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ROLE OF GEOGRAPHY IN PLASTIC POLLUTION RESEARCH AND SOCIAL IMPLICATIONS*

Introduction. – Waste management is one of the basic public services that is crucial to be implemented in every city or rural municipality around the world due to the environmental and public health concerns (Mihai, 2017). Urbanization, increasing population, and living conditions lead to higher waste generation rates compared to previous decades. Waste pollution such as plastics affects already multiple ecosystems (marine, freshwater, terrestrial environments) and geographical regions (Nyberg and others, 2023). Furthermore, biota, and human body are exposed to microplastics accumulation as detected by previous studies in recent years (Leslie and others, 2023). Therefore, the link between Anthropocene and plastic pollution requires multifaceted approach for aquatic, air, biota, and land pollution (Rangel-Buitrao, Neal, Galgani, 2023).

On this background, the relation between geography as an interface between social and natural sciences and complex waste management activities should not be ignored by geography and geographers. Moreover, spatial analysis and multi-scale perspectives form local to global levels of waste flows and their implication to natural environment and human settlements are prone to the geographical approach. On the social science side, geographies of waste are consolidated on the theoretical background (Moore, 2012; Millington, Lawhon, 2019), but also in case of practical implications for policy dimensions and concerns addressed to vulnerable communities exposed to large scale waste disposal facilities, exposition of plastic and hazardous wastes or the role of informal sector in diverting waste pollution to recycling and recovering activities.

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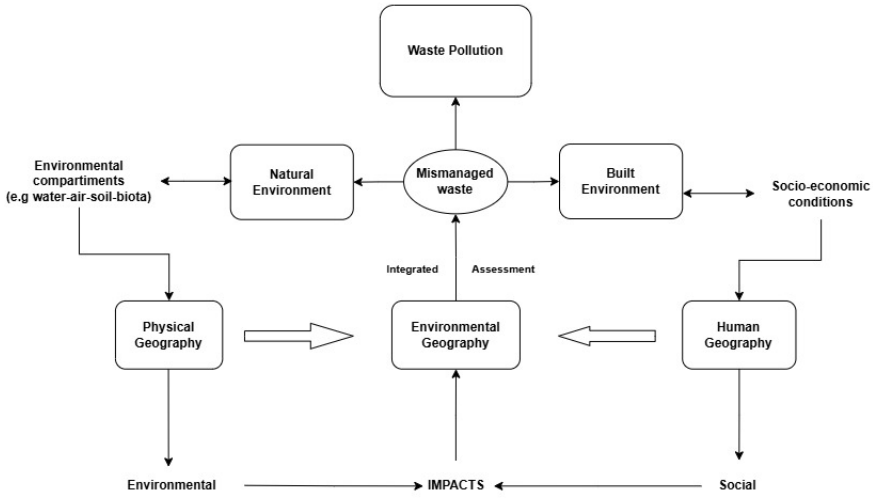
This paper focuses on plastic pollution research in relation to geography. The physical and environmental branches relies on plastic pollution process under the climatic, geomorphological, hydrological conditions (Mihai, 2018; Liro and others, 2023). Both natural and administrative areas must be taking into account when plastic pollution leakage assessment is performed using plastic pollution modelling, geospatial analysis, remote sensing, spatial statistics of waste flows and socio-economic factors related to waste, sanitation, and water management sectors.

The policy effectiveness and geographical coverage of circular plastic economy actions must be examined in line with local, regional, and country conditions to provide financial, regulatory and logistics support for plastic waste diversion from natural environment and waste disposal sites towards reduce, reuse, refilling, repair, remanufacture, and recycling practices. Besides life-cycle of plastic economy infrastructures and policies frameworks, further research should pay attention to the community response in replacing virgin plastic products with other materials, in changing consumption behavior, in participation in citizen-science based project related to plastic pollution problem (Mitrano and others, 2023) and adopting zero-waste approach priorizating the waste prevention, rethink, and redesign (https://zwia.org/zwh/) Therefore, waste management and plastic pollution imply both natural and societal dimensions. This work performs a literature review looking at the papers that examine the relation between geography and three interconnected environmental topics such as waste management, plastic pollution, and circular economy. The theoretical background, research progress regarding geography and waste related topics are examined through contributions of human, physical, and environmental geographies.

