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Environmental and geomorphic aspects of urban beaches of Naples, southern Italy

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Abstract

Integrated morphometric, granulometric, and morphoscopic analyses and environmental surveys of six beaches selected from thirty, with different characteristics and lengths ranging from a few to several tens of meters, were carried out since 2019. These sensitive transition environments between sea and land undergo bureaucratic and operational management in mutual transition between many institutions, from central to local, which often results in delayed interventions. The comparison and interpretation of the data and results allowed to outline the main morphosedimentary and geomorphological characters of these beaches, to obtain a modern morpho-typological classification including biotic and anthropogenic elements. These urban beaches can be equated in physiography and sedimentological features to pocket beaches or intermediate types between those and predominantly sandy tombolo, salient and beaches at the cliff foot. Since pocket beaches are the favorite of bathers for their beauty due to high-morphological waterscape variability, they are subject to intense anthropogenic pressure. Current erosion in these artificial environments is less intense than occurring on large natural littorals of alluvial or minor coastal plains but is relevant concerning the limited width and massive seasonal tourist pressure. Urban beaches register a high-risk factor when tourist settlements occupy the backshore. They constitute a natural buffer against undermining the behind cliff foot by storm

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waves. Consequently, the cliff is sheltered and becomes inactive. Sea waves could trigger cliff collapses or seriously damage urban structures on them. Considering the importance that urban beaches have both for a tourist-recreational issue and the safeguard of the cliff and buildings, it is necessary to protect them. Appropriate policies include proper management and targeted removal of the clay material, macroplastics, microplastics, and microfibers massed by waves, sea currents, and wind, as well as from incorrect behavior by users.

Keywords: Coastal geomorphology, urban beach, environmental design, Naples

Riassunto

La ricerca verte sullo studio delle spiagge urbane di Napoli, Italia. Sono stati svolti rilevamenti ed analisi ambientali integrate morfometriche, granulometriche e morfoscopiche di sei spiagge urbane selezionate tra trenta, con caratteristiche diverse e lunghezza da pochi ad alcune decine di metri. Questi sensibili ambienti di transizione tra mare e terra soffrono di una gestione burocratica e operativa in mutua transizione tra molti *stakeholder*, da quelli centrali ai locali, che spesso ritardano gli interventi. La comparazione ed interpretazione di dati e risultati ha permesso di delineare i principali caratteri morfosedimentari e geomorfologici per una moderna classificazione morfotipologica che include anche elementi biotici ed antropogenici. Queste spiagge urbane si possono equiparare per fisiografia ed aspetti sedimentologici a *pocket beach* o tipi intermedi tra queste e tomboli o cuspidi perlopiù sabbiosi e spiagge al piede di falesia. Poiché le *pocket beach* sono preferite dai bagnati per la loro bellezza dovuta ad un’alta variabilità morfologica del paesaggio costiero, sono soggette a stress di genesi antropica elevato. I processi erosivi in atto, seppure meno intensi di quelli dei grandi litorali che orlano le pianure alluvionali o costiere minori, sono rilevanti in relazione all'ampiezza limitata delle spiagge urbane e alla forte pressione turistica stagionale. Queste spiagge registrano un fattore di rischio elevato quando gli insediamenti turistici occupano la zona di retrospiaggia. Inoltre, costituiscono una barriera naturale contro lo scalzamento al piede della retrostante falesia operato dalle mareggiate, che così diviene inattiva. Le onde marine potrebbero innescare crolli della falesia o arrecare gravi danni alle strutture che vi fondano. Data l’importanza che hanno le spiagge urbane per motivi turistico-ricreativi, salvaguardia di falesia e strutture antropiche, è necessario tutelarle mediante una corretta gestione e rimozione mirata dei materiali fittili, macroplastiche, microplastiche e microfibre depositati da onde, correnti marine e vento, nonché a causa del comportamento scorretto dell'utenza.

Parole chiave: Geomorfologia costiera, spiaggia urbana, progettazione ambientale, Napoli

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Introduction

Vanishing beaches originated by different human pressure are a worldwide issue, with significant and sometimes unpredictable socio-economic and environmental impacts (Pezzuto et al., 2006; Donadio 2017; Lämmle et al., 2022a). Almost 90% of America's sandy beaches have been eroding (EPA, 1994), losing up to 15 m of shoreline per year (Blum & Roberts 2009) in the last few decades. In Europe, from 40% to 70% of the shoreline is eroding (Beachmed 2008), but in some cases, the problem is much worse as the concurrent factors multifaceted. Among littorals, the pocket beaches, known also as gravel beaches, are highly endangered by erosion processes and poorly monitored (Sayao 1991; Pranzini et al., 2007; Savi 2007; Simeoni et al., 2012; Bowman et al., 2014; Klumb et al., 2014), different from urban beaches. Currently, these transition environments are not yet classified and rarely studied, despite their relevance for the management of coastal zones, marine space, urban ocean, and littoral dynamics (De Pippo et al., 2003; Pranzini 2009; Blumberg & Bruno 2018; Lämmle & Bulhões 2019; Silva et al., 2021; Lämmle et al., 2022b; Souza et al., 2023).

Considering the city waterscape, urban beaches seem to place at an intermediate morphodynamic type between a beach at the foot of sea cliff and a pocket beach, but in this sense a first fitting classification related also to erosion (Table 1) was proposed by Valente (1999).

This research represents a starting point for classification, further investigations, and projects focused on safeguarding urban beaches. In the next years, these seascapes will be the subject of worldwide research programs, as evidenced by recent reports of IPCC (2019, 2021) on potential effects in islands and cities of the ongoing climate change and coastal resilience (Masselink & Lazarus 2019), as an increase in sea level, flash floods and storm surges.

