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The Shaping of Daqing: Borderless Interactions between Oil and Urban Areas

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Abstract: Since the development of the oil industry in the 1860s, petroleum products became increasingly important in economies and shaped the urban form. The impact of oil exploration, exploitation, and transformation led to the creation of districts and cities entirely dedicated to the oil industry. This dynamic relationship between economic activity and urbanization was presented in the shaping of cities and their borders. Although important, the notion of borders and its consequences on the uses of land as well as on the life of inhabitants are often ignored. This paper first conceptualizes the term borders in understanding the interlinkages between oil and other areas closely related, either geographically or for the functioning of the oil industry; it then illustrates the intertwined borders of all these spaces from the contemporary example of the city of Daqing, in Northeast China. The paper answers the question of how past borders designed during the development of Daqing in the 1960s are impacting future planning strategies and the health of local inhabitants? By mapping the current land-use of the city, this paper elaborates on the need to consider borders beyond two-dimensional perspectives by revealing how spatial planning practices in oil-dependent cities can be an environmental issue today and in the future. The objective is to demonstrate the influence of past planning decisions linked to industrial activities on contemporary urban spaces.

Keywords: borders; Daqing; land use; oil industry; pollution; spatial planning

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1. Introduction

As a resource and with all its related industries, oil has shaped the planning and development of many cities worldwide. With the development of industrial oil drilling in the 1860s in the United States, the oil industry gradually expanded along with its influence over the development of cities and nations [1]. In line with the oil industry, infrastructure construction started to shape spaces and influence the development of cities. In the hinterland, oil businessmen shaped spaces above the underground oil reserves by installing pumping stations or derricks (Figure 1). Around coastal areas, the shipment, storage, and transformation of petroleum products similarly impacted the spatial development of many port cities [2]. The distinctive spatial elements of the oil industry, represented by pipelines, refineries, and tankers, rapidly became part of the landscape [3]. With the growing use of petroleum products, not only for military purposes but also in daily life, the construction of oil facilities drastically increased in the first half of the 20th century.

Addressing oil and its activities' effects on the built or natural environments aims to demonstrate the threat of oil on Daqing's territory, its inhabitants, and the planning challenge it represents. The absence of strict borders between these polluting activities and contaminated sites and houses is a risk to the health of local inhabitants as well as a challenge for public authorities responsible for the spatial planning strategies of the city [4]. Borders are here discussed both as administrative and physical delimitations between industrial and urban activities, and between oil and both natural and urban environments. Yet, borders are also evolving and moving in time, dividing or merging depending on land-use strategies of the different periods.

Figure 1. Large stereoscopic views of the Pennsylvania oil region. Eastside, Triumph Hill, 50 derricks, by Franke Robbins, in 1846. From New York Public Library, Public domain, via Wikimedia Commons.

In Western countries, this industrial development led in many places, especially in port cities, to a high concentration of oil sites. For instance, in Dunkirk in northern France, before the Second World War, more than fifteen storage or refining sites appeared [5]. At the time of their construction, local businessmen investing in oil built these facilities mainly on the periphery of cities. Nevertheless, with the constant demographic and urban growth after World War II, urban planners turned many of these sites into housing districts; however, the lack of interest in environmental and health protection of the time, along with oil-induced disasters, their pollution, and their influence on contemporary urban planning, remain largely undiscussed. The visible infrastructure of the oil industry and its economic benefits must not overshadow all the visible and invisible detrimental effects on inhabitants and the environment that go with it.

Up until the international rise of environmental concerns in the 1970s, public authorities and private actors did not consider environmental and health protection a priority. With the first Earth Summit in Stockholm and the publication of the "Limit to Growth" book in 1972 [6], the importance of a clean environment and a sustainable use of resources for future generations were not discussed. In this perspective, decision-makers viewed the borders of industrial sites mainly in an administrative way without considering the potential threats. Such planning practices lasted even after the emergence of the environmentalism movement in the 1970s, and the discussions around the topic of sustainability and environmental protection required regular updates and debates until today [7–9].

This paper emphasizes the need to shift from a two-dimensional perspective of borders in planning policies and documents toward a three-dimensional one. The two-dimensional aspect refers here to the administrative borders of infrastructures or areas on maps and planning documents, while the three-dimensional notion entails both horizontal and vertical perspectives of borders. The porosity of oil borders, and the exchanges possible through them, is an equally vital factor to consider in the discussion over borders, as it determines the interactions of oil and its derivatives with its surrounding environment, and thus the depth of their impacts. Only through this three-dimensional understanding can local and national authorities grasp the full extent of oil activities' consequences on cities, their environments, and their inhabitants.

From this perspective, the case of Daqing in northeast China is a perfect example of this necessity. The oil city of Daqing was a national project in the 1960s. The Chinese central government gave political and economic support to the Ministry of Petroleum Industry to quickly establish the oil industry and its related infrastructure in the region. The Ministry of Petroleum Industry promptly developed its own presence in the region and exercised the powers of local government in the form of a state-owned enterprise. The state-owned oil enterprise dominated the local planning power in Daqing, specifically the spatial planning.

The relevance of this article stems from a missing link in current discussions between industrial pollution and the health of inhabitants from a spatial planning perspective. Not only do past industrial activities affect the quality of the environment for an extended period, but also the life of local inhabitants [10–12]. These impacts originate from planning strategies aimed at improving the efficiency of industrial activities rather than protecting the environment, thus the health of local inhabitants. The contemporary consequences of such detrimental decisions can be invisible because of the disappearance of the infrastructure, such as in Dunkirk. In this case, historical analyses are required to pinpoint former borders between industrial and urban areas to explain current sanitary developments. Yet, the importance of Daqing as a case study lies in its recent and continuous development. The question of borders is not only still visible in this case, but also more illustrative thanks to the network of surface waters. Daqing illustrates the contemporary value of borders and planning. The oil dependence of the city on oil, with its visible interactions, creates the link with past examples in transition for researchers and decision-makers to discuss the future of pollution and health.

The article continues the previous research by both authors on the oil industry's impact on the development of cities and port cities. This work has demonstrated the changing porosity of borders between oil industrial sites and housing areas and the influence of the oil companies in creating such borders; it pushes forward the discussion on the role and importance of borders in industrial port cities [2]; however, the investigations focused on Dunkirk, in France, as a place of trading, storage, and transformation of oil; it linked historical industrial development and influence to the current shape of the port city. The oil industry, the borders, and the spatial analysis remain here the primary focus of the paper, but rather focus on the case of Daqing. On the one hand, Dunkirk was a port city shaped by private actors' interests, with an old and disappearing oil industry focused on storage and refining activities. On the other hand, Daqing is a more recent case starting from the early 1960s, an extraction site with an extensive oil landscape around which public authorities built a porous and borderless city.

The aim of this paper is not to compare both cities. The focus is here on Daqing, using Dunkirk and the studies achieved by both authors on this city as an example of past oil borders that disappeared yet keep impacting the city and its inhabitants. The context is different in both cities, but both have been shaped by and for the oil industry. When public authorities in Dunkirk have to deal with the post-oil context, it can serve as an example for public authorities in Daqing to avoid the same consequences (lasting soil pollution, lost industrial sites, low sanitary conditions). In the meantime, Daqing is an illustration of how borders in relation to oil-related activities were created, and why they can be a threat to inhabitants and the future planning of the city. One can wonder how different the borders between oil, urban, and natural areas can be in a city built and still developed around the exploitation of an oil field? Did past examples of oil cities and the 1970s movement towards environmental protection influence a stricter definition of borders during the urban development of Daqing? This paper demonstrates the need for cross-disciplinary approaches within the pollution and health-related discussions.