Therefore, this paper aims to reveal some key geographical research directions to fill the knowledge gaps : i) how geography could relate to current plastic pollution challenges based on previous studies covering the waste management issues; ii) how the main geographical branches (physical, human, environmental) are interconnected with plastic pollution concerns and could fill the knowledge gaps; iii) how geographies of plastic waste and circular economy could enhance future plastic pollution research and transition towards a circular society based on a zero-waste approach.

Geographies related to waste management. – The waste pollution on surrounding areas as an environmental threat was the primary research interests for geographers in the last decades (Mihai, 2012). For example, how waste pollution affects communities in polar regions (Boumérias, 1977) or industrial landfill sites in Catalonia as a geography of contamination (Alió, Brú, 1990), however the waste disposal facilities still remain a difficult environmental and societal topic to be managed that requires attention from geographers (Blowers, 2021). Therefore, both natural landscapes and built environments are affected by waste pollution through mismanagement practices (e.g. illegal dumping) engaging researchers from both human and physical branches as revealed in figure 1.

Fig. 1 – *Waste management connections to geographical research*



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Waste are generated by every main economic sector (agriculture, industry, tertiary sector as services) besides residents of a municipality. Therefore, specific geographies of waste flows needs to be revealed including spatial and seasonal variations. On this background, plastic waste and their relation to geography is further investigated in the next sections. To reduce environmental and social impacts at multi-scale levels and for all waste flows around the globe, the role of circular economy systems must increase in following years (Pollard and others, 2016) particularly for plastic

waste that raised major environmental concerns among air-water-soil-biota nexus.

Relation between geography and plastic pollution - Physical geography. – Macro and micro plastic pollution affects environmental compartments such as air, water, soil and biota including human bodies (Leslie and others, 2023). Therefore sources of pollution distributed into a particular area using natural borders (e.g. river basins and sub-basins, seas and oceans) or administrative borders (city, village, region, country), must take into account the natural geographical features (mountain area, hilly, lowland, deltas, coastal, island communities, high-altitude plateau, glaciers) with particular challenges in managing plastic waste pollution. At local scale, geomorphological, hydrological and biota (e.g. riparian vegetation, forest areas) features could affect the predisposition of water bodies and terrestrial environment to plastic pollution (Liro and others, 2023). While the socio-economic and waste management infrastructures dictate the amount of mismanagement plastic leakage (Mihai, 2018), the natural conditions of rivers and landscape influence the areas of plastic concentration, plastic mobilization process, retention level of plastic waste by river morphology, plastic fragmentation process (Liro, Zielonka, Van Emmerik, 2023). The land use is also important in plastic pollution assessment because the degraded lands (e.g. gully erosion, landslides) could be exposed to illegal dumping of waste as well as former quarries or favoring plastic mobilization (altitude, slope) to river or lake systems while satellite data and GIS analysis could track the plastic pollution hotspots (Kruse and others, 2023). Meteorological and climatic conditions play a key role in microplastic mobilization from one area to another via wind transport (micro and nanoplastic) at long distances (Xu and others, 2023) that could reach water bodies or land while macroplastics are carried on short distances nearby sorting stations or landfills (e.g. plastic bags). Also, the heavy rains in short periods lead to plastic mobilization disposed of or littered on torrents, dry riverd beds of river channels. Drought events reveals the historical plastic pollution captured by sediment (retreated water level of lakes or rivers) or by vegetation mixed with wood debris on rivers and its tributaries (Gallitelli, Cutini, Scalici, 2024).

Climate change is linked to life cycle of plastics who is responsible about 3.7% of global emissions in 2019 (OECD, 2023) while mismanagement plastic leakage into natural environment could be further mobilized

and transported to downstream areas due the increasing frequency of extreme events such as floods, hurricanes, storms (Ripple and others, 2023).

Hydrological events such as floods increase the plastic mobilization potential and transport magnitude to river mouths, coastal areas and marine environments. However, further research is required to test local and regional hydrological conditions and retention levels by sediment, riverbanks, vegetation and wood debris entrapment, plastic sinks and how plastic loads are transported from sub-basins to large river systems taking into account the seasonality, but also the role of extreme events.