Geological and geomorphological framework

The city of Naples is in the eastern sector of the Phlegraean Fields active volcanic area (Fig. 1). The hilly morphology is mainly due to the presence of explosive monogenetic volcanoes and rare lava domes, mantled by thick Phlegraean pyroclastic deposits. The landscape was modeled by the down-faulting displacement associated with the collapse of two nested Late Pleistocene calderas (Petrosino et al., 2020). The oldest and largest one is associated to the Campanian Ignimbrite eruption (CI, ~40 ka BP; Giaccio et al., 2019; De Vivo et al., 2001), the youngest, inner one is related to the Neapolitan Yellow Tuff eruption (NYT, ~15 ka BP; Deino et al., 2004).

The presence of small volcanic centers as Mt. Echia and Nisida Island (3.9 ka BP), along the

Table 1: Classification of urban beaches and erosion mitigation mechanism or process (after Valente 1999).

COAST TYPE			MECHANISM OR PROCESS
1	**Urban**		**Imposed**
	a	seafront with defense structures	emerged breakwater
	b	waterfront	quay, wharf
	c	port	port dike, dock
2	**Peri-urban**		**Soft**
	a	waterfront with sparse defense structures	submerged breakwater
	b	peri-urban littoral	artificial nourishment, dewatering
3	**Sub-urban**		**Hybrid**
	a	absence of defense structures	artificial nourishment protected at the foot
			naturalistic engineering interventions
	b	high rocky coast	light and reversible works on the dune

coastline, testifies to recent explosive activity inside the city (Scarpati et al., 2013, 2015). The coast is exposed to Southwest and Northwest sea storms and featured by an alternation of small promontories and coves with some pocket beaches. Fluvial-marine erosion and deposition processes triggered by vertical ground motions and postglacial sea-level fluctuations remodeled the inherited landscape during the last 5 ka (Cinque et al., 2011; Donadio 2019). Several ruins of Roman age are present along the coastland and seabed down to about 6 m of depth between the Castel dell'Ovo (NE) and Nisida Island (SW) (Günther 1913; Simeone & Masucci 2009; Stefanile et al. 2018). These archaeological structures were downlifted by local bradyseismic phenomena still ongoing (Aucelli et al. 2017a,b; Stanislao 2018; Donadio et al., 2019; Pappone et al., 2019). The pyroclastic deposits are dissected by urban streams which supply some urban beaches. The embankments of the 1930s and postwar, the seaward enlargement and artificial progradation of the modern port, Santa Lucia, and Viale A. Gramsci neighborhoods (SE and SW), modified the waterfront (Brandolini et al., 2020). Currently, erosion processes of the tuff sea cliff are mainly due to sea wave action and intense rainfall triggering non-negligible effects on the waterscape. Landslides, flash floods, and accelerated erosion formed rock piles and small coastal alluvial fans in the urban beaches and along the seabed. The anthropic embankments and quarrying contributed to modify the original coastal physiography since the Roman age and especially during the last five centuries. Considering all the geoenvironmental features of the coastland and the waterscape morphology, the presence of straight urban streams, vertical ground motion, sea-level rise, seismicity, active volcanoes in the peripheral areas, the tsunamigenic processes to which this area is prone, and the dense urbanization, the overall geomorphological hazard results from high to extreme as this engineered littoral is a *technocoast* (De Pippo et al., 2002a, 2008, 2009; Anthony 2014; Valente et al., 2014; Ferrando et al., 2021; Clemente et al., 2022).

Naturalistic features

The morphological and sedimentological aspects of urban beaches are currently controlled by the mutual interaction between physical, biotic, and anthropic