2. Theory

Public and private authorities around the world have long ignored the industrial activities' air, water, and soil pollution and their consequences on public health. Before the 1970s, authorities dismissed health and environmental protection [13,14] or even tried to purely prevent debates around industrial risks [15]. In China, the Central Government had not addressed the importance of environmental protection until the first introduction of the Environmental Protection Law in December 1989. The objective for both public and private authorities of the time was to avoid the emergence of regulations linked to environment and health protection that could have hindered industrial development [16–18]. In this context, the definition of borders separating industrial and housing districts was of prior importance, and past practices relating to borders still impact cities' current shape.

These borders can take different forms, both visible and invisible, and are the results of spatial, social, and economic factors or policies [19]. Visible as they can be expressed through walls, roads, buildings, or networks, restricting movements and visions. Or they can be invisible and lie in historical developments or influences, cultural processes, or drawn on maps and defined by planning documents [20]. In both cases, depending on their porosity or absence, borders can transform cities into more or less porous spaces [21]. Thus, the past borders' definition affects the current shape of cities, and impacts the security and health of inhabitants [11], as well as the efficiency of planning policies around industrial and oil spaces; it is especially true in the era of fast industrialization following the Second World War, which mostly ignored the notion of environmental protection. This appears to be especially true in China, where before 1979 and the beginning of the globalization process in Chinese cities, spatial, social and economic structures aimed at unity, efficiency, and solidarity, prevented the creation of visible borders both socially and spatially [22].

This chain of events and decisions leading to the current situation is developed in the literature under the concept of "Path Dependency"; it is a concept firstly conceived and widely used in economic studies, which describes a sub-optimal decision made in the past creating strong market dependency [23]. Various scholars in urban studies have introduced this concept into their empirical analyses of a city or a region [24]. By asking how and in which manner historical decisions have gradually shaped the cities' current paths. Sorrensen, Canadian sociology and urban scholar, argues that path dependency is one of the crucial tools providing a robust research framework for planning history studies [25]. Ramos, an American scholar in the field of planning history, excellently defined this concept in 2021, explaining that: "Path dependence identifies those critical historical junctures that helped both to constitute historical trajectory, as well as those that precipitated change toward new directions" [26]. The notion addresses the importance of past decisions in defining the present. Nevertheless, it needs to be understood in a broad perspective in which the situation is not locked and unavoidable but evolving according to external factors and events.

The existing body of knowledge is rich in analyses of the dispersion [27,28], and the effects of pollutants [29,30]. Despite the numerous industrial disasters and their related pollution in cities, their impacts on public health and the environment remain understudied [31]. Current discussions in public reports and articles tend to focus on technical explanations of the nature of the pollutants, and how they interact with the natural environments around, but do not look beyond these interactions to identify the precise origin (activity, location, or policy) and its consequences on human health [4]. This is due to a lack of inter- and transdisciplinary perspectives in the literature, which in turn fails to identify the reasons behind certain health statistics or indicators. Such a gap makes the source of the polluting challenge and its impacts impossible to locate and determine for public authorities. Investigating the consequences of oil activities and pollution on health can improve the management of polluted sites and further improve the sanitary situation of urban and natural spaces around industrial places [32]; it is imperative to address the health issue in the present case study, where swamps are omnipresent, as oil pollution spreads faster in the presence of water or a humid environment [33]. The existing literature has extensively discussed the effects of petroleum pollution on health, with its blood, liver, and neurological issues [34,35]; however, only a few articles have investigated petroleum developments with their pollution, land use, and environmental consequences, particularly through the lens of urbanization [36]. To fill this gap in the literature, it is of prior importance to consider the role of urban borders, and their porosity, in protecting or affecting inhabitants' health.

This layered influence of oil actors and products over a diversity of fields refers to the notion of palimpsest and global petroleumscape developed by Hein, professor of history of architecture and urban planning at TU Delft [37,38]. Oil facilities, products, and actors participated in shaping the landscape around oil spaces. Cities, the environment, the public opinion, or the local or national decision-making process were all affected by the oil industry's influence, especially around oil spaces. Besides, the global character of the petroleumscape notion makes it transferable and not grounded in specific case studies. Thus, this article aims to contribute to this multi-layered perspective by investigating the influence of borders and their potential effects on the environment and the health of oil cities' inhabitants.

Moreover, a short sampling of the literature notes a missing link between oil pollution, water, health, and border considerations. This lack of investigation appears through the identification of 1097 papers and the analysis of their abstracts, in the search of the combination of keywords "({oil pollution}) AND (health)" in the Scopus database (1956–2020). The sanitary topic receives little attention compared to the 18,202 documents emerging from the search {oil pollution} within the same database. Many articles are technical, dealing with chemical jargon and perspective. Out of these 1097 documents, the term "health" is mentioned in 221 abstracts, whereas only eight publications mention the term "border". Meanwhile, the abstracts of only 54 papers refer to "urban", illustrating the lack of consideration for spatial and urban planning topics when discussing pollution issues. Only 14 of the reviewed abstracts mentioning "urban" also discuss "health"; however, the link between "water" and "health" is identified explicitly, with 119 references citing both. On another note, out of the eight references mentioning the notion of border, only one is linked with "urban" considerations and two with "health". Authors tend to focus slightly more on the question of borders when discussing water pollution, as five papers refer to both. This short analysis of the literature demonstrates the importance given to the question of water in pollution discussions but also the lack of focus on the link between pollution and health issues, primarily through the lens of urban or spatial considerations.

3. Methodology

3.1. Case Study

The oil city of Daqing is located in Heilongjiang Province, in the far northeast part of China. The city took the name from the oilfield discovered in 1959, which meant a great celebration in Chinese. The then leaders of the Heilongjiang Province proposed to nominate the oilfield Daqing to celebrate the 10th anniversary of the founding of the People's Republic. The discovery of the oilfield and installation of the oil industry in it marked a historical moment in China: domestic oil independence. In 1963, four years after the launching of the oil industry in Daqing, its annual production met the domestic usage and could even be exported to neighboring countries, such as Japan, in the early 1970s [39]. Daqing's petroleum and petroleum chemical productions greatly supported the domestic economy, which was facing a crisis as a result of the ensuing political campaigns. Because of this contribution, the Central Government promoted the practices in Daqing, specifically the built environment and the lifestyles, as the national models for all the industrial cities in China [38].

When the oil development started in the early 1960s, the local administration system operated within a combination of both the state-owned oil enterprise (SOE) and the local municipality. In this set-up, the SOE was responsible for any construction associated with the oil industry, while the local municipality was in charge of the construction of civic facilities. In the case of Daqing, the SOE was the Ministry of Petroleum Industry (MPI) while the local municipality was the Municipality of Anda, a prefecture-level city affiliated with the Heilongjiang Province. The combined local administration was the Committee of the Great Oil Campaign. But the SOE gained dominance over the local administration by sending the minister and the vice-ministers as the prominent leaders of the committee [40].

