

Article

Correlations of Stormwater Runoff and Quality: Urban Pavement and Property Value by Land Use at the Parcel Level in a Small Sized American City

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Received: 26 September 2019; Accepted: 11 November 2019; Published: 12 November 2019



Abstract: As the urban environment keeps growing, stormwater management programs have been adopted to address unregulated nonpoint runoff and pollutants across the world. Extensive studies on stormwater runoff and quality at smaller spatial scales exist, but are rare at larger spatial scales. Using the City of Corvallis, Oregon, a small sized American city, as a test-bed, this study estimates urban stormwater runoff and quality by zoning, which specifies land uses, and by parcel, which defines land ownership using the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model and high resolution land use and land cover data. The correlations between stormwater runoff volume, stormwater quality, parcel land cover sizes, and values are then analyzed and visualized in RStudio. The results indicate that stormwater runoff and quality are determined by complex biophysical processes, with strong correlations between urban spatial sizes and property values for some land uses being observed. The research results provide suggestions for low impact development applications for different land uses, and the findings in this research can be used to suggest stormwater management policy for various land uses in small sized cities.

Keywords: urban pavement; stormwater runoff and quality; land use; parcel; property value; correlation

1. Introduction

Urbanized areas are often covered by man-made impervious hard surfaces such as building roofs, paved roads, sidewalks, and parking lots, as well as pervious surfaces such as natural vegetation, bare land, or water [1,2]. Extensive studies have shown that stormwater runoff often occurs during precipitation when the land does not allow water to soak into the ground, and with the increase of impervious hard surfaces, the volume of urban stormwater runoff has increased significantly [3]. When the stormwater flows over impervious surfaces, it accumulates contaminants and sediment that impact water quality drastically [4,5]. However, how stormwater runoff quantity and quality, land pavement, and property values are correlated on the land parcel level of different land uses is unclear [6–8].

Small and medium sized cities have been growing increasingly in the United States, driven by the potential to stimulate inclusive economic developments that bridge the urban-rural divide [9]. As self-standing municipalities outside major urban agglomerations, small cities play an important role in protecting natural environments [10–12]. In many large cities in the United States, storm pipes are integrated with sanitary sewers and connected to treatment plants where runoff is treated during precipitation events; however, stormwater is usually discharged directly into natural rivers and storms in small cities due to the lack of funds and facilities [13]. In light of these points, small cities need more diverse and comprehensive stormwater management strategies and policy to prevent nonpoint source pollution [14]. Corvallis, OR, was ranked as the third best small city to live in the U.S. in 2018

by livability [15]; however, the stormwater quality has deteriorated over time, and it does not meet the water quality standards established by the U.S. EPA (U.S. Environment Protection Agency) Clean Water Act [16]. The City of Corvallis has its own zoning designation, which specifies land uses such as commercial, residential, or industrial, and land parcel data define ownership with detailed property attributes, such as parcel size, building size, and market and assessed property value. The city also has detailed data of pervious land area and impervious land area (building footprint, road and driveway, sidewalk and path, parking lot), all in geographical information system (GIS) formats.

Using Corvallis as the case study, this research estimates its stormwater runoff quantity and quality by the well-known Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) water yield and pollutant export models. Modelling results are used to quantify their correlations with land pavement sizes and property values for residential, industrial, and commercial land uses classified from the zoning map at the land parcel level. InVEST was developed and calibrated in the Willamette River area within which the city of Corvallis is located [17] and has been applied well in the other coastal areas in Western North America in previous studies [18,19]. Utilizing the high resolution land use and land cover data on the parcel level provided by the city [20], this study chose Corvallis to take full advantage of the model. The research results aim to analyze: (i) what are the spatial factors (different land cover sizes) and value factors (property values) that need to be considered for stormwater management regulation in different land use parcels; (ii) to identify where to apply low impact development techniques to manage stormwater in different land uses parcels.

Urban stormwater runoff is heavily influenced by urban impervious surfaces and drainage systems in a watershed [21]. The change of natural lands into urban built-up areas in a watershed entails the removal of vegetation, alteration of soil characteristics, and creation of impervious surfaces, as well as interference of stream networks [22]. These changes are the leading causes for high runoff and peak discharges [23,24], which have been associated with many environmental problems, for example the destruction of aquatic habitats [25], alteration of hydrology [26], and increased incidents of flooding [27]. Specifically, Hao et al. (2015) showed that from 1986 to 2013, stream flow increased by 58% and land cover changes into impervious surface contributed more than 80% of the stream flow in a southern China watershed [28]. Lepeska (2016) demonstrated that buildings, roads, and parking lots contributed 40%, 31%, and 25% to the total urban runoff, respectively, in a watershed dominated by man-made land areas [29]. Schneider et al. (2012) demonstrated that urban sprawl with various impervious surfaces decreased the city's ability to regulate flooding, and the residential area expansion resulted in 15–48% more urban runoff [30]. Wu et al. (2013) quantified the impacts of impervious surface and climate change on stream ecosystems and found that an impervious surface increase from 5.2% to 17.1% led to a large increase in peak discharge, flashiness, and runoff ratio to 49.5%, 39.3%, and 73.9%, respectively [31].

Urban development with vast impervious surfaces not only contributes to more stormwater runoff, but also degrades stormwater quality. In an investigation of the relationship between impervious surfaces and water samples collected in the City of Lubbock, TX, Heintzman et al. (2015) concluded that impervious pavement percentage is positively related to polycyclic aromatic hydrocarbons and suggested that in urban stormwater management, streams surrounded by more pervious covers and buffers should have fewer pollutants in the water [32]. In addition, Hogan and Walbridge (2007) found a significantly nonlinear correlation between phosphorus concentration and impervious surface percentage [33]. Ramirez et al. (2014) analyzed land cover variables with iron concentrations in stormwater in Puerto Rico and found significant linear regressions among chemical concentration, impervious surface, building density, road density, and pipe density [34].