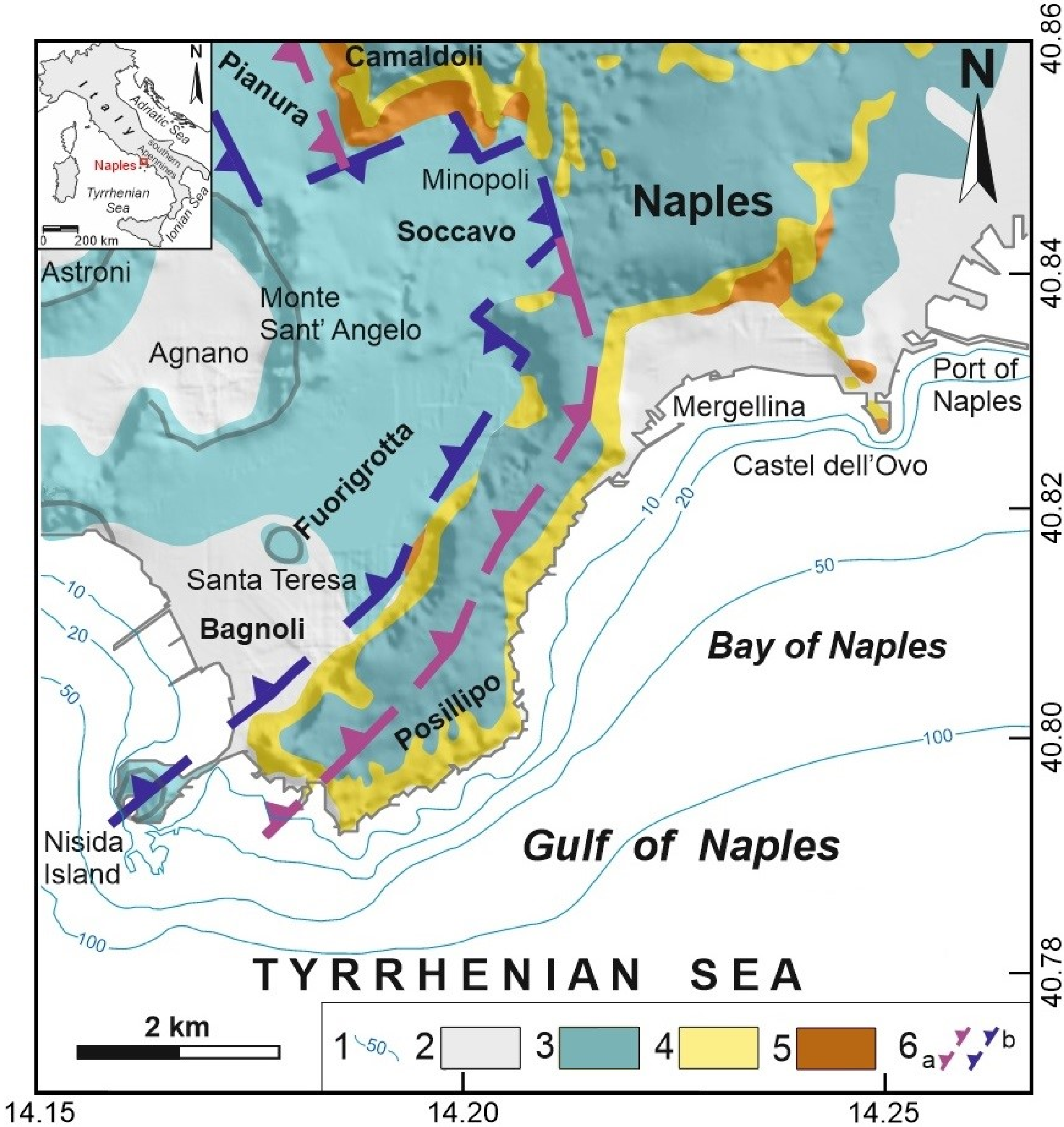

Figure 1: Geological map of the western coastland of Naples: 1, isobath (-m a.s.l.); 2, fluvial-marine, lagoon-marsh, dune-beach, and reworked pyroclastic deposits (Upper Pleistocene-Holocene); 3, Phlegraean Fields pyroclastic products (Quaternary); 4, Neapolitan Yellow Tuff (NYT, ~15 ka BP); 5, Campanian Ignimbrite (CI) and older volcanics (≥40 ka BP); 6, caldera rim: a, CI; b, NYT.

elements of the emerged and submerged coastland. The beaches are exposed to wind and waves coming from the I, II and III quadrant: the heaviest storm surges come from SE and SW.

Among the main environmental components that control genesis and development and characterize these sandy beaches, often dismantled or developed by storm surges and recent anthropogenic changes along the coast, there are climate, flora, and fauna.

Thermo-pluviometric data recorded in the period 1872-2006 by the Meteorological Observatory of the University of Naples Federico II classify the Mediterranean climate of Naples as subtropical, slightly continental, and humid-subhumid (Mazzarella 2007). According to the Köppen-Trewartha climatic formula, the climate is subtype Csa (Köppen 1936; Trewartha 1980; Kottek et al., 2006). In particular, the data of 2019 (Mazzarella et al., 2019) indicate for the period May-October 22-30 days with T_{max} > 20°C, 2-4 days with T_{min} ≤15°C and 2-13 days of rain, with the highest number of rainy days in February-March and October-November amounting to 908.3 mm/yr. These mild climatic conditions are very favorable to the use of urban beaches for about six consecutive months a year, between late spring and early autumn. The bioclimatic framework in the coastal zone favors the development of the ecosystem of Mediterranean maquis (Fig. 2), a composite association in which evergreen shrub and tree species with leathery leaves prevail.

The maquis results from anthropic interaction with the natural environment for millennia, therefore only rarely, where environmental conditions do not allow further plant evolution, can be considered spontaneous and depending on the primary maquis. Secondary maquis originates from degradation due to anthropic activity (*i.e.*, cuts, fires, agriculture, etc.) and more rarely from natural processes. The maquis would cover extensive stretches of the Neapolitan coastland, but intense anthropogenic changes currently sparse it. Urban beaches, used for seasonal bathing, do not allow the

Figure 2: Mediterranean maquis along the top of NYT sea cliff at Posillipo (photo C. Donadio 2013; W-E view).

colonization of any spontaneous vegetation, only some ephemeral psammophiles.

The steep tuffaceous sea cliffs with numerous coastal cavities and tafoni stimulated many birdlife species, protected by the EU Birds Directive since 1979, to frequent and nest in the urban area. Among the various birds that usually settle there are the herring gull (*Larus michahellis*), common swift (*Apus apus*), blue rock thrush (*Monticola solitarius*), white wagtail (*Motacilla alba*), some species of falcons as the peregrine (*Falco peregrinus*), kestrel (*Falco tinnunculus*), lesser kestrel (*Falco naumanni*, Fleischer 1818), the last considered a migratory species. The coast, especially in winter, is frequented by water birds such as the great cormorant (*Phalacrocorax carbo*), great crested grebe (*Podiceps cristatus*), sandwich tern (*Thalasseus sandvicensis*), and the colorful common kingfisher (*Alcedo atthis*), as well as by pelagic birds such as shearwaters (*Puffinus yelkouan*, *Calonectris diomedea*). About reptiles, mainly lizards (*Podarcis muralis*, *P. siculus*) and the Moorish gecko (*Tarentola mauritanica*) are present. Most of these animals share the coastal environment with humans.

On the beaches are abundant shells and bioclasts of mobile and rocky bottom organisms within 10 m of depth (Pérès & Picard, 1964), such as bivalve mollusks of Veneridae, Donacidae, Ostreidae, gastropods *Natica millepunctata*, *Nassarius mutabilis*, Muricidae, the uncommon *Aporrhais pespelecani* and the rare *Monoplex partenopaeum*. Numerous fragments of gastropods *Patella coerulea*, *Phorcus turbinatus*, *Haliotis tubercolata*, of bivalves *Mytilus galloprovincialis*, and *Arca noae*, of cirriped *Balanus improvisus* and Polychaeta from the submerged rocky substrate of sea cliffs and breakwaters, are widespread. The organogenic fraction composes a large part of the studied beach deposits, together with pyroclastic and lava minerals and debris, pumices, twigs, leaves and rhizomes of marine phanerogams, and allochthonous material (Fig. 3, 4, 5 and 6).

