ENVIRONMENTAL IMPACTS OF RAPID URBANIZATION: NON-POINT SOURCE POLLUTION IN LINGANG NEW CITY, SHANGHAI, CHINA

by

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ABSTRACT

XUCHU MENG. Environmental impacts of rapid urbanization: non-point source
pollution in Lingang new city, Shanghai, China. (Under the direction of Dr. WEI-
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Lingang New City is a new urbanization project in Shanghai, China. It is planned and designed artistically with emphasis on water protection given lake view is the highlight of the landscape. However, water quality degrades soon after the urban development. Non-point source pollution (NPSP) is suspected to be among the causes of water pollution. Missing the subtle land use and land cover characteristics and specialties could have misled planning to address the water quality issue. An innovative method for LULC classification—Multi-Attribute Land Object—is proposed to embrace spatial complexity by incorporating all relevant elements from the natural, built-up, and socioeconomic subsectors of urban ecosystem. A case study is done to testify whether spatial complexity is strong explanatory factor for urban ecosystem dynamics by comparing the concentration of pollutants in storm water from surfaces with different and special attributes in Lingang. Results indicate that NPSP is a significant source of water pollution in Lingang. Factors like motor vehicle use, industrial activities, unmanaged commercial behaviors, and urban forest have strong relationship with NPSP, while well managed commercial behaviors, mild human activities in residential and business areas, and urban landscaping vegetation have relatively low impacts. It is an unfortunate truth that these high-impact factors are inherent in the urbanization due to the superior pursuit of economic growth, protocols of urban planning, codes of implementation, and daily management, which are unlikely to be solved merely by ecological practices. More collaborative efforts including further investigating the high-impact factors, reviewing and revising current protocols and codes of urban planning and management, and regulating human behaviors are appealed in order to improve the situation.

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CHAPTER 1: INTRODUCTION

Rapid urbanization in China in the past three decades has contributed gigantically to the economy of this country as well as caused severe environmental consequences. The economic growth and social transformation after the “reform and open-up policy” since 1978 have triggered stringent needs of urbanized landscape and lifestyle. By 2009, more than half of China’s population are living in urban areas (Cheng and Hu 2009). In the meantime, urbanization is also accused for deteriorating the environment. For example, rivers supplying potable water are severely polluted due to urban development (Wang et al. 2007). Haze and smog in big cities are so severe that the U.S. Embassy has to set up their own air quality sensors and broadcast the data to advise U.S. citizens living in China for proper protection. These urban environmental hazards are not only threatening people’s wellbeing, but also compromising the international reputation and economic future of this country.

Assigning urbanization as the “engine” of the economy for this country (Proposal of the 12th Five-Year Program, 2010), the Chinese government is eager to find a model for urbanization that can both keep the pace of development and maintain good environment (Cheng and Hu 2009). Such desire poses challenges as well as opportunities for urban planning. Although the short-term benefits of urbanization often “make the path towards urban sustainability extremely rugged” (Godschalk 2004), the need of an economy-environment-friendly urbanization model is creating tremendous motivation and possibility for innovation and improvement of urban planning theories and practices.

Lingang New City is one of the trials seeking such innovative model of urbanization. Economically, Lingang is regarded as the new growth pole of Shanghai. It is located on the southeast tip of Shanghai along the east coast of China (Figure 1.1), which used to be agricultural fields and coastal marshes before 2000. In less than 15 years, a 300 km^2 modern city has taken shape. Noticeably, 45% of its land is reclaimed from marshes and seabed (Figure 1.2). Being geographically located in the middle of the two most important ports of Shanghai—the Pudong International Airport and the Yangshan Deep Water Port, Lingang is a natural hub of cargo and transportation that attracts capital and business. It is now a crucial part of the Shanghai Free Trade Zone (SFTZ). Shanghai Municipal Government even has relocated the head quarter of SFTZ to Lingang to symbolize the importance of this place and government’s confidence on it.

In the center of the city is a 5.56 km^2 large, round-shaped artificial fresh water lake—Lake Dishui. In Chinese, “Dishui” means a drop of water. The shape of the city is based on a metaphor of concentric ripples formed by a drop of water falling into the lake (Figure 1.3). An artificial stream network is excavated to connect the lake to exterior water system for water supply. The general urban form looks like the Garden City concept, which is meant to be in favor of both the convenience of modern city life and the pleasant environment of rural area (Howard 1898). Because the Yangtze Delta where Shanghai is located is famous for its traditional Chinese water town scenery, Lingang is tagged to be a “modern water town”.

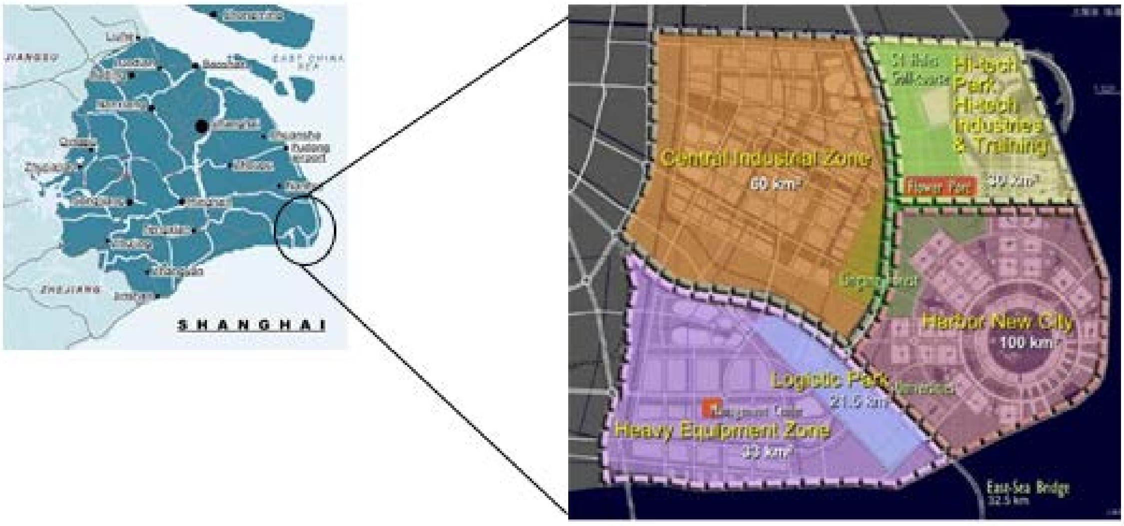

FIGURE 1.1: Lingang New City, Shanghai, China

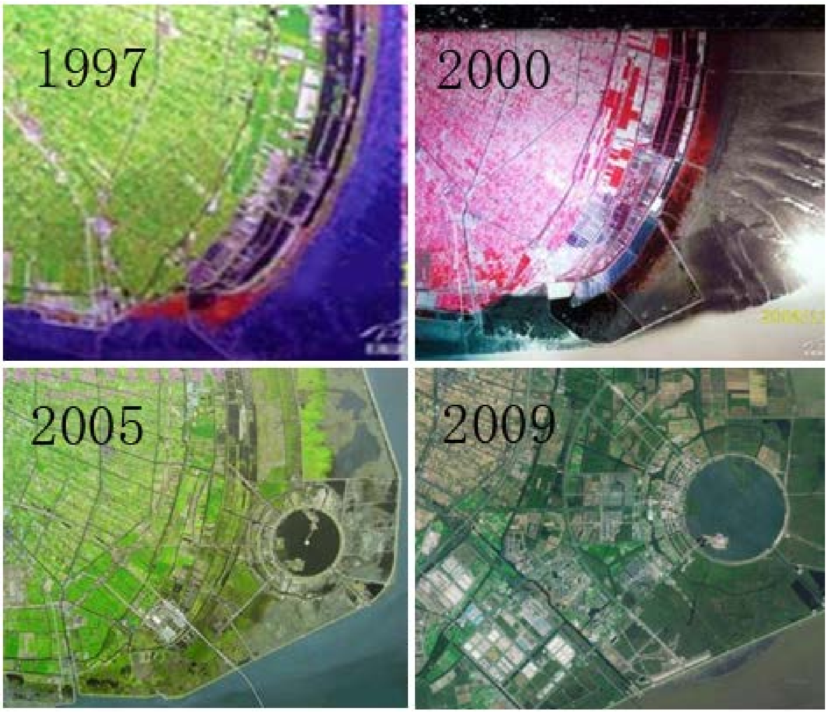

FIGURE 1.2: Land use/land cover changes in Lingang (A: 1997; B: 2000; C: 2005; D: 2009)

Naturally, water quality is a key environmental concern for the planning of Lingang. It is mandatory that at least 45% of the surface shall be covered by green space. Green belt, urban forest, roadside trees, and a variety of other forms of vegetation are deployed. Buildings are constructed in a compact manner to minimize the impact of development. Point-source pollution like waste water is piped to treatment facilities before being discharged. Biofilters, riparian buffers, permeable pavements, and other practices and technologies are applied to mimic the natural surface to minimize pollution and sediments in surface runoff.

FIGURE 1.3: Rendering of Lingang New City

However, these efforts do not pay off sufficiently. Only a few years into the development, water quality of Lake Dishui has degraded to a critical level (Wu 2006; Zhang et al. 2006; Xu 2010). None-point source pollution (NPSP thereafter) is suspected to be responsible, given other potential pollution sources such as domestic or industrial waste water, or polluted supplementary water from upstream have been properly monitored and controlled. An earlier study also indicated that surface runoff was one of the major contributors of water pollution in Lingang (Zhang et al. 2006). Though NPSP is widely recognized as a source of urban water pollution in urban areas (USEPA 1993; Basnyat et al. 2000; Hatt et al. 2004), the failure of the ecological design in the planning is unexpected and confusing.

This study attempt to explain this situation from the aspect of the relationship between urbanization and NPSP. To achieve this purpose, the following research questions shall be answered:

1. What is the key factor that makes ecological dynamics in urbanized areas unpredictable?

2. How can this key factor be addressed and applied to explain the impacts urbanization has on none-point source pollution in Lingang?

3. Why does surface water quality degrade so quickly while it is a key planning concern of environment in Lingang?

This article is written in the following structure: Chapter Two reviews the literature of NPSP-LULC relationship and LULC classification systems. Chapter Three introduces a new method of LULC classification and a case study using this method to investigate the NPSP-LULC relationship in Lingang. Chapter Four discusses the causes and countermeasures of the NPSP issue in Lingang. Chapter Five draws the conclusions.

CHAPTER 2: LITERATURE REVIEW

2.1. Relationship between Urbanization and Surface Water Quality

Urbanization is often accused to be the cause of water quality degradation (Paul and Meyer 2001; Knox and McCarthy 2005; MEA 2005). The phenomenon that pollution concentrations correlating with proximity to the urban core is found at many places (e.g. Omernik 1976; Pouyat et al. 1995; Meybeck 1998; USGS 1999; Wollheim et al. 2005; Zhang et al. 2009). Among all pollution sources, NPSP in untreated storm water is considered the leading one (Ventura and Kim 1993; Hatt et al. 2004; Zhou et al. 2005; Wang et al. 2007). Surface change is the most obvious phenomenon during urbanization, which often favors the creation, accumulation, and transportation of NPSP. For instance, the drainage system is usually designed to remove storm water as efficiently as possible to mitigate flood, without paying too much attention that pollutants and sediments are also transported efficiently (Mitchell et al. 2001; Cadenasso et al. 2008).

Land use and land cover are common variables for studying the relationship between urbanization and NPSP. They can reflect the changes to the land surface that are caused by urbanization, which might interfere the mechanism of NPSP. Dale et al. (2000) even claimed that LULC is a “fundamental source” of change in the global environment.

The increase of imperviousness is found to be a good indicator of urban NPSP. One reason is that impervious surfaces generate more runoff due to reduced infiltration (Dunne & Leopold 1978; USEPA 2000; Davis et al. 2006). For example, Sloto (1989) demonstrated that 25% imperviousness could lead to a 54% increase in peak discharge. In vegetation-free areas, more than 60% precipitation is transported through storm water drains, while in vegetated areas, only 5–15% of the precipitation runs off the ground (Bernatzky 1983). More surface runoff leads to more urban street pollutants being transported to receiving water bodies (Haughton and Hunter 1994; Paul and Meyer 2001; Mansell 2003). Significant correlation between proportion of imperviousness and yield of NPSP is found repeatedly (Basnyat et al.1999; Basnyat et al. 2000; Hatt et al. 2004; Cadenasso et al. 2007).

On the other hand, vegetation is often found effective in NPSP removal by facilitating biological assimilation, physical setting, or biogeochemical decomposition or transformation via soil microbial communities (Wu et al. 1998; Basnyat et al. 2000; Bernhardt and Palmer 2007; Read et al. 2008; Cheng et al. 2009). Enlightened by these findings, NPSP mitigating practices are mostly designed to restore or mimic the pre-developed hydrological regime in urban areas in order to intercept, attenuate, and retain storm water flows prior to discharge (Rushton 2001; Walsh et al. 2005; Davis et al. 2006; Bernhardt & Palmer 2007; Bratieres et al. 2008). The principle is to minimize imperviousness while maximize pervious surfaces, most ideally with vegetation (Lee and Heaney 2000; Hatt et al. 2004). Practices following this principle are commonly referred to low impact development (LID) (Basnyat et al. 2000), including (but are not limited to) biofilters, detention/retention pond, pervious paver road, cluster housing, shared driveways, etc. (Goonetilleke et al. 2005; Bedan and Clausen 2009).

Biological retention (bioretention or biofilter) is a widely adopted LID method. In flexible forms such as vegetated strips along roadsides, rain gardens within private yards or public open space, riparian buffers along streams, and individual street trees (Li et al. 1998; Bratieres et al. 2008), biofilters function by extending retention time and enlarging contact surface areas with the storm water runoff (Davis et al. 2001). Hatt et al. (2009) concluded that biofilters can effectively attenuate peak runoff flow rates by at least 80% and reduced runoff volumes by 33%, and consequently reduce the loads of pollutants significantly.

Green roof and permeable pavement are two rising LID technologies. Green roof usually consists of thin and light media with different plants (VanWoert et al., 2005; Carter & Jackson, 2007; Dietz, 2007). Hydrologic modeling and practical application demonstrated that widespread green roof implementation could significantly reduce peak runoff rates, particularly for small storm events (Mentens et al. 2006; Oberndorfer et al. 2007; Carter & Jackson, 2007). Dietz (2007) introduced that green roof could retain 60-70% of rainfall by average in a variety of climates. A permeable paver is typically made up of a matrix of concrete blocks or a plastic web-type structure with voids filled with sand, gravel, or soil. These voids allow storm water to infiltrate through the pavement into the underlying soil (Brattebo & Booth, 2003; Dietz, 2007). It is reported to be good at reducing both concentrations and loads of pollutants in surface runoff (Brattebo & Booth 2003; Dietz 2007).

Retention/detention ponds and basins are also effective on NPSP removal. They function by reducing the rate of storm water delivery to streams (Zhu et al. 2004; Hogan and Walbridge 2007). Detention ponds are found particularly effective in removing solids.

Wu et al. (1996) reported 93% removal of total suspended solids (TSS) in storm water by detention ponds. Davis et al. (2001) even observed a removal efficiency of 100% for several small storms.

These results have provided theoretical and practical basis for developing ecological-based strategies for urbanization. Examples include (but are not limited to) green urbanism: to live within the ecological limits (Beatley 2000; Swanwick et al. 2003); neo-traditional urban planning or compact city: to pursue a pedestrian or transit oriented planning (Newman 1997; Dumreicher et al. 2000; Nasar 2003), urban containment: to restrain urban growth and prevent the outward expansion of the urban field by greenbelts (Ewing 1995), etc.

But conclusions are not always conclusive. A study done in Baltimore found that some suburban watersheds with a high level of development can still retain “surprisingly high” 71% of nitrogen inputs (Pickett and Cadenasso 2006), which suggests that artificial structures “have not obliterated all biological processes that determine ecosystem function” (Groffman et al. 2003). Pickett and his colleagues presented results that suburban watersheds had substantially and significantly higher loading of nitrogen than the dense urban settlement attributed to lawn runoff, septic inputs, or a legacy of prior agricultural land use (Pickett and Cadenasso 2006; Pickett et al. 2008). They further pointed out that though urban land use decreases water quality, it is not always the densest and most intense form of urban settlement that has the greatest impact.

Vegetation, pervious surfaces, or LID facilities sometimes became source of NPSP due to particular physical, biological, structural, maintenance and other conditions (Bannerman et al. 1993; Davis et al. 2001; Bedan and Clausen 2009; Hatt et al. 2009). For example, Dietz (2007) reported negative effects of pollutant removal by both green roof and permeable pavement. The failure of green roof was likely to subject to leaching of nutrients from the planting media, while polluted storm water penetrating permeable pavement could contaminate the ground water.

Riparian buffers are strips of vegetation bordering aquatic ecosystems that can intercept terrestrial pollutants prior to entering aquatic environments (Peterjohn & Correll 1984; Naiman et al. 2005; Mayer et al. 2007). But most riparian buffers that were reported effective on pollution removal were in less urbanized (Cadenasso et al. 2008). Paul & Meyer (2001), Groffman and Crawford (2003), Groffman et al. (2003), and Cadenasso et al. (2008) all indicated that urban riparian zones were not necessarily sinks of pollutants. Storm water draining pipes bypass riparian zones from the terrestrial ecosystem thereby compromising the filtering function of these buffers. In addition, groundwater tables can be lowered because of decreased infiltration and channel incision, causing a “hydrological drought” in riparian soils, which ultimately make the buffers pollution sources instead of sinks (Sukopp 1998; Paul & Meyer 2001; Groffman et al. 2002; Groffman et al. 2003).

These inconsistent results suggest that how LULC affect the dynamics of NPSP depends on site specific physical, biological, and chemical mechanisms (Goonetilleke et al. 2005). Hatt et al. (2004) criticized it to provide “little insight” by assigning a pattern of pollutant output to a particular LULC type. Mitigating urban NPSP by simply adding or removing particular LULC features was unlikely to achieve universal effectiveness.

It is undeniable that characteristics, spatial distribution, and management practices of

LULC in different places are appreciably different (Goonetilleke et al. 2005). Such variety is called “spatial complexity” or “spatial heterogeneity (Cadenasso et al. 2008). It is an extremely valuable concept to urban ecology and planning because most of the environmental problems in urban ecosystems are locally generated based on these specific conditions (Richards et al. 1996; Lammert and Allan 1999; Bousquet and Le Page 2004). They should be resolved by solutions accounting for the site-to-site variation (Basnyat et al. 1999; Bolund and Hunhammar 1999).

Nevertheless, spatial complexity has not been paid enough attention it deserves. Environmental (including NPSP) problems are often attributed to simplified measures of urbanization (Alberti et al. 2005) with a rough and vague description of urban surface. To list a few examples, Bolund and Hunhammar (1999) compared the environmental quality of “urban ecosystems” with their “rural equivalents”. Basnyat et al. (1999, 2000) identified “residential/urban/built-up” areas as strong contributors, and established significant correlation equations on the yield of nitrate and sediment by “forests”, “residential”, “agriculture”, “orchards”, and “grasslands”. Lee and Bang (2000) ranked the magnitude of pollutants unit loading rate of “urban land uses” in the following order (from high to low): high density residential, low density residential, industrial, and undeveloped. Paul and Meyer (2001) claimed that nitrogen concentrations in streams from “urbanization” were similar or greater than those draining “agricultural catchments”. Wang et al. (2007) reported that the water quality in “urban” areas was poorer than in the “suburban” or “rural” areas. Ballo et al. (2009) gave a different rank which made “commercial” the leading contributors of nitrogen, followed by traffic, industrial, and residential areas.

While the reality of “urban” is substantially complicated and different from place to place, the presentation of “urban” is often simplified to agglomerations of development or built-ups (Alberti et al. 2005). Environmental problems caused by site specific factors are attributed to the generalized term of “urbanization”. Mitigating the impacts becomes the recovery and restoration of “urban ecosystem” that only accounts for the green or blue areas in cities (McDonnell and Pickett 1990; Bolund and Hunhammar 1999; Cadenasso et al., 2006B; Gill et al. 2008; Yapp et al. 2010). Pickett et al. (1997A) entitled this type of urban ecology as “ecology in cities”, which treats urban environmental problems as an “averaging effect” of urbanization rather than depicting the specific ecological functions of each LULC feature in urban ecosystem (Goonetilleke et al. 2005). The multiplex human activities, which are the driving force of urban LULC changes and critical for explaining the highly complex differences of LULC features across spaces, are usually generalized as “human impacts” that only exacerbate already distinctive biophysical features of urban areas (Wilby 2003; Wilby and Perry 2006; Gill et al. 2007). These approaches link the overall environmental effects with the bulk of urbanization, leaving the subtle inherent mechanism veiled. Such conclusions can be misleading when the purpose is to make detailed decisions for particular urban design or development.