Soil-groundwater infiltration of microplastics via agricultural practices or plastic fragmentation need to be further examined since groundwater are essential for water drinking purpose in most of regions of the globe. Studies that are targeting specific and remote ecosystems such as coral reefs (Pinheiro and others, 2023), ocean abyss (Chiba and others, 2018) or mountain glaciers lakes are need to picture how plastic pollution reach such places and their sources and pathways.

Human geography. – The waste management discrepancies around the world are also a result of geographical, economical and societal inequalities in providing basic public waste services (Mihai, 2017) is examined between Global North and Global South, between economic and/or geopolitical regions such as EU or OECD. The multi-scale analysis is important to tackle the plastic waste challenges in various circumstances form apartment level (Horne and others 2022) to city level, rural regions (Mihai and others, 2022), cross-cities (Skamlova, Klobučník, 2021) or cross-country studies.

Besides waste management infrastructure, policies, regulations, law enforcement the social norms and environmental awareness within a community may play a key role in diverting plastic waste from landfills and open environments towards sorting, recycling, reuse and refilling practices. Therefore, the geography of waste examines the social and economic interactions with waste management systems and community involvement in the process (Jones, Comfort, 2019).

Vulnerable communities related to waste pickers and informal recycling sector gained attention to social exclusion and environmental injustice issues (Chen, Feng, Chen, 2023; Sharma, 2023). However, the role of informal sector in diverting dry recyclables from open environments and supporting local economies should be recognized as a complementary policy

action for increasing plastic waste capture levels for recycling and reuse systems in both urban or rural areas.

Littering behavior is another research topic that could be handled by human geographers. Cigarette butts are recognized as one of the most littered plastic-related item either in urban environment or in touristic destinations (Marah, Novotny, 2011).

Spatial analysis of such waste could indicate the hotspot of littering behavior at local levels helping decision makers to response with better logistics and law enforcement procedures (Valient and others, 2020). Tourism impact on domestic waste management systems is problematic because it could feed the mismanagement plastic waste flow (Yuxi and others, 2023). Plastic abundance generated in developed regions and low performances of domestic recycling schemes lead to plastic crisis (Nielsen and others, 2020) particularly after the China ban on importing low quality of plastics from abroad. On this background, international trade networks proliferate including illicit channels. Social and geographical inequalities are amplified in less developed regions as a result of plastic pollution problem (Abrahms-Kavunenko, 2023). Therefore, societal side of plastic pollution must be a concern for human geographers in future research (Liboiron, 2016). The new plastic treaty needs to address the social justice issues at global level besides the full life-cycle approach of plastics (Dauvergne, 2023).

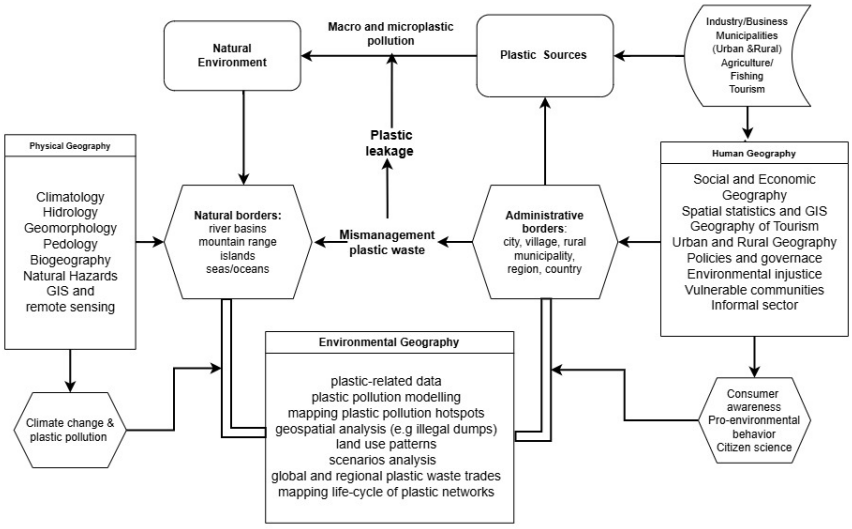
Environmental geography. – As a general framework, the environmental geography should blend the natural and socio-economic conditions of a particular area together with plastic waste management performances to provide a holistic assessment of plastic pollution at administrative level or natural borders (e.g. river basins) as shown in figure 2.

