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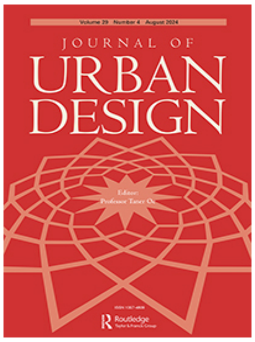

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From past to future: understanding urban development in flood-prone coastal Rome

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ABSTRACT
This paper explores the spatial evolution of a flood-prone, sub-urban coastal area, Municipio X of Rome. The study investigates land use change through a diachronic analysis, providing empirical data to retrace the implication of the factors that shaped the study area and highlighting the connection between environmental vulnerabilities and planning measures. Qualitative and quantitative assessments are provided to understand the political and social factors that contributed to rapid urbanization in the area. This investigation aims to grasp how past developments influence current issues and assist planners and decision-makers in tackling present and future vulnerabilities more effectively.

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Climate change; urban coastal areas; urban development; urban floodings; climate adaptation; urban resilience

Introduction

Currently, in Europe, over 200 million people live within 50 km of the coastline, and there is a growing trend of migration towards coastal areas (Vousdoukas et al. 2020). Climate change and its impact on coastal cities is a primary concern for policymakers and planners, as these areas host vital infrastructures, commercial activities, and ecosystems (EEA 2006).

The majority of coastal flood damages are expected in the Netherlands, UK, Germany, France, Italy, and Belgium (Vousdoukas et al. 2018). Most countries located in the North Sea region are planning to cope with the consequences of sea level rise. However, a concerning number of European countries lack comprehensive plans or have only minimal preparations in place (McEvoy, Haasnoot, and Biesbroek 2021). As urbanization and the impacts of climate change persist, coastal urban populations face escalating vulnerabilities because population densities along Europe's coastlines surpass those of inland regions and are further expanding at a swifter pace. Notably, many affected areas also encompass some of Europe's most precious coastal ecosystems and economic hubs, as exemplified by the Mediterranean region (EEA 2006). In fact, over millennia, the Mediterranean's varied climates, political contexts, and socio-economic conditions have created a unique co-evolution between humans and the environment. However, despite the ongoing efforts, gaining a complete understanding of the intricate interactions

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between human societies and this fragile, diverse environment remains challenging. This understanding requires site-specific investigations that explore the historical dimension of how societies have influenced and adapted to the environment (Barnett 2020; Thiébault and Moatti 2016). A fortiori, despite the efforts for a common European perspective (European Commission 1999), urbanization in Europe still develops according to local practices and domestic actors involved.

Considering the planning perspective in southern Europe (Giannakourou 2005), the in-depth analysis of the coastal built environment is of even greater importance. This is due to a significant discrepancy between planned urban development and the actual urban forms that have emerged, with exurban constructions comprised of unauthorized developments and other forms of spontaneous expansion leading to urban sprawl, which are more vulnerable to the effects of climate change (Salvati 2015).

Thiébault and Moatti (2016) examined several factors influencing climate change future scenarios for the Mediterranean area, highlighting past trends and projections for sea level rise, precipitation, wind direction and speed, and droughts. The advancements in modelling make predictive models for climate change increasingly reliable, particularly for the short to mid-term. Nevertheless, many uncertainties persist regarding the impacts of the numerous interconnected factors influenced by climate change and the outcome of the compound effects (Noto et al. 2023).

In the context of uncertainty assessment, it is important to note that there are different levels of uncertainty to characterize the varying degrees of knowledge. At Level 1, often called ‘shallow uncertainty’, decision-makers can list and assess multiple alternative outcomes. This level of uncertainty implies a relatively clear understanding of the available options and a certain level of confidence in estimating their likelihood. At Level 2, or ‘medium uncertainty’, individuals can still enumerate multiple possibilities. However, they cannot precisely rank these alternatives based on their perceived likelihood. Level 3 represents ‘deep uncertainty’. At this level, decision-makers can enumerate various alternative scenarios but face considerable difficulty ranking or assigning probabilities. The uncertainty is so profound that establishing a clear hierarchy of likelihoods among the alternatives becomes elusive and a source of contestation. Finally, at Level 4, ‘recognized ignorance’, there is an admission of limited knowledge and an inability to enumerate multiple possibilities comprehensively, recognizing the potential for surprises or unforeseen developments (black swans) (Kwakkel, Walker, and Marchau 2010). In this study, when discussing uncertainty concerning the built environment in the context of climate change’s long-term effects, socio-economic developments, human-related factors, and compound effects, the reference is to level 3, deep uncertainties.

Historically, urban forms were conceived to accommodate stable environmental conditions over extended periods. However, this may no longer suffice in addressing the complex and uncertain urban dynamics brought about by environmental changes (De Roo and Boelens 2016) and socio-economic shifts. However, as Thiébault and Moatti point out, it is crucial to emphasize that the presence of uncertainties should not be used to justify inaction. On the contrary, uncertainties further motivate understanding the intricate cause-and-effect relationships that connect climate with various environmental and human-related factors (Rauws 2017). Uncertainties also highlight the importance of collaborative planning and navigating through potential solutions to advance climate change adaptation and disaster risk reduction (Busayo and Mukalazi Kalumba 2021).

Effective climate change adaptation, involving both public and private sectors, hinges on understanding how people respond to rising flood risks, their incentives for adaptation, and the consequences for societal resilience (Mannucci et al. 2022). Floods can trigger climate gentrification, with higher-income households pushing up demand and prices for safer locations, resulting in socio-demographic shifts in urban areas. However, the adverse economic impacts of floods disproportionately affect economically vulnerable individuals, leading to environmental injustice and undermining the socio-economic resilience of low-income households (Meerow, Pajouhesh, and Miller 2019; Joseph 2021; Quigley, Blair, and Davison 2018; Koning and Filatova 2020).

Conveying uncertainties is crucial in using scientific findings to guide comprehensive coastal adaptation planning. In climate adaptation planning for the water sector, planners are increasingly relying on novel approaches collectively known as Decision Making Under Deep Uncertainty (DMDU) (Bloemen et al. 2019; Kalra et al. 2014; Lempert et al. 2013; Tarrant and Sayers 2012) to deal with uncertainties. These novel approaches reflect a paradigm shift from ' predict-then-act' to ' monitor-and-adapt'. However, the application of these approaches in urban planning and design is still in its infancy (Mannucci and Morganti 2022; Mannucci et al. 2023).

In order to advance the understanding of the many intertwined drivers generating complexity and uncertainties in coastal Mediterranean areas, this study discusses the case of Municipio X, a flood-prone suburban coastal area of Rome. The research examines the linkages between flood risk, land consumption, political, societal, and economic changes, highlighting how the absence of interventions and institutional *laissez-faire* contributed to and still influences urban vulnerability. The investigation is framed within the general discussion outlined regarding the complexity generated by the many interrelated factors resulting in the current urban form fostering vulnerability to climate-exacerbated phenomena. To aid urban planners and decision-makers in addressing current and future vulnerabilities in complex urban areas, the study provides an in-depth, evidence-based analysis of the urban evolution of Municipio X, highlighting the socio-economic factors and the impacts of misguided or missing policies that generated sprawl and informal developments that nowadays are still in place. These analyses can help draw guidelines to inform and support the development of context-specific, equitable, long-term adaptive plans, which can identify past triggers and patterns to prevent future undesirable or unexpected outcomes.

This contribution is structured accordingly. First, the method employed to carry out the quantitative spatial analysis is discussed. Then, the case study is framed by highlighting the general context and environmental issues. The subsequent section provides the diachronic narrative of the area's urban development, providing the social, economic, and political context that influenced the area's urban development. Following, the quantitative data of the mapping analysis presented in the methods section are discussed; first, are provided the data concerning the whole X Municipio, and then an in-depth analysis of a selected area that is particularly vulnerable is addressed. Based on the assessment derived from the qualitative and quantitative analyses is structured the discussion section which also provides a debate regarding the challenges of urban planning in flood-prone, low-lying areas. Lastly, the future outlooks for the presented research are explored.

Material and methods

For this study, both qualitative and quantitative methods were employed to investigate the evolution of the coastal area of Rome. First, a collection of documents, books, and journal articles were reviewed to build a narrative of the factors that influenced the actual shape of the urban area. Second, a diachronic land use change analysis was conducted using a Geographical Information System to map the area's historical development for different periods: 1918, 1936, 1951, 1962, and 1988.

The key idea is to provide the historical, political, and social context under which the urban developments took place and to couple this with the diachronic analysis. Each period represents a specific snapshot of factors that influenced the development of the urban tissue differently from the planning prescriptions, leading to the actual urban form. The choice of these analyses serves a twofold purpose: first, to assess which land use classes had the greatest impact on soil sealing[1] and, consequently, to understand the drivers of development; and second, to assess current exposure to floods by coupling the quantitative data with the narrative emerged from the literature concerning the area.

The quantitative analysis carried out to quantify urban growth was performed using a Geographical Information System (GIS) with a level III classification in the National Land Cover Map. The reference system employed was UTM (Universal Transverse Mercator) with WGS84 datum. For this analysis, QGIS software was utilized. ISPRA provided the base map from 2017, and the historical maps, are obtained relying on IGM (Geographical Military Institute) cartographies acquired at a scale of 1:25000 for the periods 1918,1936, 1951, 1962, and 1988. Two macro classes of consumed soil are identified: (I) Permanent consumed soil and (II) No-permanent consumed soil. The classification uses the codes (SNPA 2018) in Table 1.

Additionally, to assess the vulnerability of the built environment, a more detailed analysis was conducted on the areas most affected by floods in 1962, 1988, and 2017. A digital terrain model was used to visually depict these zones, highlighting areas at or below the current sea level. This step was taken to evaluate the extent of buildings currently affected by floods while also considering the historical development of the built environment.

Framing the case study: context and environmental issues

Municipio X of Rome has an extent of 15.061 ha with approximately 231.220 inhabitants (Comune di Roma 2019). It is the tenth administrative subdivision of the fifteen that compose Rome. Municipio X is further subdivided into urban zones for planning

Table 1. Classification system.