Addressing spatial complexity is critical to study and solve environmental problems in urban ecosystem. Urban areas are “Coupled Human and Nature Systems” (CHANS) where human and nature are dramatically interacting (Liu et al., 2007, p639). The environmental problems in urban areas are the comprehensive effects of such interactions (Cataldo and Rinaldi 2010). To address such comprehension, Pickett et al. (1997A) developed a new paradigm of urban ecology: “ecology of cities”. In this perspective, an urban ecosystem consists of everything that is ecologically relevant within the scope of urban area. Natural, built-up, and socioeconomic sectors are regarded as three interlinked subsystems of an integrated urban ecosystem (McDnnell and Pickett 1990; Pickett et al. 1997B; Grimm et al. 2000; Cadenasso et al. 2006; Cadenasso et al. 2008). Each of them represents a complex system of its own and affecting all the others ecologically at various structural and functional levels (Alberti 2005).

To capture the spatial complexity, it is essential to acknowledge that “urban” is an ambiguous, flexible, and localized term. It can only be meaningful in an explicit spatial and temporal background (Pickett and Cadenasso 2006; Schneider et al. 2010). For instance, in the U.S., urban area usually represents a place with a population no less than 50,000 with the population density at the central area no less than 1000 persons/mi^2 (about 390 persons/km^2) (OMB 1998; Knox and McCarthy 2005). In China, a place is considered “urban” when population density reaches 1500 persons/km^2, which is almost four times as that in the U.S. (Gu et al., 2008). The configuration of biophysical features, composition of built-ups, density of development, intensity of human activities, and style of human behaviors in urban ecosystems of these two countries would by no means be similar. The discrepancy in the definitions of “urban” determines how the scope of “urban ecosystem” is delineated.

Different definitions lead to different and complex physical appearances of “urban area” in localized urbanization practices. Urban landscape is often perceived as a mosaic of patches (Machlis et al. 1997). Unlike the relatively large homogenous patches in natural or agricultural landscapes, urban mosaics are smaller in size and differ dramatically in structure, composition, richness, functions, changes, and frequency (Cadenasso et al. 2006A). Scenes of landscape are various even within very short distances due to the mix of different features (e.g. buildings, surfaces, and plant species). The ecological effects of a certain urban area, thus, are presented by the combined functions of each individual feature in that area. For instance, a street tree could be a biofilter (Bratieres et al. 2008); pavement could act as collector of surface runoff; road curbs that are not outstanding in topographic data could actually dominate the pathway of surface runoff. The appeared environmental phenomenon is a sum of all these individual effects. McIntyre et al. (2000) stated "recognizing urban systems as heterogeneous mosaics was the key to explore urban ecological processes". Cadenasso et al. (2006B) also pointed out that spatial complexity yield a useful hypothesis for explaining the ecological interactions and changes in the city.

Environmental impacts due to human factors are rather huge. Urbanization is a necessity for the progression of humanity and civilization (DeFries et al. 2004; Kremen and Ostfeld 2005). The LULC transactions along with are promoted by human needs and wills of development (Svoray et al. 2005). Sometimes they can even be the primary drivers controlling urban ecological processes (Logan and Molotch 1987; Gottdiener and Hutchison 2000; Alberti et al. 2005; Grove et al. 2006). Every LULC feature in urban ecosystem carries some human-socioeconomic value (Cataldo and Rinaldi 2010). Some studies even noticed that people's education and income levels could also affect yields of NPS pollutants from residential gardens or yards due to various fertilization behaviors (Dietz and Clause 2004; Cadenasso et al. 2006B). The incorporation of human-affected biophysical features, artificial built-up, and socioeconomic influences have made urban ecosystems highly complicated and unpredictable (Bousquet and Le Page 2004).

LULC stand out reasonably to be a crucial tool for addressing spatial complexity. By definition, land cover refers to the observed biophysical cover of the lands’ surface irrespective of its uses; land use stands for how the land is being used by human; human activities occurring on the surfaces (FAO 1999; Danoedoro 2006; Cadenasso et al., 2007; Cadenasso et al. 2008). LULC information is the direct description of the three subsystems composing urban ecosystem—biophysical, built-up, and socioeconomic (Bauer and Steinnocher 2001; Bousquet and Le Page 2004; Kaye et al. 2006; Cataldo and Rinaldi 2010). Accurate and timely LULC information shall be valuable to reflect the complexity of urban ecosystems (Gilbert 1989; Sukopp et al. 1993; Breuste 1994; Pauleit and Duhme 2000; Cadenasso et al. 2006B).

2.2. LULC Classification Systems

LULC classification is used to manage LULC information on the basis of their commonalities (Sharpiro 1959; Witmer 1978). It names, defines, and describes land-surface features and categories them into designated classes (Shackelford 2003). To capture spatial complexity, a good LULC classification system shall be able to embrace the occurring, structure, and inherent interaction of surface features in the urban ecosystem. Unfortunately, most existing LULC classification systems do not own such comprehension and sophistication.

It has to be pointed out that, firstly, the following discussion is confined within the scope of urban and suburban areas that are intensively affected by urbanization, especially in Shanghai and Lingang. Rural, natural, or wild landscapes are not the target of this article. Secondly, the discussion of LULC in this article stays on the conceptual interpretation of urban ecosystems, including the contents, structures, and relationships. Specific technologies, such as remote sensing sensors or classification algorithms, are not interested, though they would be mentions if necessary.

2.2.1. Conventional LULC Classification Systems

Typically, there are two steps in a process of developing a LULC system: division and grouping (Witmer 1978). The targeted land surface is first divided into distinctive patches/objects based on their physical or socioeconomic appearances. After that, all patches/objects are grouped into various classes as long as objects in a class have "definable characteristics in common" (Sharpiro 1959). Coarser scale classes can be further broken down to more detailed fine-grained subdivisions using the same processes.

Regular top-level division is to separate human and natural sectors (Witmer 1978; Cadenasso et al. 2006B). The human sector refers to urban development that is thoroughly affected by human activities and dominated by the built-up environment (Pickett and Cadenasso 2006; Schneider et al. 2010). "Urban" is therefore distinguished from natural or biophysical features, only representing the impervious built-up environment together with associated socioeconomic human activities (Chapin and Kaiser 1979; Wolman 1987; Bhaduri et al. 2000; Jansen and Di Gregorio 2003). On the other hand, the natural sector refers to biophysical features such as vegetation and water bodies (Cadenasso et al. 2006A).

The separation of human and nature makes a dichotomic understanding of urban ecosystem (Cadenasso et al. 2008). The loci of urban studies is primarily within the social sciences, geography, economics, and urban planning fields, with scant attention paid to ecological impacts (Pickett and Cadenasso 2006; Dale et al. 2000). On the contrary, ecologists, even in urban ecology fields, usually focus mainly on natural elements within the urban areas. Human factors are often regarded as negative external influences because ecological processes in urban areas are presumably overwhelmed by human alterations (Cadenasso et al. 2006A; Pickett and Cadenasso 2006). Such specifically focused research requires dedicated LULC data to meet their needs. Therefore, LULC classification systems can be usually sorted into two major types—urban-oriented ("people-oriented" as in Anderson et al. 1976) and natural-oriented.

2.2.2. "Urban-Oriented" LULC Classification Systems

The following two LULC systems have shown great efforts to classify urban land uses during the vast urbanization processes post war. They provide significant conceptual and structural basis for the development of newer systems. During the 1950s and 1960s, American planners across all levels of government were actively engaged in land use and land cover mapping activities as part of planning for the anticipated urban expansion (Anderson 1971). To guide land use and land cover data collection and information generation, new LULC systems were developed in place of their "predominantly morphological" ancestors (Anderson 1971), such as the Major Land Uses in the United States (Marschner 1950). Stimulating representatives of these systems include the one proposed by Sharpiro (1959) and the Standard Land Use Coding Manual (SLUCM 1965).

Sharpiro characterized his system emphasizing human activities because he believed that urban areas are geographic footprints of human activities (Sharpiro 1959). This system is “extracted from all individual human activities that people could experience in an urban life at that time”, which makes it exclusively human centric (Table 2.1).

TABLE 2.1: Sharpiro’s land use system (partial) (Sharpiro 1959)

Primary Activity	**Corresponding Types of Establishment**
Buying	Buyer, Residence Buyer
Communicating	Broadcasting and Receiving Station, Newspaper Publishing Establishment
Displaying	Art Gallery, Museum
Dwelling	
Housekeeping	Family Unit, Trailer Camp
Non-housekeeping	Hotel, Rooming House
Entertaining(or Playing)	
As Spectators	Athletic Field, Motion Picture House
As Participants	Bowling Alley, Dance Hall
Instructing	College, Vocational School
Selling	
Retail	Camera Shop, Stationery Dealer
Wholesale	Building Materials Yard, Produce Dealer
Transporting	Railroad Trackage
…	…
Raising and/or developing	Chicken Hatchery Greenhouse

The Standard Land Use Coding Manual (SLUCM, 1965) introduced a regulation of categorizing LULC types into a hierarchical mechanism, which shed lights on how to arrange LULC across various scales for followers. It developed a thorough inventory of LULC types (primarily for urban uses and activities) by breaking down them into four levels of detail. On the top (the coarsest) level were nine one-digit categories, cascaded to

67 two-digit categories (Table 2.2A), 294 three-digit categories, and 772 four-digit categories with each representing finer grained land uses respectively (Table 2.2B).

TABLE 2.2: Land use classes in the Standard Land Use Coding Manual (partial) (SLUCM 1965)

A. One-digit categories and a sample of two-digit categories (including all nature related classes)

Code	Category	Code	Category
1	Residential	11 12 13 14 15 19	Household units Group quarters Residential hotels Mobile home parks or courts Transient lodgings Other residential, NEC
2	Manufacturing		
3	Manufacturing (cont.)		
4	Transportation, communication, and utilities		
5	Trade		
6	Services		
7	Cultural, entertainment, and recreational	76	… Parks
8	Resource production and extraction	83	… Forestry activities and related services …
9	Undeveloped land and water areas	91 92 93	Undeveloped and unused land area (excluding noncommercial forest development) Noncommercial Forest development Water areas

TABLE 2.2 (Continued): Land use classes in the Standard Land Use Coding Manual (partial) (SLUCM 1965)

B. A sample of three- and four-digit categories (including all nature related classes)

Code	Category	Code	Category
110	Household units	1100	Household units
121	Rooming and boarding house	1210	Rooming and boarding houses
122	Membership lodgings	1221 1229	Fraternity and sorority houses Other membership lodgings
…	…	…	…
761	Parks—general recreation	7610	Parks—general recreation
762	Parks—leisure and ornamental	7620	Parks—leisure and ornamental
763	Other parks, NEC	7630	Other parks, NEC
…	…	…	…
831	Commercial forestry production	8311	Timber production—predominantly for pulp wood
		8312	Timber production—predominantly for saw logs
		8313	Timber production—predominantly for veneer logs
		8314	Timber production—mixed uses
		8315	Tree products production—predominantly gum extracting (except pine gum) and bark
		8316	Tree products production—predominantly pine gum extraction
		8317	Timber and tree products production—mixed uses
		8319	Other commercial forestry production
832	Forestry services	8321	Forest nurseries
		8329	Other forestry services
839	Other forestry activities and related services	8390	Other forestry activities and related services
…	…	…	…
910	Undeveloped and unused land area (excluding noncommercial forest development)	9100	Undeveloped and unused land area (excluding noncommercial forest development)
921	Forest reserves	9211	Forest reserves (wilderness areas)
		9212	Forest reserves (wildlife refuges)
		9219	Other forest reserves
922	Nonreserve forests (undeveloped)	9220	Nonreserve forests (undeveloped)
931	Rivers, streams, or creeks	9310	Rivers, streams, or creeks
932	Lakes	9320	Lakes
933	Bays or lagoons	9330	Bays or lagoons
934	Oceans and seas	9340	Oceans and seas
939	Other water areas	9390	Other water areas

These two systems have shed light on the development of new LULC systems. Spatial explicitness underlying Sharpiro’s theory is integral to the identification of distinctive ecological characteristics and functions of urban ecosystem features (Cadenasso et al. 2006A). It is a core value for addressing spatial complexity. The hierarchical approach of SLUCM (1965) provided well-stated logic basis of managing LULC data, which has been widely adopted by subsequent LULC classification practices, including the well-known Anderson’s classification system (Anderson 1971; Anderson et al. 1976; Witmer 1978).

2.2.3. The Industrial Standard: Anderson’s “Natural-Oriented” LULC Classification System

By adopting the essences of the Shapiro’s and SLUCM systems, Anderson and his colleague achieved great success on creating a new system that almost became role model of LULC classification. The 1970s’ saw an increasing demand for the knowledge about land use and land cover in the United States to deal with land resource problems (Anderson et al. 1976). Knowing the LULC distribution, area, and information on their changing proportions could help determine better land use policies. Meanwhile, with the emersion of remote sensing (RS) technologies and data, a firm standardization for RS data processing was critical to gain better spatial data and facilitate data reuse (Hardy and Anderson 1973; Anderson et al. 1976). In order to provide such a relevant and useful tool for the management of national land resources, Anderson and his colleagues developed a new LULC system.

Unlike the two predecessors that focused on urban uses, the developers specifically emphasized that nature resources were the primary focus of the new system (Anderson et al. 1976, p.14):

> *Although there is an obvious need for an urban-oriented land use classification system, which accounts for less than 5% of the total area of the United States, there is also a need for a resource oriented classification system whose primary emphasis would be the remaining 95% of the United States land area.*

Anderson’s system has nine top-level (coarsest) categories of features, among which only one was human related—“urban or built-up land” (Table 2.3 and Table 2.4).

This system immediately became the “industry standard” of LULC classification because of its generality and completeness (Cadenasso et al. 2007). It has been used either directly or as the basis for developing more dedicated LULC systems in a wide variety of disciplines over the world, including (but not limited to) land resource management, agriculture and food, forest management, urban planning, environmental monitoring, climate change studies, etc.

Unsurprisingly, studies using Anderson’s system or its derivatives automatically adopted the philosophy of dividing human and nature into two separate systems when had an inclination to underestimate the urban sector. “Urban” is often simplified into an assembly of static and planar patches of man-made objects. These systems (conventional systems, thereafter) have serious conceptual deficiencies on interpreting the complex urban ecosystem in the following ways.

TABLE 2.3: Level I and II of Anderson’s classification

Level I	**Level II**
1. Urban or Built-up Land	11. Residential
	12. Commercial and Services
	13. Industry
	14. Transportation, Communications, and Utilities
	15. Industrial and Commercial Complexes
	16. Mixed Urban or Built-up Land
	17. Other Urban or Built-up Land
2. Agricultural Land	21. Cropland and Pasture
	22.Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas
	23. Confined Feeding Operations
	24. Other Agricultural Land
3. Rangeland	31. Herbaceous Rangeland
	32. Shrub and Brush Rangeland
	33. Mixed Rangeland
4. Forest Land	41. Deciduous Forest Land
	42. Evergreen Forest Land
	43. Mixed Forest Land
5. Water	51. Streams and Canals
	52. Lakes
	53. Reservoirs
	54. Bays and Estuaries
6. Wetland	61. Forested Wetland
	62. Nonforested Wetland
7. Barren Land	71. Dry Salt Flats
	72. Beaches
	73. Sandy Areas other than Beaches
	74. Bare Exposed Rock
	75. Strip Mine Quarries, and Gravel Pits
	76. Transitional Areas
	77. Mixed Barren Land
8. Tundra	81. Shrub and Brush Tundra
	82. Herbaceous Tundra
	83. Bare Ground Tundra
	84. Wet Tundra
	85. Mixed Tundra
9. Perennial Snow or Ice	91. Perennial Snowfields
	92. Glaciers

TABLE 2.4: Level III classes for urban residential areas

Level I	Level II	Level III
1. Urban or built-up	11. Residential	111. Single-family Units 112. Multi-family Units 113. Group Quarters 114. Residential Hotels 115. Mobile Home Parks 116. Transient Lodging 117. Other

2.3. Conceptual Deficiencies of Conventional LULC Systems on Representing Urban Ecosystem

2.3.1. The Dilemma of Urban Greenness

In LULC, urban greenness is in an awkward situation due to the separation of "urban" and "natural". In order to generalize the endlessly evolving elements on urban surfaces into a fixed set of pre-defined classes, most conventional LULC systems unavoidably simplify or reduce the aspects they do not emphasize, even though those aspects are complicated or significant (Jansen and Di Gregorio 2002; Alberti 2005; Cadenasso et al., 2006). For example, Anderson et al. 1976 (p.17) stated that the "urban or built-up" category should dominate the urban greenness:

> *The Urban or Built-up category takes precedence over others when the criteria for more than one category are met. Residential areas that have sufficient tree cover to meet Forest Land criteria will be placed in the Residential category.*

While Schneider et al. (2010, p.1735) thought otherwise:

> *Urban areas are places that are dominated by the built environment. The 'built environment' includes all non-vegetative, human-constructed elements, such as buildings, roads, runways, etc. (i.e. a mix of human-made surfaces and materials), and 'dominated' implies coverage greater than or equal to 50% of a given landscape unit (here, the pixel). Pixels that are predominantly vegetated (e.g. a park) are not considered urban, even though in terms of land use, they may function as urban space.*

Such understanding and presentation of urban greenness is not rare. More examples are listed in Table 2.5.

TABLE 2.5: Examples of LULC systems that treat "urban" and "nature" as separated sectors

Sources	**Purpose**	**LULC classes**	**Scale**
Bhaduri et al. 2000	Hydrologic impacts (NPSP) of LULC changes	Urban LULC ● Low-density residential ● High-density residential ● Commercial ● Industrial Non-urban LULC ● Agricultural ● Grass/pasture ● Forest	Watershed & subbasin

TABLE 2.5 (Continued): Examples of LULC systems that treat "urban" and "nature" as separated sectors

Sources	**Purpose**	**LULC classes**	**Scale**
Jansen and DiGregorio 2003	LULC data collection	Urban LULC ● Commercial ● Residential ● Industrial ● Transportation facilities ● Recreational facilities ● Sewage disposal/treatment Non-urban LU ● Agriculture ● Forestry ● Water reservoirs	City
Schneider et al. 2010	Mapping global urban areas	Urban LULC ● Urban areas Non-urban LULC ● Evergreen needleleaf forest ● Evergreen broadleaf forest ● Deciduous needleleaf forest ● Deciduous broadleaf forest ● Mixed forest ● Closed shrubland ● Open shrubland ● Woody savanna ● Savanna ● Grassland ● Permanent wetlands ● Croplands ● Crop-vegetation mosaic ● Snow, ice ● Barren ● water	Global

TABLE 2.5 (Continued): Examples of LULC systems that treat "urban" and "nature" as separated sectors

Sources	**Purpose**	**LULC classes**	**Scale**
CLUC 2007	National standard of land use classification standard in China	Urban LULC ● Business and services ● Industry and warehouses ● Residential ● Administrative and public service ● Special ● Transportation Non-urban LULC ● Agricultural ● Orchard ● Forest ● grassland ● Water	National
Basnyat et al. 1999	Linking LULC types with NPSP yield	Urban LULC ● Residential area Non-urban LULC ● Forest ● Barren land ● Orchards ● Agricultural ● Grassland	Watershed
Ballo et al. 2008	Management of urban runoff	Urban LULC ● Residential ● Industrial ● Commercial ● Road surfaces ● Public facilities Non-urban LULC ● Agricultural ● Greenbelts (forest) ● Miscellaneous purposes	Local (blocks)

TABLE 2.6: Urban greenness in urban Shanghai (1990-2008)

Year	Area of urban greenness (ha)	Number of street trees (10,000 trees)	Proportional coverage of vegetation (%)
1990	3 570	23	12.4
1995	6 561	33	16.0
1996	7 231	41	17.0
1997	7 849	43	17.8
1998	8 855	48	19.1
1999	11 117	54	20.3
2000	12 601	57	22.2
2001	14 771	65	23.8
2002	18 758	68	30.0
2003	24 426	74	35.2
2004	26 689	80	36.0
2005	28 865	83	37.0
2006	30 609	86	37.3
2007	31 795	69	37.6
2008	34 256	73	38.0

Source: Shanghai Statistics Year Book (2011)

From ecological perspective, it is not appropriate to merge greenness into urban development or exclude it from the concept of “urban”. In a “coupled human and nature” urban ecosystem where the highest intensity of human-nature interaction takes place (Liu et al. 2007), greenness and built-ups are commensal. Greenness occupies a non-ignorable portion of urban surfaces. By 2008, the proportional coverage of vegetated surface in Shanghai has reached 38% (Table 2.6). On the other hand, in cities, especially big ones like Shanghai, purely natural-born vegetation is scarce. Plants are cultivated and maintained regularly by human. Ecosystem functions or services of urban greenness could be different from its natural siblings. Bolund and Hunhammar (1999) summarized six direct ecosystem services offered by urban greenness: air filtering, micro-climate regulation, noise reduction, rainwater drainage, sewage treatment, and recreational and cultural values. Each is related to humanity. The perspective that either diminishes or excludes urban greenness is likely to underestimate its impacts (especially negative ones) to urban ecosystem, which might lead to misleading conclusions or strategies.