The principle of local planning advocated by the MPI was 'industry first, living second'. The extreme shortage of funds forced MPI to adopt such a planning principle, which manifested itself in the building of oil workers' homes next to workplaces such as oil wells and refineries [41]. In this way, the homes could share the electricity, water and gas systems of the industrial facilities. In turn, MPI can devote all its material and human resources to industrial construction; however, after the 1980s state-owned enterprises and local administrations began to separate from each other. Local governments began to gain more power in urban planning [42]. Nevertheless, many spatial planning powers remain in the hands of state-owned enterprises.

Nowadays, swamps and puddles are widely seen in Daqing because of the saline soil characteristic, which is poorly permeable but retains well water and fertilizer. Specifically, after the development of the oil industry in Daqing by the Chinese government in the 1960s, more and more swamps and puddles emerged as a result of the water injection during the oil extraction. This is due to the nature of the oil reservoir in Daqing, where oil workers had to inject large amounts of water into the ground to extract the oil. This process is linked to the multi-layered characteristic of the oil field, and is meant to keep the pressure high enough in the reservoir to extract oil as efficiently as possible [43]. The process led to an intimate relationship between oil and water in the city, and one of the main reasons behind the choice of this case study. The ability of water to transport and spread pollution through the surface and underground networks makes the discussion around borders even more meaningful.

Before installing the oil industry, Daqing's surface water resources came mainly from rainfall during the rainy season. The climate in Daqing is dry, and the average annual rainfall and surface evaporation are almost equal. As a result, surface water resources were essentially non-existent before. After the construction of the oil industry began in 1960, surface water was mainly generated by the oil industry and the domestic drainage. At this time, surface water puddles of varying sizes began to appear in Daqing, locally known as 'Paozhao', a Chinese name for a specific form of the swamp. A Paozhao is a body of water with no apparent flow and exists independently of the surface. They are called alkaline swamps because they have a gently sloping bottom, narrow open water, shallow water levels, a round or oval lake shape, open banks and alkaline water. The Paozhao could quickly dry up in dry seasons, while in wet seasons, the water in the Paozhao was massive, forming swamps [44].

However, because of industrial pollution and the fact that there is only one drainage outlet in the area, the local surface water quality was not good. Since the 1960s, due to the lack of attention to environmental issues, oil extraction caused the neighboring swamp to contain suspended oil. The petrochemical production started working without a sewage treatment device, so the wastewater was directly discharged into the swamps without any treatments, resulting in the pollution of the swamps [45]. At the same time, the water body of the swamps was mainly renewed by natural precipitation. As the evaporation was significant, the pollution components were constantly concentrated and deposited in the swamps, which aggravates the pollution level of the water body of the bubble marsh.

As a result, in mid-1968, the provincial government of Heilongjiang started constructing a project called the 'Yin Nen Project' to bring water from the Nen River to Daqing. By bringing in better quality water from the Nen River, the Heilongjiang government attempted to dilute the water's high salinity and pH levels caused by the oil industry without radically isolating the source of the contamination from the water source. The emergence of the 'Yin Nen Project ' gave impetus to the construction of local reservoirs, and from 1968, the Heilongjiang provincial government built three reservoirs in the Daqing region (Daqing Reservoir, Hongqi Reservoir, and Nanyin Reservoir) to carry the water brought in from the Nen River. The Daqing Reservoir was constructed specifically for industrial and agricultural purposes, while the Hongqi Reservoir was built for Daqing Refinery in the Longfeng District. Nanyin Reservoir was intended for fish farming (Figure 2) [44].

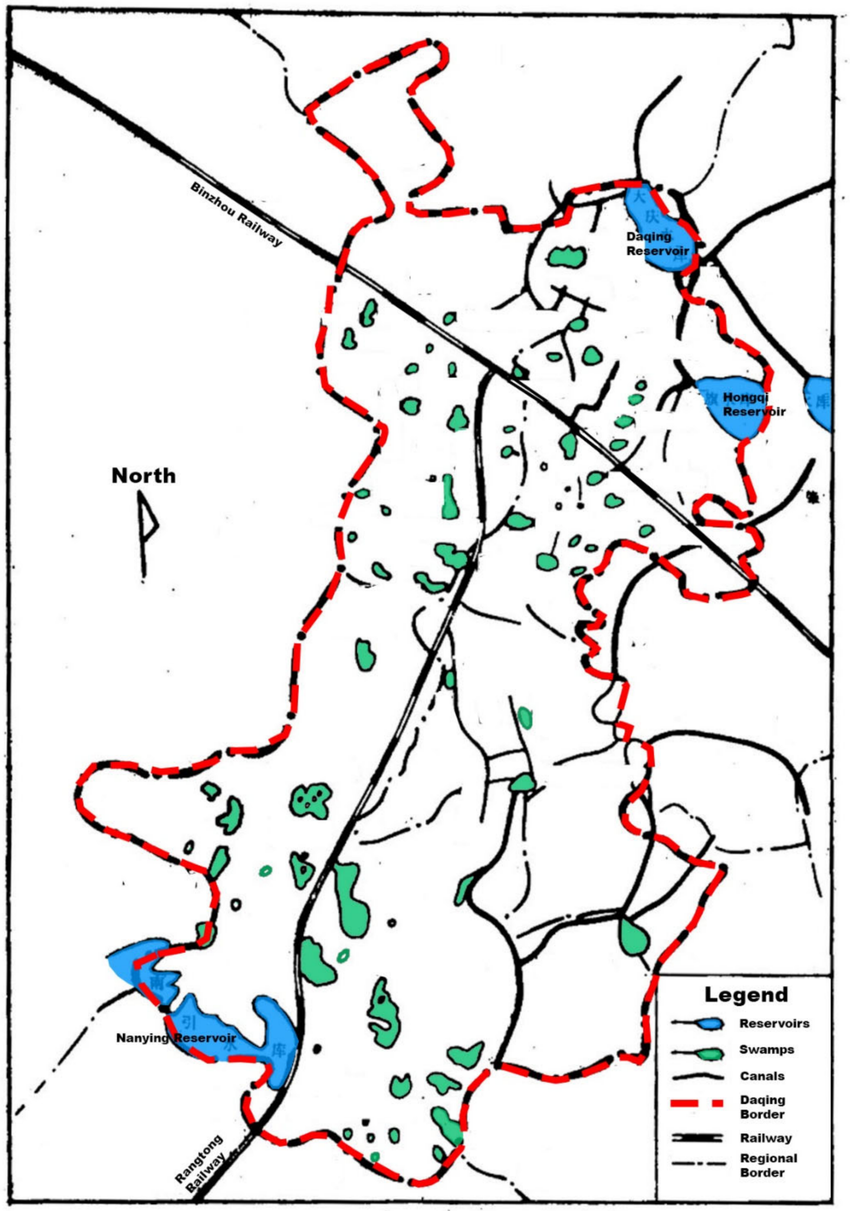

Figure 2. Distribution of Reservoirs and Swamps in Daqing 1989; Source: The Editorial Group of Daqing Land and Resources, modified by Penglin Zhu.

3.2. Mapping Method

This article spatially analyzes the city of Daqing in relation to the border issue of oil and water by using satellite images in the mapping of the city with ArcMap, in addition to the analysis of historical images and maps. By doing so, it demonstrates the spatial and temporal threats of the oil industry through the lens of its borders on the city scale and its potential effects on inhabitants' health. The spread of petroleum via water and land has not been quantitatively measured in a precise way, considering the difficult temporality of past industrial activities. The lack of public documents presenting statistics regarding death rates and health problems in relation to these activities remains similarly challenging to obtain. A previous analysis in Dunkirk demonstrated that this is a common issue, as both the literature and health reports from public authorities omit to discuss the link between industrial activities, spatial planning strategies, and health indicators [4]. Therefore, this paper aims first to conceptualize the notion of borders in dealing with pollution and then illustrates its significance by mapping the oil sites from the example of Daqing.