11 Permanent land consumption	12 Reversible land consumption
111 Buildings	121 Dirt roads
112 Paved roads	122 Construction sites
113 Train railroad	123 Mining areas
114 Airports	124 Quarry
115 Ports	125 Solar fields
116 Impervious non-built area and sport fields	126 Other land consumption
117 Paved Greenhouses	
118 Landfills sites	

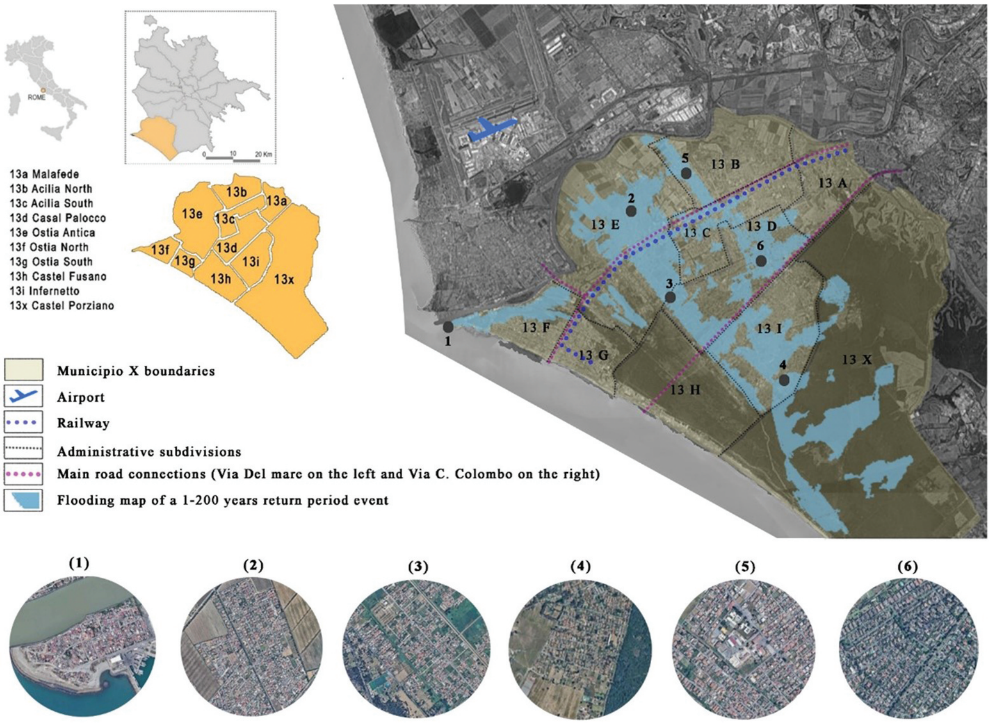


Figure 1. Framing the study area: national scale (top left), Rome municipalities scale. Municipio X is detailed in orange and enlarged providing the zoning division of municipio X. on the right side it is provided a more detailed close up of the area and its surrounding context, showing the main road connections, the railways and the areas that are more affected by floods (here it is provided a 1 in 200 year event. Notably, in the bottom of the image are depicted the 6 specific different urban tissues affected by floods: (1) is the only recognized informal settlement. (3) – (4) – (5) developed both informally and during the speculation period. (2) and (6) were both part of the planned expansions of the area, still they are affected by urban floodings. More information regarding the evolutions of the area are provided in the text.

purposes, as each zone has a different urban fabrics that results from the distinct history that characterizes the area (Figure 1). Although it is one of the most populated districts in Rome, the population density is 1533,9 in/Km^2, which is relatively low compared to other Municipalities. This is because Municipio X includes several natural reserves. The site is located between the Tiber River and the Tyrrhenian Sea, a privileged position that ensured that this part of the coast was flourishing during the Roman expansions, as proven by the Ostia Antica archaeological site, which is one of the biggest in the world. It is a flood-prone, lowland area with some parts below sea level.

The developments within Municipio X were inherently intertwined with the city's (Rome) broader urban dynamics. This interconnection can be attributed to a combination of planning actions and initiatives that remain closely tethered to the socio-economic factors associated with Rome while operating within and outside formal planning instruments. The informal settlements and unauthorized constructions that emerged in Municipio X during the post-war era were partly a direct consequence of the socio-economic disparities and housing challenges experienced in Rome. As Rome's economy burgeoned and its population grew, the demand for housing outstripped the availability of formal, planned developments. This led to the proliferation of informal settlements as a pragmatic response to the housing crisis.

Nowadays, Municipio X is one of the most flood-affected municipalities in Rome. The area's drainage system cannot cope with the anthropic pressure generated by the urbanization growth that was not supported by the implementation of adequate infrastructures. Currently, the drainage system is divided into four basins. Figure 2 presents the different basins and the hazard zones related to the drainage system connected to the sea. The basins' names also indicate the area's altitude (*alte, medio, basse* – high, medium, low). The areas below or at the sea level fall within the '*Acque basse*' (*Acque basse inferiori* are below the sea level and are highlighted in yellow. *Acque basse superiori* are mostly at sea level and are highlighted in light blue). A pumping implant ensures the drainage of these waters. The areas at intermediate altitudes fall into the '*Acque Medie*' basins (highlighted in blue), whose drainage is ensured by gravity through the drainage channels with outlets into the Tyrrhenian Sea via canals. The areas located at higher altitudes fall within the '*Acque Alte*' basins (highlighted in red), which drain directly into the Tyrrhenian Sea. Figure 2 also depicts the areas that are affected by urban flooding deriving from the drainage channels (areas overlaid in light blue), and Table 2 contains the key data concerning those areas obtained from the report 'Il Consumo di Suolo di Roma

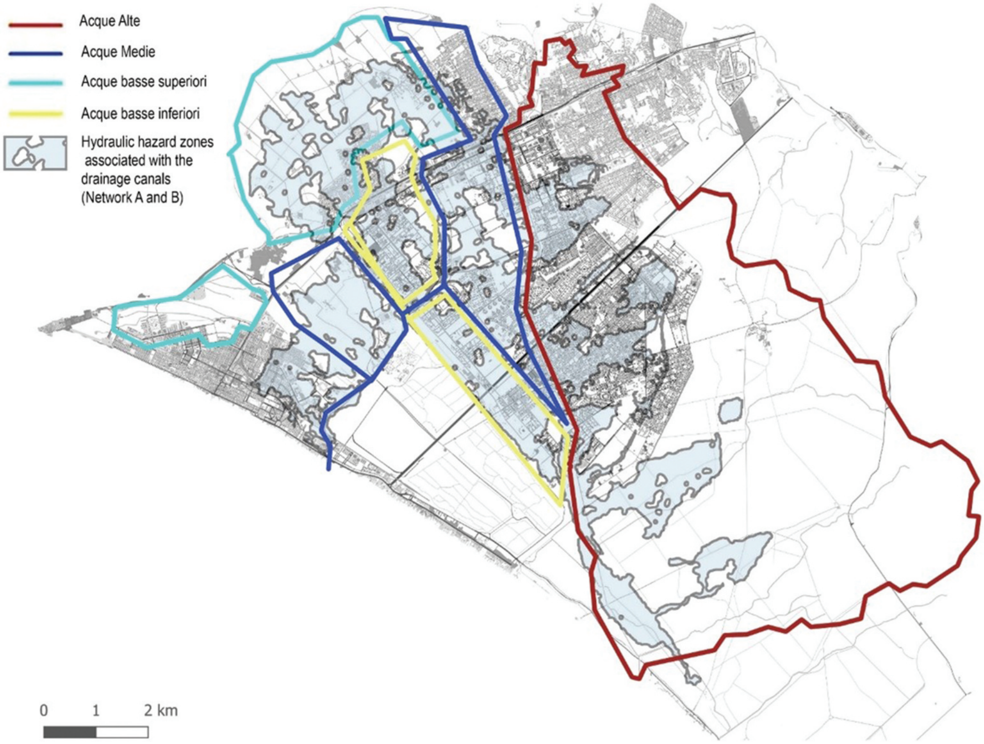


Figure 2. The drainage system division in different basins (source: authors' elaboration from the information provided by consorzio di bonifica litorale nord) overlapped with the zones of hydraulic hazard associated with the drainage channel (network A and B).

Table 2. Land consumption in relation to hydraulic hazard zones.

	Consumed soil (ha)	Reversible consumed soil (ha)	Tot. Consumed soil (ha)	Non consumed soil (ha)	Population (abs)
A	623,46	61,44	684,90	2115,32	57.538
B	113,62	6,76	120,38	475,77	7.254

Capitale' (Soil Consumption in Rome); which includes an in-depth analysis of hydraulic hazard, developed using project land consumption data, population data from the Civil Registry Office of Rome, and maps of hazard areas for the main, secondary water network and drainage channels, provided by the Tiber River Basin Authority (ISPRA 2018).

Furthermore, the'*Acque basse inferiori*' basin retraces the perimeter of the area of the drained pond 'Stagno di Levante' (Eastern Pond), connected to the sea via a channel used to produce salt (Figure 3). In that area the drainage by infiltration is not ensured since the aquifers are shallow, and because of the soil composition. In addition to these characteristics, it is noteworthy that the built environment in the southern part of the '*Acque basse inferiori*' was mostly developed informally during the years of building speculation.

Additionally, Figure 4 presents the perimeters of the flooding for the different return periods considered (10, 30, 50, 200, 500 years). The maps are generated according to the data obtained from the Hydrology and Hydraulics Technical Report provided by Consorzio di Bonifica Litorale Nord (https://www.consorziobonificalitoralenord.it/).

As argued by Recanatesi and Petroselli (2020), the change in land cover has a crucial role in environmental risk assessments, particularly in Mediterranean coastal areas, which are affected by urban sprawl (Munafò, Salvati, and Zitti 2013). The urban water cycle is strongly influenced by soil sealing, and the contribution of urbanization to land-use

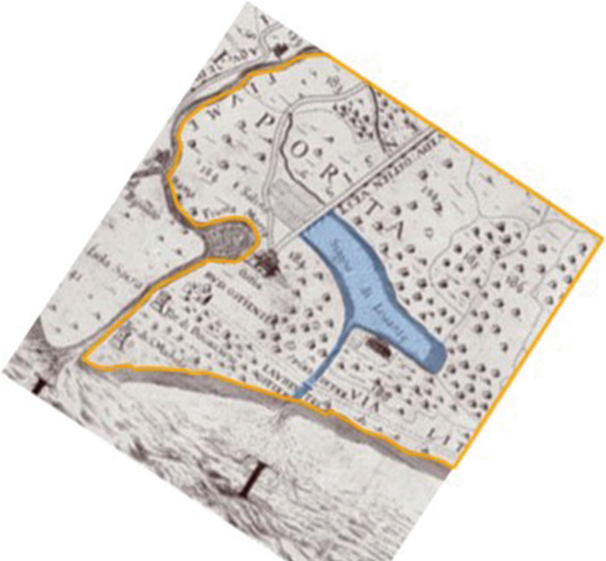


Figure 3. A map of Ostia showing the former lake. Authors' elaboration from the map published in 1774 by G.B. Cingolani.