2.3.2. LULC beyond Remote Sensing Interpretation

The booming of remote sensing (RS) techniques is tremendously beneficial to LULC data application. Techniques and products such as high-resolution images, Radar, LiDAR, Sonar, multi-spectral sensors and other RS devices have created a huge pool of resources for LULC data extraction (Lucieer 2008). Emerging new algorithms (e.g. per-pixel, subpixel, object-oriented, per-field, fuzzy, contextual, neural network approaches, etc.) have improved the accuracy and precision of LULC interpretation (Lu and Weng 2007; Beekhuizen and Clarke 2010; Blaschke 2010; Ustin and Gamon 2010).

Unfortunately, advantages of modern RS technologies are not fully appreciated because the conceptualization of urban LULC does not keep up with the progress of urbanization. High-resolution RS imagery guarantees delineation of finer grained objects (which indeed helps depict complexity). But these fine-grained objects could be converted to accurate LULC data only when there are correct pre-defined classes existing in the applied LULC system, which is unfortunately often not the case (Lu and Weng 2007; Cadenasso et al. 2007; Gill et al. 2008). For instance, Carleer et al. (2005) assessed the accuracy of four imagery interpretation algorithms based on high-resolution images. The algorithms were highly capable in identifying fine-grained patches. But these patches were classified into classes such as residential, urban administrative zones, urban dwelling zones, which were initially defined for statewide- or intrastate-scale applications. Similar examples of mismatching the level of details between detailed patches captured by RS and rough LULC classes are not rare (e.g. Bhaduri et al. 1997; Charbeneau and Barrett 1998; Brezonik and Stadelmann 2001; Tong and Chen 2002; Zampella et al. 2007). Valuable information concerning spatial complexity is lost (Cadenasso et al. 2007).

2.3.3. The Measurement of Density

Density is an important metric in urban ecology and urban planning. The Oxford dictionary defines density as “The quantity of things in a given area”. In urban planning, the definition of density can be specified as the quantity of development or population in a given urban area. It indicates the level of intensity and efficiency human make use of land resources (Neuman 2005). It has significant value for urban planning and ecology in terms of urban forms, efficiency of urban economic performance, urban sustainability, urban livability, etc. (e.g. Cervero 2001; Neuman 2005; Li 2007; Schneider and Woodcock 2008; Zhao 2011). Some people argued that compact cites with higher density are more sustainable and economically efficient because of the conservation of land, better utility of energy and resource, higher accessibility, less dependence on motor vehicles, less social segregation, etc. (McHarg 1969; Jackson 1985; Downs 1994; Echenique and Saint 2001; Fulton et al. 2002). Others insist that for a livable city, functions and population must be dispersed at lower densities in order to enjoy more peaceful life, better environment, attractive view sights, etc. (Wiersinga 1997; Song and Knaap 2004).

Conventional LULC systems usually use terms like “open space”, “low density/intensity", "medium density/intensity", and "high density/intensity" to describe density. The National Land Cover Database defined these terms in particular (Homer et al. 2004, p836):

> Developed, Open Space: Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
>
> Developed, Low Intensity: Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20–49 percent of total cover. These areas most commonly include single-family housing units.
>
> Developed, Medium Intensity: Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50–79 percent of the total cover. These areas most commonly include single-family housing units.
>
> Developed, High Intensity: Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses, and commercial/industrial. Impervious surfaces account for 80 to 100 percent of the total

cover.

The “impervious coverage ratio” (ICR) is a widely accepted measurement for urban density (Bhaduri et al. 1997; Lee and Bang 2000; Jansen and Digregorio 2003; Pan et al. 2008). It indicates the ratio of the areas of imperviousness over the total area.

However, ICR is not sufficiently correct for contemporary urban areas because it neglects an important factor—the vertical dimension. The spread of urban areas is not just two-dimensional. Cities are growing taller. Using Shanghai as an example, the past decade has witnessed an incredible 483% increase of high-rise buildings in this city (Table 2.7). The vertical dimension is important to density measurement because the rise in height actually multiplies the carrying capacity (or volume) per unit area.

A more accurate measurement for density would be the floor area ratio (FAR). It stands for the ratio of the gross floor area of all buildings over the total area in a given piece of land (Pan et al. 2008). But information of height is not easy to retrieve. Probably it is why FAR is not sufficiently used in LULC related studies. Only a few techniques are able to provide height information, such as the Light Detection and Ranging (LiDAR), field survey, or estimating building shadows from high resolution RS images (Pan et al. 2008). But these methods are either costly or time/labor consuming while their reliability is not high.

TABLE 2.7: Number of buildings higher than 8 floors in Shanghai

	Unit	**2000**	**2009**	**2010**
Total	Buildings	3,529	19,183	20,579
	10^4m^2	6,180	20,464	21,911
8～10 floors	Buildings	536	2,369	2,744
	10^4m^2	451	2,196	2,430
11～15 floors	Buildings	684	8,992	9,672
	10^4m^2	875	5,783	6,320
16～19 floors	Buildings	831	3,995	4,247
	10^4m^2	1,100	4,199	4,449
20～29 floors	Buildings	1,266	2,852	2,936
	10^4m^2	2,695	5,203	5,504
≥30 floors	Buildings	212	975	980
	10^4m^2	1,059	3,083	3,208

Source: Shanghai Statistics Year Book 2011

It is recommended to measure ICR and FAR together in order to fully address urban density. Figure 2.1 demonstrates four scenarios of ICR and FAR combination using real-case examples in Shanghai:

A. High ICR (0.65) with High FAR (4.5);

B: Low ICR (0.4) with High FAR (3.0);

C: High ICR (0.55) with Low FAR (1.5);

D: Low ICR (0.5) with Low FAR (0.9).

It is for sure that the “high-high” scenario represents high density, while the “low-low” scenario indicates low density. The other two lies in between but represents different utilization patterns of land resources. High ICR with low FAR indicates a sprawl situation, suggesting inefficient use of land (Pan et al. 2008). On the contrary, low ICR with high FAR suggests a compact development situation where more land is conserved.

FIGURE 2.1: Examples of density scenarios

2.3.4. The Discrepancy between “Land Use” and “Land Cover”

Land use and land cover are two terms with distinct definitions (socioeconomic activity vs. physical state) yet intertwine tightly with each other. In many cases, land use and land cover are often used interchangeably. Urban area and associated impervious surface are sometimes recognized as land cover (e.g. Hatt et al. 2004; Homer et al. 2004; Fry et al. 2009) or as land use in some other cases (e.g. Paul & Meyer 2001; Groffman et al. 2003; Jansen and DiGregorio 2003; Lubowski et al. 2006). Anderson et al. (1976) pointed out that:

> *Concepts concerning land cover and land use activity are closely related and in many cases have been used interchangeably. The purposes for which lands are being used commonly have associated types of cover.*

The assumption is that when a class is defined in an LULC system, it is automatically attached with a package of “definable characteristics in common” which distinguish it from the others. Therefore, it is possible to extract socioeconomic information from RS imagery by assessing physical patterns of urban areas (Alberti 2005). Most urban ecology studies follow this assumption when using LULC as explanatory variables. When “urban” is equaled to “built-up”, urban environmental problems are very likely to be only attributed to the artificial things made of steel and cement (e.g. Wang et al. 2007, Zhang et al. 2009).

Such rigid definition of LULC types simplifies the complexity of urban ecosystem. It has to be acknowledged that features of the same LULC class in different places might not be the same at all (Pauleit and Duhme 2000). For example, low-density development would easily be connected to high coverage of greenness by default. But it is not always true. Real-world LULC is much more complicated than the digitized LULC data.

Inside the physical development are tanglesome mixtures of human activities. For example, in China, people would appreciate daily services within walking distance. Mixed land use with maximum access to a variety of service is welcome. Figure 2.2 shows a rather special case of a business-residential dual-purpose building. The land is zoned as commercial and business use. But the suites in the building are used as either apartments or offices. There is even a shopping center and a health care facility in it. It is hard to tell what this building is used for only based on its appearance. The patch of this building is likely to be classified as a “mixed use” type according to the Anderson’s classification, which only makes it fussier.

Beyond the complexity of mixed human activities are the rather complicated ecological performances. For instance, in the aforementioned dual-purpose building, whether a suite is used as apartment or office would cause fundamentally different ecological implications such as (but not limited to) energy consumption, wastes production, demand of vehicle-trips, etc. The only chance for handling these characteristics properly is when the LULC data is more specified rather than generalized.

FIGURE 2.2: Outlook of a business-residential dual-purpose building

2.4. LULC Systems Attempted to Incorporate Urban Ecosystems

What is encouraging is that spatial complexity has been drawing increasing attention. New classification methods are proposed to incorporate it into LULC data. Examples include soft classifier, the urban morphological types (UMT) approach, knowledge-based approach, and the High Ecological Resolution Classification for Urban Landscapes and Environmental System (HERCULES). Soft classifier assigns multiple LULC types to one pixel in a remote sensing imagery instead of assigning the pixel only with the major type (Whitford et al. 2001; Pauleit et al. 2005; Beekhuizen and Clarke 2010). Each type occupies a share of the pixel based on its proportional coverage. But its usefulness is diminishing when higher resolution imageries are available (Ustin and Gamon 2010).

The UMT approach attempts to provide more accurate LULC data for modeling environmental performance of urban areas (Gill et al. 2007). All urban LULC are classified into 29 urban morphological types, which are defined by their specific configuration of built-up and natural elements (Gill et al. 2008). Each UMT has a set of distinctive characteristics, whose proportional coverage is pre-determined (Pauleit and Duhme, 2000; Gill et al. 2008). For example, “high-density residential” consists of 30.5% buildings, 37.5% other impervious surfaces, 7.25% trees, 7.5% shrub, 15.25% mown grass, 0.25% rough grass, 0.25% cultivated area, 0.5% water body, and 1% bare soil or gravel. Therefore, the UMT of “high-density residential” is a combination of nine land cover types. However, by assigning constant values of land cover proportion, UMT can only distinguish the inter-type variations. In reality, parcels of the same UMT could have very different percentage of each LULC type.

Knowledge-based classification focuses on collecting comprehensive LULC information other than RS image extraction. Thanks to the increasing resources of ancillary data, such as terrain, soil types, housing, census, traffic network, and climate, information beyond what can been seen from RS imagery can be deduced. For example, topographic data could be helpful to differentiate vegetation species; land uses and human activities can be distinguished based on census data (population, housing, and road densities) (Lu and Weng 2007). It is particularly useful when direct data of human activities is not available.

HERCULES (High Ecological Resolution Classification for Urban Landscapes and Environmental System) focuses on revealing the heterogeneity of urban ecosystems (Cadenasso et al. 2006A; Cadenasso et al. 2007). Unlike other systems that try to differentiate as many distinct LULC types as possible, HERCULES simplifies urban surface into merely three major classes—building, surface, and vegetation, and nine subclasses (five for building—single structures, connected structures, mixed structures, high-rises, and towers; two for surface—paved, bare soil; and two for vegetation—fine, coarse). When every patch in the LULC map has been assigned to a subclass, a grid is laid onto the map to determine the surface cover in each cell—similar to some soft classification methods (e.g. Whitford et al., 2001; Pauleit et al., 2005). A cell is defined by the class and subclass it is assigned to, and their respective proportional coverage. It shows not only the physical existence, but also the spatial pattern of the land the cell represents (Cadenasso et al. 2008). HERCULES is able to reflect the land surfaces more realistically than the rigid UMT approach. But the designer of HERCULES did not attach any land use information to it, which became its primary deficiency.

In summary, the reviewed literature identifies a gap in our knowledge and understanding of urban systems and gives rise to my primary hypothesis: spatial complexity is the key factor leading to the variation of ecological dynamics in different urban ecosystems. Urban areas are the hot spots where human and natural forces interacting intensively. Physical and socioeconomic attributes intertwine actively to create new or deviated ecological effects that differ from how people generally understand if they were in a natural ecosystem. In addition, some of these attributes are inherent and sometimes invisible. Few of existing LULC classification methods, no matter conventional or innovative ones, are able to embrace all these attributes comprehensively. Consequently, the complexity of urban ecosystem is often underestimated. In this article, an innovative LULC classification method is introduced in responding to the desire for addressing spatial complexity. It is then applied to a case study that investigates the LULC-NPSP relationship in Lingang, in order to testify the relevance of spatial complexity in explaining urban ecosystem dynamics, and look for explanation to the water degradation problem in Lingang as well.

CHAPTER 3: METHODOLOGY AND CASE STUDY

3.1. The Innovative LULC Classification: Multi-Attribute Land Object (MALO)

To ultimately testify the primary hypothesis that spatial complexity is the key explanatory factor for urban ecological dynamics, a LULC classification system that can properly reflect spatial complexity is essential. Such a system shall be able to 1) incorporate natural, built-up, and socioeconomic subsystems as equally valuable components in urban ecosystem; 2) accommodate information from all possible sources; and 3) link discrete physical and socioeconomic information to reflect interactions and relationships internally and externally.

In responding to these requirements, an innovative method is proposed: the Multi-Attribute Land Object (MALO) approach. Enlightened by the aforementioned classification systems, particularly Sharpiro's for spatial explicitness, UMT and HERCULES for LULC structure, MALO arranges LULC characteristics with three primary components: Object; Attribute; and Scale.

An object represents a unit or patch that has distinguishable boundaries from the surroundings on the land surfaces. It can be a tree, a sidewalk, a building, a block, or a larger piece of land, depending on what level of detail is desired. Each object is a container of LULC information. Its meanings, characteristics, and relationships to other objects are all determined by the attributes attached to it.

Attribute describes the physical or socioeconomic traits of objects. Each attribute indicates one aspect of land use or land cover, which can be categorized into one of the three subsystems of urban ecosystem. A fundamental difference of MALO to the conventional systems is that, instead of having a fixed set of attributes, a land object in

MALO can contain infinite number of attributes simultaneously as long as they are relevant for defining the object.

Scale determines the level of detail that the objects and attributes shall approach to meet the needs of the user. Scale is relevant because it controls the effectiveness of objects and attributes. For example, if the research focuses on the impacts of roof materials to rain water quality (e.g. Ballo et al. 2009), finer scale would be preferred given individual buildings or pavement surfaces are the research units. If the environmental impact of density is the major concern, objects should be defined at the level of blocks or neighborhoods, since ICR and FAR cannot be calculated on the basis of individual buildings.

Table 3.1 demonstrated to classify a piece of roadside landscaping green space by MALO. The object is the entire piece of greenness. The vegetation certainly puts this object into the natural sector. A second attribute within the natural sector is permeability. This piece of land is pervious. It seems to be redundant to assign “pervious” to a vegetated surface. But sometimes, urban vegetation might not be completely permeable due to the way in which they are planted or structured. On the contrary, pavements are not always impervious due to new technologies such as permeable paver. It has to be noticed that, in MALO, it is not suggested to assume automatic bond between attributes (such as “green space is permeable”). Each attribute is independent.

In a conventional method, the classification is done. But in MALO, the object still needs to be put into the other two subsystems: socioeconomic and physical built-up. The first socioeconomic attribute is maintenance. Plants in this piece of land rely on human affects such as planting, trimming, watering and fertilizing, etc. The second human/socioeconomic attribute is the type of the green space—roadside landscaping. Its primary purpose is for recreational or aesthetic use, which is recognized as the most significant ecosystem service of urban greenness (Bolund and Hunhammar 1999). In the built-up sector, this green space also has an attribute: it is placed in a frame of concrete curbs. This is a very common structure for urban greenness in Shanghai. But the ecological consequence of such structure is significant. It alters the hydrology by preventing surface runoff flowing in. In summary, the sampled object is a piece of human maintained roadside-landscaping vegetation with multiple species of plants restrained by concrete curbs. The attributes can be further extended if any other information (e.g. types of plants) is of particular information.

TABLE 3.1: Example of object and attributes in MALO

	Attribute	LULC	Subsystem
1	Coarse vegetation (mixture of trees, brushes, and grass)	Land cover	Natural
2	Fully Permeable	Land cover	Natural
3	Artificially planted and maintained	Land use	Human/ socioeconomic
4	Roadside landscaping for recreational use	Land use	Human/ socioeconomic
5	Restrained by concrete curbs	Land cover	Built-up

In general, MALO organizes LULC not by generalization or classification, but by assembling and connecting information from various sources and aspects. New elements or new attributes of existing elements are introduced into urban ecosystem in an unprecedentedly rapid pace. It is unlikely that a system with finite number of pre-defined

LULC classes can keep up with these changes. MALO is more flexible because in addition to defining new classes, it reflects the “personality” of objects by making new combinations of existing classes. Objects can be grouped by attributes they share, and differentiated by attributes that are distinctive from others. This is the method how MALO addresses spatial complexity. In the following section, the effectiveness of MALO will be tested by a case study in Lingang focusing on the relationship between urban LULC and NPSP.

3.2. Case Study

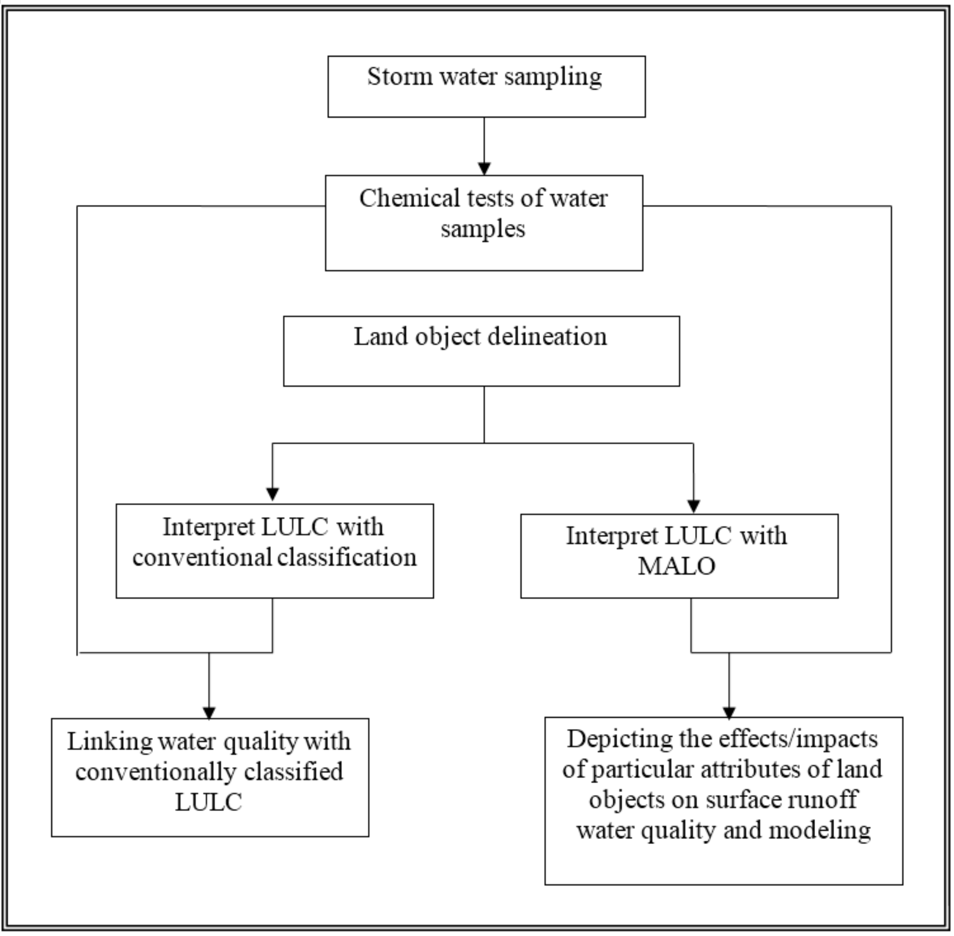

FIGURE 3.1: Method flow of the case study

Instead of attributing urban ecological phenomena to generalized LULC items, the hypothesis of this article argues that it is the very localized and specific combination of LULC objects and attributes that affects ecosystem dynamics and causes the various results. A case study is conducted with the purpose is to testify whether spatial complexity indeed has stronger explanatory power to achieve deeper insight of the LULC-NPSP relationship. Figure 3.1 shows the general pathway of the case study.

3.2.1. Study Area

This study was conducted in the urbanized area of Lingang, covering a 22 km^2 piece of the main city and a part of the logistic park (Figure 3.2). In accordance with the master zoning plan, the study area is divided into different functional zones (Figure 3.3). Immediately next to the lake is the business/commercial (BC) area primarily consists of high-density office building complexes. Next to BC is an urban forest (UF) in the form of a green bend. Like most urban vegetation, UF is cultivated and maintained by human. To the west of UF is a clustered residential area (CR) of apartment neighborhoods. Two universities (Shanghai Ocean University and Shanghai Maritime University) are located to the southwest of CR. This area is labeled as educational (ED). The logistics park, labeled as industrial/warehousing (IW), is next to ED towards southwest. It is the hub of transportation detaining goods in and out of Lingang.