However, this is a difficult approach to implement due to the current knowledge gaps, incomplete data, plastic modelling limitations, but multidisciplinarity of plastic pollution research confirms the holistic requirement. Spatial analysis using GIS tools is one approach that takes both natural and built environment to evaluate the suitability location of the waste disposal sites or to assess the areas susceptible to illegal dumping practices for urban or rural areas.

These geographical approaches have direct interests for decision makers and local community and there is a need to scale up such initiatives. Spatial analysis reveals both environmental and societal concerns such as

environmental injustice and vulnerable communities (Margai and Barry, 2011). GIS and remote sensing applications are used to assess the plastic leakage either in riverine environments (Tran-Thanh and others, 2020) or terrestrial environments (Kruse and others, 2023).

Fig. 2. – *Plastic pollution research and connection to the main geographical branches*



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Spatial analysis of waste statistics is another important approach to reveal local and regional disparities in terms of plastic waste management performances. The improvement and availability of plastic waste data for various fractions (municipal waste, packaging waste, e-waste, textile waste, construction and demolition waste) is necessary to develop better plastic pollution assessment with relevance for local and regional geographies. Testing waste statistics with geographical factors (socio-economic data, land-use, plastic recycling networks etc.) to better understand the plastic waste flow and its traceability. Thus, future predictions of plastic pollution leakage into river systems based on hydrological data coupled with socio-economic conditions and relevant plastic waste statistics is expected to improve (Rinasti and others, 2022).

Cleaning campaigns performed on lakes or rivers should provide weighted plastic data that could be useful in plastic pollution modelling.

Monitoring of illegal dumping sites and open burning practices are necessary to understand how mismanagement plastic waste ends up into natural environment and reach river systems.

Environmental monitoring of plastic pollution requires a sound database and web-GIS platform could be a proper solution also beneficial for business sector in revealing the complex networks of stakeholders involved in plastic production, sorting, recycling and collection (Paul, Bussemaker, 2020).

Tourism impact on plastic pollution is another research topic that requires attention in plastic pollution modelling or field measurements. For example, Orthodoxou and others (2022), reveals that touristic beaches in Cyprus have more than five times cigarette butts while this plastic item is most prevalent in coastal environments. The impact of tourism on local or regional plastic pollution needs to be determined taking into account the tourist flows in natural or cultural destinations. A geodatabase for experimental studies related to plastic litter in diverse ecosystems such as rivers, lakes (Miranda-Peña and others, 2023), marine environments (Haarr, Falk-Andersson, Fabres, 2022) and soils would refine the plastic pollution research from local to global levels. The agriculture is an important source of plastic pollution related to greenhouses (Afxentiou and others, 2021) and multiple agricultural systems in different geographical regions must be examined as plastic pollution source for aquatic and terrestrial environments. Furthermore, more attention to plastic waste management practices from fishing, aquaculture, and agriculture need to be analyzed (Briassoulis and others, 2013) and how these systems can be transformed towards a circular economy pathway.

Spatial analysis using GIS provide the means to assess the agriculture plastics generation and pollution risks in multi-scale context from local to national levels (Blanco and others, 2018) and further geographies of plastics could be discovered. Improvement of plastic pollution modelling of rivers and river basins associated with mismanagement plastic waste flow is imperative at global (Nyberg and others, 2023), regional (Liro and others, 2023) and local levels (Mihai, 2018). The interconnection between plastic waste management (performances indicators, plastic waste statistics, plastic waste infrastructure), plastic sources (municipalities, industry, agriculture) and specific geographical topics should be further developed in plastic pollution research as shown in figure 2.

Geographies of plastic waste and future perspectives. – The abundance of plastic waste in natural environment is significant and geographical distribution of macro and microplastic in various environmental compartments need to be known to reduce the current knowledge gaps and to reveal some spatial patterns and interconnection mechanisms (Kachef, 2023). The wide distribution of plastic pollution around the globe lead to new geographies such as "geography and geology of plastics" (Gabbott and others, 2020) or "geography of marine plastics" (Black and others, 2020) in line with current research interests related to this critical environmental threat. The fast fashion based on synthetic clothes is also a source of macro and microplastic pollution and trade between countries with the blurry distinction between second-hand clothes and textile waste could revel complex geographies. The geography of plastics clothes follows the product circuit beyond production to daily use, storage, repair and recirculation with seasonal and spatial changes (Stanes, Gibson, 2017).