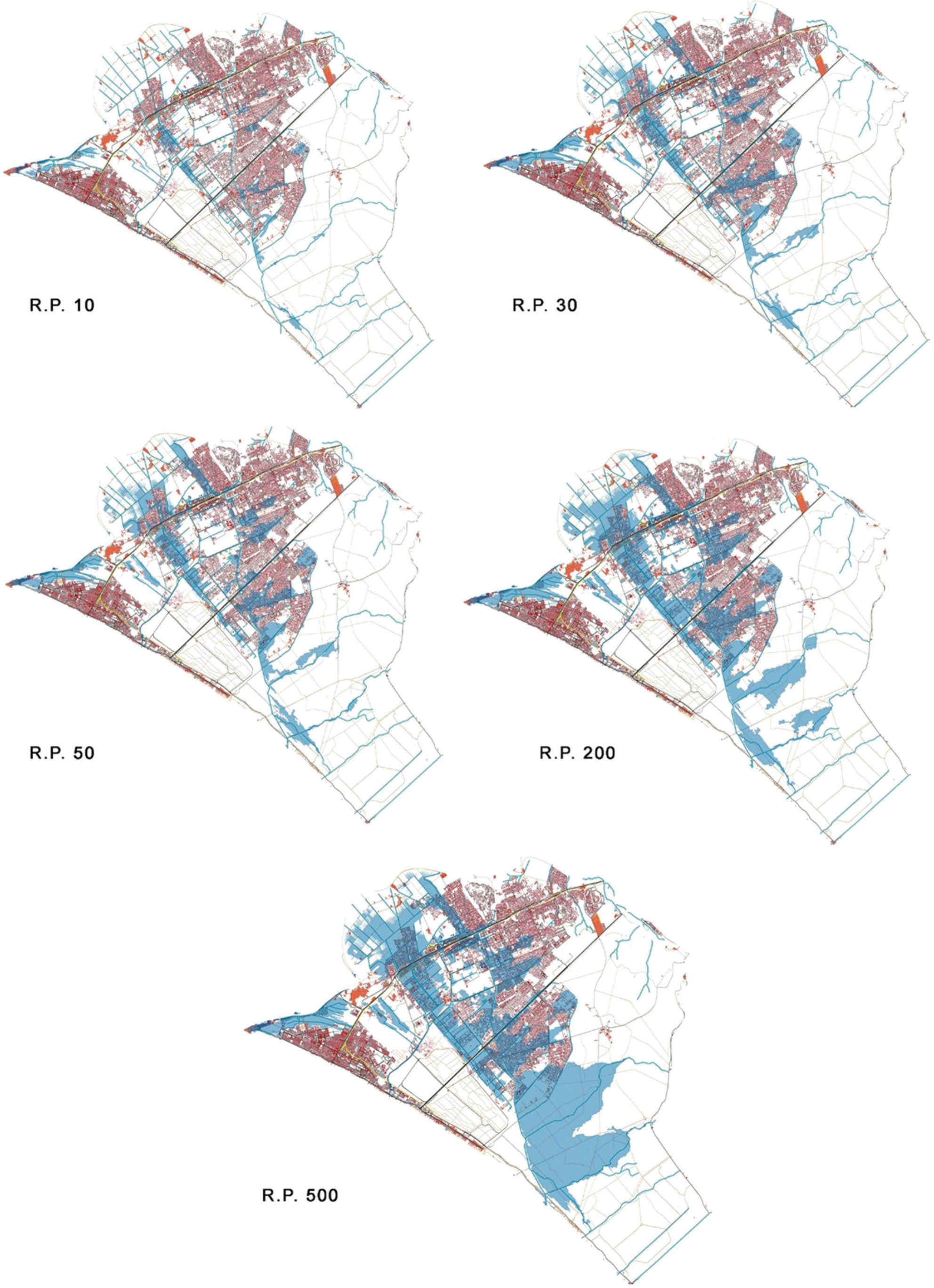


Figure 4. Inundations maps for different return periods (10, 30, 50, 200, 500 years).

change is significant. Furthermore, some land use classes substantially impact infiltration, evapotranspiration, and runoff (Hu et al. 2018; Yao, Wei, and Chen 2016).

While this paper primarily focuses on the various drivers of change that have contributed to the current form of Municipio X, it is essential to address the soil typologies in the area. This emphasis on soil typology highlights the necessity of meticulous urban planning interventions to address future challenges based on site-specific characteristics. As depicted in Figure 5, Municipio X features various soil types, each with unique drainage characteristics. Specifically, it is noteworthy for the presence of abundant aquifers in areas primarily composed of sandy, well-draining soils (5). In contrast, regions dominated by clay and silts exhibit properties similar to an 'aquiclude', a geological formation known for its impermeability to water flow (6). This aquiclude-like behaviour is particularly evident in

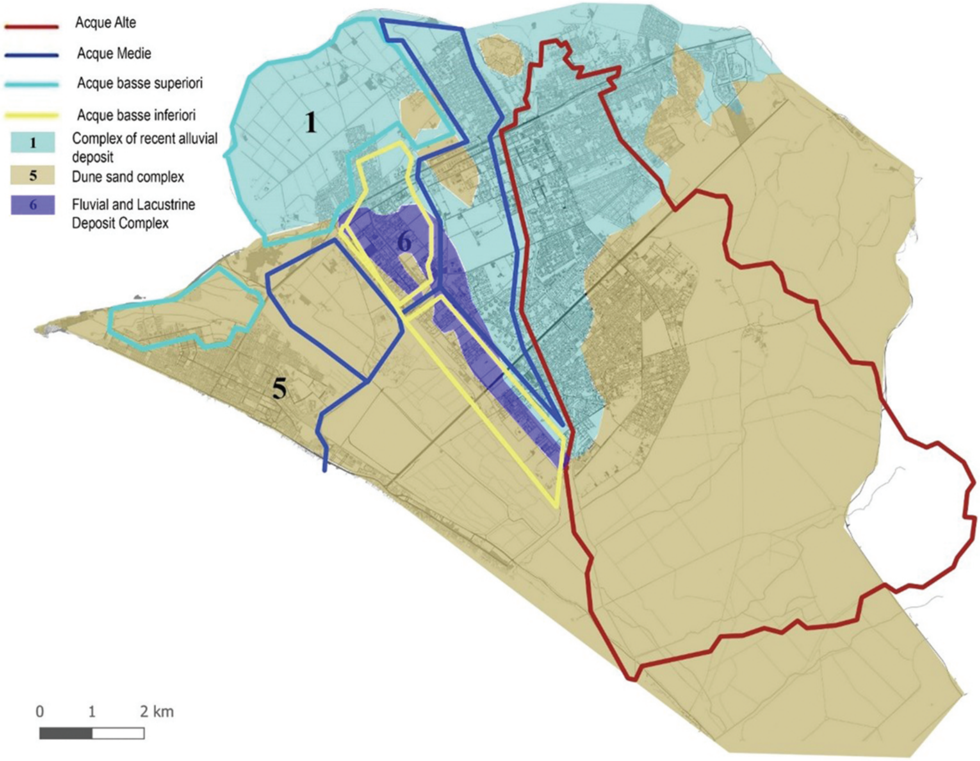


Figure 5. The main soil types found in municipio X. 1) complex of recent alluvial deposits. The aquifer potential ranges from low to moderately high. These deposits consist of gravelly, sandy, and clayey alluvial sediments. The thickness of these deposits varies from a few meters to over one hundred meters and contains multi-layered regional aquifers. 5) medium to high aquifer potential. Dune sands, interdune deposits, recent sand deposits, and deltaic dunes. Thickness ranges from several tens of meters. The complex hosts a significant subsurface water circulation, giving rise to continuous and extensive aquifers whose productivity is limited by the low permeability of the sand. 6) low aquifer potential. Predominantly composed of silt-clay deposits in marsh, lake, and brackish facies with local gravel and/or travertine intercalations. Thickness varies from a few meters to several tens of meters. The prevalent clayey nature of this complex hinders significant subsurface water circulation. The presence of gravel, sand, and travertine may give rise to limited local aquifers. The complex can assume the role of an aquiclude. Adaptation of information from the hydrogeological map of Rome.

the soil composition of the former lake region, which lies below sea level. This area is highly susceptible to flooding, primarily due to its proximity to drainage channels connected to the sea.

The next section introduces the diachronic narration of the area's urban development, which is coupled with quantitative data in the following section.

Diachronic urban development of the area

This section provides the main planning actions and socio-economic and historical facts that influenced Municipio X's development chronologically, which serves as a background narrative to understand the results of the land use mapping analyses. Figure 6 outlines the timeline of planning development initiatives from the first general development of Rome. The image also shows the boundaries of the general development plan of Rome in the different considered periods and the areas of development of the coast and the agricultural inland of Acilia, which will be discussed in this section as the first example of

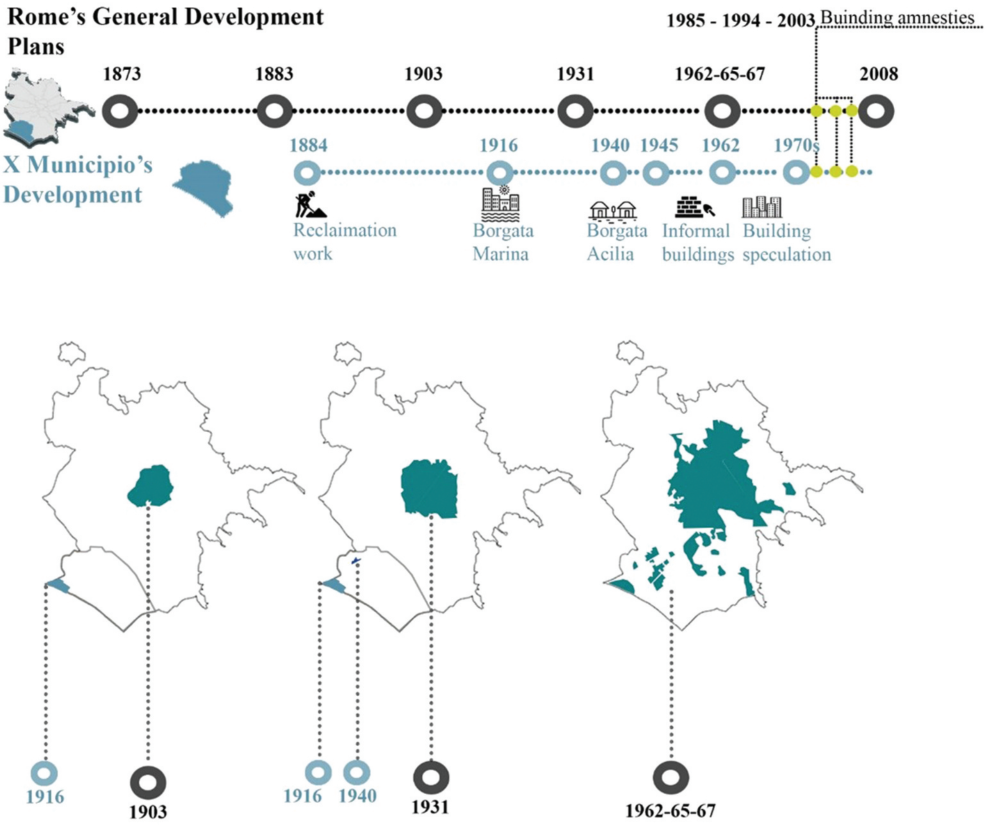


Figure 6. Timeline of the General developments of Rome and timeline of development of municipio X and the evolution of the zones indicated as boundaries for the built environment according to the different development plans indicated in the timeline. The 1962 General development plan is the first plan where municipio X is included with the center of Rome.

planning initiative outside the city’s boundaries, leading to an uncontrolled urban growth connected to private initiatives and building speculations as outlined in the timeline.

The area’s history can be traced back to Roman times when it was a colony used for its strategic position during the imperial age (Salomon et al. 2018). However, it was gradually abandoned during the 3rd century C.E. because the Tiber River changed its route, isolating Ostia from trade routes with Rome. Later, it was permanently left because of malaria. In the 19th century, the area was described as swampy and was only used to produce salt in ‘Stagno di Levante’.

Around 1884, a colony of labourers from Ravenna (Ravennati) was settled in the area to carry out land reclamation works through a series of drainage channels connected to either the sea or the river. The reclaimed lands were meant to be used mainly for agricultural purposes. However, in the first years of the 20th century, a series of initiatives developed for Rome paved the way for future urban expansion.

In 1916, a new development plan for Ostia envisioned the area as a ‘*borgata marina*’ (seaside suburb). This resulted in the construction of a railway connecting the coast with the centre of Rome, which became operative in 1925, followed in 1936 by a road with a similar route (Via del Mare).