The mapping of Daqing is limited to the central area where the oil field is exploited, and its immediate urban, agricultural, and natural surroundings. This limitation prevents an analysis that would go beyond the city's core, where the oil field and its exploitation meet the urban area. Using the world imagery provided by the software ArcMap, the authors mapped the different land uses visible or identifiable. The projected coordinate system used in this context was WGS 1984 Web Mercator Auxiliary Sphere. The first surface created was the area of the city where the oil field was exploited, and identifiable through the numerous derricks visible (Figures 3–5). The authors chose to identify the entire area as one rather than trying to illustrate all the oil wells or oil derricks because of their important number and small size in the images.

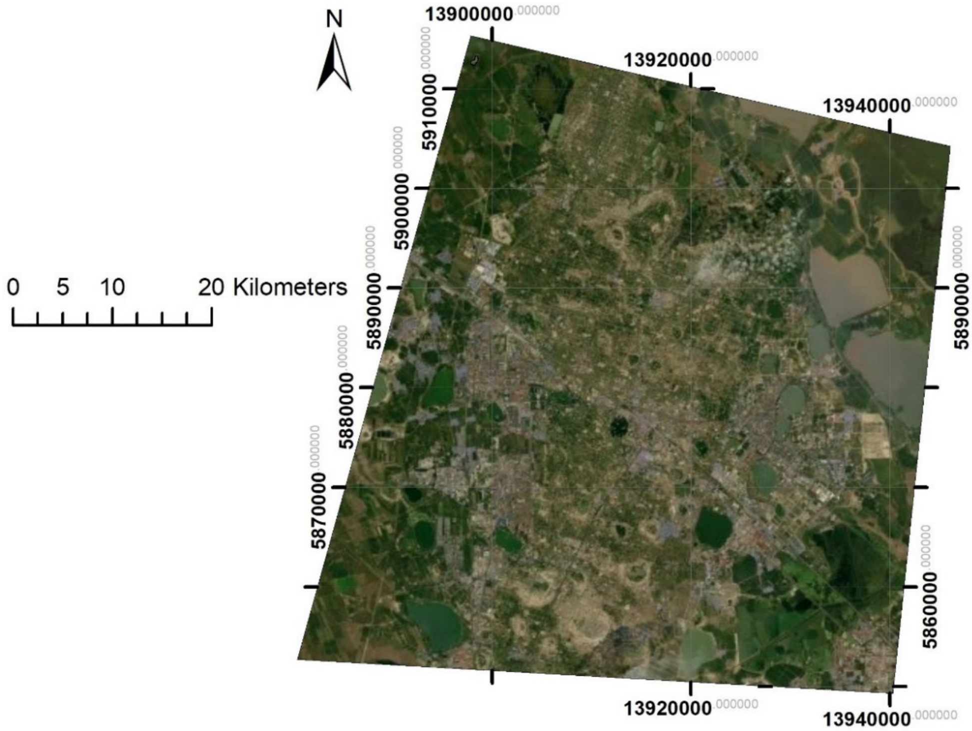

Figure 3. Area of Daqing considered for the mapping and centered around the oil field. This latter is identifiable through the numerous light color patches. Picture from the World Imagery of ArcMap.

The following phase required the mapping of water, agricultural, and urban areas. Considering the extensive layers to identify and their overlapping characteristics, the authors attempted, in vain, to use the image classification option available on ArcMap. Because of the extensive surface considered for the mapping (3263.97 km^2), the paper relies on an image of Sentinel-2 to locate and represent the range of water bodies. Thus, the layer dedicated to water essentially comes from the 2020 land use/land cover image from Sentinel-2 (ESRI), published in July 2021. The accuracy of which was corrected or completed when needed based on visual observations. The other layers from the Sentinel-2 file of this area were, however, not relevant for the analysis as they were not overlapping with the visible elements of the World Imagery, nor were they dividing the specific land uses considered for this paper. Thus, the authors mapped all the other layers manually. The urbanized area refers to all the buildings or urbanized blocks and patches identified in the World Imagery. The mapping of the remaining layer, the agricultural lands, also relied on visual analysis, taking into account the colors, shapes, and location to assess whether they could be considered as such. To better highlight the question of borders and to improve the clarity of the maps, the extensive oil extraction zone has been positioned in the background.

Figure 4. The central area of the mapping area of Daqing where the oil field and the city meet. Picture from the World Imagery of ArcMap.

Figure 5. One of the numerous areas of the oil field of Daqing where oil derricks can be identified on the satellite image. Picture from the World Imagery of ArcMap.

The result allowed the further interpretation and discussion that follows. The pictures produced through this method demonstrate the proximity between the different land uses identified and the apparent lack of borders or their porosity. Mapping is here used as an illustrative tool to locate environmental hazards around sensitive places, such as houses and urban areas, and to allow a better understanding of the risks for public authorities to define more compatible land uses in the area [46].

3.3. Limitations

As opposed to what was achieved in former studies on this topic and on Dunkirk in particular, the authors could not develop a historical analysis of Daqing as well as elaborate on the sanitary situation of the city. There is an absence of available historical aerial pictures of the area that would allow for an analysis of the evolution of Daqing. This is the main reason behind the previous clarification around the presence of Dunkirk as a supporting material of the influence of past decisions rather than as a comparative case study.

The limitations also relate to a lack of precise and usable datasets on land uses and land covers of the area studied. This is due to the strategic importance of the oil field and the restricted access to data linked to the area. Beyond the data extracted from the Sentinel-2 image, the lack of available materials to use led the authors to solely rely on the visual analysis of the World Imagery to identify the oil-related zone. The restricted area of Daqing that the authors mapped derived directly from these conditions and the complexity of the (manual) mapping process. The changing periods of the World Imagery between the different scales made the identification of areas more difficult as colors and water levels changed depending on the season.

All these obstacles explain why mapping was not extensively used as a precise tool to define the issue and its location, but rather as a mean to demonstrate and illustrate the close interactions between oil industrial zones and urban and natural areas. The maps aimed to support the argument of borders and past decisions' importance in the long-term for both public authorities and inhabitants.

4. Analysis

Out of the 3263.97 km^2 of the frame used to map Daqing, a third of it is meant for oil extraction. With the delimitation of the area that includes most of the oil wells representing 1065.26 km^2, the dedication of Daqing for oil activities and its expansion around this purpose is evident. The total surface of the urbanized area is 684.28 km^2; however, another indicator demonstrating the dependence of the urban expansion on oil extraction comes to light when considering that almost two-thirds of this surface is located within the perimeter of the oil field (452.86 km^2) (Figure 6). When knowing the capacity of oil pollutants to travel horizontally and vertically, and reach underground water networks [47], it is undeniable that these urban areas in Daqing are directly affected by the pollution [33,48]. Not only can pollutants be found far from extraction and transformation sites [49,50], but they also remain for long periods in natural environments and organisms [51,52]. For inhabitants, this can cause liver or neurologic issues, or cancer [34,35,53].