Case studies

The research focused on the study of six different urban beaches, selected among some thirty, in a stretch of 6 km of the western coast of Naples at the foot of the Posillipo hill, between Mergellina (NE) and Coroglio (SW). The beaches were surveyed, sampled, analyzed, and for the first time classified according to their geomorphological and environmental aspects in response to the degree of anthropization to which they are prone. From East to West, the studied environments are the Circolo Relax, Bagno Sirena, Spiaggia delle Monache, Spiaggia delle Telline, Cala della Zafferana, and Coroglio beaches (Fig. 3 and 4). The physiography of the coast summarizes in the following morphological elements, controlled by volcano-tectonics: a steep tuff sea cliff with a foot within -6 m of depth and a series of pocket beaches confined between short promontories. Structures which are best classified as artificial or induced by anthropic activity are coastal defenses, ports, and urban beaches. The morphology of the submerged landscape, at the foot of the active cliff, is characterized by low-sloping sandy-pebbly seabed extending down to about -15 m of depth. Here, the edge of a steep paleo-cliff covered by sand, whose base is at a depth of about -25 m, extends parallel to the current coastline (Monti et al., 2015).

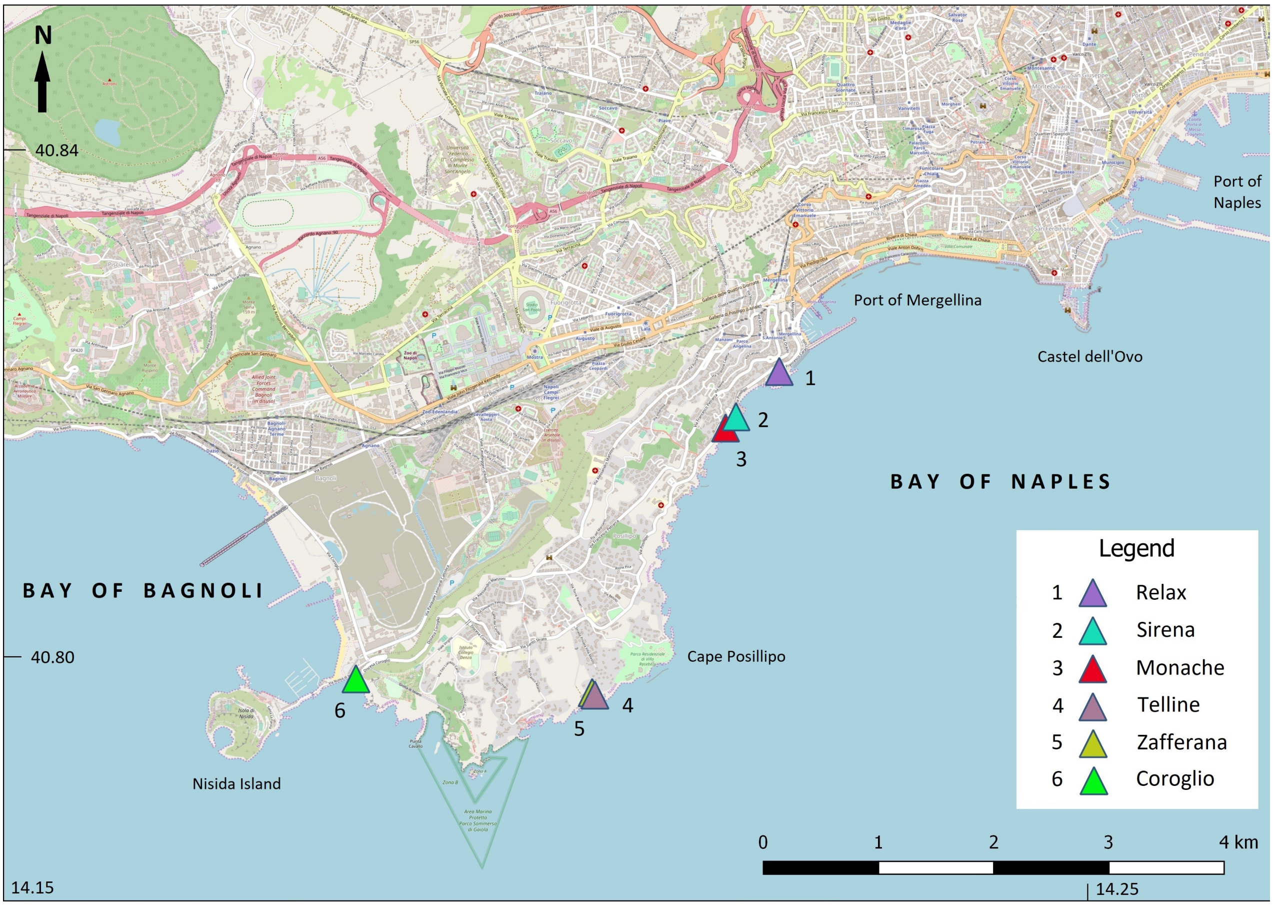

Figure 3: Location of the six studied urban beaches along the western coast of Naples.