Insolera and Einaudi (1960) identifies the origin of one of the first ‘*borgata fascista*’ (suburban housing for the working class, typical of the fascist period) urban zone 13b (Acilia North), in 1924, to accommodate people dislocated for ‘*sventramenti*’(demolitions). During the so-called ‘*sventramenti*’ (Kallis 2012), people from the centre of Rome were moved to make room for Caesar and Trajan’s forum. However, there is discording information concerning the ‘*borgata*’ in Acilia (Villani 2012); in fact, the administrative confusion deriving from mass relocation to the suburbs caused by the demolitions significantly influenced the lack of precise chronology in the decisions made for Rome’s periphery. The ‘*borgata*’ of Acilia, during the period indicated by Isolera, was a small rural settlement called ‘Borgo Acilio’ outside the perimeter of the plan for both Ostia (*borgata marina*) and Rome. While many assume people from the ‘*sventramenti*’ in Rome were relocated partially to Acilia with the small community of farmers, it still represented one of the first examples of an unplanned settlement carried out during the fascist regime (Insolera and Einaudi 1960). The paradox regarding building without permission outside the General Development Plan, which was a practice invented during the Fascist regime, is investigated in depth by Berdini and Donzelli (2010). The urban developments were intertwined with the rise of the fascist regime. In fact, as Mussolini gained power, land-owning families of several agricultural plots in the area gave the dictator the endorsement for his ascent. In return, a loophole in the rules imposed by the General Development Plan was found (Berdini and Donzelli 2010). A small fraction of an agricultural plot was given to the collectivity (State or Municipality) to build public housing, and the State covered the infrastructure cost in the area. Consequently, once a plot was equipped with primary urbanization structures, all the properties in the proximity increased in value, and the territory once used for agriculture could generate more profit as a building plot (Insolera and Einaudi 1960).

Although building outside the boundaries established in the General Urban Development Plan for Rome was forbidden, discretionary exceptions by the delegated authority were allowed. The delegated authority could approve construction if the builder provided the necessary infrastructures (Insolera and Einaudi 1960). Therefore, it was assumed that building outside the General Plan for Rome or the '*borgate marine*' was not forbidden.

Acilia, as a proper *borgata* was born in 1940 to accommodate 'large families' as a part of Mussolini's efforts to increase the country's population. This marked the beginning of the city's expansion towards the coastline, an idea the regime's leader evoked as its inevitable natural outlet. A decree was issued in January 1941 concerning the 'master plan for the city of Rome's expansion towards the sea'. The idea was to extend the boundaries of the outdated 1931 Development Plan, including the areas between Rome centre and the newly built EUR (residential and business district, part of Municipio IX, designed to steer the city's growth in the south-western direction, bridging the gap to the sea). However, this decree was never converted into law, and Acilia remained the first rudimentary nucleus of this imminent expansion, which, without interruption, would lead to an extensive district comprising numerous suburbs connecting to the coastline.

A second road, Via Cristoforo Colombo, was completed in 1954. The drainage system designed for agricultural land use was also completed in the same period. Remarkably, despite substantial urbanization, the same drainage system, with minimal changes, is still used today.

During the fascist period, the periphery was born, becoming an incisive trait of the post-war urban expansion, gaining more importance in the second post-war period ('60-'70) (Salvati 2013). The desolation that followed after World War II forced people living in rural areas and from the South of Italy to move towards more prominent cities. However, unlike the cities in the North of Italy, Rome did not develop a robust industrial sector. Instead, the economy was mainly connected to the presence of ministries, offices, and the rising construction industry. This, coupled with the increased population, formed the origin of a precarious low-income social class (Cellamare 2010). Therefore, a national policy regarding social housing construction was enacted, but the programme was far from adequate in quantity, quality, and timing; hence, to cope with housing demand, the development of informal settlements that appeared after the war became extensive.

The growth of informal settlements in Rome is copiously discussed in the literature (Aureli Cutillo and Mingella Calvosa 1989; Berdini and Donzelli 2010; Cellamare 2010; Chiodelli et al. 2021; Clough Marinaro and Solimene 2020). The migration of the population towards Rome was exponential, and policies regarding public housing were insufficient for creating an adequate alternative to informal constructions (Berdini and Donzelli 2010). Moreover, the building industry was meant to promote a newly found trust in the future. Hence, construction sites were used as political propaganda for economic growth. Rome came out of the war mostly intact. Thus, an empty territory such as the former reclaimed seaside represented an opportunity for expansion. The exemptions to the General Development Plans (1931 and 1962) changed the density of the built environment in all the housing clusters dramatically, becoming fertile soil for speculations and additional informal constructions (Insolera and Einaudi 1960) for more than two decades (1950–1975 circa)(Berdini and Donzelli 2010).

During the 1950s, the economy flourished, agriculture was not the primary source of sustenance, and the area where the salty lake was located was not particularly suitable for crops. Therefore, the area was exploited to accommodate housing demand that the formally planned expansions were not fulfilling in terms of pricing. Consequently, an informal city grew here. This area is nowadays affected by floods, as the drainage system was designed for the assumed agricultural land use.

In 1985, 1994, and 2003, most informal settlements were regularized through three building amnesties. The first amnesty, approved before the first environmental law in Italy was adopted, was supposed to be a turning point. Only the informal settlements built out of necessity were condoned, and ad-hoc laws, policies, and planning were intended to solve the problems of illegal constructions (Berdini and Donzelli 2010). These actions, however, never addressed the issue. Nowadays, regulation and planning are still not coping with housing emergencies and growing land use. Thus, the conditions that led to uncontrolled expansion are still in place. Thirty-five years after the first amnesty, many municipalities in Rome are still vulnerable, lacking adequate infrastructure, and exposed to adverse and changing environmental conditions. In the 2008 regulation plan for Municipio X, many constructions are still indicated as 'former informal settlements awaiting recovery interventions'.

Land use change mapping results

This section presents the results of the historical mapping and the effects of floods on the built environment. Figure 7 shows the urban growth in Municipio X over time. Two distinctive patterns emerge: Ostia (Subdivision 13 f and 13 g in Figure 1) experienced compact growth and became an important urban centrality and part of the 'consolidated city', whereas the various low-density settlements experienced scattered growth while representing the majority of the urban expansion (Salvati 2015). Furthermore, this section highlights subdivisions that are more vulnerable to flooding. The scattered nature of their urban patterns and a lack of infrastructure and connections suggest significant growth associated with self-construction or building speculation. This has led to sprawl in former agricultural areas. Based on the flooding maps and the historical development maps, the analysis was targeted on subdivisions 13e – Ostia Antica – 13d – Casal Palocco – and 13i – Infernetto –.

Figure 8 shows a percentage-wise breakdown by land use class for each considered year. Figure 8a shows the percentage of land cover for each land use class in the analysed period. Figure 8b shows the percentage of each land use class in the whole Municipio, including non-built areas. Figure 8c shows the growth rate for each land use class for the analysed points in time, compared to 2017. Table 3 quantifies the surfaces in hectares for each land use class.

The data support the narrative of the previous section. The urban growth in Municipio X has been constant, driven by the land use classes 'buildings' and 'impervious non-built area'. For 'buildings', from 1949 to 1962, the growth is 206%; from 1962 to 1988, the growth is 172%; from 1988 to 2017, the growth is 53%. The overall increase from 1949 to 2017 is 1182%. Likewise, for the 'Impervious non-built area', from 1949 to 1962, the growth is 344%; from 1962 to 1988, the growth is 187%; from 1988 to 2017, the growth is 95%. The overall increase from 1949 to 2017 is 2381%. The growth from 1949–1962 is noteworthy and coincided with the post-war Italian economic boom. This was also a primary driver for migration towards Rome, in line with the narrative of the area's urban development.

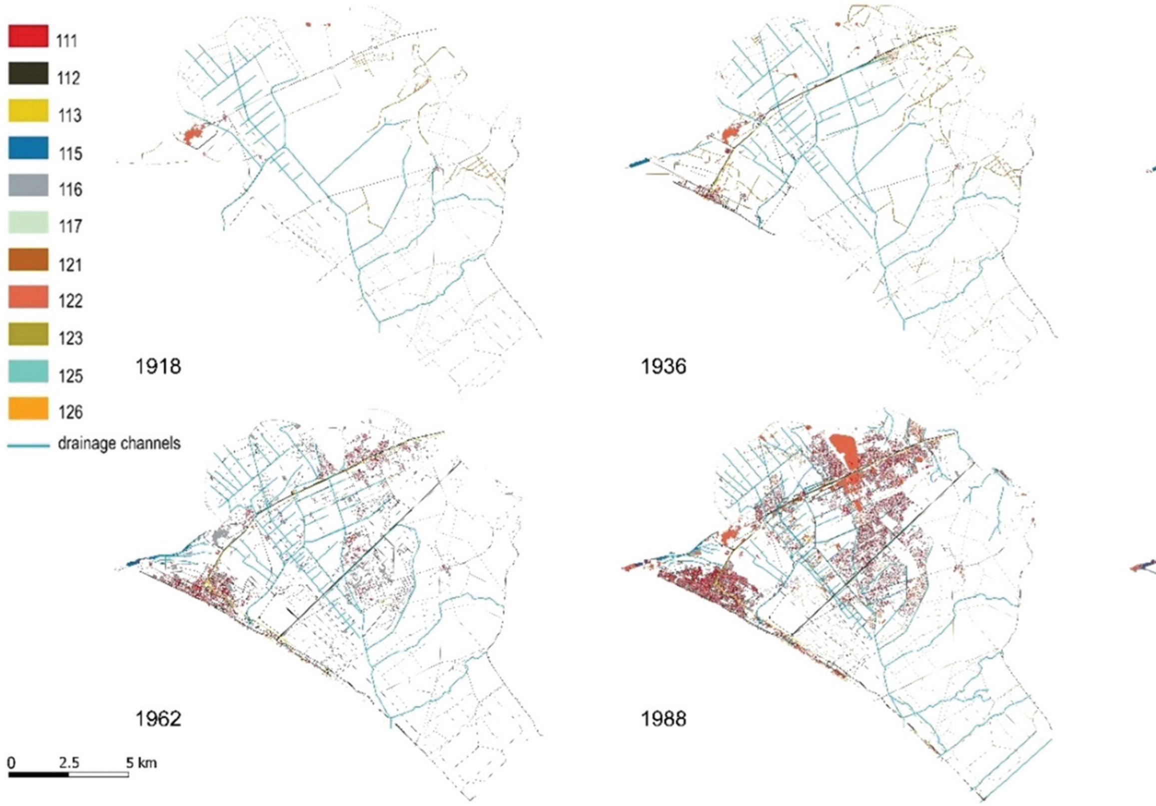


Figure 7. Maps of the urban growth in municipio X of Rome. The growing land consumption is classified with the land use classes in Table 1. However, in the maps provided are shown just the land use classes present in the area. Authors' elaboration.