The geographical discourse about waste and plastic waste management must go beyond the recycling topic (Barr et al, 2013) since transition to a circular economy is regarded as a core objective for environmental policies. On this background, a geography of circular economy is discussed in literature regarding the technologies and innovation frameworks in Europe (Fusillo, Quatraro, Santhià, 2021) while supporting creative spaces is required to catalyze such innovation prospects (Hobson, 2016). The circular economy benefits to job market and local development must be pointed out (Niang and others, 2023) while opportunities offered by digital economies could offer multiple benefits for environment, but also social inclusion (Lekan, Rogers, 2020).

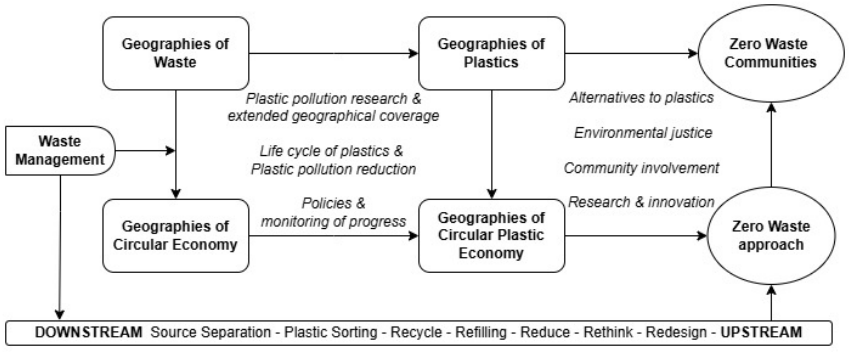
Some societal issues related to plastic waste management need to be further examined such as plastic international trade through formal and illegal channels, vulnerabilities of informal sector (Schlitz, 2020) and remote communities (Phelan and others, 2020), community involvement in source-separation, cleaning campaigns or citizen science in plastic pollution problem, the role of new plastic waste treaty in reducing plastic pollution. The shift to circular economy requires to support reuse and refilling system than material recycling (Taylor and others, 2023; Lynch 2022,) and avoid as much as possible the waste to energy plants and landfills.

In fact, these waste disposal sites feed the cross-border trade of plastic waste inside and outside of EU for example particularly Eastern European

countries like Romania where landfill fees are low (around 20 euro per tone). Export of plastic waste trade from high-income countries indicates domestic waste management deficiencies in line with circular economy principles while consumer awareness is misled and plastic waste responsibility passed to less developed regions (Mihai, Ulman, 2024; Barnes, 2019). The relation between plastic waste trade (formal and illegal channels) and additional pollution to domestic sources must be further studied and all interconnections between plastic stakeholders (origin country-transient destinations–final destination) could reveal complex geographies and made available in web-GIS format for public access. Monitoring of global and regional recycling markets changes particularly after the China ban on plastic waste imports depicts new geographies in plastic waste trades networks (Wang, Miao, Chen, 2022).

Therefore, the shift of paradigm from waste management with focus on downstream issues (waste, sanitation and water management sectors) to upstream sector (reduce-redesign-reuse-efficient recycling systems) where plastic industries must be also part of efforts towards a circular economy transition as shown in figure 3.

Fig. 3. – *Geography and future prospects towards a "zero-waste" society*



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To provide a holistic approach, both downstream and upstream sectors are required to be examined at different geographical scales to proper monitoring the progress towards circular societies. In other words, the geographies of waste and geographies of circular economy would try to fill such gaps providing an environmental and societal impact of transition efforts from a linear towards a circular plastic economy. Beside technical

and environmental footprints of plastic industries, the urban and rural municipalities progress and community engagement to such societal transformation requires also a geographical perspective. Reducing geographical inequalities in terms of sound waste management services, but also to increase access to reuse/refilling mechanisms and development of alternatives for plastics (e.g. packaging sector) is crucial to divert plastics toward higher steps of zero-waste hierarchy principles.