The zones mapped as urbanized areas at the center of the oil field could have been storage and processing sites. In this case, the pollution of these industrial sites within the oil field would have been less impacting on inhabitants; however, the two main industrial sites identified were located on the central east and west parts of the oil field, also adjacent to water bodies and residential districts (mainly the Ziqiang residential district on the East side). No industrial facilities could be visible on the World Imagery within the central area of Daqing's oil field. Thus, the most vulnerable zones at the center of the oil extracting area are residential districts that correspond to the original settlements of the city (mainly Sa'ertu, Tieren, and Huzhan residential districts).

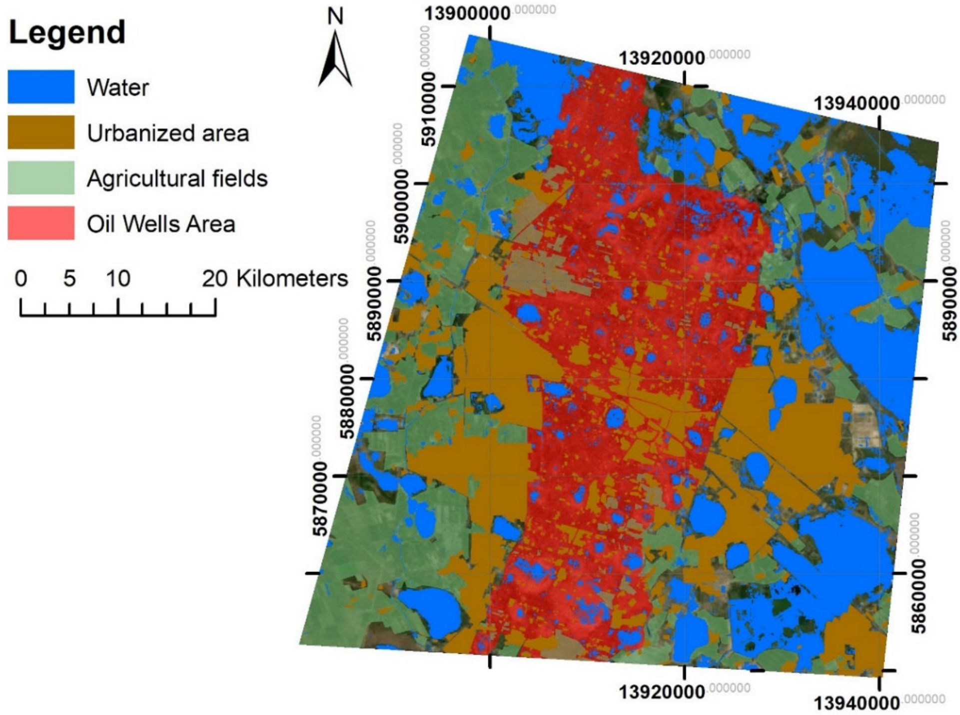

Figure 6. Result of the mapping of Daqing area with the different layers. Map by S. J. Hauser with the software ArcMap.

The mapping of water in the area also revealed important elements to consider. The overlapping of the information from Sentinel-2 with the World Imagery required additions and modifications. Because of the humid nature of the area, water levels can change between periods. Thus, when possible, the visual observation relied on images where the highest level was visible. The authors chose this way of mapping to demonstrate better both the moving potential of the pollution and the interconnections between the different bodies of water. Besides, the precise identification of buildings necessitated a close zoom-in, which highlighted small canals going through the oil area. These canals cross the oil field and connect many of the various water sources, creating a dense and interconnected water network, especially in the northern part of Daqing and its oil field (Figure 7). This map shows that, even though the main bodies of water are outside the main oil wells area, the grid of canals going throughout the area makes them also affected by the oil activity.

The water network highlighted by the map is, however, solely focusing on the visible part, surface water. Although this analysis already demonstrates the great interconnections of the entire surface water, it does not take into consideration the underground network, likely to be similarly connected [54,55]. Considering the technique used to extract oil is based on sending water into the oil reservoir, the contamination of the underground network seems inevitable.

The maps detail that the immediate periphery of the city of Daqing is dedicated to agricultural activities. If the area mapped represents 739.9 km^2, it has to be considered with precaution as the visual identification is difficult and can be confused, in some cases, with the development and preparation of the land for oil exploitation. Once both are exploited, the color of the image between agricultural land and around oil derricks can appear to be similar; however, the combination of an interconnected water network with oil and agricultural activities is also affecting food production. Previous studies on Daqing already demonstrated that agricultural fields were contaminated with pollution. The visual analysis is only confirming while showing the reason behind such contamination. The water used for agriculture from nearby water bodies connected to canals going within the oil field explains the migration of pollutants towards the periphery until agricultural fields [56].

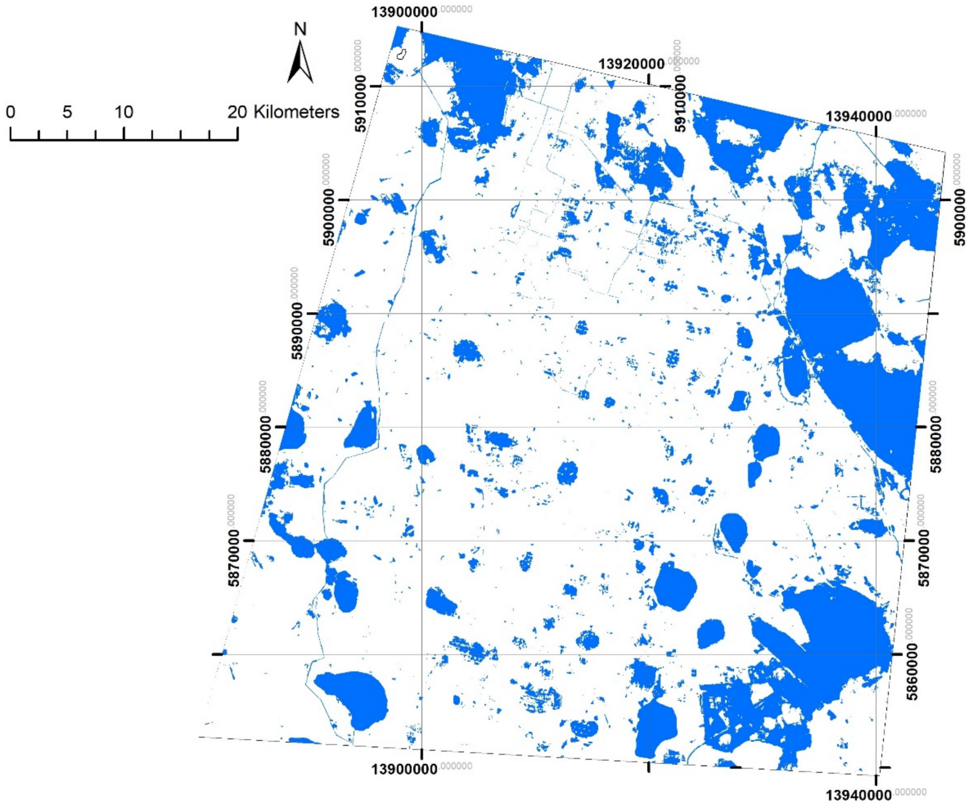

Figure 7. The water network of Daqing. A combination of the data on the area from Sentinel-2 and of visual mapping. Map by S. J. Hauser with the software ArcMap.