FIGURE 3.2: Study area (yellow framed)

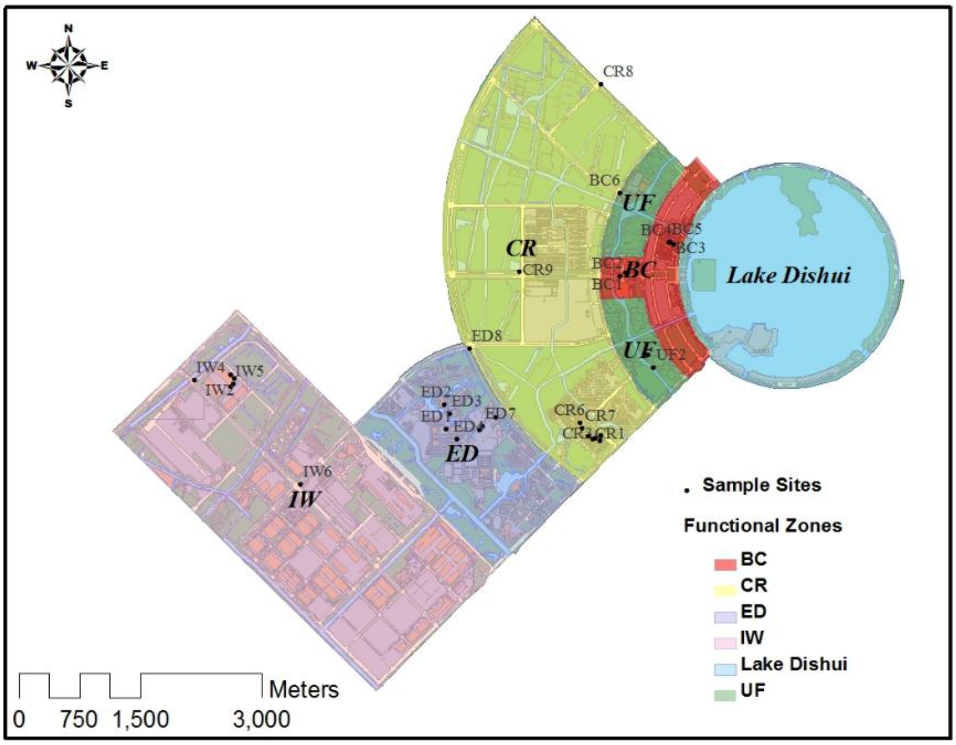

FIGURE 3.3: Distribution of functional zones and sample sites in the study area

3.2.2. Methods

3.2.2.1. Storm Water Sampling and Testing

Storm water samples were collected in nine rainfall events in two years (4 in 2010 and 5 in 2011). Samples were taken at roadside drainage inlets (catch basins) catching incoming storm water. For the four trips in 2010, 8 sites were sampled each time. For the five trips in 2011, 31 sites were sampled each time. The distribution of the sites is: (For 2010) 2 in BC, 1 in UF, 3 in CR, and 1 in IW; and (for 2011) 6 in BC, 2 in UF, 8 in CR, 8 in ED, 6 in IW, and 1 in construction area (see Figure 3.3). Two tipping buckets (Model: HOBO Data Logging Rain Gauge - RG3-M, Onset Computer Corporation, U.S.) were installed on the roof of two buildings in the study area to take records of precipitation data (Table 3.2).

TABLE 3.2: Hydrologic description of sampled rainfall events

Date yyyy-mm-dd	Precipitation (mm)	Duration (min)	Mean Intensity (mm/5min)	Peak Intensity (mm/5min)	Time since last rain (hr)
2010-04-21	25.8	83	1.5	4.40	170
2010-06-21	5.6	79	0.35	0.81	20
2010-09-01	2.6	67	0.19	0.49	49
2010-12-12	21.9	152	0.72	3.58	236
2011-04-22	13.0	582	0.11	0.50	150
2011-05-23	N/A[1]	N/A[1]	N/A[1]	N/A[1]	N/A[1]
2011-06-04	16.2[2]	1546[2]	0.05[2]	N/A[1]	N/A[1]
2011-08-07	30.4	664	0.23	3.33	155
2011-09-15	9.8	154	0.32	2.14	99

Different methods for taking water samples were applied. For the four events in 2010, water samples were collected manually at all eight sites simultaneously with polyethylene buckets as soon as surface runoff was generated. A 1L sample was taken

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[1] Data not available due to equipment malfunction.

[2] Data retrieved from China Meteorological Bureau (www.weather.com.cn).

from each site every 5 minutes for the first 30 minutes of the rainfall. After 30 minutes, the interval was extended to once every 20 to 30 minutes until the end of the rain. Water samples were stored in sealed 1L polyethylene sample bottles immediately after collection, transported in a cooler, and stored at 0~4°C in the Lab of Urban Ecology at East China Normal University, Shanghai, China.

Sampling method was changed for the 5 trips in 2011 because the manual sampling was too labor and time consuming to cover a wider area for more distinctive attributes for reflecting the spatial complexity[3]. Nalgene 1100 storm water samplers were used to grab up to 1L first flush storm water by hanging in the catch basin. No human facilitation is needed for water collecting. Therefore, number of sample sites grew from 8 to 31. Water samples were retrieved on the next day of each rainfall event.

Concentration of total suspended solids (TSS), total phosphorus (TP), ammonium nitrogen (NH_4^+-N), nitrate nitrogen (NO_3^--N), and chemical oxygen demand (COD) in the water samples were tested by the Lab of Urban Ecology at ECNU using the methods described by the State Environmental Protection Administration of China (Table 3.3).

TABLE 3.3: Methods of testing water quality parameters (SEPAC 2002)

Parameters	Method of determination
TSS	Gravimetry (GB 11901-89)
COD_{cr}	Digestion Spectrophotometry (HJ/T 399-2007)
TP	Ammonium molybdate spectrophotometry (GB 11893-89)
NH_4^+-N	Natrium reagent spectrophotometry (HJ 535-2009)
NO_3^--N	Ultraviolet spectrophotometry (GB/T 11894)

Table 3.4 and 3.5 summarize the results of chemical test of all the 137 water samples taken in the 9 trips. To make the 2010 data comparable with the 2011 ones, the first grabbed

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[3] Manual sampling and complete profile of storm water were required by a parallel project of the research team co-working with the author.

bottle of water samples at each site are used as the representatives for 2010 rainfall events. Number of samples is different due to reasons such as insufficient precipitation (no runoff generated), loss of samplers, or sites being added in the middle of the sampling period. The Chinese national standard of surface water quality (NBEP 2002) categorizes the quality of water into five grades. Grade I to Grade III water can be used as supply of drinking water or aquaculture. Grade IV water is suggested to be used for industrial purposes. Water of Grade V can only be used for agricultural or landscaping purposes. Water worse than Grade V is considered severely polluted that shall not be used for any purposes directly (Note: NO_3^--N and TSS are not metrics of surface water quality in the Chinese national standard). In Table 3.6, it can be seen that 74.5% (102/137), 56.2% (77/137), and 68.6% (94/137) of the samples are worse than Grade V in terms of ammonium nitrogen (NH_4^+-N), total phosphorus (TP), and chemical oxygen demand (COD) respectively. The results proved that NPSP is a significant source of water pollution in Lingang. More detailed water quality data can be found in Appendix.

TABLE 3.4: Summary of chemical tests of water samples (mg/L)

Site Code	NO_3^--N		NH_4^+-N		TP		TSS		COD	
(#samples	**Median**	**Range**	**Median**	**Range**	**Median**	**Range**	**Median**	**Range**	**Median**	**Range**
IW1*(6)	1.87	1.25-3.97	2.74	1.61-5.45	0.282	0.130-0.460	24.49	7.03-95.89	38.697	10.39-244.90
IW3 (5)	2.05	1.23-4.15	7.50	0.82-20.68	0.720	0.445-0.929	77.34	46.88-86.58	75.094	59.29-79.32
IW4* (7)	6.28	4.73-7.30	2.56	1.88-17.98	1.450	0.234-5.183	213.20	54.13-1767.71	161.800	33.79-321.17
IW5 (1)	1.53	2.00	1.49	----	0.433	----	11.98	10.36-13.60	27.737	----
ED1 (5)	2.62	1.43-6.04	2.31	1.12-7.89	0.357	0.210-1.084	76.29	51.81-117.50	72.084	46.86-80.89
ED2 (5)	3.63	1.25-7.40	2.55	1.25-4.03	0.212	0.136-0.300	65.84	40.46-88.09	32.581	28.44-37.74
ED4 (4)	4.21	2.81-6.54	2.68	1.00-3.17	0.284	0.202-0.518	34.49	20.75-75.32	29.706	11.37-50.37
ED5 (4)	1.31	0.98-1.72	1.62	0.66-2.10	0.182	0.133-0.261	18.28	10.12-31.55	23.560	7.45-32.11
ED6 (5)	5.32	2.57-7.27	2.67	0.92-6.94	0.506	0.380-0.730	175.43	141.39-568.83	77.737	62.84-92.74
ED7 (4)	3.58	2.12-6.21	3.73	1.53-4.10	0.826	0.618-1.112	122.67	77.04-222.64	82.920	67.95-89.21
CR1* (7)	1.66	1.23-7.67	1.42	0.57-3.25	0.394	0.220-0.519	80.67	7.35-263.12	34.838	9.90-144.18
CR2* (7)	2.00	1.10-7.02	3.04	2.10-5.14	0.292	0.180-0.620	9.64	4.84-155.90	25.056	18.53-590.67
CR3 (1)	3.02	----	3.45	----	0.616	----	26.88	----	57.211	----
CR4* (7)	2.44	1.32-6.15	2.31	0.68-3.95	0.405	0.239-0.650	23.44	15.83-51.36	46.125	6.96-89.38
CR5 (5)	2.89	1.40-6.68	2.24	1.82-3.41	0.147	0.136-0.360	26.13	12.99-91.02	35.105	20.54-49.32
CR6 (4)	1.67	1.48-5.69	7.04	3.37-15.44	1.433	1.132-2.347	91.65	43.93-156.91	94.400	81.99-151.99
CR7 (2)	4.70	4.30-4.70	3.20	1.23-5.17	1.887	1.595-2.180	57.37	51.58-63.15	96.990	51.39-142.59

TABLE 3.4 (Continued): Summary of chemical tests of water samples (mg/L)

Site Code	NO_3^--N		NH_4^+-N		TP		TSS		COD	
(#samples)	Median	Range	Median	Range	Median	Range	Median	Range	Median	Range
UF1* (7)	2.88	1.73-4.95	4.21	1.76-4.58	0.603	0.267-1.350	121.90	11.26-261.00	46.404	6.96-200.80
UF2 (3)	4.05	3.47-4.63	0.78	0.48-5.42	0.780	0.480-2.820	3215.83	1361.62-7620.27	69.000	63.77116.25
BC1* (9)	5.59	2.27-8.05	2.45	1.25-9.01	0.660	0.108-1.502	154.50	106.50-538.97	85.380	44.62-171.75
BC2 (3)	4.89	3.28-6.50	4.66	4.45-15.40	0.941	0.610-1.324	248.70	237.39-1106.31	63.330	33.00-77.81
BC3* (7)	2.66	2.03-13.76	2.69	0.35-8.37	0.167	0.070-1.232	61.06	23.67-574.81	84.579	10.96-166.10
BC4 (5)	7.03	3.54-7.42	2.20	1.08-6.85	0.322	0.210-0.790	56.73	40.60-153.78	38.600	18.24-66.82
BC5 (2)	15.66	15.54-15.77	5.98	5.71-6.26	0.146	0.105-0.190	45.84	37.92-53.75	44.808	39.35-50.26
CR8 (5)	5.55	3.38-6.85	3.42	2.37-5.05	0.574	0.300-1.018	909.24	501.49-1893.12	69.842	53.04-143.53
BC6 (5)	7.70	3.29-14.29	7.47	4.47-8.93	1.252	0.410-4.016	334.43	160.80-1510.92	93.526	68.70-108.73
IW6 (4)	1.64	1.27-1.77	2.10	1.36-3.63	0.544	0.340-0.800	307.68	192.60-399.38	59.831	54.58-71.33
ED8 (4)	8.99	4.03-10.55	8.90	5.04-14.13	1.363	1.048-2.160	1239.56	595.71-1484.04	198.369	116.00-422.00
CR9 (4)	8.33	2.02-9.63	5.69	3.40-8.37	0.960	0.478-1.900	410.58	48.75-883.86	73.588	71.71-78.26

*: Sites being sampled for both 2010 and 2011.
1: blank cell for median = no observation
2: blank cell for range = only one observation

TABLE 3.5: Number of samples with water quality worse than Grade V

Site code	**Number of Samples**	**Number of samples with water quality worse than Grade V**		
		NH_4^--N (≥2.0mg/l)	**TP (≥0.4mg/l)**	**COD (≥40mg/l)**
IW1*	6	4	1	3
IW3	5	3	5	5
IW4*	7	6	5	7
IW5	1	0	1	0
ED1	5	4	2	5
ED2	5	3	0	0
ED4	4	3	1	1
ED5	4	1	0	0
ED6	5	4	3	5
ED7	4	4	4	4
CR1*	7	3	3	3
CR2*	7	7	1	2
CR3	1	1	1	1
CR4*	7	5	4	4
CR5	5	4	0	2
CR6	4	4	4	2
CR7	2	1	2	2
UF1*	7	5	4	4
UF2	3	1	3	3
BC1*	9	7	7	9
BC2	3	3	3	2
BC3*	7	4	1	5
BC4	5	3	2	2
BC5	2	2	0	1
CR8	5	5	4	5
BC6	5	5	5	5
IW6	4	2	3	4
ED8	4	4	4	4
CR9	4	4	4	4
Total	137	102	77	94

*: Sites being sampled for both 2010 and 2011.

3.2.2.2. LULC Data Extraction

LULC data (patches) was digitized from high-resolution (0.5m*0.5m) aerial orthophotos (2009) primarily by visual interpretation and manual digitizing. The sewershed of each sampling site was delineated by on-site observation based upon road curbs, road central lines, buildings, and the surface runoff flow tracks during rainfall events. Sewershed is the analyzing unit of this study, which refers to the entire surface area in which surface runoff flows into one sewage inlet (Ventura and Kim, 1993; Basnyat et al. 1999). Detailed LULC attributes in all sampled sewersheds were confirmed by on-site verification. Traffic volumes passing the sampled sewersheds were recorded during every sampling trip.

3.2.2.3. Quantitative Assessment of LULC-NPSP Relationship

The assessment of LULC-NPSP relationship is tailored based on the specialty of LULC classification and storm water sampling applied in this study. For LULC classification, MALO is designed to accommodate as many relevant attributes as possible for every land object. It deciphers spatial complexity by showing the uniqueness of the particular combination of attributes on an object. For water sampling, sewershed is used as the land object to be analyzed (analyzing unit). The small size of sewershed (usually hundreds of square meters) ensures more sites to be sampled to cover as many distinctive attributes as possible while each sewershed would not be too complicated.

Challenges for using these methods are, firstly, in MALO, objects can carry indefinite number of attributes with many being qualitative. Sampled sites do not guarantee coverage of all attributes that might be relevant. Attributes being identified in each sewershed do not guarantee the coverage of all attributes that might be relevant to NPSP in the sewershed either. Secondly, the water samples collected from a site might be impacted not only by the immediate area of the sewershed, but also by the surrounding environment (Goonetilleke et al. 2005; Styers et al. 2010). A sewershed is just a very small piece of surface within a large area with all kinds of natural and human objects and activities interacting with each other. It is unlikely that the pollution accumulated in one sewershed is only caused by the objects or activities within it. Factors such as air flows (to affect atmospheric deposition), vehicle use, animal movements, natural pathways of chemicals (e.g. seepage, nitrogen fixation, plant take-up), and many others can possibly affect the sewershed from adjacent, nearby, or farther areas. These affects shall not be neglected, but are not easy to be measured or predicted.

The limitations and uncertainties direct the assessment to a more qualitative-inclined manner with the primary purpose being detecting attributes that might have higher impacts on NPSP, rather than explaining the exact causal effects between attributes and pollution or building quantitative models to predict how much pollution would be produced. The “Compare Mean” tests (t test for comparison between two groups; ANOVA for comparison among three or more groups) are applied to serve the purpose. Distinctive attributes of each site are used to define groups (controlled variables). Mean concentration values of pollutants of groups (observed variables) are compared to each other to see whether they are significantly different or not. Any statistically significant results would indicate the potential of one attribute (or combination of attributes) having either stronger or weaker relationship with NPSP.

Table 3.7 summarizes the LULC attributes of sampled sewersheds. These attributes describe the conditions of not only the immediate area of the sewersheds, but also areas adjacent to them. “Functional Zone” indicates the general land use zoned by planning. “Land Use” indicates the exact LU purposes applied to the sewersheds. “Distinctive Attributes” are the ones only presented by a few sewersheds or sometimes even uniquely by only one sewershed. Most sewersheds are composed by both paved and vegetated surfaces. But if not particularly indicated as “effective greenness”, the vegetation in the sewersheds would not be passed by storm water from the pavement. Flows from paved or vegetated surfaces are well led to the catch basins directly. Because of this hydrological difference and the special importance of green spaces in urban ecology, sites with effective greenness (greyed in Table 3.7) are put into a separate assessment (Section 3.2.3.2). The traffic counts are the average values of onsite counting during every sampling trip. It is used as an indicator of the intensity of human activities in addition to vehicle usage.

TABLE 3.7: Attributes of sampled sewersheds

Site Code	Functional Zone	Distinctive Attributes	%Paved	Traffic per hour			
				Truck	Bus	Car	P&B*
IW1	Industry/warehouse	Ground in front of company cafeteria	86	10	0	4	24
IW3	Industry/warehouse	Loading Deck of warehouse complex with trucks and loading machines	100	46	0	18	44
IW4	Industry/warehouse	Main entrance of the warehouse complex	95	199	14	151	369
IW5	Industry/warehouse	Curbed green Space in warehouse complex; Effective greenness	0				
IW6	Industry/warehouse	Intersection of major roads	80	46	23	233	298
CR1	Residential	Low-density apartment (ICR=0.5, FAR=1.1); Driveway to main Entrance/Permiable Pavement	100	0	0	19	15
CR2	Residential	Low-density apartment (ICR=0.5, FAR=1.1); Driveway to main Entrance; Vegetated Parking Space; Effective Greenness; Permeable Pavement	72				
CR3	Residential	High-density apartment (ICR=0.5, FAR=3); Effective Greenness; Permeable Pavement	68				
CR4	Residential	High-density apartment (ICR=0.5, FAR=4); Permeable Pavement	68	0	0	12	12
CR5	Residential	Low-density apartment (ICR=0.5, FAR=1.2) Few human activity; Permeable Pavement	63	0	0	9	8
CR6	Residential	Commercial retailing/dining	100	0	0	0	120
CR7	Residential	Major road	94	0	8	58	105
CR8	Residential	Intersection of major roads; Construction Site	86	48	3	24	48
CR9	Residential	Intersection of major roads	77	6	23	116	168
BC1	Business	Major Road	70	0	41	215	293
BC2	Business	Major Road	60	0	48	218	298
BC3	Business	Driveway in office building complex	90	0	0	60	84
BC4	Business	Parking lot in office building complex	96	0	0	38	64
BC5	Business	Roof area	100	0	0	0	0
BC6	Business	Major road with few human activity	90	0	12	72	59
ED1	Educational	Campus cafeteria with high volume	77	0	0	28	368
ED2	Educational	University Library	95	0	0	0	244
ED4	Educational	University Dorm	65	0	0	5	120
ED5	Educational	Commercial area with no human activity	100	0	0	0	3
ED6	Educational	Parking space of bus terminal	100	0	52	0	0
ED7	Educational	Commercial retailing/dining	90	0	0	0	224
ED8	Educational	Major road	89	0	29	116	334
UF1	Urban forest	Saplings; Plowed soil	0				
UF2	Urban forest	Saplings; Plowed soil; Riparian area	0				

* P&B: pedestrian and bicycle

3.2.3. Results of LULC-NPSP Relationship Investigation

3.2.3.1. Results of Preliminary Assessment within Functional Zones

To make the controlled variables less complex, assessment is first conducted for sites within the same functional zone to remove possible disturbance of zoning and proximity.

(1) Industrial/Warehouse Area (IW)

The sewersheds in the Industrial/warehouse zone includes IW1, IW3, IW4, and IW6 (IW2 was not included because no usable sample was collected; IW5 is effective greenness to be assessed in the section of vegetation). IW1, IW3, and IW5 are located in a warehouse complex in the logistic park. IW4 is on the major road outside the main entrance of the warehouse complex. IW6 is at the intersection of two major roads near IW4.

Results (Figure 3.4) of the assessment in IW indicates that IW4 has significantly higher (one-way ANOVA, $p < 0.05$) mean concentrations of nitrate, TP, TSS, and COD than all other sites. IW6 has significantly higher mean TSS concentration (one-way ANOVA, $p < 0.05$) than IW1 or IW3. Both IW4 and IW6 are heavily traffic-related. They share the attribute of having high volume of motor vehicle. In addition, IW4 has about three times more truck volume than IW6. Most trucks are containers of industrial materials. It seems the effect of overlapping industrial needs with transportation might cause IW4 to perform more strongly than IW6.