To further assess the vulnerability of the built environment, the zones most affected by floods were analysed in more depth, focusing on 1962, 1988, and 2017. The choice of the area where the in-depth analysis is carried out has been made according to the following criteria: (i) the inclusion of the area of the former lake, where the soil composition does not allow water infiltration (see Figure 5); (ii) the areas below the sea level (not just limited to the different basins highlighted in Figure 2, as the built areas affected by floods are distributed among three basins – *Acque alte*; *Acque medie*; *Acque basse inferiori*); (iii) the nature of the development of the area (according to the historical reconstruction and the

Table 3. Surface in ha for each land use class.

	2017	1988	1962	1949	1936	1918
Buildings	782,01	509,60	187,00	61,04	30,89	6,61
Paved roads	612,34	478,39	379,78	222,13	152,86	68,39
Impervious non-built area	1067,00	544,92	190,93	43,32	23,93	6,31
Dirt roads	129,86	198,92	198,61	327,34	249,38	168,81
Construction sites	175,06	288,19	150,01	136,03	43,67	30,06
Other land consumption	5,81	6,93	6,83	2,53	2,30	/
Ports	23,68	21,12	21,12	13,40	13,40	/
Train railroads	26,92	26,92	26,92	26,92	18,27	/

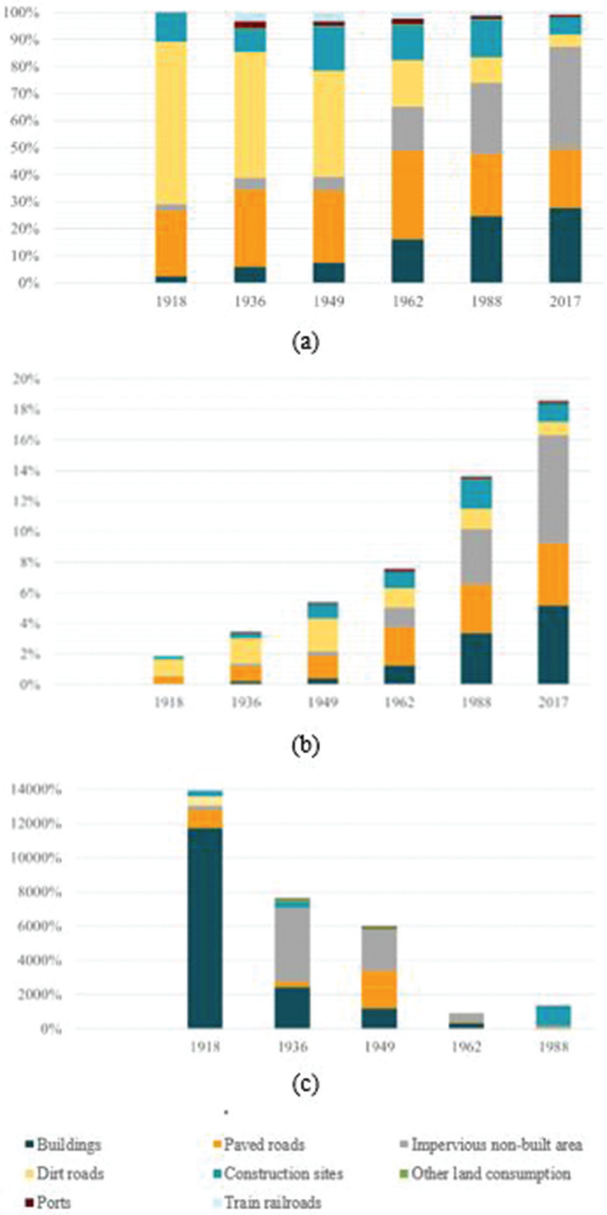


Figure 8. Summary of the data obtained from the mapping analysis. 6a: land cover per class of land use expressed in percentage; 6b: percentage of each land use class on the whole area of the Municipio; 6c: growth rate for each land use class in the analysed periods compared to 2017.

pattern of development – namely the area where informal constructions and building speculation flourished the most).

Based on those criteria, the identified area is shown in Figure 9, where a digital terrain model was utilized to highlight the areas located at or below sea level visually. Further, Figure 10 outlines the same geographic area's urban development and land

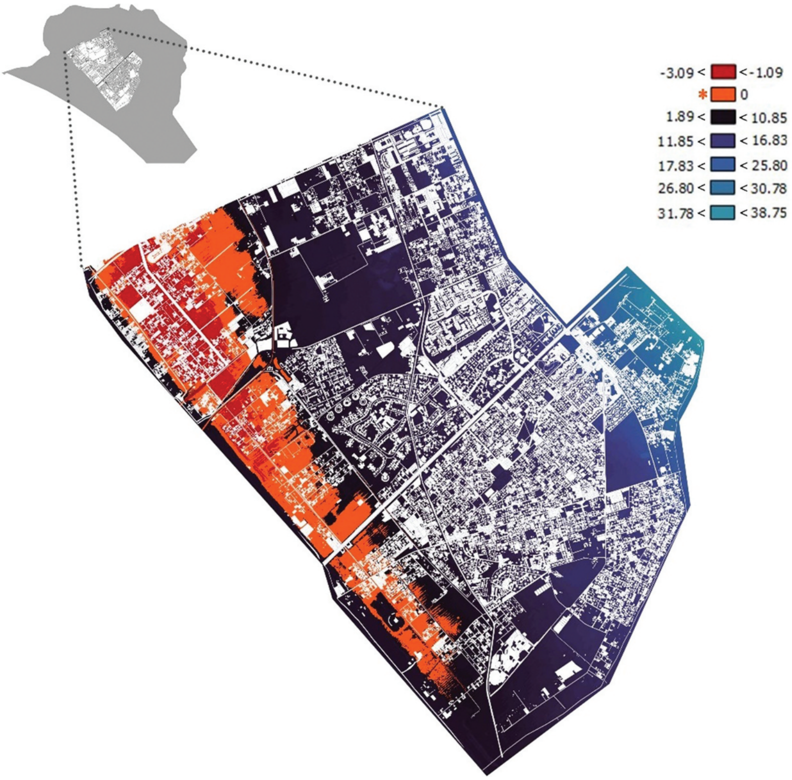
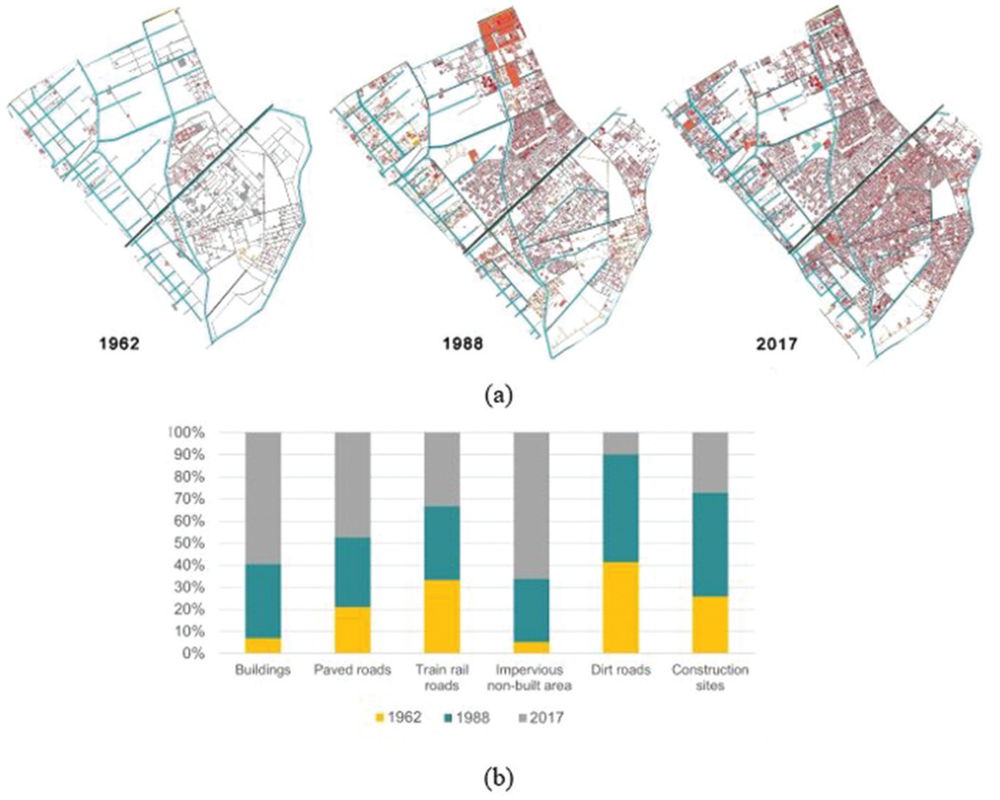


Figure 9. The area selected to assess further the exposed land use classes, according to the criteria identified in the analysis. The area is overlapped with the corresponding digital terrain Model to show the extent of urbanized areas below or at sea level.

use classifications (only 5 land use classes are present in the selected area). Even if it is impossible to map the building speculation and informal settlement (Chiodelli et al. 2021), the urban tissue provides a narrative of the development patterns. Focusing on the 'buildings' and 'paved roads' land use classes, it was observed that in 1962, the paved roads surface was larger than the surface occupied by buildings; in 1988, the value was almost even, and in 2017, the 'building' land use class overtook the surface of paved roads. Usually, roads are expected to have a greater surface area than the buildings' footprint (Brelsford et al. 2018). However, in the case of informal settlements and building speculation, a road can serve multiple properties adjacent to the street and be connected with the main lane through dirt roads, which are particularly significant in both 1962 and 1988 (Table 4).

Even though the land cover reaches only 25% of the total area, there is a significant hydraulic risk due to the anthropic pressure in the proximity of the drainage system and the aquiclude in the former lake area. A flood model is needed to accurately assess how the soil sealing change affects the flood shape over the various urban developments. Each return period's exposed land use classes in 2017 were quantified (Figure 11a,b).

Notably, 11% of the buildings are affected by flood associated with a ten-year return period. This increases to 20% and 23% with a thirty-year return period and a fifty-year



(a)

(b)

Figure 10. (8a) zoom on the selected area in the considered periods (1962, 1988, and 2017). (8b) percentages of land cover for land use class in the different periods considered,1962,1988, and 2017.

Table 4. Surfaces in ha for each land use class.

	2017	1988	1962
Buildings	293.64	166.41	34.42
Paved roads	203.52	136.44	90.25
Train railroads	1.04	1.04	1.04
Impervious non-built area	359.51	156.66	28.66
Dirt roads	10.21	50.58	43.06
Construction sites	44.05	75.88	41.73

return period, respectively. Most of the built environment is affected by 1-in-200 and 1-in-500 year floods, respectively, by 43% and 53%. In terms of hectares, just considering the buildings' footprint, these numbers are 32 ha for a ten-year return period; 59 ha for a thirty-year return period; 68 ha for a fifty-year return period; 126 and 156 ha for the two-hundred-year and five-hundred-year return periods. These data are highly relevant; even in the best case, the amount of buildings affected by a flood is already significant.