5. Permeable Borders: Between Incompatibilities and Spreading

As opposed to an oil storage and transformation city like Dunkirk and explored in previous studies [2], Daqing is a more recent example. It deals with different aspects of oil activities. The exploitation of the oil field in Daqing started in the early 1960s and with it the beginning of urban development. The oil history of the city is, thus, reasonably new, and authorities do not have to deal with the issues of lost oil sites and the regular disasters happening around refineries [5]. Yet, planning strategies of the past are still influencing the city and its inhabitants, with the original settlement still being inhabited and in the middle of the oil field.

The regular disasters happening around oil facilities and the pollution they caused did not, however, prevent dangerous urban practices in Daqing [57,58]. With almost two-thirds of the urban space within the oil exploitation field or in close contact with it, authorities ignored the incompatibilities of such porous and proximate borders. If all the buildings identified during the mapping process are not houses, the overall nearness demonstrates the priority public authorities gave to the link between industrial efficiency and spatial planning strategies. The development of oil activities and the efficiency of oil production overshadowed any concerns around the security and health of inhabitants as well as the protection of the environment.

The literature often highlights the pollution threat around oil exploitation or extraction sites, though a few only focus on land pollution [59]. Authors demonstrated the spreading characteristics of humid environments on oil spills and pollution [33], and such a context can directly be transferred to Daqing, considering the significant presence of water around and in the oil field. Knowing how difficult the remediation of oil pollution is [60], this combination of elements demonstrates the complexity of Daqing's case and the potential effects on public health. These factors illustrate the importance of strict borders in urban and spatial planning and the necessity to consider them from a three-dimensional perspective. The pollution caused by oil activities is not staying on the ground and can spread vertically and horizontally.

In the case of Daqing, the spreading of the pollution from extraction sites is supported by its water network. Oil wells are often in the middle of swamps or water bodies that can be connected to each other through canals that cross the surface of the oil field. Thus, when a spill happens around a derrick, the pollution rapidly infiltrates the soil because of the presence of water, and spread horizontally beyond the original place of the spill thanks to the numerous canal connections; moreover, the mapping in previous figures focuses on visible surface water. Yet, marshes are characterized by a dense and extensive underground water network which, in this case, would increase the speed and severity of the contamination, as groundwater and surface water cannot be considered independently [54,55,61]. The regular presence of water around oil sites, being for extraction, storage, or transformation, demonstrate not only the necessity to consider borders, but also to take into account their three-dimensional aspect.

Since 2010, the population of Daqing has been slowly declining, from a peak of 2,808,000 to 2,708,000 today. While there are many reasons why people leave, such as the slow transformation of local industries, the loss of jobs, and the extremely cold winters, the pollution caused by the oil industry is also a factor that cannot be ignored; however, around 2.7 million people still live there, nearly 34 times the population of Dunkirk, a European oil city, and they still live in dense oil installations that are at high risk of leaking oil and polluting the environment. Therefore, it is relevant for public authorities to consider the question of borders. The densification and/or the expansion of urban borders within or around the oil field will inevitably intensify the pollution issue and its sanitary consequences. Many authors took Daqing as a case study and demonstrated the pollution of its surface water and groundwater as well as its soil by oil-related activities [56,62–64]. The increasing number of inhabitants in the region will inevitably go together with an increasing number of pathologies linked to oil pollution if public authorities do not consider the origins of this issue (economic, political, and environmental) in spatial and urban planning strategies.

6. Conclusions

The fact that Daqing emerged as a town dedicated to the oil industry in the 1960s, a few years before the rise of the international environmentalism movement, could have been an influential factor in its planning; however, similarly to the slow inclusion of environmental concerns in policies and planning strategies across the world since then [65,66], the planning of Daqing relied on an economic and industrial-oriented strategy of efficiency. Past planning practices of the late 19th and early 20th centuries remained references demonstrated by the close proximity between urban and industrial environments and confirmed by visual and mapping analyses. One can only hope that this recent development with referencing oil sites and related issues will prevent the change of land use that happened in Dunkirk, and in many other cities, with an absence of cleaning of the soil.

The dominance of the State-owned enterprise in the combined local administration resulted in the creation of porous borders between industrial and residential areas in Daqing. This situation exemplifies the importance of past decisions in the future of inhabitants and the planning of cities. Daqing is an illustration of how industrial priority in the planning of industrial cities can be a threat to natural environments and the health of populations while hampering the evolution of cities. Such situations are complex not only because of the consequences of past planning decisions but also because influential actors in the decision-making tend to maintain the status quo. In the case of Daqing, there are still many planning powers left in the hands of the SOE.

In order to avoid the repetition of planning mistakes from the past and treat future health and spatial planning challenges, stakeholders (private actors from the industry and public authorities) can take action. The monitoring of oil sites connected to water bodies, and the extent of the underground water network, is of prior importance. This entails not only the identification of contemporary sites but also of all former oil-related industrial sites that may have disappeared. The knowledge of past and present oil sites would allow authorities to know the location of the most permeable and dangerous borders, where interactions are the most detrimental to water quality, natural environments, and the health of inhabitants. A complete record of these sites will enable efficient planning strategies as well as the tackling of potential sanitary issues.

To fully grasp the extent of the issue and provide decision-makers with potential solutions, the problems need to be explained holistically. This fits and follows the notion of "Wicked Problems" described by Churchman, in which solving one problem without considering its full extent and origins will only create more difficulties [67,68]. Knowledge about the challenges ahead is key to the sustainable development of a city and to improving the life of its inhabitants. Such knowledge, through the collaboration of all involved parties, is the central element behind the creation of efficient and adaptive planning policies [69–71].

Monitoring oil sites and spills from past to present may help in the identification of hazard zones. This would clarify the moving and three-dimensional borders of oil and its pollution in regions dependent on oil activities, and improve the management of petroleum contaminations. Eventually, decision-makers can use this information in the definition of planning and construction strategies by identifying areas as unsuitable for particular uses (residential buildings, vegetable gardens, water use) and the levels of pollution.

It is impossible to predict the future development of Daqing. The city could well become abandoned by the oil industry, similarly to what happened in Dunkirk, or with Abadan, in Iran, when the oil field depleted. Yet, future research in the field should focus on understanding the consequences of oil pollution and industrial pollution in general in the context of public health and spatial planning in port cities. Filling this critical gap would enhance the sustainability and coherence of planning practices in industrial cities, and tackle their poor sanitary situation.

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References

1. Hein, C. Refineries (Oil). In *Encyclopedia of Greater Philadelphia*; Mid-Atlantic Regional Center for the Humanities: Camden, NY, USA, 2016.
2. Hauser, S.; Zhu, P.; Mehan, A. 160 Years of Borders Evolution in Dunkirk: Petroleum, Permeability, and Porosity. *Urban Plan.* **2021**, *6*, 58–68. [CrossRef]
3. Hein, C.; Stroobandt, C.; Hauser, S. Petroleumscape as Heritage Landscape: The Case of the Dunkirk Port City Region. In *Oil Spaces: Exploring the Global Petroleumscape*; Hein, C., Ed.; Routledge: London, UK, 2021.
4. Hauser, S.J.; Aktürk, G. Investigate past polluting activities on public health and land uses. *Cities* **2022**, *123*, 103599. [CrossRef]