Studies on urban stormwater have been performed across various disciplinary at various spatial levels [35]. However, research at the urban zoning and land parcel level is limited, mainly due to data availability and modelling complexity [36]. As a result, these studies draw attention mainly from government agencies, non-profit groups, or scientific communities, but not from individual owners whose land development decisions/actions at specific locations physically alter the environment's

quality [37,38]. Research on environmental quality dynamics (gains or losses) at the urban land use and parcel level is rare, and policies to influence parcel level urban development by individual owners are yet to be developed [39]. Moreover, most of these studies were conducted with urban impervious surface data derived from remote sensing images with few urban land use categories at a regional watershed scale [40]. Remote sensing is a relatively inexpensive and constructive method for reconstructing a base map in the absence of detailed land survey methods, but conditions under the urban tree canopy cannot be detected accurately. The variability of nonpoint urban water quality runoff with respect to different land use procedures poses challenges in making an effective stormwater management plan [8]. Furthermore, private landowners typically make land development decisions not necessarily for the public-good from the regional perspective, but in the owner's private interest at the parcel level and in the forms of building, road, sidewalks, or parking lots, all of which are impervious surfaces [41,42]. More than 500 cities and counties in the U.S. have stormwater utilities, 60% of which raise revenues through property taxes paid into their general funds for stormwater management [43]. There exists a debate over the equality of the way to fund stormwater management from property taxes because of the claim that the cost of stormwater service to individual properties bears no relationship to the assessed value of the property [44]. Therefore, in this research, we estimate stormwater runoff and quality and explore their correlations with land pavement sizes and property values at the parcel level for major zoning categories. The aim of this research is to provide insights into the urbanization process to enhance public land use planning control and to ensure sound private land development at the parcel ownership level for different land uses. The paper is organized as follows: following the Introduction in Section 1, Section 2 specifies the methods and modelling process; Section 3 provides the results and analysis; and Section 4 summarizes the research and points out the research limitations.

2. Methods and Modelling Process

The City of Corvallis is located in the middle of the Willamette Valley in the State of Oregon. It ranked 3rd in the 2018 Top Best Small Cities to live for its beautiful natural environments, urban green infrastructure, employment opportunities, education, and medical services [15]. However, the Willamette River was ranked as the fifth most endangered river in 2019, and the stormwater pollution discharged into the Willamette River has been identified as one of the most critical and urgent issues by the Oregon Department of Environmental Quality [20]. Corvallis has a total area of 120 square kilometers, and the population grew from 55,522 in 2014 to 58,641 in 2018 with an average growth of 1.4%, which is faster than the average population growth in Oregon (0.89%) [9]. The urban parcels for residential, commercial, industrial, office, and open space land occupy 77%, 1%, 7%, 3%, and 12%, respectively (Figure 1a). The amount of total nitrogen and phosphorus contained in the urban stormwater does not meet the minimum standard established by the U.S. EPA, and the pollutants commonly observed in stormwater are nitrogen and phosphorus [16]. The impervious surface of buildings, roads and driveways, sidewalks, parking lots, and others (barren land and lands under construction) occupies 4.42%, 5.68%, 0.74%, 2.44%, and 2.20% of the total city land, respectively (Figure 1b).

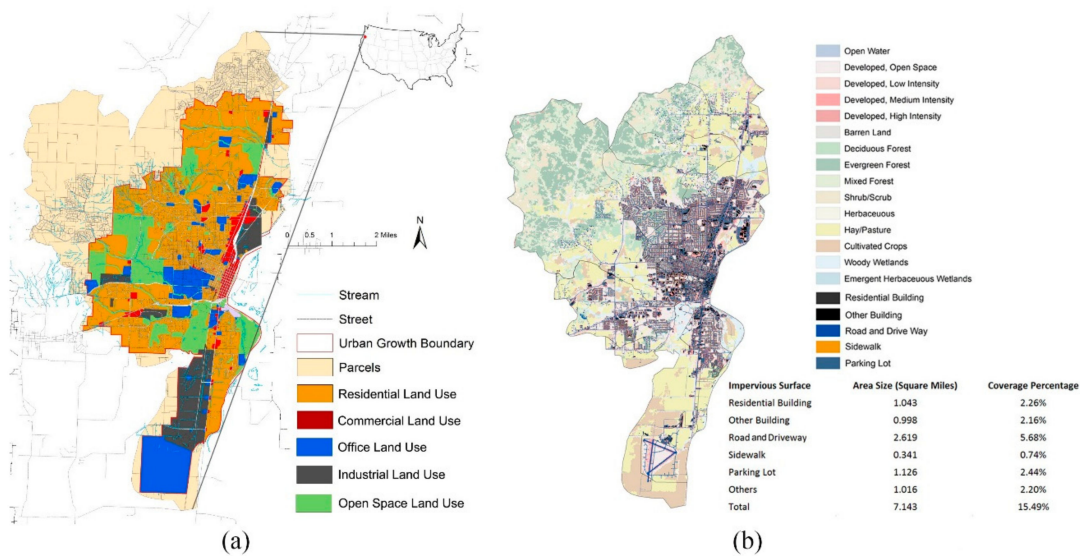


Figure 1. The City of Corvallis, Oregon. (a) Land use in Corvallis; (b) impervious surface in Corvallis [20].

2.1. Stormwater Runoff Yield Modelling

The InVEST model and its associated biophysical dataset were developed and calibrated by the Natural Capital Project in the Willamette Valley area within which Corvallis is located [17] and has been applied successfully in the other coastal areas in Western North America in previous studies [18,45,46]. This research uses the stormwater runoff yield and purification models and the biophysical data built in InVEST at $1\text{ m} \times 1\text{ m}$ pixel resolution and combines the results at the parcel level. The land uses within Corvallis's city limits are considered mainly as commercial, industrial, and residential uses based on the city's urban zoning classifications. Based on the data from the City's Planning Division, urban land surface is divided into impervious surfaces made up of buildings and paved roads, driveways, sidewalks, and parking lots and pervious green surfaces composed of grasses and trees.