The considered return periods are expected to be severely affected by climate change and the change in the water cycle due to the increasing urbanization due to the current housing emergency in Rome. Moreover, in light of the nature of the area's development, both self-constructed buildings and buildings that emerged during the period of

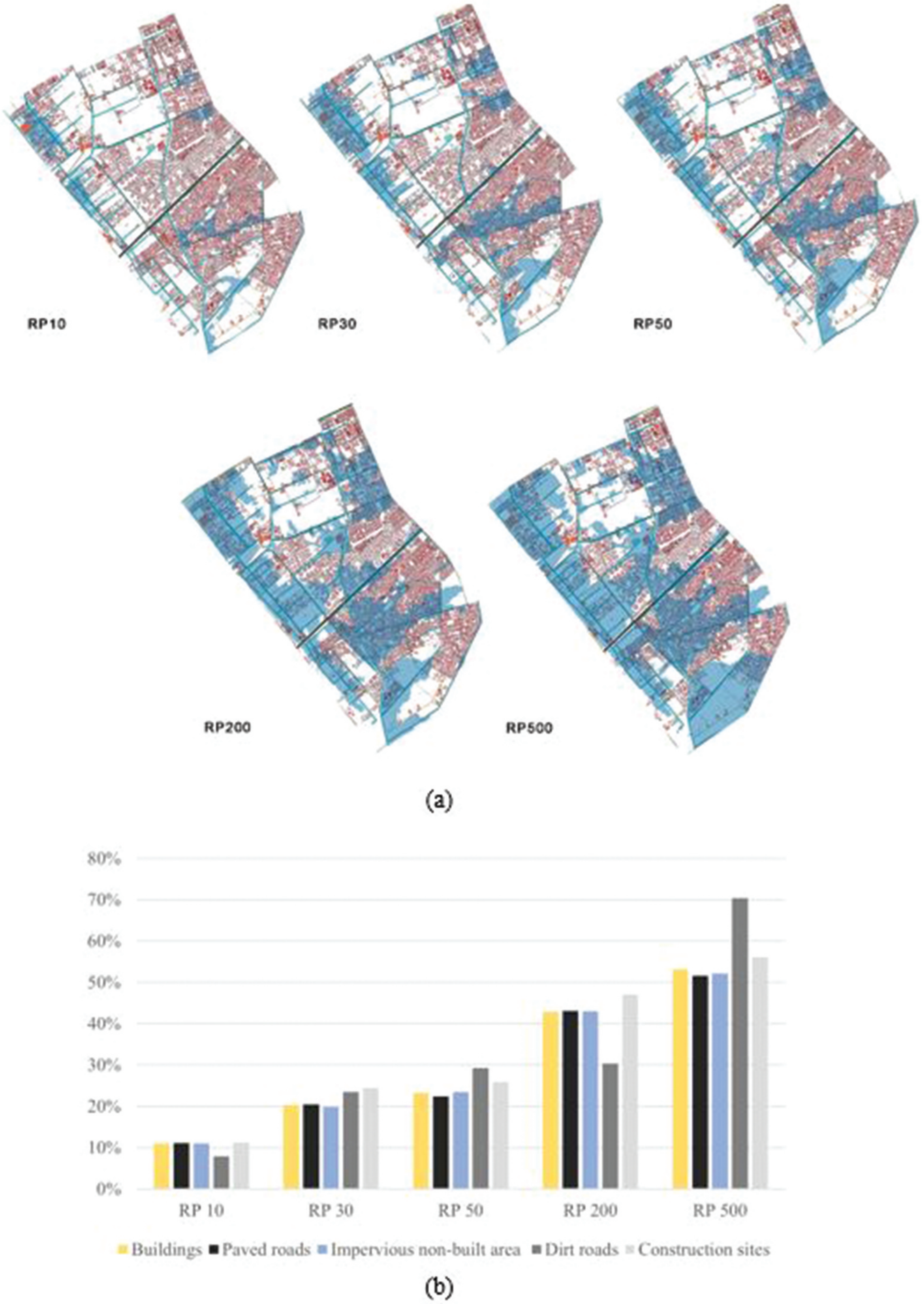


Figure 11. Urban areas affected by flood for each return period (9a). The percentage of each land use class affected by floods for each return period (9b).

speculation are even more vulnerable to floods. The current economic fluctuation and social distress create similar conditions that lead to informal construction, which can increase social vulnerability in the face of climate change.

Discussion

In Italy and the Mediterranean area in general, addressing the issues related to the different sources of urban expansions with policies and planning measures is an ongoing challenge (Romano et al. 2021). The chain of events triggered by societal modification has often resulted in inequalities and increased soil sealing. As indicated in this study, the 'do-nothing policy' is harmful in the long term. Therefore, for fragile coastal urban contexts like the case study, assessing the vulnerabilities and proactively addressing them before the changing conditions force the administration's hand is crucial. This paper summarizes a complex frame of events and intertwined factors that have resulted in a vulnerable built environment. The data show how land consumption has changed over time and what land use classes have contributed most to the area's urban development, buildings and impervious non-built areas. The expansion of Municipio X is consistent with patterns that emerged in the peripherical zones in Rome (Chiodelli et al. 2021) and, more generally, in the Mediterranean context.

The growth around the compact city – Ostia Lido, 13f and 13 g in Figure 2 – is mainly observed from the 1960s and 1970s when the growth of the population was comparable to the growth of soil sealing. Munafò et al. (2010) expressed that from the 1970s to 2006, there was a 'decoupling' process. The population was first stable and then fell during the 2000s. However, the rate of soil consumption remained steady. From the analysis of the considered period emerges the scattered pattern attributable to urban sprawl and partially to informal constructions, which moderately began in the inter-war period, and grew massively in the speculation period. Although assessing the precise number of informal buildings is challenging (Romano et al. 2021), a visual comparison was used to help evaluate how much the informal growth contributed to the actual shape of the urban tissue.

For this case study, a significant amount of land consumption can be attributed to low-density self-constructed houses, many of which were built during a period of speculation. To visually demonstrate the scale of this unplanned growth, the General Development Plan for Municipio X, adopted in 1965, was compared with the actual shape of the urban fabric in 1988 in the area selected for more in-depth analysis (Figure 12). This comparison helps illustrate how the built environment deviated from the intended plans. The deviation from the plan enacted in 1967 included the urban expansion in the 13e area (Ostia Antica) (Insolera and Einaudi 1960), which was already informally in place, as shown by the analyses. It is nearly impossible to know the exact amount of informal settlements. Still, the administration in Rome estimated that at the end of 1970, one out of six houses was illegal (Insolera and Einaudi 1960).

The initial phase of unplanned construction was driven by necessity because of high housing demand and social iniquities, with a limited response by the administration. However, an economic system based on the refurbishing and leasing of former informal houses developed. That is, informal settlements and their growth changed their character over time, shifting from necessity to convenience.

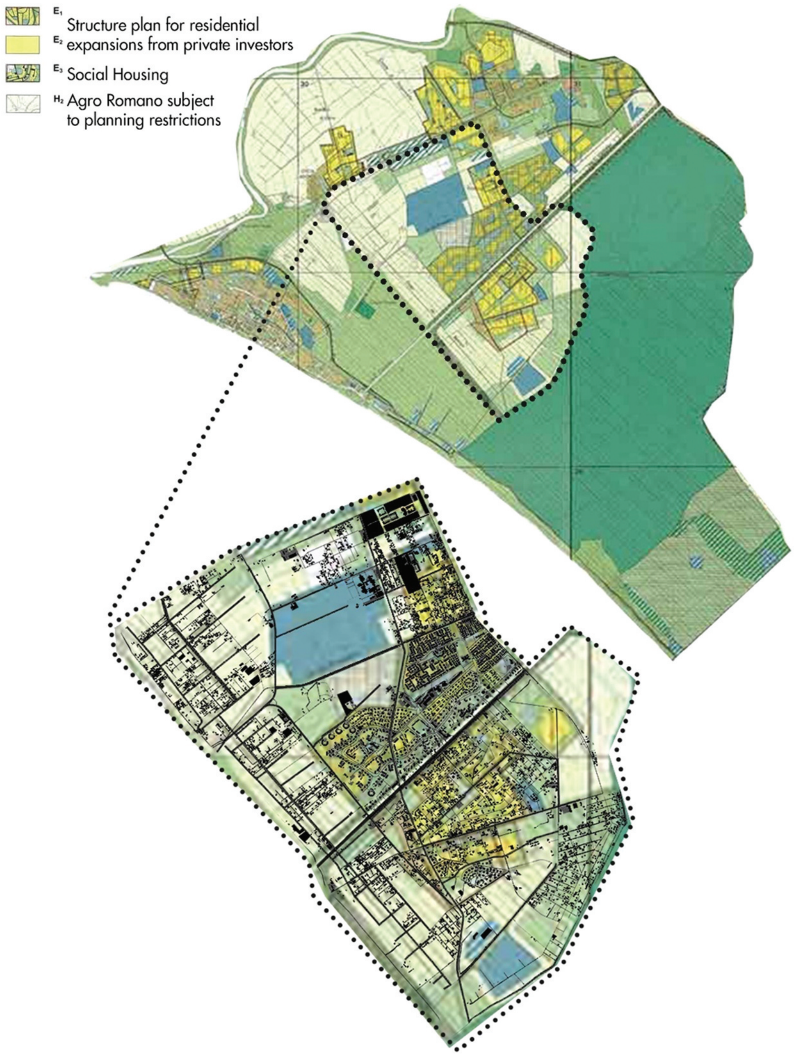


Figure 12. The General development plan for municipio X in 1965. The legend highlights the major planned expansions and the agro romano – Roman countryside with the agricultural vocation – the General development plan with the actual shape of the urban tissue in 1988 overlapped on the area of interest. Authors' elaboration.

According to Cellamare (2010), the quality of the buildings grew according to different phases of informal growth. Between 1999 and 2008, the "*Ufficio antiabusivismo del Comune di Roma*" (Office for anti-unauthorized constructive activities) identified four generations of various informal dwellers: i) The first generation, *l'abusivo semplice* [the simple squatter]; ii) the second generation, *l'abusivo speculatore* [the speculative squatter]; iii) the third generation, *l'abusivo scientifico* [the scientific squatter]; iv) the fourth generation, *l'abusivo arrogante* [the arrogant squatter]. This explanatory yet straightforward classification provides an insightful description of the urban development outside the legal boundaries from the post-war period to the early 2000s. Each generation also describes the phenomena in terms of building quality. In the first generation, simple houses were built out of necessity; in the second generation, the self-constructed detached houses built out changed their connotation, often with the aid of a private building contractor, becoming villas. On the one hand, the emerging housing model was a way for dwellers to achieve social redemption, following the lifestyle of the wealthier upper-middle class. On the other hand, soil consumption grew even more because the footprint of houses increased to fit more than one family, becoming a means to provide for new generations. In the third generation, some constructions have been renovated or rebuilt with sustainable, eco-friendly designs employing passive energy systems. The fourth generation describes the latest evolution: dwellers that moved out from informal construction, preferring other areas with better services. However, they maintained the property to rent it for profit to groups or families of immigrants who cannot easily access the real estate market.

Nowadays, recognizing which low-density building was legally built and which was condoned during the amnesties (*condoni edilizi* – L.47/1985, L. 724/1994, L. 326/2003) is not an easy task (Chiodelli et al. 2021). However, in most cases, the lack of infrastructure is a tell-tale sign, as, from the second half of the ’80s, there was a slow and progressive withdrawal of the State from providing infrastructure and services for the informal periphery (Celata and Lucciarini 2016).