Materials and Methods

Since autumn 2019 (Giovanzanti 2019; Sannino 2019; Delogu 2020), sediment samples were collected manually on six different beaches using a bailer. Samples were stored in a plastic bag with an alphanumeric code identifying the transept and transported in the laboratory for subsequent sedimentological analyzes. For each beach, two samples were collected, in total 12 samples, considering as a reference a benchmark in the backshore from which the emerged beach length was measured using a centimeter roll. The choice of sampling points is based on the geomorphological criterion, considering the storm berm or storm line and the shoreline. The sampling points were georeferenced in the WGS84 geographic coordinate system using a Garmin GPS II satellite radio receiver, the altitude (m asl) was obtained from the online GIS Google Earth Pro with which also the average gradient (%) was calculated. Finally, inclination and wave-exposure (°) of the beach were measured in the field with a Wilkie geologist's compass and clinometer.

Morphometry

To classify the beaches, morphometric parameters both through surveys carried out in the field and with Google Earth Pro tools were measured. In particular, the length (*L*), mouth of the bay (*C*), embayment (*E*), deepness of the bay (*Db*) are obtained: *L* is a curve, *C* the distance between the tips of topographic obstacles (promontories, breakwaters or both) bordering the beach, *Db* the orthogonal distance between *C* and the maximum curvature (concavity or convexity) of the shoreline, and the *L/C* ratio describing the shore line morphology (1 < *L/C* < 1 is rectilinear, 1.15 < *L/C* <1.90, is arcuate as positive if concave or negative if convex, *L/C* > 1.90 is very arcuate).

Figure 4: The six studied beaches of Naples: a, Circolo Relax, inside a dock; b, Bagno Sirena, at the NYT sea cliff foot; c, Spiaggia delle Monache, between the anthropized tuff cliff and a breakwater; d, e: peri-urban beaches of Spiaggia delle Telline and Cala della Zafferana, respectively, two pocket beaches modeled in the NYT; f, Coroglio beach, at the NYT sea cliff foot (photos C.Donadio 2019, view: a, SE-NW; b, SW-NE; c, E-W; d, e, S-N; f, W-E).

Sedimentology and Morphoscopy

Samples were analyzed for classification, texture, grain sizes, and morphoscopic analysis of quartz and silicate grains (K-feldspars and Na-plagioclases), more resistant to wear as corrosion and corrasion. Particle size analysis was carried out following the standard technique of Folk and Ward (1957). After preparation and washing with distilled water, all the samples were dried in an oven at 80°C for 72 h, mechanically quartered, and weighed with a digital balance. Then samples were subjected to dry sieving through a series of stacked sieves, with 1/2 φ class intervals from 8000 up to 63 μm, in a Ro-Tap mechanical sieve shaker machine for 15 minutes. For each sample, classification, texture group, histograms and cumulative curves were plotted, and several moment statistics were calculated, in keeping with to the graphic method of Folk & Ward (1957), were calculated through the software Gradistat v.9.1 (Blott & Pye 2001): M_z, mean size; σ_I, sorting; S_{kI}, skewness; K_G, kurtosis.

The grain size fraction of 2 ϕ (250 μm) of the 12 samples was observed through an optical stereomicroscope Leica MZ16 to recognize morphoscopic features of sand quartz and silicate grains modeled in different genetic-depositional environments. In these granulometric fractions, 100 granules of quartz and silicate for each sample, in total 1200 grains, were selected and classified into three categories, according to Angelucci & Palmerini (1964): NA, not abraded, but transparent and angular; BT, translucent blunt, with subrounded to rounded edges; RO, well rounded opaque grains. The number of granules of each class is processed with the software Tri-Plot v.1.4

Figure 5: Sandy-pebble deposits, pumices, bioclasts, twigs, and allochthonous material of the Monache beach (photo M.R. Delogu 2019; SW-NE view).

(Graham & Midgley 2000) to obtain the percentages and the triangular diagram with the three-class (NA, BT, RO) at the vertices, showing the distribution as a function of the particle size of 2 φ (250 μm).

The rounding of the granule indicates the kind of wearing experienced during transport which varies with the distance, duration, intensity, mechanical strength of the type of rock, and particle size (Ricci Lucchi 1980). The presence of well-rounded granules in the sand would indicate a long staying on the beach and strong wear by the sea waves, while well-worn granules result from transport and erosion cycles (Ricci Lucchi, 1980). Generally, the transparent non-worn quartz and silicate grains (NA) come from cliffs or paleo-cliffs surrounding the shoreline: they have more defined, angular and serrated edges, instead translucent blunt (BT) granules show less angular edges as they are corroded from water and corraded by friction with the substrate. The transport agent of the latter is attributable to a stream or paleo-stream that deposited them at the mouth or in the sediment of a detrital-alluvial fan, then distributed along the littoral. Finally, rounded

Figure 6: Sandy-pebble sediments, lava and concrete boulders with bioclasts, twigs, litter, and plastics beached on the Coroglio littoral. In the background, Nisida Island (photo M.R. Delogu 2019; NE-SW view).

opaque granules (RO) are attributable to coastal dunes, as rounding and opacity produced by the morphoselective wind action and corrasion typical of these Mediterranean and subtropical environments (Valente 2012; Balassone et al., 2016; Pennetta et al., 2016; Donadio et al., 2018a, b; Souza et al., 2022).

Results

The morphometric parameters allow comparing the physiography, size, and orientation of the six urban beaches (Fig. 7). In particular, the length varies from less than 5 m of the Spiaggia delle Telline beach to over 120 m of Coroglio beach, the average gradient is ~0.05%. The particle size analysis provided information on the origin, mode of transport, and depositional conditions of the sediments. The littoral drift, due to the longshore currents, is influenced by the breakwaters which in the sheltered area form a calm water zone where clockwise and counterclockwise circulation cells is active. Here, sand with poor pelitic fraction is deposited, according to the limit of cutoff diameter (*LCD*) of 1.25 mm (0.5 φ) of beaches in the Mediterranean-type geomorphic system (Limber et al., 2008).

