in per capita consumption. However, the integration of these data with indicators related to the quality of groundwater and distribution of the resource suggests that such reduction not always corresponds to an effective improvement of the system sustainability. In some cases, the decrease of volumes registered by public networks can be followed by an increased use of alternative sources or a progressive deterioration of aquifers used for urban supply. This phenomenon highlights how indicators based only on consumption could hide deeper vulnerabilities, which become visible through a systemic analysis of the different components of water system.

Analysis of agricultural water demand shows that the agricultural sector represents one of the main factors exerting pressure on the regional hydric system. During periods of greater climate variability, irrigation demand tends to

increase precisely when the natural availability of the resource diminishes, a dynamic that generates growing competition between agricultural, civil and industrial uses. The results of the simulations indicate that this competition can be come particularly critical in the presence of significant infrastructure inefficiencies. High losses in distribution networks lead to an increase in captured volumes, further amplifying the imbalance between supply and demand.

On the whole, the results confirm that water security of Campania region is the outcome of mixed and interconnected dynamics that involve environmental, technical and institutional dynamics. The natural availability of resource is not sufficient to guarantee the stability of the regional water system, even though it is considered a fundamental element. The application of the integrated model shows indeed how the combination between aquifers' vulnerability, climate variability, qualitative degradation of resources and management inefficiencies can engender structural insecurity even in contexts characterized by an apparent water abundance. The analysis points out the necessity to adopt management approaches based on systemic analyses and anticipatory planning tools, able to detect promptly vulnerability conditions and to guide intervention strategies towards strengthening regional water resilience.

8. Conclusion

This study demonstrates how water security in Campania represents an emblematic case of water abundance paradox in the contemporary Mediterranean context. Despite the presence of important natural resources, the region displays increasing conditions of structural variability, related to the combination of environmental, infrastructural and institutional factors. The results highlight how physical availability of the resource does not constitute itself a guarantee of water security, especially when the management is characterized by operational inefficiencies, environmental degradation and governance fragmentation.

The revision of management strategies currently adopted has shown that many policies implemented in the last decades have been focused mostly on reactive or compensative interventions, oriented towards the increase of hydric supply or management of emergency situations. Although such measures have contributed to temporarily mitigate some episodes of scarcity, the analysis of their effectiveness has highlighted important structural limits. Particularly, the persistence of leaks in water networks, the progressive degradation of groundwater quality and the growing pressure deriving from climate change indicate that the current management model is not fully adequate to face future challenges.

The different case studies here analyzed have permitted to bring to light the multidimensional nature of regional water issues. The high vulnerability of more productive aquifers shows how the main source of the region supply is exposed to significant risks of contamination and at the same time drought episodes recorded in recent years highlight a growing climate variability that makes water stress situations even more frequent. The historical degradation of Sarno River Basin represents another example of how prolonged pollution processes can turn a renewable resource into a structural environmental issue. Lastly, added to these elements there is the phenomenon of

decoupling in residential water consumption but also the growing pressures deriving from agricultural use and infrastructural inefficiencies.

This work has proposed the adoption of an integrated model of evaluation and management of water security, based on the integration of hydrological data, climate indicators and information linked to infrastructures and resource uses. The suggested approach is based on an anticipatory planning logic and on the construction of analytic tools, able to support strategic decisions in the medium and long term. In particular, the introduction of integrated monitoring systems and methodologies of water stress testing permit simulating scenarios of risk and to evaluate the resilience of the regional water system under different environmental and management pressures.

One of the most relevant aspects that emerged from the analysis concerns the central role of protecting groundwater resources and modernizing water infrastructure. Improving the efficiency of distribution networks, reducing losses and adopting advanced monitoring systems represent priority interventions to strengthen the overall resilience of the water system. At the same time, promoting more coordinated governance among various institutional levels involved in resource management appears fundamental. Beyond the specific relevance for the Campania context, the results of this study offer useful indications also for other Mediterranean regions, characterized by similar conditions. The proposed model can be adapted to different territorial contexts in which water security depends on the interaction between climate, environmental and socio-economic variables.

The research highlights how the transition from an emergency management of water resources to a systemic and preventive approach represents an essential condition to guarantee water security in the long term. The construction of integrated tools for analyzing and planning can contribute to transforming water management from a simple response to crises to a real strategic element for territory resilience.

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