This study provides both quantitative and qualitative information for understanding the dynamics that influenced the urban development of Municipio X. The land use classes that most influenced soil sealing during the different phases of expansion have been assessed, and the growth rate of each class for the different periods compared with 2017. Even if the area still preserves many areas of high environmental value, the large urbanization after 1962, both formal and informal, drastically changed the water cycle in the area. The *administration’s laissez faire attitude* towards informal growth implicitly contributed to the high hydrological vulnerability affecting the built environment.

The lack of policies and planning measures addressing the vulnerability of the built environment in Municipio X is still an open issue. Even in the new General Development Plan adopted in 2016, only a small part of the built environment is classified as a former informal settlement awaiting urban regenerative projects (Figure 13). Although just a small portion of the urban area is recognized as needing planning interventions, this does not imply that the area can cope with floods. Flood events have underscored the pronounced vulnerability to flooding within informal settlements, primarily arising from the susceptibility of these settlements to building failures, which, in turn, compromise the provision of secure shelter (Jonkman, Vrijling, and Vrouwenvelder 2008).

Challenges for urban design

Strategies to counteract flooding at the urban level are progressively leaning towards ecological methods and sustainable water management systems (Bolleter et al. 2023; Puchol-Salort et al. 2021). They aim to achieve a symbiotic relationship with natural processes, including water within the built environment. As expressed by Palazzo (2019), several academic studies have proposed synthesizing resilience frameworks and adaptive management within urban design, proposing to reconceptualize the function of urban design and broaden its traditional boundaries to include a socio-ecological

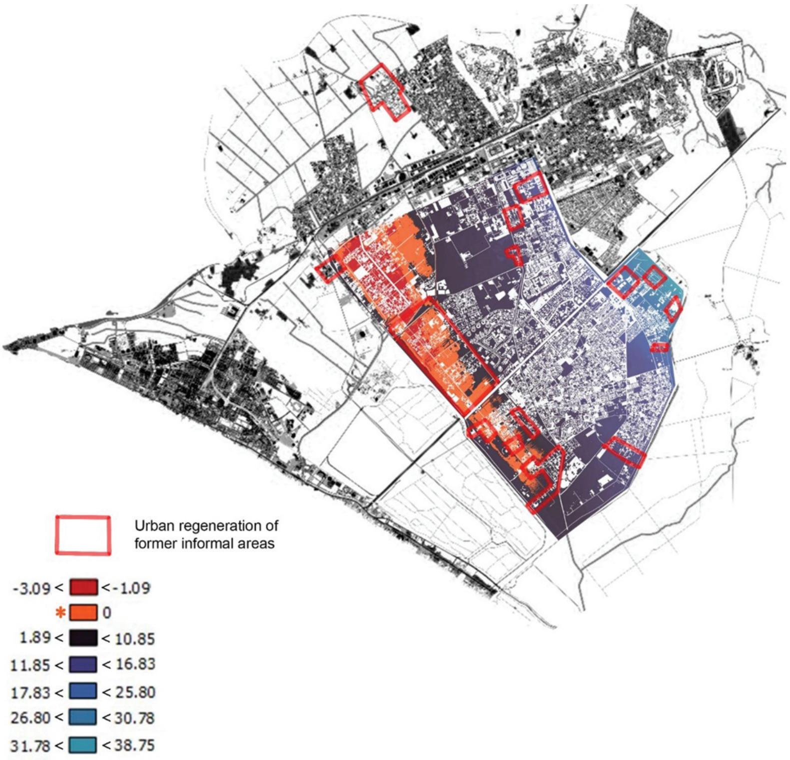


Figure 13. Indication of the former informal settlements awaiting urban regeneration overlapped with the Digital Terrain Model, showing that most of the neighbourhoods identified as former informal are located at or below the sea level. Authors' elaboration from the 2016 General development plan.

dimension. There is a growing discourse on leveraging water for urban renewal through ecologically based strategies and shared resource management, adaptable to the needs of modern cities (Camerin and Longato 2024; Fields 2009; Lennon, Scott, and O'Neill 2014; Palazzo 2019; Quigley, Blair, and Davison 2018). Nevertheless, the application of adaptive urban design remains ambiguous, and there is a pronounced disparity between conceptual ideas and their practical execution in the long term. Resilience, particularly regarding climate change, has similarities with adaptation, though they are different concepts. Despite often being discussed together, it is important to understand the subtle distinctions between resilience and adaptation. According to the IPCC, resilience refers to a system's ability to anticipate, absorb, accommodate, or recover from hazardous events while maintaining or enhancing crucial structures and functions (IPCC 2018). Ecosystems, which evolve gradually, respond to climate changes, with extreme conditions having significant impacts. When an ecosystem exceeds its resilience threshold, it is likely to transform into a new state.

The adaptive planning approach centres on managing uncertainty, which is a key aspect of the planning process. Instead of seeing uncertainty as an obstacle, adaptive planning treats it as a catalyst. This approach aims to address and reduce uncertainty by continually reassessing the viability and effectiveness of planning decisions and identifying risks at each step. Firstly, modelling and monitoring help to diminish uncertainty by improving scientific and professional comprehension of a system. Secondly, in adaptive planning, uncertainties can lead to the development of adaptive hypotheses, which guide planning and monitoring activities (Kato and Ahern 2008).

At the urban scale, particular attention must be given to community-specific strategies, public participation, and responsive governance (Barnett 2017; Dhar and Khirfan 2016). Engaging residents in planning and design strengthens preparedness and builds communal resilience (Lamond, Rose, and Booth 2015). Despite recognizing the significance of localized action and community-led adaptation, operationalizing such approaches has been challenging. Establishing a resilient and robust framework calls for a multi-tiered focus, addressing distinctive issues at urban, city, and regional scales. Developing flood-resistant infrastructure and adopting community-centred measures shape an environment resilient to flood challenges. These considerations also highlight the importance of factoring community vulnerability into planning, as variations in vulnerability across different social groups profoundly affect the ability of households and businesses to withstand and recover from natural hazards. The impacts of floods are unevenly distributed, affecting diverse community groups disparately. This inequality shapes the uneven nature of post-disaster recovery, raising critical questions about the future resilience of these communities. Consequently, alongside ecosystem-based approaches, there is an imperative need for community-centric strategies to promote equitable resilience in the face of disaster (La Rosa and Pappalardo 2020).

In Municipio X, the historical approach to managing flood risk has been predominantly centred on structural and hydraulic measures that divert water towards the river and the sea. However, this approach does not adequately account for the critical factors of climate change and rising sea levels, which increasingly impact coastal regions worldwide.

The area's vulnerability to these evolving environmental challenges is substantial, particularly due to its location, a flood-prone coastal zone. Climate change and rising sea levels can intensify flooding, posing greater risks to both the natural environment and the built urban landscape. Neglecting the integration of these evolving threats into flood risk management strategies could lead to severe consequences.

Delving into the complexities of urban planning in the context of Municipio X, it becomes evident that many challenges loom on the horizon. In addition to the pressing issues of flood vulnerability and climate change in a coastal area, several other critical challenges beset urban planners, such as: (i) the resilience of the existing infrastructure.; (ii) community engagement to create a shared sense of responsibility for the future and ensure future adaptation. (iii) Resource constraints regarding finances and access to specialized expertise create barriers to the effectively executing resilience and adaptation measures.

To effectively address these issues, it is imperative to transition from traditional hydraulic-centric flood management approaches to adaptive, context-specific measures. This transition should prioritize short-term actions and flexible, long-term solutions, considering the dynamic nature of climate change and sea-level rise.

Proactive planning should encompass a range of strategies, including enhancing drainage systems, creating flood-resistant green spaces, and promoting sustainable building practices (Al 2022; Lennon, Scott, and O'Neill 2014). Policymakers and urban planners must formulate dynamic, long-term adaptation plans that transcend static strategies. These plans should remain responsive to changing climate conditions, uncertainties about the future, and the evolving needs of urban communities (Brandsma et al. 2024).

In particular, with its outdated drainage system, Municipio X can benefit from a thoughtfully designed sustainable drainage system coupling green and blue infrastructures. Nature-based solutions, particularly sustainable urban drainage systems (SuDs), have been acknowledged for alleviating the impacts of floods. These approaches not only manage excess water effectively but also confer many benefits: they enhance local biodiversity, improve water quality, positively influence the urban microclimate, and enrich the aesthetic value of the urban environment (Haghighatafshar et al. 2018; Pappalardo et al. 2017; Rosso et al. 2016; Skrydstrup et al. 2022).

In a nutshell, SuDs rely on infiltration or detention to enhance water management efficiency (Griffiths 2016). Infiltration systems allow water to infiltrate into the soil, which can then contribute to aquifer recharge or be utilized by vegetation, returning to the atmosphere via evapotranspiration. The soil's specific characteristics are crucial for this technique's effectiveness. Meanwhile, detention and retention tactics hold water temporarily in designated spaces like ponds or basins, where it can gradually infiltrate the ground under suitable conditions or be released in a controlled manner into the drainage systems once the threat of flooding has subsided. These different approaches are fundamental for context-specific applications. In the case of Municipio X, infiltration systems can improve the water cycle, but only in the areas where the soils and the aquifers allow such solutions; applying this strategy without accounting for the context characteristic could result in a worsened flood risk.

A diverse array of sustainable drainage practices is suitable for application across different urban scales, contributing to flood risk mitigation and runoff management. These include harvesting rainwater for domestic use, reducing potential runoff, and installing green roofs or walls, which provide insulation, mitigate urban heat effects, and extend the life of building materials (an important feature for ill-built informal buildings). Further measures for retrofitting buildings incorporate wet-proof and dry-proof technologies (Barker and Coutts 2016). Dry-proofing techniques stop water from penetrating structures through the use of physical barriers for sealing, whereas wet-proofing enables buildings to withstand water exposure with minimal damage by employing water-resistant materials and incorporating design elements that facilitate easy recovery. Adopting these technologies in susceptible buildings boosts resilience, reduces the impact of flood damage, and guarantees safety and continuity for inhabitants during adverse weather conditions.

Given the informal nature of many areas within Municipio X, establishing floodable urban spaces, such as squares or playgrounds, emerges as a visionary approach. These areas are ingeniously designed to serve dual purposes: they act as temporary reservoirs for water during extreme weather events, alleviating the strain on existing drainage systems, and they simultaneously function as enhancements to the urban landscape. Floodable urban spaces not only serves as a strategy to mitigate the adverse effects of flooding but also as a proactive strategy aimed at enriching the quality of outdoor spaces – a feature often missing in such informally developed areas.

Incorporating floodable spaces within the urban fabric of Municipio X could transform underutilized or neglected areas into vibrant, multi-functional public spaces. These areas would provide residents with essential and communal gathering spots and play a critical role in the municipality's broader climate adaptation and urban resilience efforts. By integrating functionality with sustainability, these floodable urban spaces offer a practical solution to flood management while fostering a sense of community and enhancing outdoor areas' overall aesthetic and usability.