IW1 and IW3 do not have significant differences from each other on any of the pollutants. But the mean concentrations of all pollutants at IW3 are a little higher than those at IW1. It is not surprising given IW3 is the loading deck which has trucks, lifting machines, and containers. IW1, on the other hand, is near the cafeteria which is neatly managed, with less human activity. Four out of the five water samples from IW1 (except for the one collected on Sept 16, 2011) are better than Grade V for all indexes, while all samples from other sites have water quality worse than Grade V for at least one pollutant.

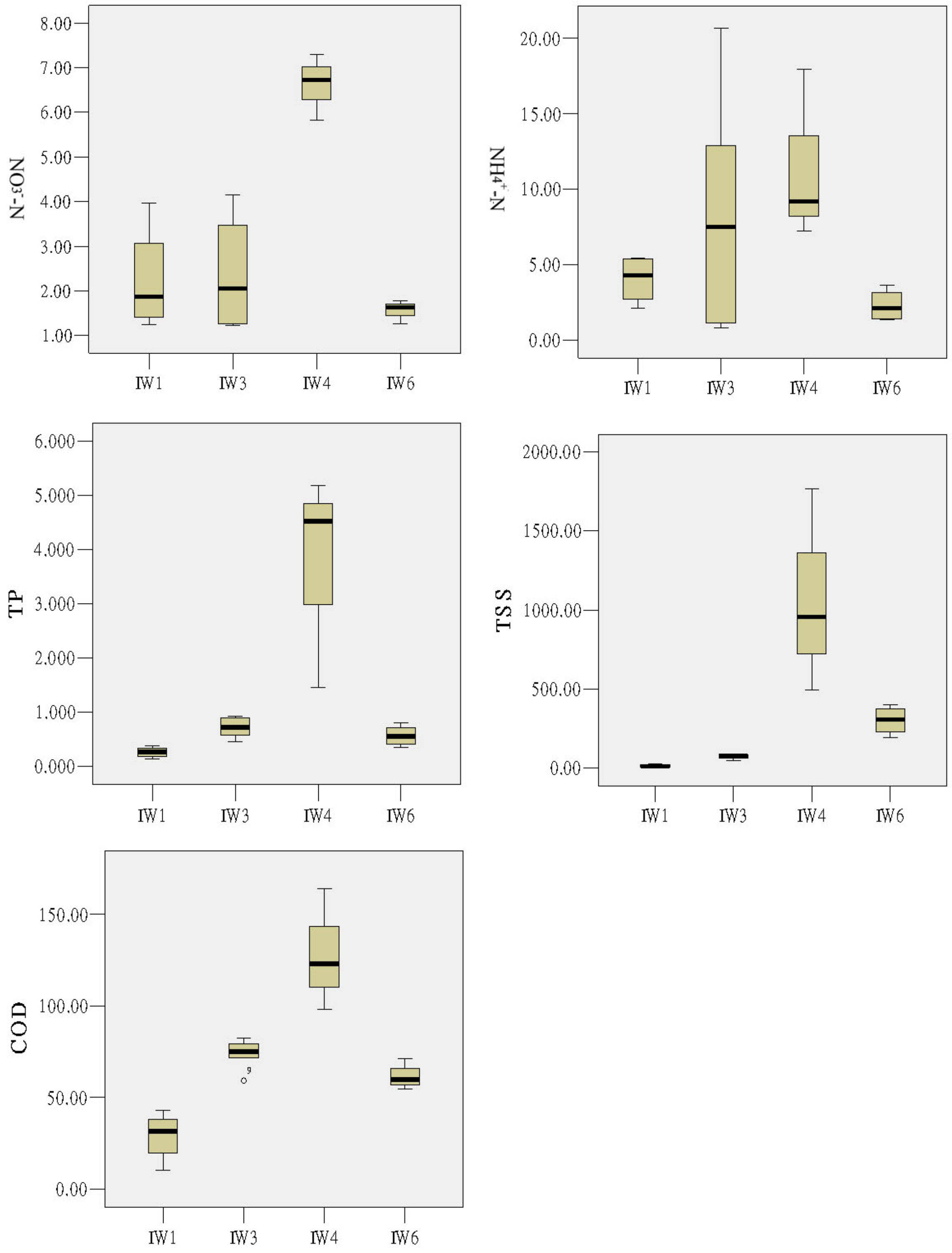


FIGURE 3.4 Comparison of mean concentration values (mg/L) by sites in IW zone [#samples: n(IW1)=4; n(IW3)=5; n(IW4)=3; n(IW6)=4]

(2) Clustered Residential Area (CR)

Nine sewersheds in the residential area are sampled. CR1 to CR5 are inside an apartment neighborhood; CR6 and CR7 are outside but close to the neighborhood; CR8 and CR9 are located at two highway-intersections, which are 3.5 km and 2 km to the neighborhood respectively. CR2 and CR3 are vegetation-related, therefore not assessed here.

Results (Figure 3.5) show that among the three sewersheds inside the neighborhood CR1, CR4, and CR5, no significant differences are found for any pollutants, regardless of the density. Another attribute that worth attention is the surface material. The road surfaces inside the neighborhood is paved with permeable material. Though its exact permeability is unknown, delayed generation of surface runoff was indeed observed. The permeable surface might also contribute to the low concentration of pollutants.

Ammonium is an outstanding pollutant in the neighborhood. Thirteen samples out of the total fifteen are worse than Grade V for ammonium nitrogen. It is understandable because ammonium is a chemical that is closely associated with human life, including (but not limited to) food, domestic waste, fertilizer, animal waste by pets, or even human metabolism. The relatively high coverage of vegetation in the neighborhood might also contribute to the yield of ammonium.

Outside of the apartment neighborhood, however, an obvious rise of pollution level is observed. CR6 is on the ground of a commercial complex next to the neighborhood. It is surrounded primarily by small restaurants together with some other domestic services. The surface is totally paved but free of vehicles. CR6 has significantly higher mean concentrations of ammonium nitrogen and COD (one-way ANOVA, $p < 0.05$), and close to significantly higher mean concentration of TP ($p=0.054$) compared to the sites inside the neighborhood. All samples from CR6 are worse than Grade V for ammonium, TP, and COD.

Even compared to the canteen site (IW1) in the industrial area which is associated to similar dining service, water quality of CR6 is worse. By further observation, it is noticed that the behavior patterns at CR6 and IW1 are different. Firstly, CR6 has more human activities than IW1 (120 versus 24 pedestrians/hour). Secondly, the owners and workers of the small restaurants at CR6 do not treat cooking wastes decently. They dispose cooking oil, grease, and sometimes even solid wastes into the storm water inlets directly. IW1, on the contrary, is well managed by the company cafeteria.

For the traffic-related sites, CR7 has constantly high TP concentrations, but very inconsistent patterns for other pollutants. Water from CR7 is mostly worse than Grade V. Both CR8 and CR9 are located at intersections of major roads with higher traffic volume. No obvious pattern could be found for nitrate, ammonium, TP, or COD. But their TSS concentrations (especially at CR8) are significantly higher than all other sites in the residential zone. CR8 is in the road at a construction site. Compared to other sites in the residential zone, it has a particularly high volume of trucks (though not as high as in the industrial zone). By on-site survey it is noticed that the trucks are mostly for transporting construction materials. Their trunks are uncovered. This could potentially contribute a lot to the TSS in this site. Almost all samples collected at CR8 and CR9 are worse than Grade V for all pollutants (except for the one taken at CR8 on April 23, 2011).

If all samples are put into two groups based on their locations as in or out of the neighborhood, clearer discrepancy can be found. Samples taken from the neighborhood have significantly lower mean concentrations of ammonium nitrogen (t-test, $p = 0.007$), TP ($p = 0.000$), TSS ($p = 0.004$), and COD ($p = 0.000$) than samples taken from outside of the neighborhood.

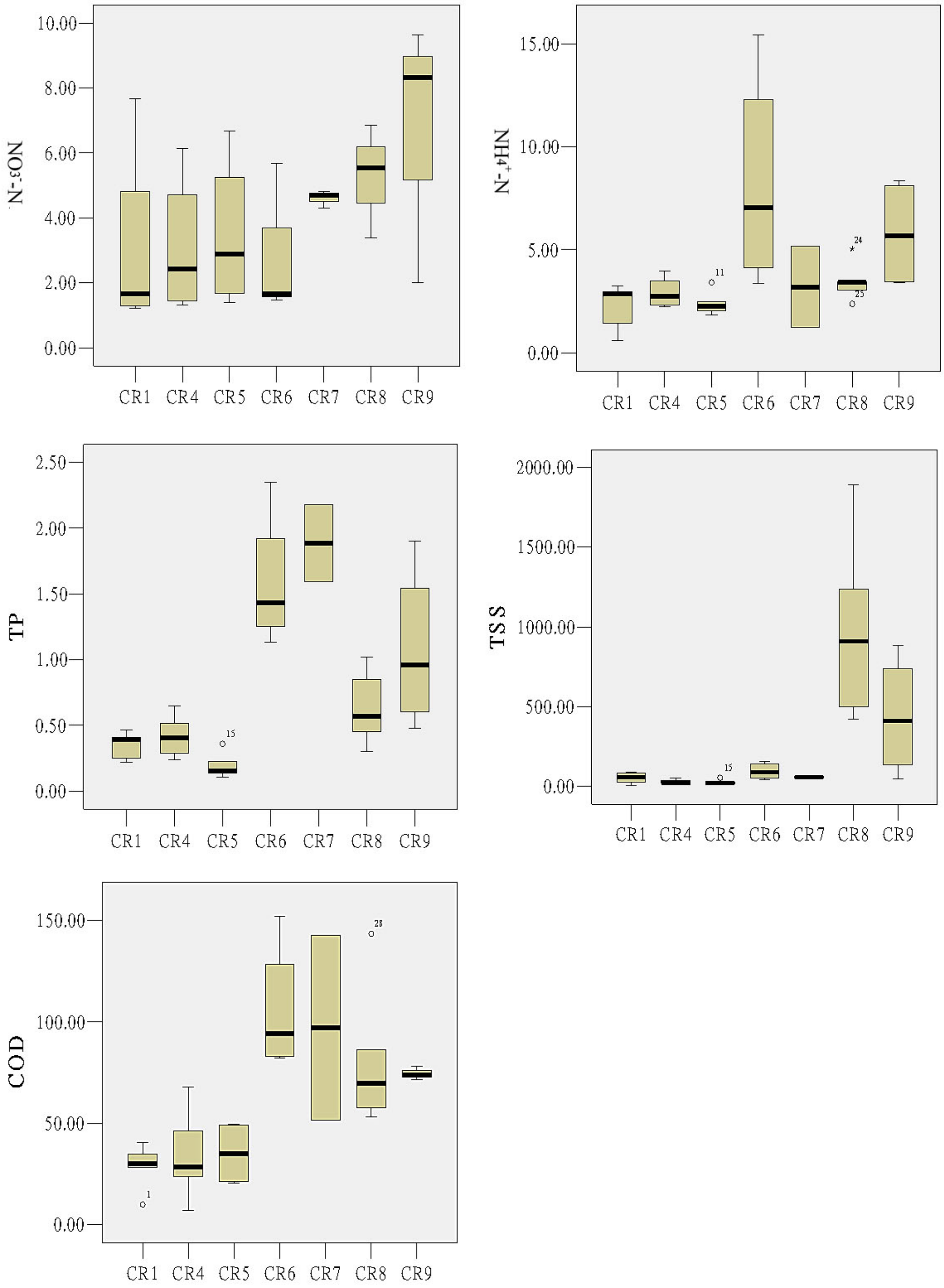


FIGURE 3.5: Comparison of mean concentration values (mg/L) by sites in CR zone [#samples: n(CR1)=5; n(CR4)=5; n(CR5)=5; n(CR6)=4; n(CR7)=2; n(CR8)=5; n(CR9)=4]

(3) Business and Commercial Area (BC)

There are six sampling sites located in the BC area, three on major roads (BC1, BC2, BC6), the others in an office building complex. BC1 and BC2 are on the two sides of the same highway. They are spatially close to each other and almost identical for their attributes. BC3 is on a driveway and BC4 is at the parking lot of the business complex. BC5 is special because it is directly connect to the gutter to the rooftop of a building to receive rain water from the roof. BC6 is at the intersection of two roads.

Not a lot of statistically significant differences are found (Figure 3.6). The roof (BC5) has higher nitrate nitrogen than other sites (one-way ANOVA, p=0.003). The most likely source of nitrate for 5 is atmospheric deposition. But it is also possible that nitrate comes from the roof material. For other sites, unsurprisingly, traffic-related ones (BC1, BC2, BC6) have significantly higher TP (p=0.007) and TSS (p=0.016) concentrations than sites in the office complex (BC3, BC4, BC5). The only uncertainty is that, among the three traffic-related sites, BC6 has substantially lower traffic volume. But its performance on NPSP is not better than the other two at all. Instead, its mean concentration values of all pollutants are higher than those of BC1 or BC2, but not significantly. On-site survey did not find any other particular attributes that might lead to such results.

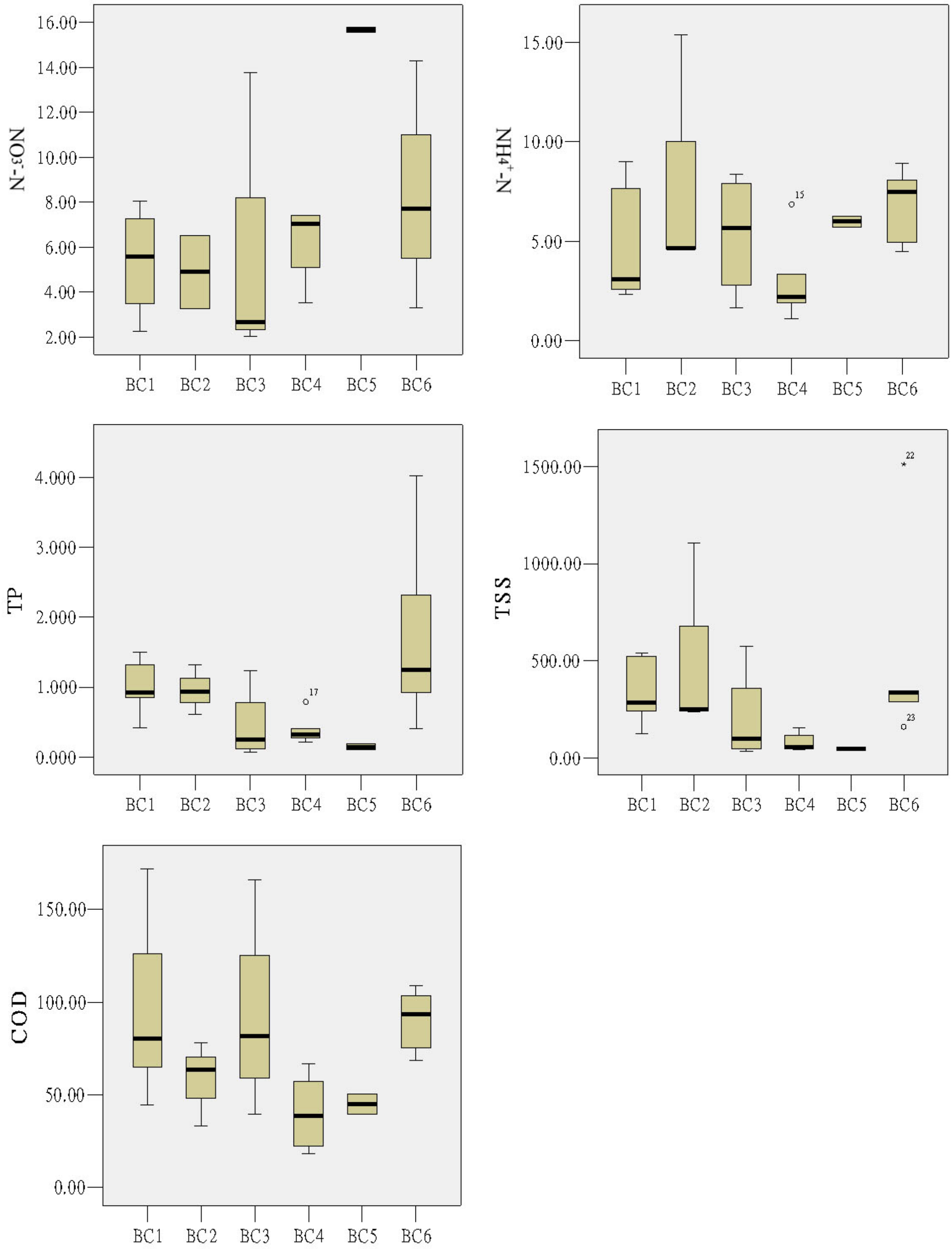


FIGURE 3.6: Comparison of mean concentration values (mg/L) by sites in BC zone [#samples: n(BC1)=5; n(BC2)=3; n(BC3)=4; n(BC4)=5; n(BC5)=2; n(BC6)=5]

(4) Educational Area (ED)

Water samples in the educational zone are collected on or near the campus of Shanghai Ocean University. The campus is designed in a pedestrian/bicycle-friendly manner. Usable water samples are available from seven sewersheds in this area. ED1, ED2, and ED4 are on-campus ones representing the attributes of cafeteria, library, and dorm respectively. ED5 and ED7 are located in a commercial compound featured by restaurants, food and drink bars, and other services. ED6 is on the parking lot of a bus terminal. ED8 is a traffic-related site at a road intersection near the university.

Results are quite interesting (Figure 3.7). It is not surprising to see the on-campus sites (ED1, ED2, and ED4) having low mean concentrations because the low-impact behavior patterns similar to those in the residential neighborhood or business complex, even though ED1 receives a large amount of pedestrians every day. It is not surprising either to see the high concentration values at the traffic-related sites (ED6 and ED8). The difference of mean values between the on-campus sites and traffic-related off-campus sites are significant for TP, TSS, and COD (one-way ANOVA, $p < 0.05$); but not for nitrate nitrogen ($p = 0.227$) or ammonium nitrogen ($p = 0.110$).

Interesting phenomenon is found between ED5 and ED7, both of which are located in the off-campus commercial compound. These two sites are highly comparable because they are actually at the same place. The two sewersheds are adjacent with similar physical surface conditions. ED7 covers the sidewalk and road surface in front of a food and drink bar with approximately 90% of its surface paved. The pervious surface in ED7 is curbed greenness which contributes little runoff. ED7 has intensity human activities, including large amount of customers or passengers and high traffic. People sometimes litter on the ground. The workers of the bar and nearby stores sometimes also dispose wastes into the catch basin.

ED5 lies right beside ED7 but has almost no human activities. It is separated from the sidewalk by a wall, which blocks people’s access. Data shows that ED5 almost keeps the lowest mean concentrations for all pollutants among sites not only in the ED zone, but also the entire study area. Except for ammonium nitrogen, ED5 has significantly lower mean concentration values for all other pollutants than ED7. Ammonium concentration is lower, but not significant.

The results suggest that, though imperviousness might transport more NPSP by generating more surface runoff (Hatt et al. 2004; Goonetilleke et al. 2005), it is not necessarily the creator of the pollution. More attention shall be focused on human activities on the surfaces, if finding the exact cause of NPSP is desired. Only using imperviousness as indicator without addressing the source could be biased.

In addition, if taking IW1 (company cafeteria), CR6 (restaurant), and ED1 (campus cafeteria) into the comparison with ED7, another phenomenon can also be reinforced: behavior pattern can be more critical to NPSP than simply intensity of human activities. These sites are all dining service related. But the amount of human activity does not dominate the results. ED1 has more human activities than ED7. IW1 even has trucks passing by. But people at the company or university canteens are more cautious about their behaviors, especially waste disposal. On the contrary, the owners and customers of the restaurants or bars are relatively reckless, causing poor sanitation conditions near their business. Hence, ED1 and IW1 have much better storm water quality than ED7 or CR6 does.