The sedimentary features of the beach samples are reported in Table 2. The deposits show unimodal or bimodal distribution with rather homogeneous grain size, are classified mostly as medium sand and subordinately as coarse to very coarse sand, poorly to moderately sorted, coarse skewed and leptokurtic. The cumulative frequency curves of the sediments grouped in the granulometric spindle show values of the average granule M_z distributed between -2 and 3 φ (Fig. 8).

The morphoscopic analysis highlighted a predominance of translucent blunt (BT) granules in the two main groups of genetic-depositional environments (Fig. 9).

Discussion

For the first time, through integrated environmental, morphometric, granulometric, and morphoscopic analyses, six urban beaches on the western coast of Naples were studied. The interpretation of results, to each other compared, allowed us to outline the main morphosedimentary features of these beaches, aiming for a modern morphotypological classification, also based on biotic and anthropogenic elements as well as the structural index *I* = 0.76 of the coasts (Vicinanza et al., 2008) equal to the ratio between the length of coastal defenses and that of littoral (Table 3). Among the six beaches, two are natural and four of anthropic genesis, the latter showing a high degree of anthropization, such as bathing facilities, residential buildings, breakwaters, and port docks. The particle size analysis showed mainly medium

Table 2: Sedimentary characteristics and classification of beach deposits: RX, Circolo Relax, BS, Bagno Sirena, SM, Spiaggia delle Monache, ST, Spiaggia delle Telline, CZ, Cala della Zafferana, SC, Coroglio; Lat., Latitude, Lon., Longitude, M_z, grain mean size; σ, sorting; S_{kI}, skewness; K_G, kurtosis; NA, transparent not abraded, BT, translucent blunt, RO, rounded opaque quartz and silica grain shape. The coordinate system is WGS84, $\varphi = -\log_2 D_{mm}$, where *D* is the grain diameter in millimeters.

Sample #	Lat. (°)	Lon. (°)	Heigh (m asl)	Gravel (%)	Sand	Classification (Folk & Ward, 1957)	Mz (φ)	σ (φ)	Skl (φ)	KG (φ)	Morphoscopy (%) NA	Morphoscopy (%) BT	Morphoscopy (%) RO
RX1	40°49'22"	14°13'06"	0.0	2.7	97.3	Medium Sand	1,633	1,509	-0.405	1,112	25	70	5
RX2	40°49'21"	14°13'06"	0.3	7.4	92.6	Medium Sand	1,584	1,302	-0.511	1,393	35	63	2
BS1	40°49'09.5"	14°12'49.1"	0.0	0.4	99.6	Medium Sand	1,419	0.731	-0.003	1,050	30	65	5
BS2	40°49'10.2"	14°12'49.4"	0.3	0.6	99.4	Medium Sand	1,528	1,092	-0.207	0.798	35	63	2
SM1	40°49'06"	14°12'46"	0.0	0.6	99.4	Medium Sand	1,735	0.615	-0.138	1,153	36	62	2
SM2	40°49'06"	14°12'46"	0.4	0.4	99.6	Medium Sand	1,353	0.509	0.031	1,063	38	60	2
ST1	40°47'52.1"	14°11'57.9"	0.0	6.2	93.8	Coarse Sand	0.008	0.759	0.034	0.937	57	40	3
ST2	40°47'51.9"	14°11'57.8"	0.2	1	99	Coarse Sand	0.665	0.560	-0.105	1,005	62	35	3
CZ1	40°47'52.7"	14°11'56.9"	0.0	19.5	80.5	Very Coarse Sand	-0.538	0.594	-0.144	1,069	40	60	-
CZ2	40°47'52.6"	14°11'56.7"	0.3	18.1	81.9	Very Coarse Sand	-0.513	0.583	0.088	1,005	35	65	-
SC1	40°47'56.7"	14°10'29.1"	0.0	-	100	Medium Sand	1,778	0.617	-0.133	1,042	32	65	3
SC2	40°47'56.4"	14°10'29.2"	0.5	0.5	99.5	Coarse Sand	0.780	0.575	0.019	1,111	31	66	3

sediments tending to coarse, with abundant bioclasts of bivalve mollusks, gastropods, and polychaetes. Three main granulometric facies were identified, *i.e.*, medium, coarse, and very coarse sand, whose dimensions mostly fall between -1.5 and 3 φ. A light decrease in the mean grain size of sand is registered from the Northeast to Southwest beach.

The color, determined through the Munsell Soil Color Chart (Cooper 1929), refers to dry beach deposit and varies from gray (6YR6/1) to dark gray (4YR4/1), sometimes with a very pale brown hue (2.5Y8/2) due to the NYT sea cliff .

The beach of Circolo Relax is a port beach. Therefore, it does not have a natural appearance and is bordered by buildings (Fig. 4a, 7a). A port beach is generally small, sandy, with allochthonous material, *i.e.*, clay and landfill material, plastics, cigarette filters, and sparse psammophilous flora as well as planted or semi-natural species such as *Crithmum maritimum* and *Capparis spinosa*. Bagno Sirena and Spiaggia delle Monache beaches (Fig. 4b,c and 7b,c), under private concession the first and public the second one, are contiguous. Both developed to the back of coastal defenses: the first one, back to a short, emerged, parallel and detached from the shoreline breakwater in whitish carbonate boulders, while the second one, back to a long, emerged, parallel and adjacent to the shoreline breakwater in dark

L/C					
a	**b**	**c**	**d**	**e**	**f**
-0.70	**0.82**	**3.38**	**0.27**	**1.05**	**0.28**

Figure 7: Morphometric parameters of the six urban beaches (after Google Earth Pro 2023): a, Circolo Relax, b, Bagno Sirena, c, Spiaggia delle Monache, d, Spiaggia delle Telline, e, Cala della Zafferana, f, Coroglio. L, length, C, mouth of the bay, E, embayment, and L/C ratio for the shore line shape.

gray lava boulder, once detached from the coast and gradually filled by sediments. Spiaggia delle Telline and Cala della Zafferana (Fig. 4d,e and 7d,e) are small sandy pocket beaches modeled into the NYT, the first one is the smallest measuring less than 5 m of length, without coastal defenses. Finally, the beach of Coroglio (Fig. 4f, 7f) is intermediate between a pocket beach and a beach at the tuffaceous sea cliff foot, mainly sandy with autochthonous and allochthonous coarse clasts, bordered by a tuff promontory to the East and a long, adjacent and emerged breakwater in whitish carbonate boulders to the West. In this beach, frequentation and sea bath are forbidden due to pollution and rockfall hazard.