InVEST runs Models (1)–(5) on raster GIS data for stormwater runoff yield calculation based on the interaction of precipitation, evapotranspiration, inflow through land cover, soil, and vegetation for each pixel x . $Y(x)$ denotes the annual stormwater runoff yield. $AET(x)$, $P(x)$, and $PET(x)$ denote the actual evapotranspiration, precipitation, and potential evapotranspiration, respectively. $w(x)$ is a non-physical and empirical parameter with the natural climatic-soil properties. $AWC(x)$ denotes the volumetric plant available water content in soil. Z is the seasonality factor determined by local hydrological features and the empirical precipitation pattern. $ET_0(x)$ is the reference evapotranspiration. $K_c(l_x)$ is the vegetation evapotranspiration coefficient and is largely determined by the vegetative characteristics associated with the land cover. $K_c(l_x)$ adjusts the $ET_0(x)$ values to the crop or vegetation type. $K_c(l_x)$ for built-up areas can be set to where f is the fraction of impervious covers in the area [47].

$$Y(x) = (1 - AET(x)/P(x)) \times P(x) \quad (1)$$

$$AET(x)/P(x) = 1 + PET(x)/P(x) - (1 + (PET(x)/P(x))^w)^{1/w} \quad (2)$$

$$w(x) = Z \times AWC(x)/P(x) + 1.25 \quad (3)$$

$$PET(x) = K_c(l_x) \times ET_0(x) \quad (4)$$

$$K_c(l_x) = 0.1 \times f + 0.6 \times (1 - f) \quad (5)$$

For each pixel x , Equation (1) is to generate annual stormwater runoff yield. Equation (2) estimates the ratio of actual evapotranspiration vs. precipitation. Equation (3) shows that the non-physical

parameter, which is capped to a value of 5 according to Donohue et al. (2012). Equation (4) indicates that potential evapotranspiration is positively related to the vegetation evapotranspiration and the reference evapotranspiration in each land cover category. In the built-up area, Equation (5) specifies the vegetation evapotranspiration in urban conditions by the percentage of impervious surface [48].

2.2. Stormwater Purification

In the stormwater quality quantification Models (6)–(8), ALV_x is the adjusted pollution loading value for pixel x ; POL_x is the standard pollutant loading coefficient based on the land use and land cover; HSS_x is the hydrologic sensitivity score, which is estimated by I_x as the runoff index and I_w as the mean runoff index in the watershed of interest. Once per pixel pollution loads are generated, the amount of downstream pixel retention can be calculated as surface runoff carrying the pollutant toward the stream. The model routes water down using runoff flow paths determined by elevation difference analysis and allows each pixel downstream from a polluting pixel to retain pollutants based on the land cover. By following the pollutant load and retention of each pixel along all the way downstream to a water body, the model also tracks how much pollutant reaches the stream.

$$ALV_x = HSS_x \times POL_x \quad (6)$$

$$HSS_x = I_x/I_w \quad (7)$$

$$G_x = 1 - E_x \quad (8)$$

Table 1 describes how the pollution retention and export removal along the routing and hydraulic routing are calculated. Ret_x is the amount of pollution retention in each pixel. E_x is the pollution filtering value (removal efficient) of the pixel determined by its land use and land cover type. G_x is the pollution export coefficient of the pixel. Exp_x is the total amount of pollution flowing out of each pixel [47].

Table 1. Pollutant retention and export process.

Pixel	$E_{x_n/p}$	$G_{x_n/p}$	ALV_x	Ret_x	$Exp_{x_n/p}$
1	E_1	G_1	ALV_1	0	ALV_1
2	E_2	G_2	ALV_2	$Exp_1 \times E_2$	$Exp_1 \times G_2 + ALV_2$
3	E_3	G_3	ALV_3	$Exp_2 \times E_3$	$Exp_2 \times G_3 + ALV_3$
4	E_4	G_4	ALV_4	$Exp_3 \times E_4$	$Exp_3 \times G_4 + ALV_4$
x	E_x	G_x	ALV_x	$Exp_{(x-1)} \times E_x$	$Exp_{(x-1)} \times G_x + ALV_x$

Compared with previous studies using remote sensing data to examine ecological indicators, another advantage of this research is that the canopy coverages on both impervious surface and pervious surface are considered to calculate urban stormwater runoff and quality through adjusting the sample biophysical table obtained from the Natural Capital Project Dataset [49] (see Table 2). For example, based on the sample data, the evapotranspiration coefficient $K_c(l_x)$ for a road surface is 0.1, and $K_c(l_x)$ for an urban canopy is 1. According to the City's Urban Forestry Management Plan [50] and previous research sample data [51], the urban canopy coverage on a street is estimated at 15%; therefore, the adjusted $K_c(l_x)$ for a road is 0.235 ($0.1 \times 85\% + 1 \times 15\%$).

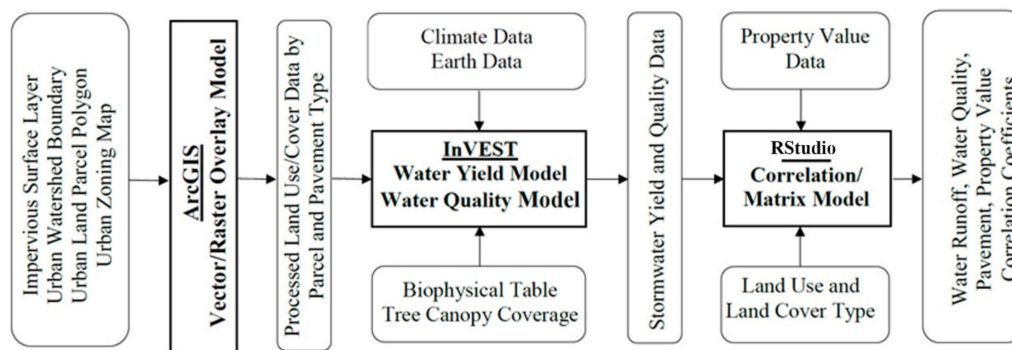
Table 2. Biophysical table for the City of Corvallis, OR.