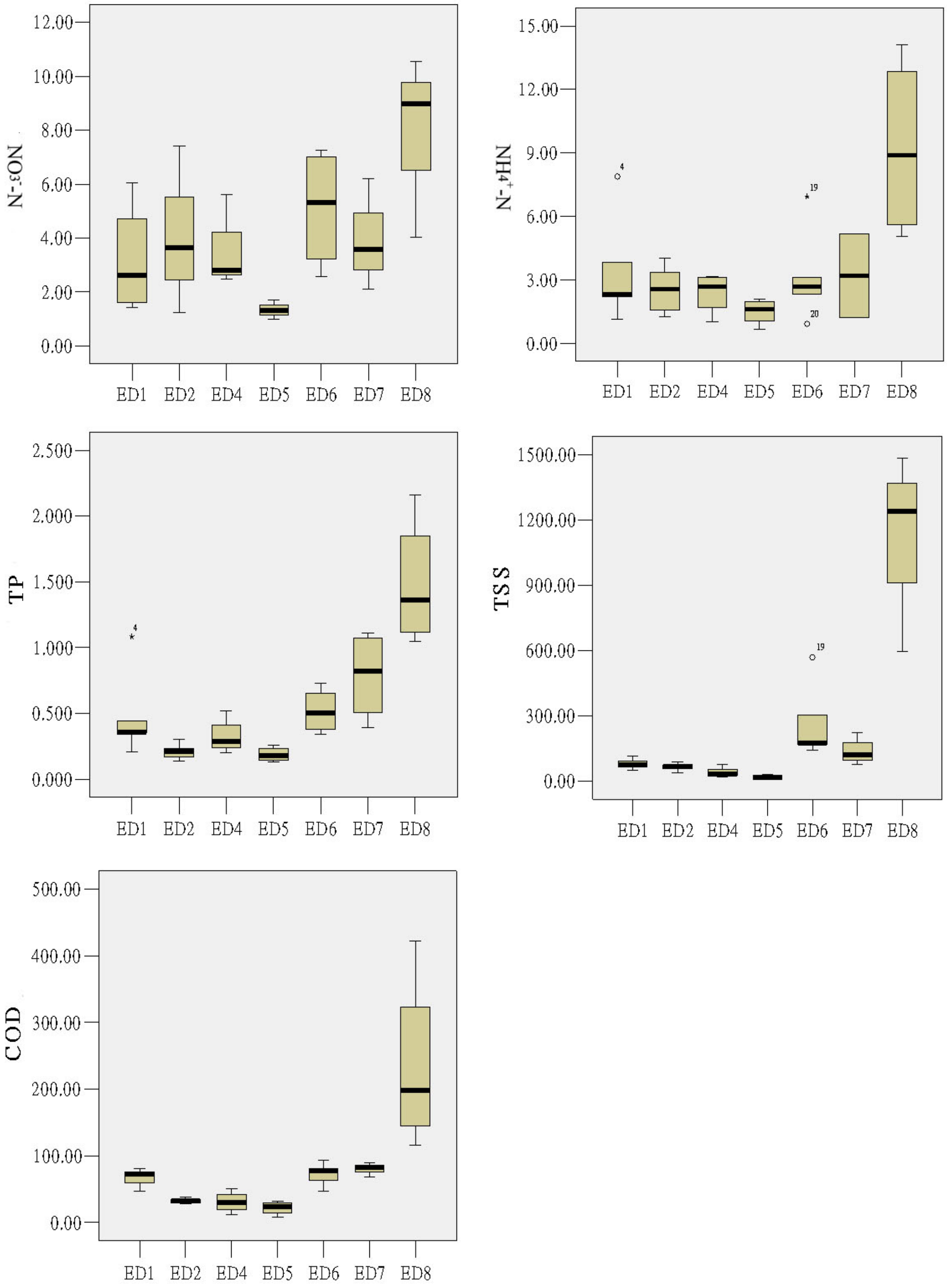


FIGURE 3.7: Comparison of mean concentration values (mg/L) by sites in ED zone [#samples: n(ED1)=5; n(ED2)=5; n(ED4)=4; n(ED5)=4; n(ED6)=5; n(ED7)=4; n(ED8)=4]

3.2.3.2. Results of Preliminary Assessment of Vegetation

Five sewersheds (IW5, CR2, CR3, UF1, UF2) are sampled to evaluate the effects that green spaces have on urban NPSP. They are sorted out for a separate assessment because 1) urban vegetation is an LULC feature with widely recognized ecological values of NPSP mitigation; 2) urbanization activities might modify the characteristics of vegetation that leads to unexpected effects; and 3) the sampled vegetated sewersheds are more complicated than other sites in terms of physical and hydrological conditions.

Green space in Lingang can be generally categorized into the following five types: forests/parks, street trees, curbed landscaping, uncurbed greenness, and potted plants (Figure 3.8). Urban forests/parks (Figure 3.8A, 3.8B) are pre-designated large area with a majority cover of trees accompanied by a mix of other plants. Unlike natural forests, trees in urban forests in Lingang are planted during and/or after the urban construction. The plants or soils are not necessarily local species, so that they are likely to require more maintenance to survive. Street trees (Figure 3.8C) and curbed landscaping (Figure 3.8D) are the most common types of urban green spaces in Lingang as well as other Chinese cities. The footprint of a street tree only cuts out a very small piece of surface from pavement. They can let in some surface runoff, but not much. Curbed landscaping often refers to a piece of vegetation with mixed species. It is surrounded by concrete curbs as a protection (Figure 3.8D). Because many species of such landscaping are non-local, they can be vulnerable to external disturbance. Storm water with high concentration of pollutants is considered such a disturbance. In addition, curbs can also protect vegetation from being run over by vehicles. On the contrary, uncurbed greenness is a type of urban green space with the intention to retain or filter storm water to reduce both the load and concentration of pollutants. Figure 3.8E shows a piece of uncurbed grass that is used as parking spaces. Grid-like bricks are applied on the top to stabilize the soil and grass. Such pervious parking space is widely adopted in Lingang, mostly in residential areas and public parking lots. Potted plants are like over-sized flowerpots. They are put on the pavement mostly for aesthetic purpose.

FIGURE 3.8: Urban Greenness in Lingang (A, B: urban forest; C: street tree; D: curbed vegetation; E: uncurbed vegetated swale; F: potted plants)

Regarding the types of greenness for the five sites, CR2 and CR3 are small pieces of uncurbed greenness; UF1 and UF2 are in urban forest; IW5 is a curbed green space with meadow and bushes. To better understand how urban vegetation affects storm water quality, each site is paired with a nearby—preferably adjacent—impervious site (if exists) that has similar attributes of the other aspects.

(1) Uncurbed Urban Greenness (CR2, CR3)

CR2 is paired with CR1, both of which are located on the same driveway in the low-density part of the residential neighborhood. CR2 contains a piece of grass used as parking space (Figure 3.8E). Storm water in the sewershed passes through the grass before entering the inlet. CR1 is on the opposite side of the driveway, without any vegetated surface. Sewersheds of CR1 and CR2 are adjacent.

The differences of pollution mean concentrations between CR1 and CR2 are trivial, except for TSS. Considering their adjacent locations and similar attributes, it is reasonable to assume that the sources of TSS for these two sewersheds would be similar. But the results show significant difference of mean TSS concentration between them (t-test, $p < 0.05$), where CR2 is about 87% lower on average (Figure 3.9). For other pollutants, however, vegetated surface does not show noticeable impacts, either positively or negatively.

Another uncurbed greenness site CR3 is paired with CR4. They are in the high-density part of the same residential neighborhood where CR1 and CR2 are located. Their attributes are highly similar, too. Particularly, the proportional coverage of vegetated surface in these two sewersheds is almost identical (≈32%). The only difference is that the green space in CR3 is uncurbed, which receives storm water from pavement, while the green space in CR4 is curbed.

Statistical test is not applied to these two sites because only one usable sample was collected from CR3 due to loss of samplers. Visual comparison found trivial differences of concentration of nitrate, ammonium, TSS, or COD (See Appendix). But the TP concentration at CR3 is 0.616mg/L—more than doubled the value at CR4 (0.289mg/L).

Such a high peak of TP is not observed at other vegetation-related sites. Because the number of samples is too small, no further tests can be run. Neither is further evidence found by on-site observation for explaining the outstanding difference.

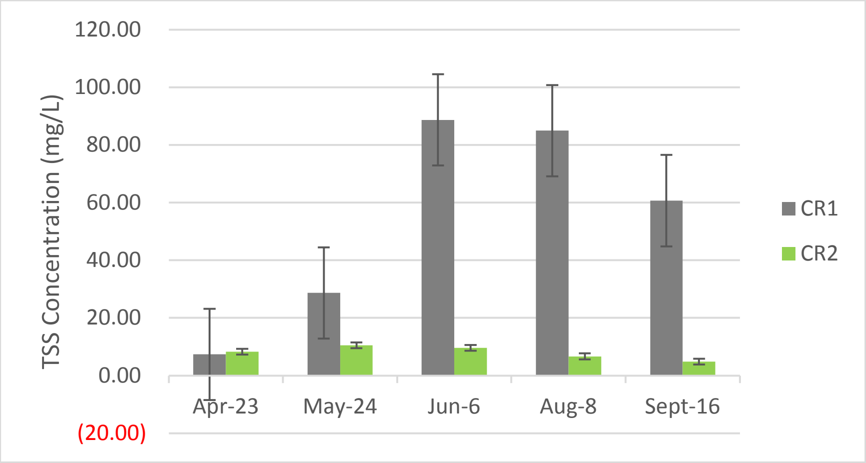


FIGURE 3.9: Comparison (bars donate S.D) of TSS concentration (mg/L) from pavement (CR1) vs. uncurbed greenness (CR2)

Interesting observation is found between these two sites regarding TSS. Storm water passing the uncurbed greenness in CR3 has higher TSS concentration (26.88mg/L vs. 23.29 mg/L at CR4). It is inconsistent with the observation of TSS removal by the uncurbed greenness at CR2. By further on-site survey, an assumption is made that the TSS reduction at CR2 might not necessarily be caused by the vegetation, but by the grid-like bricks that are used to stabilize the soil. The bricks actually formed an array of micro detention ponds on the pathway of runoff, so that sediments can sink (see Figure 3.8E). CR3, on the other hand, does not have such a structure to trap solids.

(2) Urban Forest (UF1, UF2)

Sewersheds UF1 and UF2 are inside the urban green bend, both with 100% coverage of saplings, bushes, and grass. UF1 is in the terrestrial area of the urban park. UF2 is in the riparian area along a stream. The sampling team witnessed a clear-cut due to death of plants on the May 24th trip. Dead plants were removed, soil was plowed, and new saplings were about to be planted.

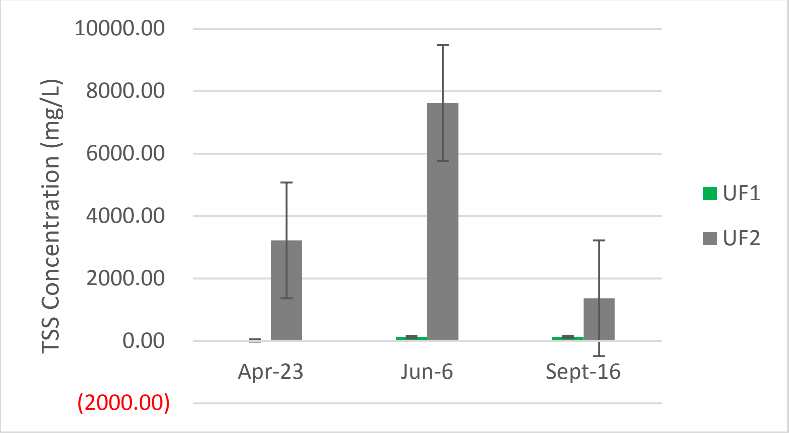


FIGURE 3.10: Comparison (bars donate S.D) of TSS concentration (mg/L) between terrestrial forest (UF1) and riparian forest (UF2)

The two urban forest sites are only compared to each other because no comparable impervious site can be found. No significant difference is found for the mean concentrations of nitrate or ammonium nitrogen between UF1 and UF2. For TP, COD, and TSS, the terrestrial site UF1 performs better than the riparian site UF2. Mean concentration values of TP and COD at UF1 are both significantly lower than those at UF2 (t test, $p < 0.5$). The difference of TSS between UF1 and UF2 is even more dramatic (Figure 3.10). TSS concentration at UF1 remains moderate. But mean TSS concentration at UF2 is about 118 times higher than that at UF1. It is possible that maintenances, such as cultivating, plowing, and fertilizing, have affected the forest leading to unstable NPSP performance. Particularly, the riparian environment makes UF2 face with a more complicated situation. The interactions between the terrestrial and aquatic systems might create extra “disturbances” to the vegetation, and consequently require more maintenances. The slope of the stream bank makes it rather unfavorable for holding solids, especially when the soil is newly plowed.

(3) Curbed Landscaping Vegetation (IW5)

IW5 is located in a curbed landscaping of mixed meadow and bushes, which only collects storm water in the meadow. IW5 is paired with IW3—the warehouse loading deck. They are also adjacent sewersheds with shared boundary.

Once again, because usable samples were collected at both sites for only one rainfall event, statistical test was not conducted. Assessment of IW5 is done by visual comparison (See Appendix for detailed data). IW5 has higher concentrations than IW3 does for both types of nitrogen, probably due to the contents of the soils or the legacy of fertilizers. TP, TSS, and COD concentrations at IW5 are noticeably lower than those at IW3. Human activities on these two sites are very different. Therefore, two alternative assumptions are made for explaining the results. First, it is the industrial activities that increase the NPSP at IW3; or second, the vegetation in IW5 does have the ability to remove certain types of NPSP. Given the fact that the mean concentration values of TP, TSS, and COD at the canteen site IW1 are close to those of the meadow, the first possibility is more likely. But TSS concentration removal by the meadow is quite obvious.

3.2.3.3. Results of Comprehensive Assessment by Attributes

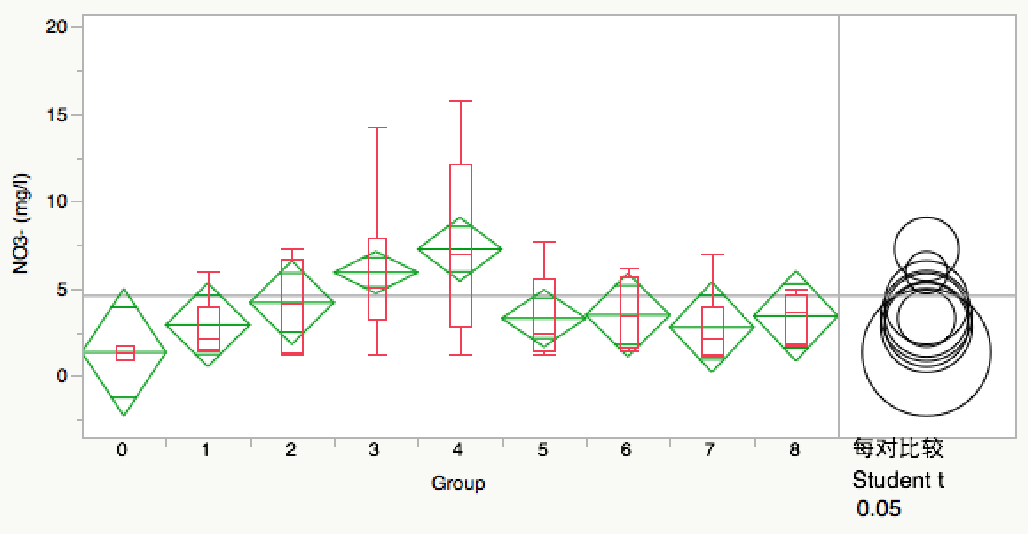
Phenomena observed in the above assessments have led to assumptions linking NPSP with particular LULC attributes within each functional zone. These assumptions are: (1) Use of motor vehicles is a strong indicator of NPSP; (2) Traditional industrial activities, such as the use of trucks and heavy machines and handling of containers, are strong indicators of NPSP; (3) Pedestrian/bicycle-oriented life style and working style have weaker relationship with NPSP; (4) Ecological impacts of commercial activities (represented by dining services) highly depend on the behaviors of people engaging such activities; (5) The quality of storm water passing through small landscaping greenness is generally not worse than that of runoff from impervious surfaces. But no evidence is found that these green spaces are effective in removing pollution. TSS removal is more likely to be subject to special structure rather than the vegetation itself; (6) Water quality in the urban forest has high temporal difference and is generally worse than that at other vegetated or impervious sites, potentially due to the maintenances and topology of the forest; and (7) impervious surface, if associated with human activity, is not observed as a direct indicator of NPSP.

Based on these assumptions, a more comprehensive assessment is done. All sample sites are re-grouped according to certain distinctive attributes they share. When possible, an attribute group shall include sites from different functional zones in order to minimize the influence of proximity to remove the homogeneity of atmospheric deposition within short distance. Analysis of variance (ANOVA) with Least Significant Difference (LSD) post hoc test is applied to compare every possible pair of groups. The results can either reinforce or reject the above assumptions. The LSD method is chosen because it is more sensitive to the difference of the group mean. It has a relatively high risk to differentiate groups that are not different (Type I error). But it has to be reminded that the causal factors of NPSP are complicated. Attributes listed in this study are the ones that might affect or contribute to the pollution in storm water, but not necessarily be the determining factor. The purpose of this test is to depict any attributes that might have the potential to affect NPSP. Therefore, a method sensitive to the difference is preferred. All sampled sewersheds are put into nine groups, with each featured by a defining attribute (Table 3.8).

Table 3.8: Group of sample sites by distinctive attributes

No.	Defining attribute	Sample sites (specific attributes)
0	Baseline	ED5 (impervious, no human activity, represent basic atmospheric deposition);
1	Managed commercial	IW1 (company canteen); ED1 (university cafeteria);
2	Industrial	IW3 (loading deck of warehouse); IW4 (main entrance of warehouse);
3	Transportation	ED6 (bus terminal); IW6, ED8, CR7, CR8, CR9, BC1, BC2, BC6 (major roads or intersections);
4	Business	ED2 (university library, similar to office complex); BC3 (driveway of office complex); BC4 (parking lot of office complex); BC5 (roof of office buildings);
5	Residential	ED4 (university dorm, similar to high-density residential); CR1, CR5 (low-density residential); CR4 (high-density residential);
6	Unmanaged commercial	ED7 (food store and drink bar); CR6 (small restaurant);
7	Landscaping greenness	IW5 (curbed meadow); CR2 (vegetated parking space, stabilized by grid-like bricks); CR3 (uncurbed meadow);
8	Urban forest	UF1 (forest); UF2 (riparian);

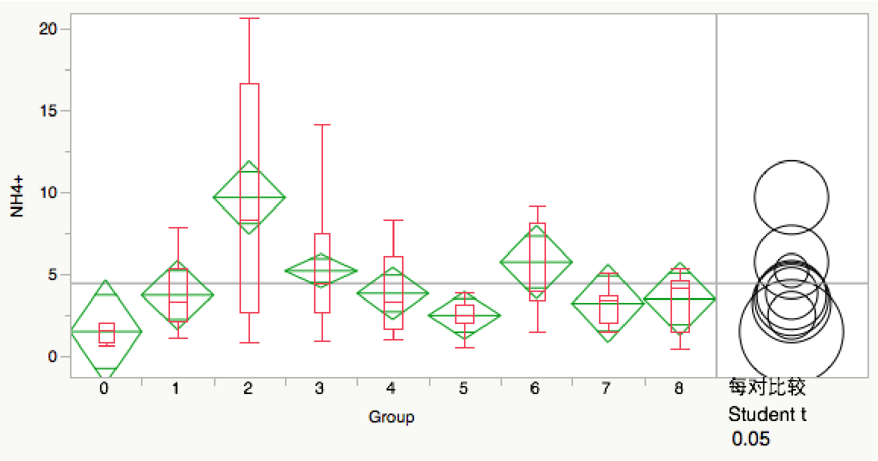
For NO_3^--N (Figure 3.12), the most outstanding group is Business (4). It has significantly higher mean concentration than other groups but Transportation (3). Transportation (3) is the second highest that is significantly different from Residential (5), Managed commercial (1), Landscaping (7), and the Baseline (0). Industrial (2), Unmanaged commercial (6), and Urban forest (8) fall into the same category of Transportation (3) to have moderately high nitrate concentration. In fact, business activity was not originally expected to be an attribute of high NPSP contribution. However, the high nitrate concentration in samples from the roof has substantially increased the group mean. It is likely that the nitrate on the roof comes from atmospheric deposition. But since high nitrate is not observed in any other nearby sites, we cannot eliminate the possibility that the nitrate on rooftop comes from the materials of the roof. If removing the samples from roof, Business (2) shall only have moderate to low concentration of nitrate.



Level				Sq. Mean
4	A			7.2541667
3	A	B		5.9217857
2		B	C	4.1900000
6		B	C	3.4742857
8		B	C	3.4216667
5			C	3.2873333
1			C	2.9157143
7			C	2.7783333
0			C	1.3366667

FIGURE 3.12: Comparison of NO_3^--N mean concentration (mg/L) by attribute w/ connecting letters report

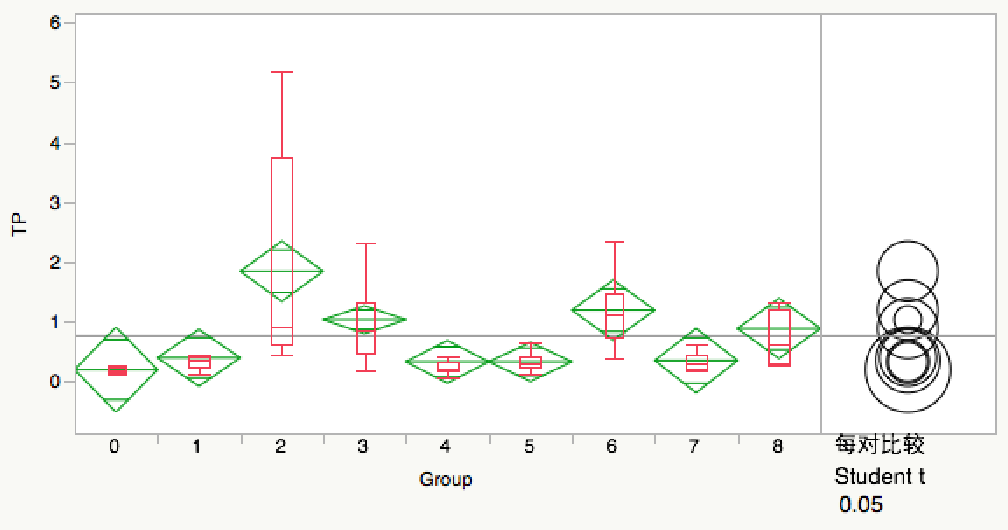
For NH_4^+-N (Figure 3.13), Industrial (2) has the highest group mean that is significantly different from all other groups. The large temporal variance poses the possibility that contents being stored at the warehouse might be a factor affecting the yield of ammonium. Unmanaged commercial (6) is the second highest and is significantly higher than Residential (5) and Baseline (0). It is understandable because the cooking wastes being randomly disposed can be a source of ammonium. Transportation (3) has the third highest mean and is also significantly higher than Residential or Baseline. Business (4), Managed Commercial (1), Urban forest (8), and Landscaping (7) have lower mean ammonium concentrations than Transportation but the difference is not significant. The relatively high ammonium concentration in the two groups of green spaces (Group 7 and Group 8) might be subject to the soil contents or fertilizer.