The actions and strategies dictated by specific interests in the mentioned areas turn out to be often in conflict but also exemplify the composite articulation of the observed phenomena. This is mainly because of a failure to integrate idiosyncratic governance decisions taken by a large number of actors: 4 summarizes the multi-scalar critical situation.

The mismanagement given by the "hyperterritorialization" of competencies and the multiplication of interests exacerbates the weakening of shorelines from a structural point of view and increases the exposure of the resident population to risks of various natures. This interaction results in an evident socio-spatial injustice that impairs the effective enjoyment of fundamental rights (Guadagno & Grasso, 2022).

In conclusion, comparing the results obtained from field surveys and laboratory analyzes carried out on the six urban beaches (Tables 2 and 3; Fig. 7, 8 and 9), it follows that two are of natural and four of anthropic genesis. All have a medium-fine to coarse grain size, and the granules in the

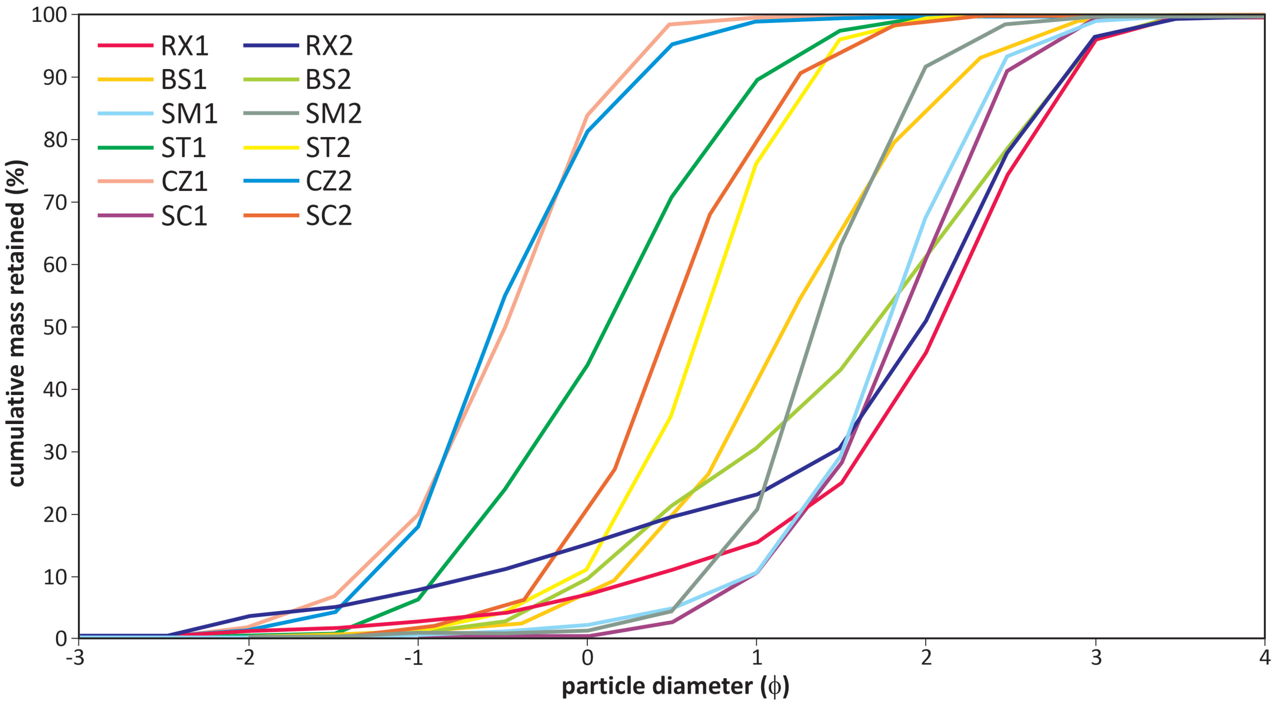

Figure 8: Granulometric spindle of the cumulative frequency curves of the two samples collected in each of the six urban beaches, along the storm berm or storm line (1) and the shoreline (2): RX, Circolo Relax; BS, Bagno Sirena; SM, Spiaggia delle Monache; ST, Spiaggia delle Telline; CZ, Cala della Zafferana; SC, Coroglio.

Table 3: Morphotypological classification of the six urban beaches of Naples, from NE to SW, based on different factors: morphometric and morphosedimentary features, granulometric classification according to Folk & Ward (1957), morphoscopy (Angelucci & Palmerini 1964; Pennetta et al., 2016; Arienzo et al., 2020) which indicates the prevailing shape class of granule, color referring to dry beach deposit through the Munsell Soil Color Charts (Cooper 1929), and anthropization which considers the degree of littoral consumption due to coastal defenses, structures and infrastructures on the emerged beach and its carrying capacity (Vicinanza et al., 2008; Carboni & Russino 2013). The arrow indicates the geographic sequence of the beaches.