5. Hauser, S.J. Long Live the Heritage of Petroleum: Discoveries of Former Oil Sites in the Port City of Dunkirk. *Urban Sci.* **2020**, *4*, 22. [CrossRef]
6. Meadows, D.H.; Meadows, D.L.; Randers, J.; Behrens, W.W. *The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind*; New American Library: New York, NY, USA, 1972.
7. Meadows, D.; Randers, J.; Meadows, D. *Limits to Growth: The 30-Year Update*; Chelsea Green Publishing: Chelsea, VT, USA, 2004.
8. Aseeva, A. (Un)Sustainable Development(s) in International Economic Law: A Quest for Sustainability. *Sustainability* **2018**, *10*, 4022. [CrossRef]
9. Turner, G. *Is Global Collapse Imminent?* University of Melbourne, Melbourne Sustainable Society Institute: Melbourne, Australia, 2014.
10. Baron, S.; Carignan, J.; Ploquin, A. Dispersion of heavy metals (metalloids) in soils from 800-year-old pollution (Mont-Lozere, France). *Environ. Sci. Technol.* **2006**, *40*, 5319–5326. [CrossRef] [PubMed]
11. Fernández-Navarro, P.; García-Pérez, J.; Ramis, R.; Boldo, E.; López-Abente, G. Industrial pollution and cancer in Spain: An important public health issue. *Environ. Res.* **2017**, *159*, 555–563. [CrossRef]
12. Hatch, M.; Cardis, E. Somatic health effects of Chernobyl: 30 years on. *Eur. J. Epidemiol.* **2017**, *32*, 1047–1054. [CrossRef]
13. Brimblecombe, P. Air pollution and health history. In *Air Pollution and Health*; Elsevier: Amsterdam, The Netherlands, 1999; pp. 5–18.
14. Mosley, S. Environmental history of air pollution and protection. In *The Basic Environmental History*; Springer: Berlin/Heidelberg, Germany, 2014; pp. 143–169.
15. Le Roux, T. La «médiatisation» de l'insalubrité industrielle: Un espace public de débats progressivement étouffé, 1770–1810. *Temps Médias* **2015**, *2*, 34–51. [CrossRef]
16. Yergin, D. *The Prize: The Epic Quest for Oil, Money & Power*; Simon and Schuster: New York, NY, USA, 2011.
17. Black, B.C. How World War I ushered in the century of oil. Observer. 2018. Available online: https://observer.com/2017/04/world-war-i-ushered-in-the-century-of-oil-global-economy-geopolitics-national-security/ (accessed on 14 December 2020).
18. McQuaig, L. *It's the Crude, Dude: War, Big Oil and the Fight for the Planet*; Doubleday: Toronto, ON, Canada, 2004.
19. Tateo, L.; Nugin, R.; Jones, A.; Marsico, G.; Palang, H. Cities of Senses: Visible and Invisible Borders in Public Spaces. In *Identity at the Borders and Between the Borders*; Springer: Berlin/Heidelberg, Germany, 2021; pp. 7–22.
20. Churski, P.; Herodowicz, T.; Konecka-Szydłowska, B.; Perdał, R. Spatial Differentiation of the Socio-Economic Development of Poland–"Invisible" Historical Heritage. *Land* **2021**, *10*, 1247. [CrossRef]
21. Jovchelovitch, S.; Dedios Sanguineti, M.C.; Nogueira, M.; Priego-Hernandez, J. Imagination and mobility in the city: Porosity of borders and human development in divided urban environments. *Cult. Psychol.* **2020**, *26*, 676–696. [CrossRef]
22. Roulleau-Berger, L. Metropolitanization, Interior Borders, and Invisible Cities in China. *Espac. Soc.* **2013**, *155*, 129–141.
23. Pierson, P. Increasing returns, path dependence, and the study of politics. *Am. Polit. Sci. Rev.* **2000**, *94*, 251–267. [CrossRef]
24. Hacker, J.S.; Pierson, P. *Winner-Take-All Politics: How Washington Made the Rich Richer—And Turned its Back on the Middle Class*, 1st ed.; Simon and Schuster: New York, NY, USA, 2010; ISBN 1416588701.
25. Sorensen, A. Taking path dependence seriously: An historical institutionalist research agenda in planning history. *Plan. Perspect.* **2015**, *30*, 17–38. [CrossRef]
26. Ramos, S.J. Resilience, path dependence, and the port: The case of Savannah. *J. Urban Hist.* **2017**, *47*, 0096144217704183. [CrossRef]
27. Hafez, T.; Ortiz-Zarragoitia, M.; Cagnon, C.; Cravo-Laureau, C.; Duran, R. Legacy and dispersant influence microbial community dynamics in cold seawater contaminated by crude oil water accommodated fractions. *Environ. Res.* **2022**, *212*, 113467. [CrossRef]
28. Okoye, C.O.; Addey, C.I.; Oderinde, O.; Okoro, J.O.; Uwamungu, J.Y.; Ikechukwu, C.K.; Okeke, E.S.; Ejeromedoghene, O.; Odii, E.C. Toxic Chemicals and Persistent Organic Pollutants Associated with Micro-and Nanoplastics Pollution. *Chem. Eng. J. Adv.* **2022**, *11*, 100310. [CrossRef]
29. Liu, Q.; Xia, C.; Wang, L.; Tang, J. Fingerprint analysis reveals sources of petroleum hydrocarbons in soils of different geographical oilfields of China and its ecological assessment. *Sci. Rep.* **2022**, *12*, 4808. [CrossRef]
30. Otitolaiye, V.O.; Al-Harethiya, G.M. Impacts of petroleum refinery emissions on the health and safety of local residents. *J. Air Pollut. Health* **2022**, *7*, 69–80. [CrossRef]
31. Eklund, R.L.; Knapp, L.C.; Sandifer, P.A.; Colwell, R.C. Oil spills and human health: Contributions of the Gulf of Mexico Research Initiative. *GeoHealth* **2019**, *3*, 391–406. [CrossRef]
32. Sam, K.; Coulon, F.; Prpich, G. Management of petroleum hydrocarbon contaminated sites in Nigeria: Current challenges and future direction. *Land Use Policy* **2017**, *64*, 133–144. [CrossRef]
33. Yanxun, S.; Yani, W.; Hui, Q.; Yuan, F. Analysis of the groundwater and soil pollution by oil leakage. *Procedia Environ. Sci.* **2011**, *11*, 939–944. [CrossRef]
34. Borowik, A.; Wyszkowska, J.; Kucharski, M.; Kucharski, J. Implications of soil pollution with diesel oil and BP petroleum with ACTIVE Technology for soil health. *Int. J. Environ. Res. Public Health* **2019**, *16*, 2474. [CrossRef] [PubMed]
35. Hartley, W.R.; Englande, A.J., Jr. Health risk assessment of the migration of unleaded gasoline–a model for petroleum products. *Water Sci. Technol.* **1992**, *25*, 65–72. [CrossRef]
36. Nelson, R.; Heo, J. Monitoring environmental parameters with oil and gas developments in the Permian Basin, USA. *Int. J. Environ. Res. Public Health* **2020**, *17*, 4026. [CrossRef]
37. Hein, C.; Sedighi, M. Iran's Global Petroleumscape: The Role of Oil in Shaping Khuzestan and Tehran. *Archit. Theory Rev.* **2016**, *21*, 349–374. [CrossRef]