Level				Sq. Mean
2	A			9.6775000
6		B		5.7487500
3		B		5.2178947
4		B	C	3.8393750
1		B	C	3.7355556
8		B	C	3.4962500
7		B	C	3.2171429
5			C	2.4894737
0			C	1.5000000

Figure 3.13: Comparison of NH_4^+-N mean concentration (mg/L) by attribute w/ connecting letters report

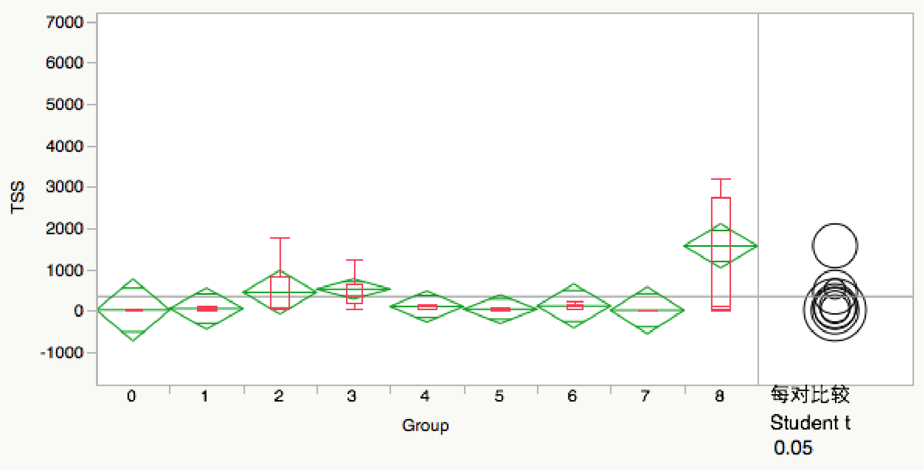
For TP concentration (Figure 3.14), Industrial (2) is significantly higher than any other groups except for Unmanaged commercial (6). The group means of Transportation (3) and Urban forest (8) are moderately high. Managed services (1), Landscaping vegetation (7), Business (4), Residential (5), and Baseline (0) are the lowest ones. Phosphorus is a common chemical in food, domestic and industrial materials, fertilizer, pesticide, as well as soils. The different performance by the two types of vegetation—Urban forest and Landscaping greenness—is more likely due to the different maintenance activities and soil contents (see Subsection 4.2.2.3 for details).



Level				Sq. Mean
2	A			1.8377500
6	A	B		1.1872500
3		B		1.0268158
8		B	C	0.8796250
1			C	0.3883333
7			C	0.3424286
4			C	0.3215000
5			C	0.3207368
0			C	0.1892500

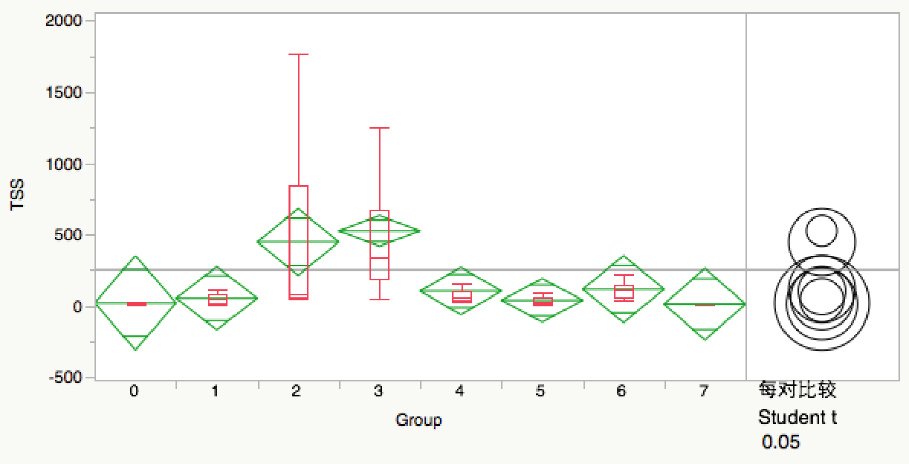
Figure 3.14: Comparison of TP mean concentration (mg/L) by attribute w/ connecting letters report

For TSS concentration (Figure 3.15), Urban forest (8) tops among all groups. Since the TSS concentration value in samples from urban forest is too high, a second test is done without urban forest (Figure 3.16), so that differences between other pairs can be revealed. In the test without forest, TSS concentration from Transportation (3) and Industrial (2) are outstandingly high. Unmanaged commercial (6) is moderate. Managed commercial (1), Business (4), Residential (5), and Landscaping (7) have low TSS. It has to be noticed that the super high TSS concentration of Urban forest (8) is primarily contributed by the riparian site UF2. The terrestrial forest site UF1 is actually stay on a moderate level that is not as high as TSS concentration of the Transportation (3), Industrial (2), or Unmanaged commercial (6) group. Maintenance of the urban forest shall be designed with site-specific conditions in mind.



Level				Sq. Mean
8	A			1567.6563
3		B		525.1103
2		B	C	446.9413
6		B	C	116.1450
4		B	C	103.0069
1		B	C	52.4333
5			C	37.9321
0		B	C	19.5575
7		B	C	11.0243

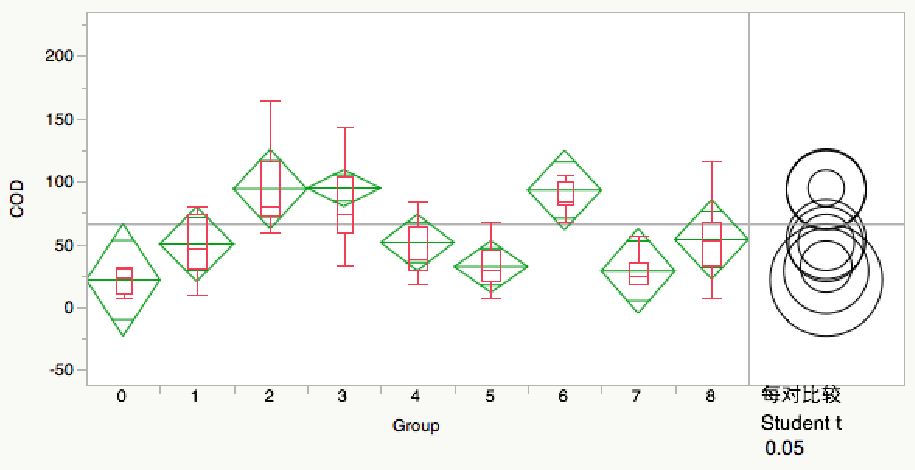
Figure 3.15: Comparison of TSS mean concentration by attribute w/ connecting letters report



Level				Sq. Mean
3	A			525.11026
2	A	B		446.94125
6		B	C	116.14500
4			C	103.00688
1			C	52.43333
5			C	37.93211
0			C	19.55750
7			C	11.02429

Figure 3.16: Comparison of TSS mean concentration by attribute (w/o forest) w/ connecting letters report

For COD (Figure 3.17), Transportation (3), Industrial (2), and Unmanaged commercial (6) are significantly higher than the other groups, indicating more organisms are captured from these sewersheds. It makes sense because common features of these attributes such as tires residuals or cooking wastes are expected to contribute a lot of organisms.



Level					Sq. Mean
3	A				94.829737
2	A	B			94.112500
6	A	B	C		93.221250
8		B	C	D	53.942500
4				D	51.511250
1			C	D	50.252222
5				D	32.238947
7				D	28.878571
0				D	21.667500

Figure 3.17: Comparison of COD mean concentration (mg/L) by attribute w/ connecting letters report

3.2.4. Summary

The case study has led to the following findings. Firstly, NPSP is an important source of water pollution in Lingang. Water quality of the majority of storm water samples collected in Lingang is worse than Grade V, indicating severely polluted.

Secondly, detailed LULC attributes can provide more insightfulness to study LULC-NPSP relationship in urban areas. Some attributes, such as transportation or industrial activities, are predictable to have stronger positive relationship with NPSP. These observations are in compliance with the conclusion of many previous studies. Some attributes are not expected before the study, such as the consequence due to unregulated cooking waste disposal by some service providers and customers; or imperviousness having low impacts. These phenomena are either not observed by other studies or inconsistent with general understanding of urban NPSP. The methodology of MALO enables the detection of these attributes and their potential contribution to water pollution.

Thirdly, among the attributes, transportation, industrial activities, unmanaged behaviors at commercial (food) services, and urban forest (at a particular stage) are more strongly related to one or some pollutants of urban NPSP. Regulated dining services, or other mild human activities and behaviors in residential, business, and educational areas shall have less impact on urban water quality. It has to be acknowledged that these relationships are rather preliminary and inconclusive. More detailed attributes and interactions shall be further investigated for better understanding the site-specific mechanism of urban NPSP.

Fourthly, urban NPSP is the result of assembled effects by many interrelated factors rather than some individual factor. NPSP can be low on pavements if no human activity is occurring, while is can be high in urban forest. Impervious surfaces often co-exist or correlate with human activities that might generate a lot pollution. Only reducing pavement without reducing the sources might not be very effective because it only “relocate” the pollution. At the same time, the vegetation shall be in right conditions (e.g. topology, maintenance, etc.) that assure it to be sink of NPSP instead of source.

CHAPTER 4: DISCUSSION: BAD IDEA? BAD PLANNING? BAD IMPLEMENTATION?

The case study in Chapter 3 has connected some LULC attributes with the NPSP in storm water. Attributes like transportation, industrial activities, unmanaged human behaviors, and urban forest are found related to high concentrations of pollutants. These attributes are indeed directly associated with or caused by the urbanization. However, they are not that difficult to be predicted. Why were these attributes not foreseen, alerted, or addressed properly in the planning even though water quality was a big concern?

4.1. Motivation: The Next Growth Pole

To answer this question, we have to first look into the purpose and the process of the urbanization in Lingang. Regardless of the fancy titles like “green city”, “sustainable city”, or “low carbon city”, Lingang, in nature, is nothing but a development zone (also known as “special economic zone”). It is a common model of urbanization in China targeting at quick economic growth by attracting foreign and domestic investments with the advantage of chartered policies (Wei and Leung 2005; Yang and Wang 2008; Zhang 2011). Establishing development zones has been recognized as “a central force in the rapid ascent of China’s economy” (Wei and Leung 2005). It is not a secret that Chinese governments and officials are primarily evaluated in a GDP-oriented system. Therefore, the “job number one” for Lingang—the new “growth pole” of Shanghai—is to promote economic development.

To guarantee success, Lingang is following the path of another huge urbanization project in Shanghai—the Pudong New Area. Pudong is arguably the largest and the most successful single urbanization project in China. It consists of four major functioning zones: Lujiazui Finance and Trade Zone, Waigaoqiao Free Trade Zone, Jinqiao Export Processing Zone, and Zhangjiang High-Tech Park. Lujiazui is the CBD; Waigaoqiao is the hub of im- and export goods; Jinqiao is the industrial base; and Zhangjiang is an incubator of high-tech and innovation. It can be seen that functional zones in Lingang and Pudong are highly identical. Lingang also has a central business area, a logistic hub for goods, a manufacture base, and a high-tech park (in construction). Lingang even has a heavy equipment manufacture zone where corporations like GM set up their factories.

The reason Lingang copies Pudong is probably because the Pudong model is so promising. Since 1995—only 5 years after the urbanization was initiated, Pudong has occupied at least 25% of total foreign direct investment (FDI) of Shanghai, and reached the peak of 45% in 2000 (Wei and Leung 2005). In 2010, Pudong contributed to nearly 30% (42.54/148.03 billion CNY) of fiscal revenue of Shanghai (data source: Shanghai Statistics Year Book 2011). To be noticed, Pudong is just one of the twenty districts of the Shanghai city.

In addition, a special economic task of Lingang's is to support the two important ports of Shanghai—the Pudong International Airport which is one of the busiest airports in the world, and the Yangshan Deep Water Port which is designated to be the largest container port in Asia. Shanghai is appointed by the central government of China to become “International Shipping Center”. These two ports are the “pillars” for this target. Many international and domestic corporations come to set up factories and warehouses because of the advantage of location, low cost of land, and preferential policies. Lingang's economic future is very optimistic. Since the first foreign investment project was settled in 2004, Lingang has attracted more than 130 projects with direct investment over 43 billion CNY by 2011 (data source: Lingang Management Commission).

We can already see two “high-impact” attributes here—transportation and industrial.

They are the two major contributors to the economy of Lingang and are not likely to diminish in the predictable future. By the time this article is written, only one-third of Lingang’s land has been urbanized. With the development going on, NPSP related to transportation and industry is more than likely to increase substantially.

4.2. Process of Planning and Implementation

In Chapter 1, it is introduced that lake view is the most highlighting environmental feature in Lingang. Therefore, it is true that the planning of Lingang always keeps water quality in mind. But one factor that shall not be ignored is that on what kind of land the lake is based.

4.2.1. Land Reclamation

Acquiring land is the first major challenge for the project because land is a scarce resource in Shanghai. Firstly, due to the very flourish real estate market in Shanghai for the past 10 years, land becomes very expensive. Acquiring land and relocating local people are extremely costly. Secondly, the China Land Management Law requires that if agricultural land is occupied for non-agricultural purposes, the developer must reclaim some other land of the same size to make up for the deficit they have caused. For a project as large as Lingang, Shanghai does not have enough non-agricultural land to compensate for the land being occupied. Therefore, it is determined to reclaim land from the coastal marshes.

Such land reclamation can have severe environmental consequences. The reclaimed land is made of coastal soils from the excavation of Lake Dishui, mixed with sand and cement. According to the results of soil test from another team of this research project, 240 soil samples were taken from the urban forest, 77% are moderately salinized or worse[4] and 40% are recognized as saline soils (Lv 2011). It would be very challenging to sustain a freshwater lake based on such soils. The soils make a “chemical time bomb” that is constantly threatening the water quality. It is also why plants in the urban forest are repeatedly cultivated. Many of the saplings cannot survive in such soils. For every re-cultivation, soils need to be plowed and fertilized. It is not surprising that water samples taken from the forest have high concentrations of pollutants.

4.2.2. Limitations of Urban Planning Process in China

The consequences of the land reclamation is not hard to predict, either. Once again, why were they not attended enough before the plan of reclamation and urbanization were implemented?

4.2.2.1. Process of Urban Planning

Urban planning in China is a little different from western understanding. Taylor (1998) summarized the art of planning in western countries into two phases—“as design or architecture” and “as technical analysis of a soft science”. In the first phase (1940s to 1960s), planning was considered as the extension of designing. Planners were trained together with architects who judged cities by aesthetics and arts. In the second phase (after 1960s), people realized that cities were entities with complicated processes. Planning was then considered as a “soft science” in which planners became coordinators who could recognize and reconcile the needs of various groups on land use related issues. Public participation and general consensus became more and more significant components of planning. Planning in China, on the other hand, remains to be “design and architecture” even in nowadays. Due to the centralized top-down system, government holds all the power of making decisions. Planners are still architects.

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[4] According to the “Saline Soil Classification Standard of China for coastal saline soil” (Weng et al., 2010), salinity of soils are categorized as: non-salinized (salinity < 1g/kg soil), slightly salinized (salinity from 1 to 2 g/kg soil), moderately salinized (salinity from 2 to 4 g/kg soil), severely salinized (salinity from 4 to 6 g/kg soil), and saline soil (salinity > 6 g/kg soil).

An interesting phenomenon is government’s paradoxical attitude towards foreign ideas. Chinese government is very willing to take advices from non-Chinese parties, as they believe that "outsiders sometimes have greater wisdom because they can look at things from the outside" (Nicoll 1993). The current design of Lake Dishui and Lingang Main City was actually proposed by a firm from Germany. But at the same time, the government also wants to make sure that the foreign planners are just architects, too. Firms are often not given the time to do thorough survey or analysis (Olds 1997). What the government expects is “shock of the new” (Olds 1997). In recent years, it is rather preferable if such shock can includes “the spirit of sustainability” because environment is a hot topic. Therefore, the firms’ focus is on making eye-catching designs by incorporating their experience of global best practices. Apparently, the pleasant Garden City-like outlook, landscaping, and the lake view have successfully caught government leaders’ eyes.

4.2.2.2. Protocols of Planning

The conceptual master plan designed by the foreign firm is then delivered to local planners to be converted into detailed and regulatory planning. In fact, Chinese law only permits state-owned firms to do urban planning on these levels. Unfortunately, the global best practices suggested by the foreign firm are likely to encounter with local regulations, which might severely compromise their effectiveness. Following are a few examples.

(1) Urban Streams and Water Bodies

To prevent urban inland inundation, the Shanghai Regulation of Urban Construction and Management states two standard practices to enhance the ability of discharging flood—“straighten the channels” to speed up flood discharge and “build embankments” to resist high water level (Li et al. 2010). They are the “standard protocols” in the regulations of urban development. The location of Lingang determines that it is facing with high risk of flooding. Therefore, designed meanders are straightened; proposed flood plains are replaced by concrete walls. In addition, the basin of Lake Dishui is entirely concreted for a second purpose—to prevent seepage by the seawater. In fact, arguments on whether it is proper to excavate such a big fresh water lake at coastal area have never ended since the proposal of Lake Dishui was accepted. Nevertheless, the beautiful metaphor of "drop and ripples" has still been turned into reality. So have the foreseeable ecological risks.

(2) Urban Greenness

Greenness is an important factor for the wellness of urban ecosystem. Percentage of greenness is often a mandatory requirements in urban planning in China. In Lingang, this number reaches a high value as 45%, purposing to enhance the city's environment quality (Chen et al. 2009). However, more vegetation does not necessarily make the ecosystem healthy. Neither does an "aesthetically beautiful" environment. The spatial complexity for urban plants is that their entire lifecycles are different from their natural counterparts'.

In Shanghai, the principle of choosing plants for urban landscaping is "green in four seasons, flowering in three". Therefore, many exotic species are introduced for aesthetical purposes. To be noticed, they are not invading species with hyper vitality. On the contrary, they are often vulnerable because of lacking adaptability to a strange environment. To survive, these plants need extensive maintenances. For example, during the two-year period of sampling, we noticed that plants in the urban forest were replaced at least twice because of massive death.

Curbing the green space is another countermeasure of maintenance to protect the plants from external disturbances. By field survey and RS image interpretation, it is found that about 87% of the green spaces in the study area are curbed (excluding the urban forest). Quarantining them from the surrounding surfaces ensures controlled living conditions (e.g. soils, water, fertilizer, etc.) for these plants to survive (China Environment News[5]). It is ironic because the mandatory line of 45% vegetation coverage in the planning was meant to be an advantage that guarantees a pleasant environment. But again, the invisible ecological health yields to the visible aesthetics, which makes plants liability instead of contributor to the environment.

4.2.2.3. Urban Management

The case study has also found that some commercial food services are closely related to NPSP, subject to improper behaviors of waste disposal by both workers and customers of the services. It has to be admitted that such behavior exists widely, not only in Lingang, but also in Shanghai, or even the entire China. It is an embarrassing truth. Mixed land use is a preferred urban form because services are conveniently available to people. But the dispersed distribution and wide spread of these services make it rather difficult to monitor, manage, or treat the NPSP incurred, because NPSP mitigation practices cannot stop the reckless behaviors. On the contrary, they might even encourage people to behave more recklessly as they believe the impacts would be remediated.

4.3. Suggestions for Improving Water Quality

Water quality degradation in Lingang is an ecological problem that cannot be solved merely by ecological countermeasures. The microscopic “high-impact” attributes indicate that the ultimate causes of the problem are lying in the macroscopic life circle of decision making, planning, and implementation. The current situation is that ecological concerns and practices can only find their “living spaces” in the gaps among the national pursuit of economic growth, the gaming for retrieving land resource, the government-dominated

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[5] http://news.sina.com.cn/green/news/roll/2012-07-26/102124848945_2.shtml

planning processes, the constraints of localizing global best practices by local conditions or protocols, the carelessness to public good for personal convenience, etc.