Land Cover	Canopy_P	Sample Biophysical Table					Adjusted Biophysical Table				
		Kc	load_n	eff_n	load_p	eff_p	Kc	load_n	eff_n	load_p	eff_p
Building	0%	0.100	0.010	0.050	0.005	0.050	0.100	0.010	0.050	0.005	0.050
Road and driveway	15%	0.100	0.010	0.050	0.005	0.050	0.235	0.609	0.133	0.005	0.133
Sidewalk	20%	0.100	0.010	0.050	0.005	0.050	0.280	0.808	0.160	0.005	0.160
Parking lot	5%	0.100	0.010	0.050	0.005	0.050	0.145	0.210	0.078	0.005	0.078
Others (grass)	25%	0.650	11.000	0.400	1.500	0.400	0.888	9.250	0.450	1.126	0.450
Urban tree	100%	1.000	4.000	0.600	0.005	0.600	1.000	4.000	0.600	0.005	0.600

Canopy_P = urban canopy coverage; Kc = the plant evapotranspiration coefficient for each land cover; load_n = nitrogen loading for each land use (kg per hector per year); eff_n = the vegetation nitrogen filtering value per pixel size for each land cover; load_p = phosphorous loading for each land cover (kg per hector per year); eff_p = the vegetation phosphorus filtering value per pixel size for each land cover.

2.3. Research Framework and Data Processing

InVEST's stormwater runoff yield and quality models require good raster land use and land cover (LULC) data (1 m × 1 m), which are compiled from various sources including impervious surface layers, watershed boundaries, land parcels, and zoning boundaries from the City of Corvallis's GIS database [20]. These are processed with GIS toolboxes, especially vector/raster conversion, overlays, and summary functions. This LULC with zoning classifications is joined with climate, earth, and modified biophysical tables as inputs to the stormwater runoff and quality models, whose outputs are joined with property values and land cover sizes at the parcel level into RStudio for Pearson correlation analyses and result visualization. The modelling process is shown in Figure 2, in which boxes with round corners are either data input or output and right-angle boxes are models in GIS, InVEST, or RStudio. Note that output from one upstream model can be used as input for downstream model, and the research focuses on the comparison of the correlation coefficients' difference to improve the analysis accuracy.

**Figure 2.** Modelling framework.

According to the modelling process, climate, geographic, planning, and biophysical data comprise the four kinds of databases needed in this research. The InVEST sample dataset provide some needed biophysical data for the area of interests. The biophysical attributes in InVEST are adjusted with the consideration of the urban canopy coverage on parking lots, streets, driveways, grass, and along the sidewalk. The urban planning vector database from the City of Corvallis provides the locations and sizes of zonings, parcels, impervious pavements, building footprints, others (grass), and urban trees [20]. Table 3 lists out the data used in the modelling process.

Table 3. Datasets used in modelling process.

Dataset	Data Name	Source	Format Adjustment
Climate Dataset	Precipitation ($P(x)$)	Climate Prediction Center [52]	GIS Raster—GRID
	Reference Evapotranspiration (ET_0)	Climate Prediction Center [52]	GIS Raster—GRID
Geographic Dataset	Digital Elevation Model	National Elevation Database [53]	GIS Raster—GRID
	Plant Available Water Content (AWC)	Soil Survey Geographic Database [54]	GIS Raster—GRID
	Land Cover Data	Pacific Northwest Ecosystem Research Consortium [55]	GIS Raster—GRID
Planning Dataset	Land Use	City of Corvallis, OR [9]	GIS Vector—Polygon
	Urban Canopy (Canopy_P)	Urban Forestry Management Plan [50]	GIS Vector—Polygon
	Impervious Surface	City of Corvallis, OR [9]	GIS Vector—Polygon
	Parcel (x)	City of Corvallis, OR [9]	GIS Vector—Polygon
Biophysical Dataset	Plant Evapotranspiration Coefficient (K_c)	FAO Crop Evapotranspiration [48]	N/A
	Nutrient Loading Coefficient (load_n/p)	Natural Capital Project Dataset [49]	N/A
	Vegetation Filtering Coefficient (eff_n/p)	Natural Capital Project Dataset [49]	N/A

The land parcel and zoning data contain 13,875 urban parcels for commercial, residential, and industrial land uses within the city limit. The city's tax lot database provides property value attributes, including land value (for the land only), assessed value (by mass appraisal), market value (by transaction), and improved value (for the building or structure on the parcel) [20]. The impervious surface data are provided by the city's planning department. This dataset shows that 15.49% of the city land is covered by either impervious pavements or buildings [20]. Spatial joins in GIS were used to classify impervious surfaces into parcels. A detailed sample of the final urban land use and land cover processed for this research is shown in Figure 3.

**Figure 3.** An example of the urban land surface in Corvallis, OR.

3. Results and Analysis

Compared with other models to assess land use planning's impacts on stormwater yield and quality, InVEST is more suitable in a situation in which the underlying ecological processes and data are well understood [56]. This study took advantage of this by describing the modelling process in the area of research interest and obtaining the required data from publicly available data to facilitate wide-spread use. The limitation of InVEST includes the requirement of the knowledge of GIS and local data. This study overcame this limitation by overlaying the local data (city planning data) on the regional data (geographic data) using spatial operation tools in ArcGIS Map. Then, the research analyzed the Pearson correlations among the economic variables (labelled land value, assessed value, improved value, and market value), spatial variables (impervious pavement (labelled parking lot, road and driveway, building footprint, sidewalk and path), pervious green cover (labelled others for land covers with grasses)), ecological variables (stormwater runoff volume (labelled stormwater yield), and stormwater quality (labelled nitrogen export, and phosphorus export)) for parcel level commercial, industrial, and commercial land uses in RStudio. The results are visually summarized in scatterplots in Figures 4–9 with correlation coefficients labelled with colors ranging from purple, as lower coefficients, to orange, as higher coefficients.