	Beach	Genesis	Granulometry	Morphoscopy	Color	Anthropization	Classification
NE	Circolo Relax	Anthropic	Medium sand	ST	Gray	High	Port beach
	Bagno Sirena						Breakwater beach
	Spiaggia delle Monache						
	Spiaggia delle Telline	Natural	Coarse sand	NA		Nil	Pocket beach
	Cala della Zafferana		Very coarse sand	ST		Low	
SW	Coroglio	Anthropic	Medium to coarse sand		Dark Gray	High	

highest percentage are the translucent blunt ones (BT, 60-65%), probably linked to repeated cycles of corrasion in a sheltered and calm water environment, followed by the transparent not abraded ones (NA, 35-40%). The very low percentage of rounded opaque (RO, 3%) granules suggests the presence of paleodunes in neighboring areas not far away (Valente 1999; De Pippo et al., 2002b), both in the NW (Bagnoli-Fuorigrotta Plain) and SE (Riviera di Chiaia), as currently there are no coastal dunes to the back of these small urban beaches.

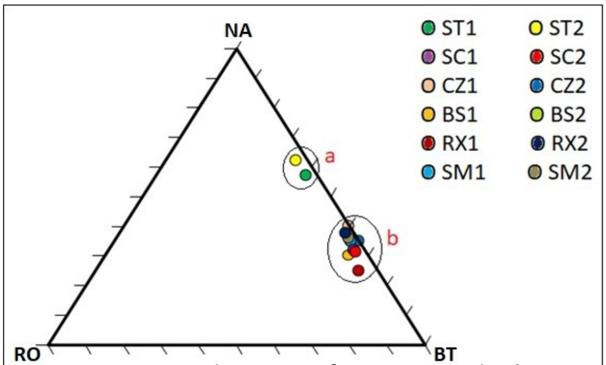

Figure 9: Distribution of quartz and silicates grains of 250 µm resulting from the morphoscopic analysis: NA, transparent not abraded; BT, translucent blunt; RO, rounded opaque. The grains are grouped in two main fields, with a prevalence of ST (b) on NA (a). RX, Circolo Relax; BS, Bagno Sirena; SM, Spiaggia delle Monache; ST, Spiaggia delle Telline; CZ, Cala della Zafferana; SC, Coroglio urban beaches.

The beaches differ in the degree of anthropization: the Circolo Relax beach has a higher degree than the others, both as is a port beach used for bathing and the presence of allochthonous material transported by the sea, often of anthropic genesis, also due to misbehavior by beach users as in other cases. Unlike the other urban beaches, its shoreline is convex (*L/C* = -0.7; Fig. 7) for sediment accumulation and, due to its strong anthropic genesis, this beach has only sparse psammophilous vegetation in the backshore.

The Bagno Sirena beach once was in a small open bay, now its current degree of anthropization is attributable to the presence offshore of a breakwater in boulders parallel to the shore, a licensed beach facility, a jetty at sea until 2019, a bar and a restaurant. The constant frequentation of the beach and the mechanical tools used for its maintenance, especially after the autumn-winter period or intense sea storms, rework the sediments eroded by the surface of the nearby tuff cliff, transported by waves and sea currents, partially limiting their accumulation.

The Spiaggia delle Monache, on the other hand, a very arcuate beach (*L/C* = 3.38; Fig. 7), is into a closed bay with a lower degree of anthropization than the other two, attributable mostly to a barrier adhering to the shore and bathing as it is one of the few free beaches managed by the Municipality. These, in addition to their natural conditions, are subject to strong human pressure linked to the intense tourist development which is putting their conservation at risk.

The Spiaggia delle Telline and Cala della Zafferana are two natural pocket beaches, superimposed on a paleo stream, of different dimensions but same morphodynamics, with some surfaced and submerged Roman ruins excavated in the NYT.

Finally, Coroglio beach is an intermediate type between a previous narrow beach at the sea cliff foot transformed in pocket beach after the construction of a long breakwater from the coast to the Nisida Island, to protect the road.

This proposed classification of the Naples urban beaches (Table 3) integrates existing ones based on physical and quantitative elements (Table 1; Valente 1999). Urban beaches are ephemeral environments that may rapidly form or disappear due to erosion, transport and deposition processes. They often represent a buffer between the wave action and the inactive cliff behind, with structures and infrastructures, protecting it from undermining. Their complex management depends also on several stakeholders (Table 4), from central to local ones (Donadio & Guadagno, in press).

In this regard, it would also be necessary to evaluate the beaches anthropic carrying capacity (Carboni & Russino 2013). This is a key element toward an effective management of the number of bathers that each place can support without compromising its environmental features, including the immediately adjacent areas (*e.g.*, sensitive natural habitats).

Due to their tourist-recreational importance and for the protection of the cliff, beaches should be preserved through correct management. Appropriate policies are the

Table 4: Mosaic composition of stakeholders' skills and interests for the Neapolitan coast, often juxtaposed without integrating.

Campania Region	Metropolitan City of Naples	City of Naples	Local municipalities	Linear infrastructure managers	Coast Guard
Hydrographic District of the Southern Apennines	Naples Port Authority	Cultural heritage protection organizations, including UNESCO, and Marine Protected Areas	Marine Protected Area “Gaiola Underwater Park”		
Operators and managers of beaches	Environmental associations (*e.g.*, Legambiente)	Movements for public beaches (*e.g.*, Mare Libero e Gratuito Napoli)			

removal with sustainable techniques of pollutants as clay material, macroplastics, microplastics, and microfibers transported by the littoral drift of sediments, waves and sea currents, and wind, but above all attributable to incorrect user behavior (Jambeck et al., 2015; Choy et al., 2020; Arienzo & Donadio 2023). Together with the morphosedimentary features, the environmental design and ecological aspect must also be considered, to safeguard the habitat and biodiversity of these highly vulnerable urban environments.

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