38. Hein, C. Oil Spaces: The Global Petroleumscape in the Rotterdam/The Hague Area. *J. Urban Hist.* **2018**, *44*, 887–929r. [CrossRef]
39. Editorial Group of Daqing City. *Local Record Record of Daqing*; Nanjing Publishing House: Nanjing, China, 1988.
40. Leading Group of the Songliao Petroleum Congress of the Ministry of Petroleum Industry (Acting). *Notice on the Division of Labour among the Leading Members of the Songliao Petroleum Congress of the Ministry of Petroleum Industry*; Ministry of Petroleum Industry: Beijing, China, 1960.
41. Xinhua News Agency. *The Employees of the Daqing Oilfield are Proud of Living in 'Gandalei' Houses*; Xinhua News Agency: Beijing, China, 1966.
42. Editorial Group of the CCP's History in Daqing. *The History of Daqing's Reform and Opening up 1978–2009*; History of Chinese Communist Party Publishing House: Beijing, China, 2010; pp. 87–99.
43. Pei, X.; Yang, Z.; Li, B.; Yaning, L. History and actuality of separate layer oil production technologies in Daqing Oilfield. In Proceedings of the International Oil & Gas Conference and Exhibition in China, OnePetro, Beijing, China, 5–7 December 2006.
44. The Editorial Group of Daqing Land and Resources. *Daqing Land and Resource*; People's Publisher of Heilongjiang Province: Harbin, China, 1989.
45. Zhou, Y.; Guan, L.; Zhong, S. *The Comprehensive Land Use Plan in Daqing*; Heilongjiang Science and Technology Press: Harbin, China, 1992.
46. Aktürk, G.; Hauser, S.J. Detection of Disaster-Prone Vernacular Heritage Sites at District Scale: The Case of Fındıklı in Rize, Turkey. *Int. J. Disaster Risk Reduct.* **2021**, *58*, 102238. [CrossRef]
47. Grimaz, S.; Allen, S.; Stewart, J.R.; Dolcetti, G. Fast prediction of the evolution of oil penetration into the soil immediately after an accidental spillage for rapid-response purposes. In Proceedings of the 3rd International Conference on Safety & Environment in Process Industry, CISAP–3, Rome (I), Citeseer, Rome, Italy, 11–14 May 2008; pp. 11–14.
48. Alloway, B.J. Soil pollution and land contamination. *Pollut. Causes Eff. Control* **1996**, *3*, 318–339.
49. Okandan, E.; Gümrah, F.; Demiral, B. Pollution of an aquifer by produced oil field water. *Energy Sources* **2001**, *23*, 327–336.
50. Ejike, C.; Eferibe, C.; Okonkwo, F. Concentrations of some heavy metals in underground water samples from a Nigerian crude oil producing community. *Environ. Sci. Pollut. Res.* **2017**, *24*, 8436–8442. [CrossRef]
51. United States Environmental Protection Agency Office of Emergency Remedial Response and United States Environmental Protection Agency Emergency Response Division. *Understanding Oil Spills and Oil Spill Response*; Environmental Protection Agency, Office of Emergency and Remedial Response [and] Emergency Response Division: Washington, DC, USA, 1993; Volume 93.
52. Arockiaraj, S.; Kankara, R.S. Assessment of Potential Oil Spill Risk Along Vishakhaptnam Coast, India: Integrated Approach for Coastal Management. In *Coastal Management*; Elsevier: Amsterdam, The Netherlands, 2019; pp. 449–463.
53. Scovronick, N.; Wilkinson, P. Health impacts of liquid biofuel production and use: A review. *Glob. Environ. Change* **2014**, *24*, 155–164. [CrossRef]
54. Roulet, N.T. Hydrology of a headwater basin wetland: Groundwater discharge and wetland maintenance. *Hydrol. Process.* **1990**, *4*, 387–400. [CrossRef]
55. McCarthy, T.S. Groundwater in the wetlands of the Okavango Delta, Botswana, and its contribution to the structure and function of the ecosystem. *J. Hydrol.* **2006**, *320*, 264–282. [CrossRef]
56. Wang, X.; Zang, S. Distribution characteristics and ecological risk assessment of toxic heavy metals and metalloid in surface water of lakes in Daqing Heilongjiang Province, China. *Ecotoxicology* **2014**, *23*, 609–617. [CrossRef]
57. Granot, H. The dark side of growth and industrial disasters since the Second World War. *Disaster Prev. Manag. Int. J.* **1998**, *7*, 195–204. [CrossRef]
58. Woolfson, C. Preventable disasters in the offshore oil industry: From Piper Alpha to Deepwater Horizon. *New Solut. J. Environ. Occup. Health Policy* **2013**, *22*, 497–524. [CrossRef]
59. Rosell-Melé, A.; Moraleda-Cibrián, N.; Cartró-Sabaté, M.; Colomer-Ventura, F.; Mayor, P.; Orta-Martínez, M. Oil pollution in soils and sediments from the Northern Peruvian Amazon. *Sci. Total Environ.* **2018**, *610*, 1010–1019. [CrossRef]
60. Sun, Y.; Lu, S.; Zhao, X.; Ding, A.; Wang, L. Long-term oil pollution and in situ microbial response of groundwater in Northwest China. *Arch. Environ. Contam. Toxicol.* **2017**, *72*, 519–529. [CrossRef]
61. Hose, G.C.; Bailey, J.; Stumpp, C.; Fryirs, K. Groundwater depth and topography correlate with vegetation structure of an upland peat swamp, Budderoo Plateau, NSW, Australia. *Ecohydrology* **2014**, *7*, 1392–1402. [CrossRef]
62. Wang, J.F.; Xu, L.; Xu, W.P.; Liu, X.T. The Research of Microbial Remediation of Oil Pollution Wetland—Aim at the Oil Pollution of Daqing Oil Field the Wetland. *Adv. Mater. Res.* **2013**, *610*, 2074–2078.
63. Wu, T.; Wang, L.; Wang, L.; Kong, Q. Evaluation of groundwater quality and pollution in Daqing Oilfield. *J. Groundw. Sci. Eng.* **2018**, *6*, 40–48.
64. Zhang, H.; Bian, J.; Wan, H. Hydrochemical appraisal of groundwater quality and pollution source analysis of oil field area: A case study in Daqing City, China. *Environ. Sci. Pollut. Res.* **2021**, *28*, 18667–18685. [CrossRef] [PubMed]
65. Brinkmann, F.J.J. Lekkerkerk. In Proceedings of the Studies in Environmental Science, Noordwijkerhout, The Netherlands, 23–27 March 1981; Volume 17.
66. Almer, C.; Winkler, R. Analyzing the effectiveness of international environmental policies: The case of the Kyoto Protocol. *J. Environ. Econ. Manag.* **2017**, *82*, 125–151. [CrossRef]
67. Churchman, C.W. *Guest Editorial: Wicked Problems*; INFORMS: Catonsville, MD, USA, 1967.
68. Rittel, H.W.J.; Webber, M.M. Dilemmas in a general theory of planning. *Policy Sci.* **1973**, *4*, 155–169. [CrossRef]

69. Weber, E.P.; Khademian, A.M. Wicked problems, knowledge challenges, and collaborative capacity builders in network settings. *Public Adm. Rev.* **2008**, *68*, 334–349. [CrossRef]
70. Levin, K.; Cashore, B.; Bernstein, S.; Auld, G. Overcoming the tragedy of super wicked problems: Constraining our future selves to ameliorate global climate change. *Policy Sci.* **2012**, *45*, 123–152. [CrossRef]
71. De Abreu, M.C.S.; de Andrade, R. Dealing with wicked problems in socio-ecological systems affected by industrial disasters: A framework for collaborative and adaptive governance. *Sci. Total Environ.* **2019**, *694*, 133700. [CrossRef]