3.1. Scatterplot Matrix for Commercial Land Use

The correlations for all the commercial parcels are shown in Figure 4. The four economic variables had significant linear correlations among them, except for the one between land value and improved value. Land value correlated most with parcel size with $R = 0.899$, while improved value correlated most with building footprint or with $R = 0.777$. Among the spatial variables, parcel size was correlated well with the sizes of the main impervious surface building footprint and pervious surface land grass. This confirmed that parcel-based analyses are needed to make or evaluate planning policies to improve regional environmental qualities [57,58]. Among the ecological variables, nitrogen export was highly correlated with phosphorus export. Stormwater yield volume was highly correlated with land value, building footprint, and parking lot sizes, but not with sidewalk and path and road and driveway sizes. This could be explained by the urban canopy's role in retaining water and higher tree coverage percentages on sidewalks and streets [59]. The coefficient between stormwater yield volume and land value was as high as 0.900, which indicates the land value could be considered to be a factor in setting up the stormwater utility fee in commercial parcels. The stormwater yield volume was strongly correlated with the parking lot size. This recommends identifying parking lots as priority sites for low impact development in commercial land uses. The nitrogen and phosphorus exports were both highly correlated with others, which could be explained by the fact that although the grass soil had the ability to filter out pollution from the stormwater [60], private urban land parcels with grasses are sometimes significant non-point sources of nitrogen and phosphorus potentially due to the use of fertilizers and the nitrogen and phosphorus generated by the grass surface itself flowing into the stormwater that was originally relatively clear [61]. This indicates that urban grass field is an important component of the urban ecosystem, but the location of the grass field needs to be analyzed to perform effective environmental spatial planning. It is suggested that urban lawn should be planned close to the upstream watershed with pollution sources, so the amount of pollution retention by urban grass is more than its pollution generation. Management such as reducing fertilization rates according to temperature and seasons is needed in maintenance practice to increase the efficiency of fertilization and reduce nitrogen or phosphorus accumulation [62]. Environmentally friendly landscape management is also recommended, including thoughtful planning and design, routine soil analysis, appropriate native plants that require less water and fertilizer, and fewer pesticide applications [63].

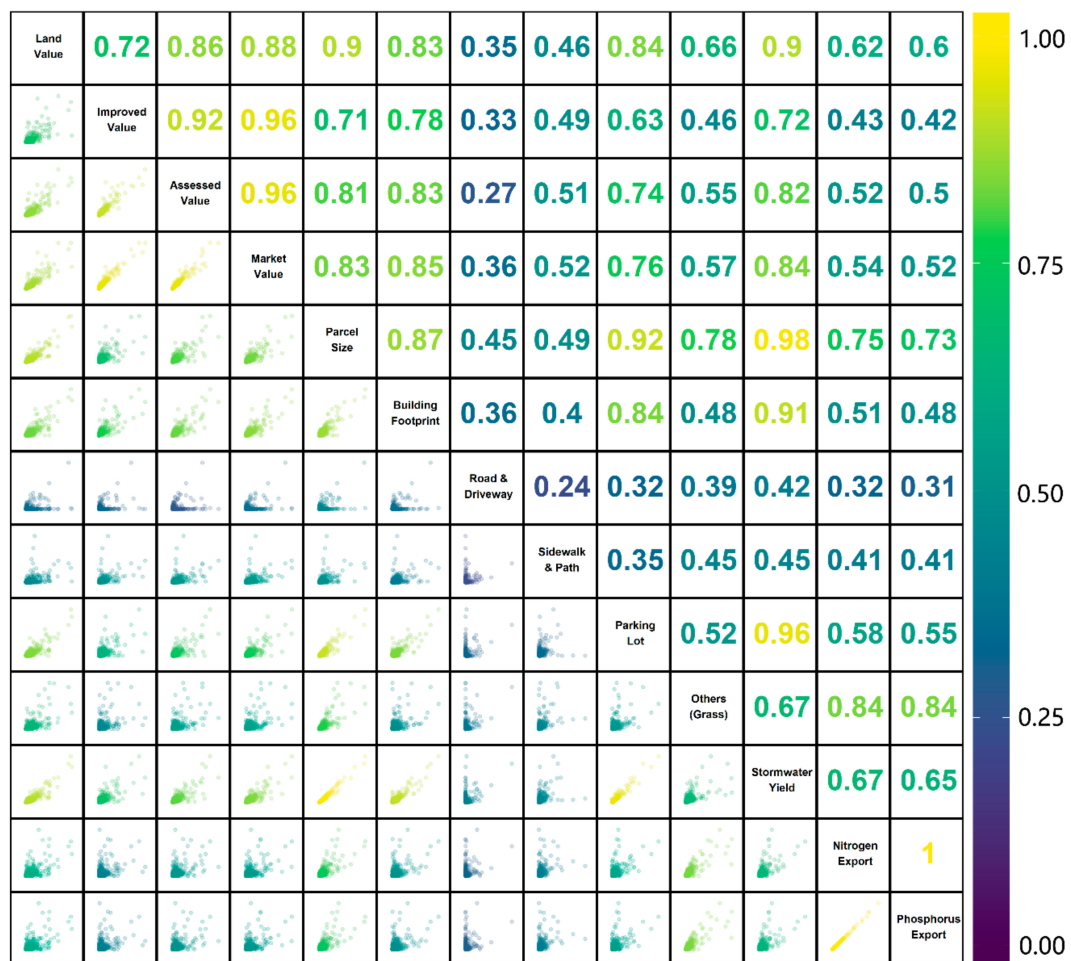


Figure 4. Pearson correlations for commercial parcels.

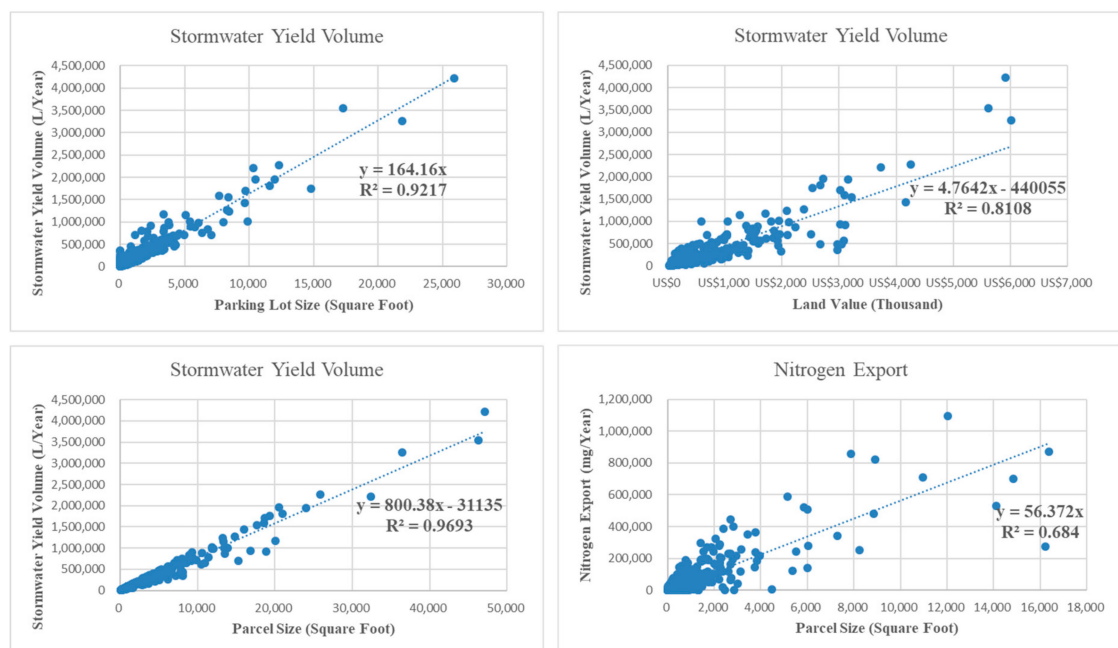


Figure 5. Strong correlations in commercial parcels.

