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Urban Green Space Analysis and Identification of its Potential Expansion Areas

Martin Mwirigi M'Ikiugu [a*], Isami Kinoshita[a] , Yoritaka Tashiro[a]

[a]*Chiba University, Graduate School of Horticulture, 648 Matsudo, Matsudo City, Chiba 271-8510, Japan*

Abstract

Urban Green Spaces (UGS) are essential constituents of the urban structure that enhance residents' quality of life and behavior. This study introduces a process of analyzing UGS using landscape metrics and identification of potential expansion areas through suitability checklist and proximity buffering done in a GIS environment. Central Nairobi was selected as the representative study area, whose UGS were found to be unevenly distributed, lacking in size, character and most out of public access. A final composite potential map was formulated, that if its identified high potential areas are adopted for expansion of UGS, the above shortcomings could be rectified.

Keywords: Urban Green Space (UGS); landscape metrics; UGS Suitability Checklist; composite potential map

* Corresponding author. Tel.: +81-80-3524-6962; fax: +81-47-308-8880.
E-mail address: mwirimart@yahoo.com.

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1. Introduction

The quality of a city's environment manifested in its Urban Green Spaces (UGS) reflects in many ways the quality of life and societal behavior found in it. A city devoid of quantity and quality UGS becomes a concrete jungle or a polluted city vulnerable to calamities, behavioral vices, and low livability index. UGS provide benefits to the city that helps mitigate these negative effects (Ridder, 2004), and are valuable amenity-recreation venues, wildlife refuge and essential livable-city ingredients (Jim, 2003). Population explosion in urban areas is continuously threatening the land available for urban green spaces. Land uses that make more direct economic returns to public, and private investors constantly consume it. With accelerated urbanization, the landscape as a whole becomes more fragmented ecologically, more complex compositionally and geometrically (Buyantuyev et al, 2009). In developing countries where the population growth and rural-urban migration are highest in the world, municipal intervention where it exists oftenly limits to street planning. It practically never provides for future green space, thus most new Third World urban areas are commonly treeless (Olembo and Rham, 1987). This study goal was to formulate a GIS process for quantitatively analyzing urban areas for their existing UGS, as well as their potential for expansion of the same. The analysis objective was to answer the following questions: (1) whether the urban area could afford adequate UGS benefits to influence the quality of life, societal behavior, and environmental well being. (2) Whether it had potential areas that could be utilized for future expansion of UGS to help improve spatial, environmental, as well as, residents' quality of life and behavior. The authors selected the City of Nairobi as a representative city for the study. They subsequently analyzed UGS in Central Nairobi, for its size, composition, distribution, and access. This included evaluation of UGS and other land uses and land cover areas (LULC) for their potential in supporting expansion of UGS. The study area comprised of the inner wards of the city of Nairobi, composed of the Central Business District and its environs, identified herein as Central Nairobi. They are the oldest part of the city, most urbanized area and exhibits a wide range of land uses.

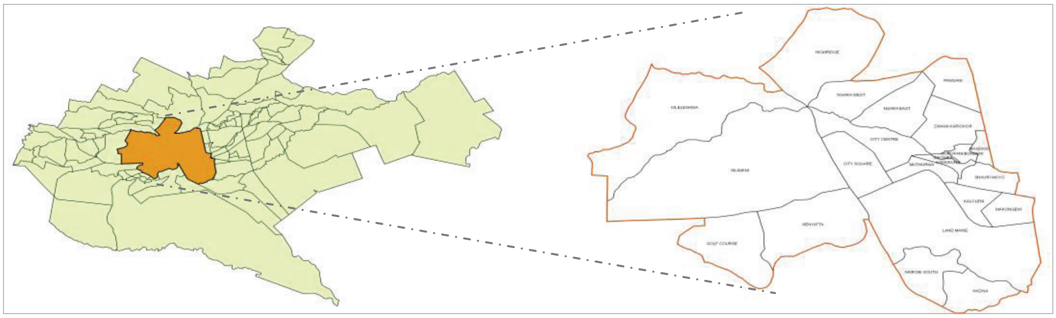

Fig. 1. Map of Nairobi City showing the study area (Central Nairobi)