Specifically, this planning strategy could be a feasible solution for the former lake area. As previously discussed, the soil in the former lake area is impervious; furthermore, the area is currently recognized as a former informal settlement awaiting regenerative intervention. From this standpoint, the example of the water squares adopted in Rotterdam and in Tiel (Figure 14) could be an excellent demonstration of how urban spaces can be used to mitigate and adapt the built environment to exacerbated events while enhancing the quality of the outdoor spaces. The Rotterdam Water Square, known as 'Benthemplein Water Square'(Syahirani and Ellisa 2021), emerges as a pioneering urban design project, blending the realms of public recreation and water management into a cohesive solution. This innovative concept directly addresses the recurring challenge of urban flooding triggered by intense rainfall, particularly in areas with inadequate drainage infrastructure. Under normal weather conditions, the square functions as a dynamic public space, hosting sports, gatherings, and leisure activities. However, it ingeniously transforms into a water storage facility when heavy rains occur, demonstrating its dual functionality. The square features three basins of varying depths, each meticulously designed to capture and temporarily store excess rainwater, thereby preventing overflow into streets and buildings. The shallowest of these basins are tasked with handling water from lighter rains, facilitating its return to the ground and easing the pressure on the sewer systems. In contrast, the deepest basin is allocated for significant rainfall events, holding large volumes of water that are either gradually released back into the drainage system or absorbed into the ground once the risk of flooding diminishes. Beyond its primary role in flood mitigation, the basins are repurposed for recreational use in drier times, incorporating amenities such as amphitheatre-style seating and green spaces to ensure the square's year-round utility to the community. Moreover, the Water Square serves an educational purpose, raising awareness among residents about water management challenges and the potential for innovative design solutions to address climate adaptation. It also aids in urban cooling, with the presence of water and vegetated areas helping to moderate the microclimate during warmer periods.

The Tiel Waters square follows the same principle. At the heart of the square lies a sports field that doubles as the main basin for rainwater collection. Winding around the field is a 'playful snake', a landscaped area marked by varying elevations that form a series of smaller basins. Under normal weather conditions, rainwater is directed into the smaller basins, where it gradually seeps into the ground, aided by a rain garden and permeable surfaces. The central basin is reserved for exceptional weather events, collecting runoff from adjacent streets during heavy downpours or prolonged rainfall, and also acting as an overflow for the shallower basins. Once the excessive rainfall subsides, the stored water is channelled back into the stormwater drainage system.

Adopting such innovative, nature-based solutions, coupled with the strategic retrofitting of existing structures with wet-proof and dry-proof technologies, presents a holistic pathway towards urban resilience. Municipio X can navigate the complexities of urban flooding and climate change by prioritizing sustainable drainage systems and integrating

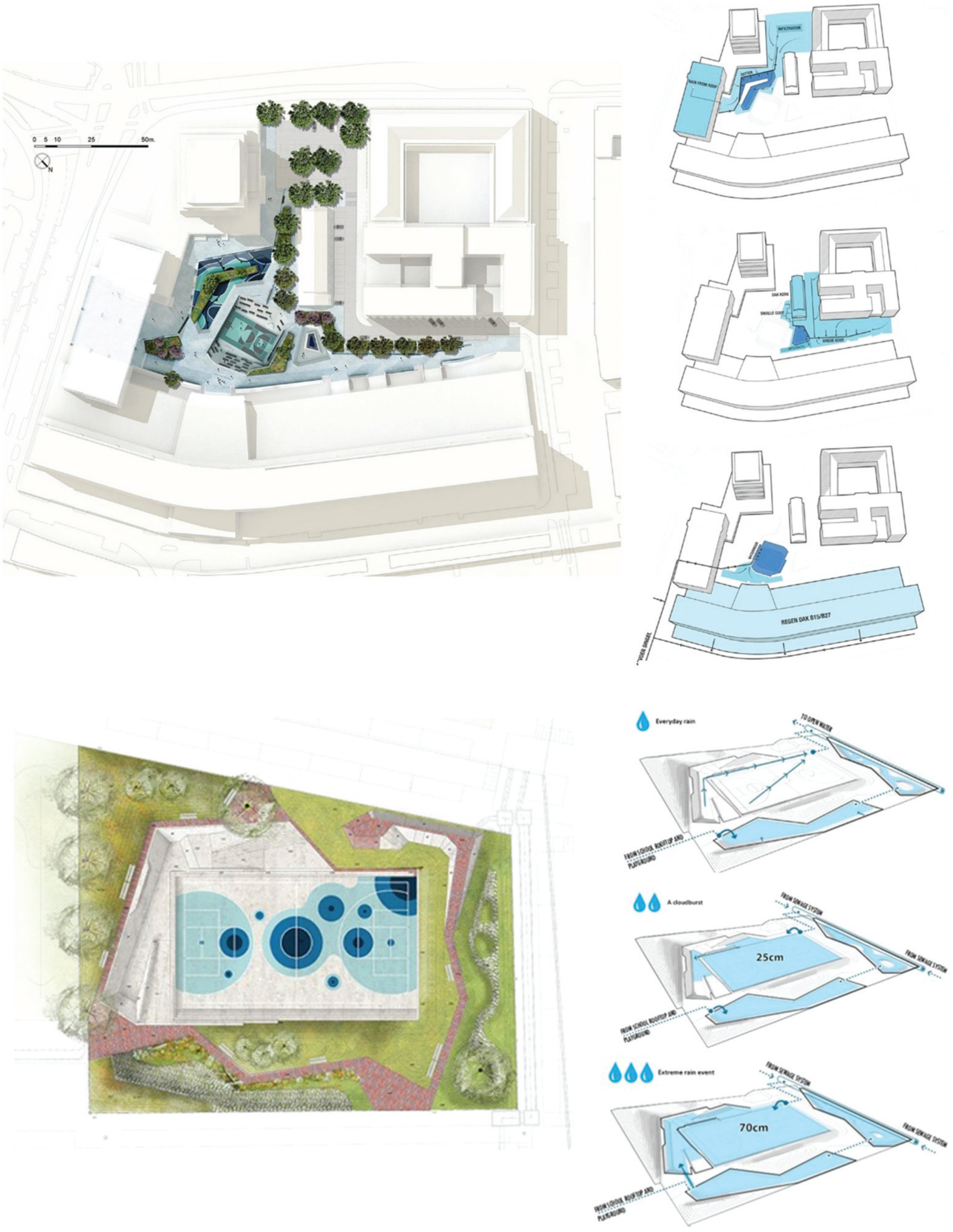


Figure 14. Rotterdam's innovative Water Square (top), a multifunctional urban space that transforms into a water storage facility during heavy rainfall to prevent flooding. Featuring recreational amenities and green spaces, it exemplifies sustainable design by combining flood management with community leisure and urban cooling. At the Tiel Water Square (bottom), a multifunctional sports field transforms into a rainwater collection basin amidst a 'playful snake' of landscaped elevations, creating a vibrant community space. Designed with input from local children, this innovative area offers diverse activities within its natural playscapes, playgrounds, skate basins, and green areas, cleverly managing rainwater through infiltration and storage during varying weather conditions. ©the urbanisten (www.theurbanisten.nl).

community-centric planning strategies. This forward-looking approach addresses the immediate challenges and lays the groundwork for a resilient, adaptive, and sustainable urban future. Urban design is pivotal in confronting the multitude of challenges posed by climate change, especially in vulnerable coastal zones like Municipio X. With urban areas swelling, particularly in sensitive coastal regions, the urgency to weave resilience and sustainability into the fabric of urban planning is paramount. This endeavour goes beyond traditional development frameworks, advocating for creating adaptive spaces adept at weathering environmental shifts. It involves harnessing green and blue infrastructure and deploying nature-based solutions to bolster urban resilience. Moreover, this field must navigate the socio-economic terrain, ensuring that development does not deepen vulnerabilities or disparities among urban dwellers.

Through fostering collaborative planning efforts and engaging multi-sectoral stakeholders, practitioners can champion the uptake of innovative solutions to environmental challenges. This includes leveraging technology and data-driven insights to guide planning efforts and promote policies incentivizing sustainable development.

Furthermore, this approach can transform urban landscapes into more habitable and resilient environments. Thoughtfully designing public spaces, infrastructure, and buildings can elevate the quality of life for residents while enhancing the area's resilience against climate impacts. This necessitates a holistic approach that considers environmental, social, and economic dimensions, ensuring urban development harmonizes sustainability with resilience, acknowledging the context-specific characteristics.

Conclusions and future outlooks

In conclusion, this study has delved into the intricate dynamics that have shaped the urban landscape of Municipio X, a flood-prone suburban coastal area of Rome within the broader context of coastal Mediterranean regions. The research has explored the multifaceted relationships between flood risk, land consumption, and the influence of political, societal, and economic changes. It has underscored the significant impact of the absence of interventions and institutional *laissez-faire* in contributing to the area's present urban vulnerability to exacerbated climate phenomena.

By offering an evidence-based analysis of Municipio X's urban evolution, including the socio-economic factors and the repercussions of misguided or absent policies, this study provides valuable insights for urban planners and decision-makers. These insights emphasize the necessity of formulating context-specific, equitable, and long-term adaptive plans that can prevent the recurrence of undesirable or unexpected outcomes in the future.

This research addresses the intricate weave of historical, societal, and environmental threads that have shaped the fabric of Municipio X, underscoring the profound impact of past decisions on its present-day vulnerability to flooding.

Drawing upon the insights garnered from the analysis of Municipio X, it becomes evident that the solution to urban vulnerability lies not just in the application of innovative engineering or design practices, but in the reimagining of urban planning as a dynamic, inclusive, and adaptive process. The role of community engagement, in particular, emerges as a cornerstone of resilience, emphasizing the necessity of involving local populations in the planning process to ensure that the solutions devised are not only effective but also equitable and reflective of the community's needs and aspirations.

The study's findings advocate for a paradigm shift in urban planning, from reactive measures to proactive strategies that anticipate and mitigate the impacts of climate change. This entails not only the adoption of nature-based solutions and green infrastructure but also a concerted effort to retrofit existing urban areas with an eye towards enhancing energy efficiency, water management, and social cohesion.

Moreover, the paper underscores the importance of scalable and transferable strategies that can be adapted to different urban contexts, both within Italy and globally. As cities around the world grapple with similar challenges of flooding, climate change, and rapid urbanization, the lessons learned from Municipio X offer valuable insights that can inform global practices in urban resilience.

In essence, this research serves as a pertinent reference point for understanding the complexities of urban development in coastal Mediterranean areas. The study of Municipio X offers a critical foundation for advancing the resilience and sustainability of coastal urban areas. Future trajectories should be characterized by proactive, adaptable, and community-centred approaches to urban planning and resilience building. By addressing the multifaceted interplay of historical factors contributing to urban vulnerability, these regions can chart a course towards more sustainable, just, and resilient urban futures in the face of evolving environmental exigencies.

Note

1. Soil sealing refers to changing the nature of the soil such that it behaves as an impermeable medium (for example, compaction by agricultural machinery). Soil sealing is also used to describe the covering or sealing of the soil surface by impervious materials by, for example, concrete, metal, glass, tarmac and plastic. Source: https://www.eea.europa.eu/help/glossary/eea-glossary/soil-sealing.

Author contributions

Contributor Roles Taxonomy according to CRediT descriptors:

S. Mannucci (Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing Original Draft, Writing Review and Editing, Visualization)

J. H. Kwakkel (Conceptualization, Methodology, Writing Original Draft, Writing reviewing and Editing, Visualization, Supervision)

M. Morganti (Conceptualization, Writing Original Draft, Writing reviewing and Editing, Supervision)

M. Ferrero (Writing Original Draft, Writing reviewing and Editing, Project administration)

Disclosure statement

No potential conflict of interest was reported by the author(s).

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