Although pleasant environment is always desired, approaching it is tremendously difficult. It requires each of the related parties to compromise some of their benefits. Would local government be willing to earn fewer credits by slowing down the pace of economy and deploying environmental strategies that might only benefit their successors? Would the process of urban planning be deregulated so that the decisions are made based on assessment of feasibility (by both international and domestic experts) rather than leader’s wish? Would the developers agree to pay significantly more for existing land instead of creating new lands with ecological fallacies? Could the protocols of planning, construction, and management be revised in a less rigid way so that they do not become obstacles of innovative ecological practices? Could local people be more alerted and responsible for the environment? The answers might not be optimistic.

Based on the high-impact attributes detected in this study, some suggestions are given for resolving the water quality issue in Lingang.

Firstly, further study on the high-impact attributes is needed to investigate the exact mechanisms that link them to NPSP. This study only detects attributes that are related to NPSP in a statistical manner. It is possible to mistaken “co-existence” with “causal effects”. Co-existence only makes the attributes indicators. But indicators do not necessarily cause the problem. For example, it has to be made clear whether it is the contents in the containers, or the emission by the lifting machines, or other factors that make industrial sewersheds hotspots of NPSP. Mitigation strategies can only be effective if they are “curing the disease” rather than “treating the symptoms”.

Secondly, changing the way of configuring and maintaining the “natural” elements in urban areas. If vegetation is expected to perform more ecological functions rather than just “being beautiful”, it should be treated in the right way. Covering 45% of the surface, green space is still a big opportunity for improving surface water quality in Lingang. The challenges now being noticed are soils, choice of species, and structure. They are interrelated matters that can be managed in a coordinated way. Indeed, the quality of soil in Lingang is not ideal. But there are still plenty of species that can survive. It would take substantially less time and maintenance for such species to become self-sustaining than the exotic ones that are introduced only for aesthetics purpose. For example, in the field trips we found that local farmers planted broad beans in the urban forest. The beans grew much better than the saplings. In addition, it is fortunate that “softening” the stream banks has been consistently appealed by the urban ecology community. Innovative technologies on restoring riparian buffers are being developed.

Thirdly, reinforcing the regulations and education of environmental sanitation. Waste disposal shall be more rigorously regulated. It is also an area that public participation is highly appreciated to enhance the sense of responsibility by propaganda and education. People shall be encouraged to engage in efforts of promoting healthy life style and habits, and monitoring improper behaviors as well.

CHAPTER 5: CONCLUSIONS

This article describes a study addressing the surface water quality degradation issue in a rapidly urbanized area—Lingang New City in Shanghai, China. As a city featured by lake view and planned with environment in mind, Lingang's landscape is designed with artistic water system and high coverage of green space. However, the efforts do not pay off environmentally as expected. Rather, Lingang suffers the incident of surface water quality degradation soon after its development.

This study is conducted to address this issue by answering the following three questions.

Question 1: What is the key factor that makes ecological dynamics in urbanized areas unpredictable?

The case study has provided strong evidence to support the primary hypothesis of this article that spatial complexity is the key factor. Every urban area is a coupled human and natural system composed by mosaic of patches that differ dramatically in structure, composition, richness, functions, changes, and frequency (Cadenasso et al. 2006A, Liu et al. 2007). The characteristics of these patches in different places are appreciably different (Goonetilleke et al. 2005). Spatial complexity is defined by such explicit and site-specific combinations of various objects, attributes, and interactions. The ultimate ecological phenomenon in urban ecosystem is the results of accumulated effects by dynamics within and among patches of the mosaic. Changing one patch or one trait of a patch in a mosaic could lead to significant diversity of ecological impacts in different urban environments. For example, the height of the curb constraining green spaces can be as low as 10cm. It is too trivial to be detected by most topological data. But it is able to utterly change the hydrology of the area, which further alters the interactions between pervious and impervious surfaces. Failing to capture such subtle changes is likely to misestimate the ecological functions. Therefore, urban ecosystems are perceived as unpredictable.

Question 2: How can this key factor be addressed and applied to explain the impacts urbanization has on none-point source pollution in Lingang?

To reflect spatial complexity, urban composition must be shown as the various and unique combinations of interacting LULC elements, rather than the assembly of discrete patches. Addressing spatial complexity therefore requires an LULC classification system that can recognize and accommodate every relevant LULC component from the natural, built-up, and socioeconomic subsectors of urban ecosystem. A major disadvantage of conventional LULC classification methods is the attempt to generalize and simplify urban landscape into homogenous patches. Considerable amount of information is missing by such simplification which is in the opposite direction for uncovering spatial complexity.

A new LULC classification, the Multi-Attribute Land Object (MALO) approach is proposed to address spatial complexity. In brief, MALO considers urban ecosystem as the combination of a bunch of land objects carrying multiple attributes at certain scale. Land objects are patches with distinguishable boundaries. Instead of categorizing each patch into a pre-defined LULC type, MALO defines objects by assigning infinite number of attributes based on real-world conditions. Each attribute represents one trait in one of the three subsectors of urban ecosystem. Objects can be grouped by attributes they share and differentiated by attributes that they own distinctively. Spatial complexity is represented by the unique combination of attributes associated to each object.

MALO is applied to a case study focusing on the relationship between LULC and NPSP in Lingang. Objects are delineated at sewershed level in order to cover as many distinctive attributes as possible while making sure that the combination of attributes is not too complicated. Water samples are taken at 31 sewersheds for testing concentrations of nitrate nitrogen, ammonium nitrogen, total phosphorous, total suspended solid, and chemical oxygen demand in the storm water. Results of the study indicate that traffic of motor vehicle, traditional industrial activities, unmanaged behaviors by commercial services, and improperly maintained urban forest are more strongly related to NPSP. Managed commercial services, mild human activities in residential and business areas, and small landscaping vegetation have relatively low impact to the environment in terms of NPSP. Two special phenomena are observed. Firstly, pavement with no human activities shows low contribution to NPSP. Secondly, outstanding TSS removal is observed at some vegetated spaces used for parking, which might subject to the micro detention ponds formed by the grid-like bricks used to stabilize the soil

Question 3: Why does surface water quality degrade while it is a key planning concern of environment in Lingang?

The developing Lingang is motivated by economic growth. Industry, manufacture, and logistics service are among the most critical components of Lingang’s economy. Economy has been and will consistently be the driving force for the increase of transportation and industrial activities. Pleasant environment, or “sustainable city” is desired, but not superior to the economy. Compromising economy for environmental purposes is unlikely.

In addition, environmental considerations and practices encounter challenges from the institutional system, regulations, and processes of urban planning and management. Due to the centralized system, decision-making for planning are dominated by the government, often based on singular target (e.g. economy). Practices for overcoming some major challenges (e.g. land reclamation, embankments) are likely to have created new environmental hazards. Aesthetically pleasant landscaping design does not necessarily lead to ecologically reasonable results. Absence of management further indulges people to behave inappropriately. Every incident in the chain of urbanization can potentially compromise the legitimacy of the strategies or practices attempting good environment.

The contributions of this study are as follows:

In the aspect of theory, this study reinforces the importance of spatial complexity in urban ecology and planning. Complexity due to explicit and site-specific LULC conditions and interactions lies in every aspect of urban ecosystem. One subtle change in a simple feature might lead to significantly different ecological consequences. Godschalk (2004) concluded that to pursue urban sustainability, land use planning should not only focus on the macro scale of the city, metropolis, or region, but more importantly at the micro scale of the block, street, and building. Only by fully understanding the mechanisms at the most detailed level, can planners accurately evaluate risks and design well targeted practices. Failing to recognize spatial complexity by attributing particular ecological phenomenon to generalized or simplified LULC features could be misleading.

In the aspect of methodology, this study introduces an innovative method of LULC classification to embrace spatial complexity. Only with proper tools can the complicated components and dynamics of urban ecosystem be sufficiently perceived. MALO is designed to be the tool to fulfill such needs. It is innovative in ways that, firstly, it subvert the “pre-define and categorize” sequence of LULC data interpretation by conventional methods. Conventional systems lose information by ignoring or misclassifying characteristics that do not have a pre-defined class. On the contrary, MALO welcomes all attributes that help define the objects in a collaborative manner. Secondly, it breaks the rigid bond between LULC types and characteristics. In conventional methods, each LULC type has a fixed set of characteristics that are exclusive to another type. But in the real world, patches classified as the same type can have fundamentally different sets of characteristics. MALO breaks down “defaults” and select attributes that can reflect the reality as closely as possible.

In the aspect of application, this study depicts the factors in Lingang that might be closely related to NPSP. Unfortunately, these “high-impact” factors are imbedded in every link of this urbanization project. Fixing the problem requires the participation of all related parties, from the decision makers to end users. Mutual benefit can be reached only when everyone is willing to make the essential compromise and sacrifice.

Future work is suggested to focus on (1) Improving the MALO method. The current MALO is only a prototype. More work is yet to be done on standardizing the process including object delineation, attribute collection and screening, scale determination, etc.; and (2) Investigating the mechanisms of how the high-impact factors affect NPSP in order to make better targeted and effective strategies for improving water quality in Lingang.

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APPENDIX: RESULTS OF CHEMICAL TESTS OF WATER SAMPLES

1. NO_3^--N Concentration

Code	Functional Zone	Distinct Attribute	Concentration (mg/L)			
			05-24-2011	06-06-2011	08-08-2011	09-16-2011
IW1	Industry/warehouse	Dining	1.25	2.17	1.57	3.97
IW3	Industry/warehouse	Loading Deck	1.30	2.80	1.23	4.15
IW4	Industry/warehouse	Main Entrance		6.73	5.82	7.30
IW5	Industry/warehouse	Meadow	1.53			
IW6	Industry/warehouse	Road	1.77	1.27	1.64	
ED1	Educational	Cafeteria	3.41	1.82	1.43	6.04
ED2	Educational	Library	3.63		1.25	7.40
ED4	Educational	Dorm	2.81	2.49	5.60	
ED5	Educational	Vacant	1.72	1.31	0.98	
ED6	Educational	Bus terminal	3.90	7.27	2.57	6.73
ED7	Educational	Food and drink bar	3.65	3.50	2.12	6.21
ED8	Educational	Road	10.55	4.03	8.99	
CR1	Residential	Low-density apartment	1.23	1.35	1.96	7.67
CR2	Residential	Vegetation in low density	2.70	1.30	1.10	7.02
CR3	Residential	Vegetation in high density	3.02			
CR4	Residential	High-density apartment	3.27	1.32	1.60	6.15
CR5	Residential	Low-density apartment (internal)	3.83	1.40	1.95	6.68
CR6	Residential	Small restaurants		1.48	1.67	5.69
CR7	Residential	Road		4.82	4.70	4.30
CR8	Residential	Construction site	5.55	6.85	3.38	
CR9	Residential	Road	8.33	9.63	2.02	
UF1	Urban forest	Forest (inland)	3.85	1.73	1.90	4.95
UF2	Urban forest	Forest (riparian)		4.63		3.47
BC1	Business/office	Road	8.05	6.50	2.27	4.68
BC2	Business/office	Road	3.28	6.50		
BC3	Business/office	Driveway of office complex	2.66	13.76	2.03	
BC4	Business/office	Parking lot of office complex	3.54	7.42	7.40	6.65
BC5	Business/office	Roof of office building			15.54	15.77
BC6	Business/office	Road	14.29	7.70	3.29	

2. NH_4^+-N concentration

Code	Functional Zone	Distinct Attribute	Concentration (mg/L)				
			04-23-2011	**05-24-2011**	**06-06-2011**	**08-08-2011**	**09-16-2011**
IW1	Industry/warehouse	Dining	2.15		5.45	5.33	3.32
IW3	Industry/warehouse	Loading Deck	20.68	0.82	1.14	12.88	7.50
IW4	Industry/warehouse	Main Entrance			7.24	17.98	9.18
IW5	Industry/warehouse	Meadow		1.49			
IW6	Industry/warehouse	Road		1.36	1.52	3.63	2.69
ED1	Educational	Cafeteria	3.83	2.31	1.12	7.89	2.22
ED2	Educational	Library	4.03	2.55	1.58	3.36	1.25
ED4	Educational	Dorm	3.02	1.00	3.17	2.35	
ED5	Educational	Vacant	2.10	0.66	1.81	1.43	
ED6	Educational	Bus terminal	6.94	0.92	2.31	2.67	3.13
ED7	Educational	Food and drink bar		1.53	3.57	3.89	4.10
ED8	Educational	Road		5.04	11.59	14.13	6.20
CR1	Residential	Low-density apartment	2.95	1.42	2.84	3.25	0.57
CR2	Residential	Vegetation in low density	5.14	2.10	3.76	3.04	3.54
CR3	Residential	Vegetation in high density		3.45			
CR4	Residential	High-density apartment	3.50	2.73	2.31	3.95	2.23
CR5	Residential	Low-density apartment (internal)	3.41	1.82	2.49	2.24	2.05
CR6	Residential	Small restaurants	15.44		3.37	9.19	4.90
CR7	Residential	Road				5.17	1.23
CR8	Residential	Construction site	5.05	2.37	3.04	3.44	3.42
CR9	Residential	Road		3.40	7.88	8.37	3.49
UF1	Urban forest	Forest (inland)	3.64	4.62	4.24	4.21	4.58
UF2	Urban forest	Forest (riparian)	0.48		0.780		5.42
BC1	Business/office	Road	7.65	2.57	2.31	9.01	3.09
BC2	Business/office	Road	15.40	4.66	4.45		
BC3	Business/office	Driveway of office complex	3.92	1.65	7.42	8.37	
BC4	Business/office	Parking lot of office complex	3.32	1.08	6.85	2.20	1.88
BC5	Business/office	Roof of office building				5.71	6.26
BC6	Business/office	Road	8.09	4.47	7.47	8.93	4.93

3. TP concentration

Code	Functional Zone	Distinct Attribute	Concentration (mg/L)				
			04-23-2011	**05-24-2011**	**06-06-2011**	**08-08-2011**	**09-16-2011**
IW1	Industry/warehouse	Dining	0.239		0.300	0.376	0.13
IW3	Industry/warehouse	Loading Deck	0.885	0.929	0.720	0.445	0.57
IW4	Industry/warehouse	Main Entrance			1.450	5.183	4.52
IW5	Industry/warehouse	Meadow		0.433			
IW6	Industry/warehouse	Road		0.340	0.461	0.627	0.80
ED1	Educational	Cafeteria	0.210	0.351	0.445	1.084	0.36
ED2	Educational	Library	0.169	0.136	0.300	0.212	0.23
ED4	Educational	Dorm	0.268	0.202	0.299	0.518	
ED5	Educational	Vacant	0.154	0.133	0.209	0.261	
ED6	Educational	Bus terminal	0.384	0.341	0.506	0.730	0.65
ED7	Educational	Food and drink bar		0.389	0.618	1.112	1.03
ED8	Educational	Road		1.188	1.048	1.538	2.16
CR1	Residential	Low-density apartment	0.224	0.465	0.408	0.394	0.25
CR2	Residential	Vegetation in low density	0.272	0.385	0.292	0.219	0.18
CR3	Residential	Vegetation in high density		0.616			
CR4	Residential	High-density apartment	0.239	0.289	0.405	0.513	0.65
CR5	Residential	Low-density apartment (internal)	0.147	0.136	0.222	0.105	0.36
CR6	Residential	Small restaurants	1.500		1.132	2.347	1.37
CR7	Residential	Road				1.595	2.18
CR8	Residential	Construction site	0.298	0.450	0.846	1.018	0.57
CR9	Residential	Road		0.478	0.732	1.189	1.90
UF1	Urban forest	Forest (inland)	0.279	0.267	0.307	0.772	1.33
UF2	Urban forest	Forest (riparian)	0.482		0.780		2.82
BC1	Business/office	Road	0.421	0.924	0.846	1.502	1.32
BC2	Business/office	Road	0.941	0.610	1.324		
BC3	Business/office	Driveway of office complex	0.066	0.167	0.327	1.232	
BC4	Business/office	Parking lot of office complex	0.213	0.278	0.322	0.407	0.79
BC5	Business/office	Roof of office building				0.105	0.19
BC6	Business/office	Road	0.408	0.926	1.252	4.016	2.31

4. TSS concentration

Code	Functional Zone	Distinct Attribute	Concentration (mg/L)				
			04-23-2011	**05-24-2011**	**06-06-2011**	**08-08-2011**	**09-16-2011**
IW1	Industry/warehouse	Dining	7.48		7.03	20.92	28.07
IW3	Industry/warehouse	Loading Deck	86.58	46.88	77.34	83.86	61.96
IW4	Industry/warehouse	Main Entrance			1767.71	495.68	955.52
IW5	Industry/warehouse	Meadow		10.36	13.60		
IW6	Industry/warehouse	Road		264.50	192.60	399.38	350.86
ED1	Educational	Cafeteria	93.30	117.50	76.29	51.81	69.50
ED2	Educational	Library	88.09	74.65	65.84	40.46	57.11
ED4	Educational	Dorm	20.75	36.13	32.85	75.32	
ED5	Educational	Vacant	10.12	18.03	18.53	31.55	
ED6	Educational	Bus terminal	568.83	169.12	141.39	303.08	175.43
ED7	Educational	Food and drink bar		132.77	112.57	222.64	77.04
ED8	Educational	Road		1228.74	1484.04	1250.39	595.71
CR1	Residential	Low-density apartment	7.35	28.67	88.68	84.95	60.69
CR2	Residential	Vegetation in low density	8.29	10.50	9.64	6.66	4.84
CR3	Residential	Vegetation in high density		26.88			
CR4	Residential	High-density apartment	15.83	23.29	23.44	51.36	39.86
CR5	Residential	Low-density apartment (internal)	15.23	21.65	26.13	12.99	55.54
CR6	Residential	Small restaurants	121.80		43.93	156.91	61.50
CR7	Residential	Road				63.15	51.58
CR8	Residential	Construction site	501.49	420.63	909.24	1893.12	1237.70
CR9	Residential	Road		229.92	883.86	48.75	591.23
UF1	Urban forest	Forest (inland)	11.26	43.15	126.61	40.61	121.90
UF2	Urban forest	Forest (riparian)	3215.83		7620.27		1361.62
BC1	Business/office	Road	283.67	241.87	524.04	538.97	123.32
BC2	Business/office	Road	248.70	237.39	1106.31		
BC3	Business/office	Driveway of office complex	32.69	61.06	140.19	574.81	
BC4	Business/office	Parking lot of office complex	40.60	56.73	153.78	115.56	54.87
BC5	Business/office	Roof of office building				37.92	53.75
BC6	Business/office	Road	334.43	346.38	1510.92	160.80	288.90

5. COD concentration

Code	Functional Zone	Distinct Attribute	Concentration (mg/L)				
			04-23-2011	05-24-2011	06-06-2011	08-08-2011	09-16-2011
IW1	Industry/warehouse	Dining	10.39		33.53	29.57	43.87
IW3	Industry/warehouse	Loading Deck	71.67	79.32	82.47	59.29	75.09
IW4	Industry/warehouse	Main Entrance			98.00	122.84	164.22
IW5	Industry/warehouse	Meadow		27.74			
IW6	Industry/warehouse	Road		54.58	60.37	59.29	71.33
ED1	Educational	Cafeteria	46.86	80.89	76.16	72.08	58.92
ED2	Educational	Library	34.90	37.74	28.79	28.44	32.58
ED4	Educational	Dorm	11.37	50.37	32.47	26.94	
ED5	Educational	Vacant	7.45	32.11	25.63	21.48	
ED6	Educational	Bus terminal	62.84	77.74	79.84	92.74	46.88
ED7	Educational	Food and drink bar		89.21	83.53	82.31	67.95
ED8	Educational	Road		422.00	224.05	116.00	172.69
CR1	Residential	Low-density apartment	9.90	29.84	28.26	40.48	34.84
CR2	Residential	Vegetation in low density	18.53	36.16	18.79	18.66	25.06
CR3	Residential	Vegetation in high density		57.21			
CR4	Residential	High-density apartment	6.96	67.74	23.53	28.44	46.12
CR5	Residential	Low-density apartment (internal)	21.18	49.32	35.11	20.54	49.13
CR6	Residential	Small restaurants	104.74		84.05	151.99	81.99
CR7	Residential	Road				142.59	51.39
CR8	Residential	Construction site	53.04	86.16	69.84	57.79	143.53
CR9	Residential	Road		78.26	73.53	73.65	71.71
UF1	Urban forest	Forest (inland)	6.96	46.40	33.53	34.46	61.17
UF2	Urban forest	Forest (riparian)	69.00		63.77		116.25
BC1	Business/office	Road	64.80	80.37	126.05	171.75	44.62
BC2	Business/office	Road	63.33	33.00	77.81		
BC3	Business/office	Driveway of office complex	39.31	84.58	78.79	166.10	
BC4	Business/office	Parking lot of office complex	18.24	22.47	57.21	66.82	38.60
BC5	Business/office	Roof of office building				39.35	50.26
BC6	Business/office	Road	75.49	93.53	103.25	108.73	68.70