The zero-waste certification is another approach undergoing in Europe that could be applied from micro level (business) to local and regional levels (zero waste cities, zero waste municipalities) in revealing best practices that could be implemented in other geographical regions, but with similar waste management and socio-economic background (https://www.missionzeroacademy.eu). However, the spatial and seasonal heterogeneity of plastic waste collection, reuse and recycling systems at household or business levels for particular geographical areas must be further investigated (Hage and others, 2018). On one hand, the scalability of best practices to achieve zero-waste standards from local to regional levels and other geographical regions requires research, innovation and community involvement beside logistics, finance and regulatory framework. On the other hand, environmental injustice related to international plastic waste trade networks, mismanagement practices, vulnerable communities exposed to plastic pollution need to be addressed through international cooperation, better law enforcement and monitoring procedures related to plastics flows including plastics from other waste streams such as textile, e-waste, or end-of-life vehicles.

Education of younger generations related to zero-waste approach is necessary through a multi-disciplinary approach including the participation of geography in this process (Guaran, Venturini, 2022). Better training of researchers in plastic pollution is required in following years due to the multi and interdisciplinarity actions to provide a holistic analysis at various geographical levels (Mitrano and others, 2023). Studies based on field measurements in diverse ecosystems and creating large databases require also the participation of citizen science projects (Mihai and others, 2022). The plastic production, plastic waste management and geographical disparities need to be revealed while plastic pollution research related to natural or built environments should fill the current geographical coverage gaps.

Conclusions. – Geography as interface between natural and social sciences complete the holistic view related to waste management sector in the last decades and current plastic pollution threats require a multi and interdisciplinary approach. Plastic waste leaked into every ecosystem type and most human settlements around the globe are predisposed to plastic pollution. In this context, geography and geographers must participate in revealing the magnitude and geographical scale of this pollution from local to global levels, the role of geographical factors in plastic pollution assessment and prevention efforts. The geography can address the plastic pollution issues taking into account a holistic assessment between natural and built environments (e.g. environmental geography) or to target specific topics and related knowledge gaps concerning geospheres and subdomains of physical geography (hydrology, climatology, geomorphology, pedology, biogeography, etc.) or related to social challenges specific to human geography scope (geographical inequalities, environmental injustice, informal sector, community involvement, consumer behavior, tourism impact, traditional alternatives to plastic use, plastic-related policies, governance, trades, etc.). Circular economy framework and zero-waste approaches require a major improvement of geographical realities towards a more sustainable and plastic-free society.

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Ruolo della geografia nella ricerca sull'inquinamento da plastica e implicazioni sociali. – Il presente documento si propone di rivelare come la geografia interagisca con la ricerca sull'inquinamento da plastica e con le attuali sfide sociali, mentre questo flusso emergente di rifiuti pone rischi a una gamma diversificata di ecosistemi, regioni geografiche che coinvolgono livelli multiscala. Le relazioni specifiche tra i principali rami geografici (fisico, umano, ambientale) sono ulteriormente studiate. Pertanto, il presente documento evidenzia come i temi geografici possano essere rappresentati nella ricerca sull'inquinamento da plastica in relazione alle caratteristiche naturali di una particolare area (idrologia, geomorfologia, rischi naturali). La dimensione della geografia umana gioca un ruolo chiave nella generazione, composizione e distribuzione dei flussi di rifiuti plastici da parte di varie fonti di generazione (residenti, imprese,

turisti), mentre il ruolo delle disuguaglianze geografiche, delle comunità marginalizzate o remote deve essere integrato nelle future ricerche sulla plastica. Le disparità nel monitoraggio ambientale e nelle infrastrutture di gestione dei rifiuti influenzano i livelli di inquinamento da plastica di origine nazionale, mentre il commercio dei rifiuti di plastica richiede una migliore cooperazione internazionale. Pertanto, diverse geografie e geografi di tutto il mondo devono essere ulteriormente coinvolti nella ricerca sull'inquinamento da plastica per fornire un quadro olistico della ricerca su questa minaccia ambientale e sociale globale.

Keywords. – Inquinamento da plastica, Geografia, Rifiuti zero

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