3.2. Scatterplot Matrix for Industrial Land Use

Storm water management is crucial on industrial lands due to the potential range and amount of pollutants that could flow into the urban runoff receiving natural water body [64]. For industrial parcels in Figure 6, the stormwater yield volume is still correlated with parcel size and land value with $R = 0.981$ and 0.836 , respectively. This suggests that the stormwater utility fee tailored to an individual site could be regulated based on the parcel size or the land value as well. Furthermore, the stormwater volume was related to the parking lot size with the highest coefficient, which suggests adding more perviousness in the parking space to manage stormwater. There exists a high correlation between stormwater yield volume and nutrient exports with $R > 0.700$, indicating that more urban runoff carries out more nutrients from industrial parcels. Additionally, stormwater management techniques that reduce stormwater quantity are also effective at improving stormwater quality, for example in cost effective water sensitive planning in industry parks (WSP) that controls urban runoff and minimizes the negative impacts of stormwater [65].

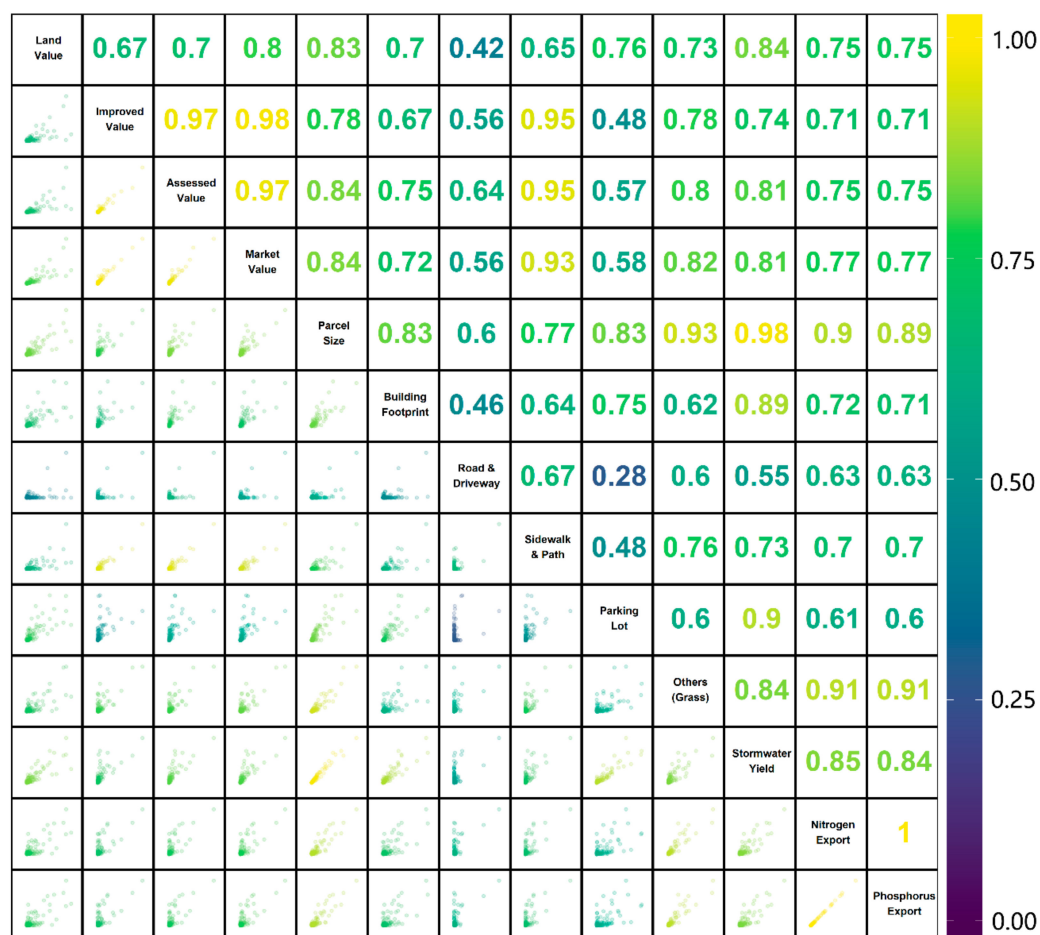


Figure 6. Pearson correlations for industrial parcels.

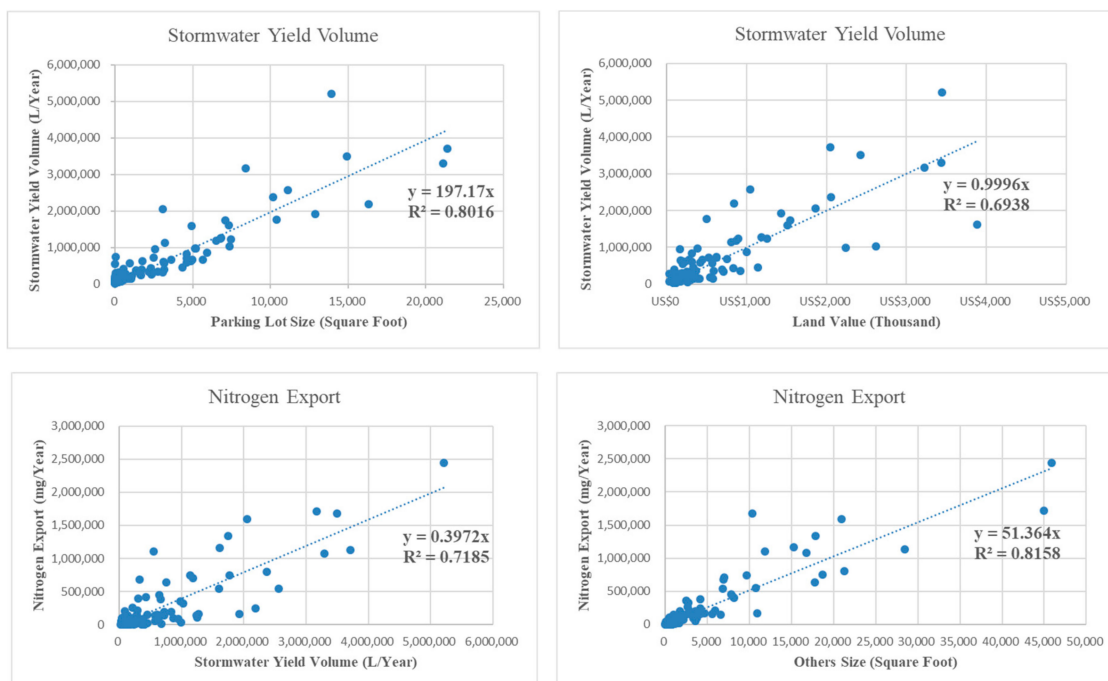


Figure 7. Strong correlations in industrial parcels.

3.3. Scatterplot Matrix for Residential Land Use

The correlation matrix for residential parcels is shown in Figure 8. Among the spatial variables, stormwater yield volume was related with the building footprint (roof) size most strongly, which suggests extensive green roof utilization in single family houses and extensive green roof utilization in apartments could efficiently reduce stormwater yield [19]. The correlation between stormwater was both with the parcel size and the land value, but the correlation coefficient with the parcel size was much higher. Furthermore, the amounts of nitrogen and phosphorus exports were correlated with the parcel size, and their relationship with property values was not clear. This implies regulating the stormwater utility fee according to the size of the parcel rather than the property value in residential parcels. Due to household actions and pet ownership [66], urban grass is a predominate source for watershed nitrogen and phosphorus input in residential parcels as well. It is suggested to maintain a dense cover of turf grass not only to reduce surface runoff volume, but also to retain nutrients [67].

In summary, through the correlation analysis, it was found that stormwater yield was positively correlated with at least one of the economic variables, and nitrogen and phosphorus exports were highly correlated with each other and were both correlated with the size of land categorized as grass for all land uses. Correlations existed between nutrients exports and economic variables for industrial parcels; however, no strong linear correlation was found between nutrient exports and economic variables for residential and commercial parcels. For industrial and residential parcels, more urban runoff carried out more nutrients, but this was not clear for commercial parcels, implying that residential and industrial land uses are more relevant to stormwater yield and quality, and hence are more important for the city's ecosystem safety [68]. The land value and parcel size are suggested to be useful factors to regulate stormwater utility fees in commercial and industrial land uses, and the parcel size is the only factor in residential parcels to be suggested for regulating stormwater utility fee. Parking lots are suggested to be priority sites for low impact development in commercial and industrial parcels, but the unstandardized coefficients were different in the correlation test. Building roofs are suggested to be priority sites for low impact development in residential parcels. Although the weight bearing requirement and the cost of installing are higher, green roofs with native vegetation require less routine maintenance than some other low impact development techniques and reduce building energy use by cooling roofs [12]. Therefore, green roofs are cost effective in the long run.

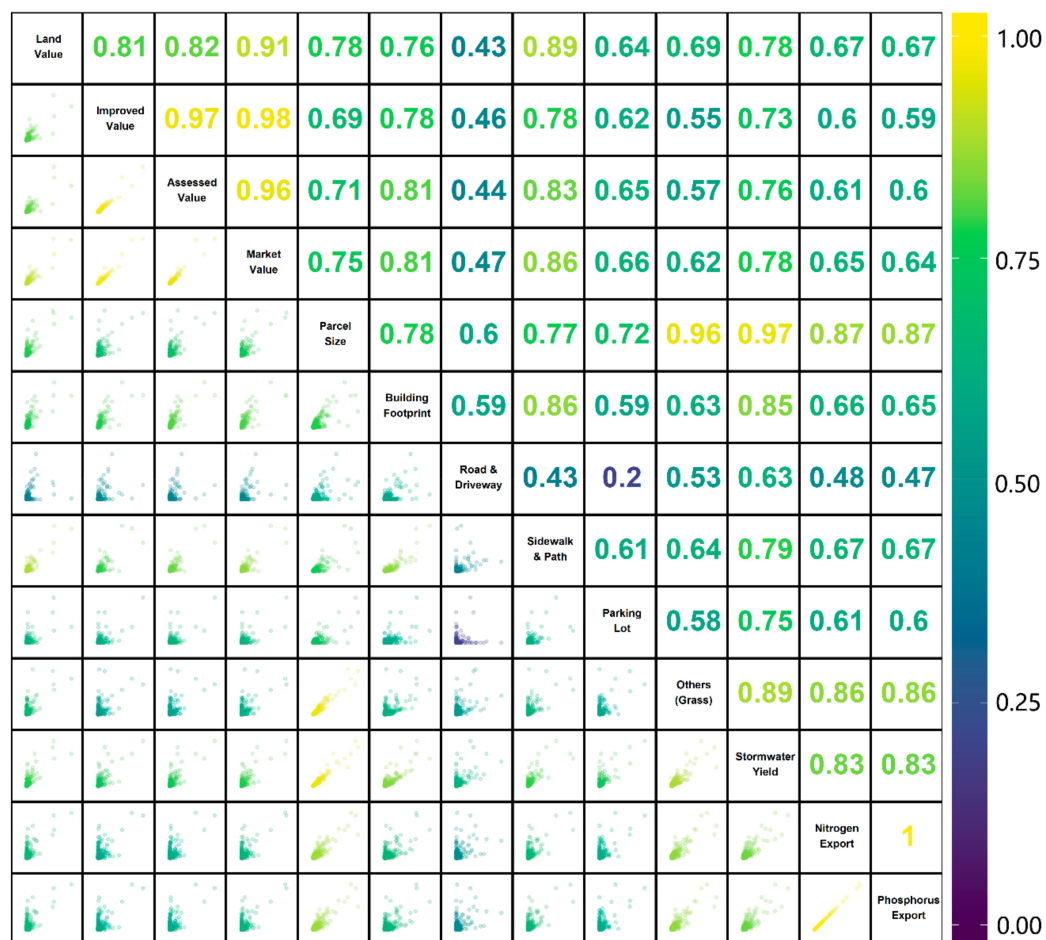


Figure 8. Pearson correlation for residential parcels.

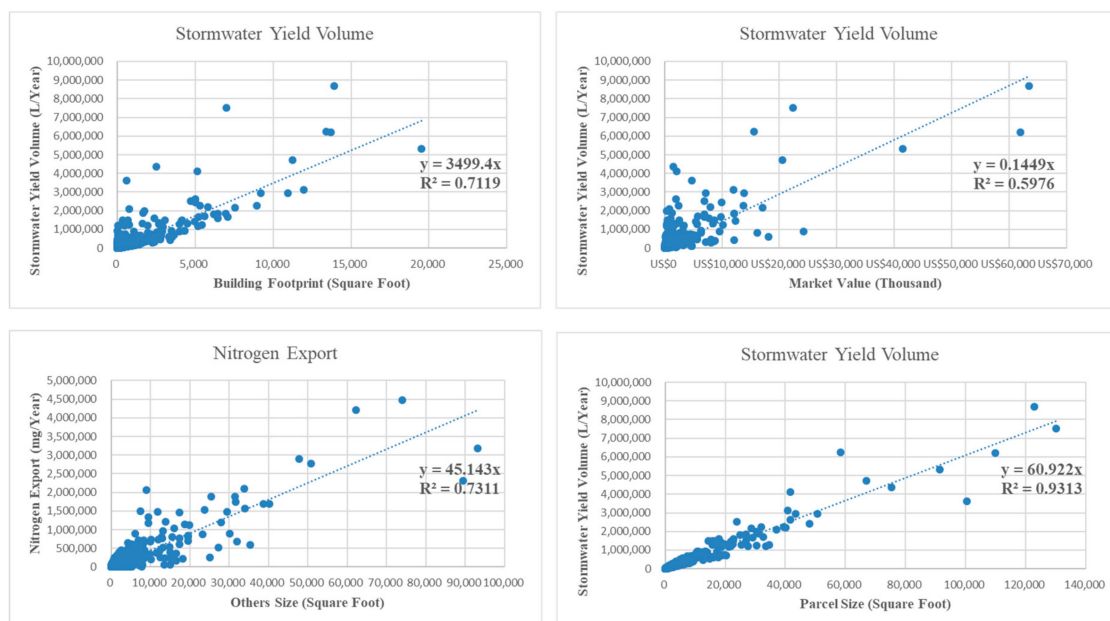


Figure 9. Strong correlations in residential parcels.

4. Conclusions and Research Limitations

Stormwater runoff retention and pollution purification have been studied extensively with various modelling resolutions and land covers worldwide, mostly for large geographical areas, such as regions, countries, cities, or watersheds using remote sensing data, but not at the urban zoning and parcel levels, which define land use specifics and ownership responsibilities. This research quantified stormwater yield volume and purification as two important environmental impact measures for each urban parcel using climatic, biophysical, and urban planning data with tools in GIS and models in InVEST. The estimated stormwater runoff and quality as ecological variables were explored for plausible correlations with property values as economic variables and pavement sizes as spatial variables at the land parcel level. Some strong correlations between ecological, economic, and spatial variables were established and summarized for commercial, industrial, and residential land uses. This may be utilized to study environmental impacts in terms of stormwater runoff and quality under various urban development scenarios in terms of LULC or pavement types and sizes, hence relevant not only to local jurisdictional agencies, whose public policies matter, but also to individual parcel owners or users, whose decisions directly alter lands and/or buildings. The sound correlations may also be utilized as alternatives to estimations of property values for owners and property taxes or environmental remedy fees by parcel or land use for local jurisdictions. The results indicated that funding stormwater management from property taxes is reasonable in commercial and industrial parcels, but not in residential parcels. Stormwater authority fees are more equitable than a property tax for residential parcels, but the high political visibility and legal obstacles can affect their effective implementation [69]. In addition, a city's building footprint, impervious pavement, pervious cover, parcel, and land use data are more detailed than remote sensing data and hence are more accurate for the measures and correlation analyses. There are thousands of waters listed for impairments from stormwater sources in the U.S. These impaired waters need a total maximum daily load (TMDL), which identifies the total pollutant loading that a waterbody can receive and still meet water quality standards and specifies a pollutant allocation to specific point and nonpoint sources [56]. Sources of these TMDL pollutants in urban areas typically include runoff from existing commercial, residential, and industrial land uses; runoff from new construction development; runoff from urban transportation systems; runoff from landscaping and parking lots [70]. The results could help local governments allocate the pollution loading reduction generated from cities' TMDL model to each of the parcels of different land uses based on the economic variables, land cover sizes, and the correlations found in this research.

The research could be improved in several ways. It may be extended to more urban land uses beyond commercial, industrial, and residential. Stormwater purification as nitrogen and phosphorous exports can be extended to include other chemicals. Stormwater yield and pollution export can be modelled to generate daily results with consideration of extreme weather events. Furthermore, the extent of the accuracy of using parcels or land uses in this study with respect to using remote sensing and smaller spatial scales in the literature needs to be quantified and verified, ideally over the same geographical area of a city and under the same climate and biophysical conditions. Last but not least, the analysis was based on one city in the U.S. and so is not widely representative, and there is a need to carry out similar tests in comparable cities. All these call for additional research.

Funding: This research was funded by the National Natural Science Foundation of China (No. 51708399), the Macao Cultural Affairs Bureau Academic Research Grant (No. 2018), the Macao Foundation (MF 1921), and the City University of Macau Foundation.

Acknowledgments: The author acknowledges the anonymous reviewers for their constructive comments, which have helped to improve the paper significantly.

Conflicts of Interest: The author declares no conflict of interest.

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