2. Literature Review

Urban Green Spaces can be defined as outdoor places with significant amounts of vegetation. They exist in cities mainly as semi-natural areas, managed parks and gardens, supplemented by scattered vegetated pockets associated with roads and incidental locations (Jim and Chen, 2003). A city with high quality and generous green spaces epitomizes proper planning and management, a healthy environment for humans, vegetation, wildlife populations (Godefroid, 2001) and bestows pride on its citizenry. While some cities manage to retain or even extend their green spaces, others experience degradation and destruction (Jim, 2004). We need proper planning control to ensure green spaces for current and future generations (Ahris et al., 2006). Olembo and Rhan (1987) propose extensive urban forestry programs, amenity corridors, wedges in a green-space web (van der Valk, 2002), and linear greenway sites (Flink and Seams, 1993). With lots, green spaces should be allocated in the grounds of residential, office, government, institutional and community land uses (Jim, 2004). Understanding the structure of urban areas is beneficial to urban management for reasons such as runoff control, urban forest planning, air quality improvement, and mitigation of global climate change (Myeong et al., 2003). There are various methodological approaches employed in the field of urban green space analysis, all with diverse aims and results. Nowak et al. (1996) reviews several methods of determining urban green cover from aerial photographs. They include; crown cover scale, transect method, dot method and scanning method, which is more precise, detailed and integrates well with GIS. Buyantuyev (2009) quantifies the land use and land cover change in Phoenix Arizona from 1985 to 2005 using landscape metrics computed from Landsat derived maps that revealed temporal patterns of landscape composition and configuration. Landscape metrics and LULC maps, derived from remotely sensed images with various spatial, temporal, and thematic resolutions frequently characterize the patterns of urbanization. Liu and Liu (2008) propose the application of ecological niche modeling techniques that show the necessary distribution estimates of green spaces. They caution that its results should not be used in green space construction, because it does not consider conflicts between spaces and other human barriers. GIS has proved useful in vegetation distribution, and site selection. This is in relation to ecological and socio-economic variables, assessing impacts on environment for development projects, and in space and resource allocation to conflicting types of use (Liu and Liu, 2008). Suitability analysis is a common and classic GIS application that consist several steps. They include attribute and location-based queries, buffers, spatial-joins and overlays (Gorr and Kurland, 2008). Areas suitable for expansion of UGS can be identified using Land Suitability Analysis (LSA) based on GIS, an effective application within the land-use planning and habitat analysis (Nowak et al., 2003). LSA supported by spatial analysis functions of GIS including data collection, weighting, data integration, analysis and output evaluation (Uy, 2006) can be used to establish various potential values of different areas to receive green spaces. This study employs multiple approaches to analyze the existing conditions of Nairobi Central urban green spaces and identification of the potential areas to expand the same. The above review points out mainly computer based methods of analyzing and processing data, while this study engages human inputs and judgment that can fill-in gaps in the data. This is vital in adoption and actualization of the results if need be.

3. Methodology

The study used orthographic photographs, GIS vector maps and a UGS suitability checklist as the basic data collection and generation elements. Department of Survey in Kenya provided orthographic photographs and vector maps, and The Nairobi City Council maps containing land use planning and zoning data. The authors conducted structured interviews among Nairobi based experts in the fields of urban planning and landscape architecture, including those in the civil service, academic institutions, and private practice. The interviews generated complimentary insight on spatial and other factors influencing UGS in Central Nairobi. They also generated priorities used to calculate the weights of variables used in both suitability checklist and proximity buffering. Orthographic photographs and vector maps were verified and corrected through physical survey of the study area, and data sets prepared and processed in ArcGIS 9.3.1, to create a geodatabase. Similar disjointed layers of both raster and vector data were merged and extracted to the study area. They were subsequently traced, digitized and attributes described for areas forming part of green space. These included areas with: substantive tree canopy, substantive mixture of trees, grass and shrub cover, or substantive wetland vegetation, in both density and extent.

Using various landscape metrics, we analyzed Central Nairobi UGS using the digitized map and its attributes for areas with UGS. The common usage of 'Landscape Metrics' refers exclusively to indices developed for categorical map patterns. They are algorithms that quantify specific spatial characteristics of patches, classes of patches, or entire landscape mosaics (McGarigal 2002). The authors adopted these metrics to analyze composition and configuration of Central Nairobi UGS as described in Table 1 below. UGS per capita (UPC) was calculated and UGS distribution pattern examined. This was done using visual identification of UGS patches, and how they vary across the areas in number, size, shapes and class.

Table 1. Landscape level metrics and their description.

Landscape Metric	Description (unit)
Total area (TA)	The total area of the study area (unit: km^2)
UGS abundance (UA)	Total area occupied by UGS (unit: km^2)
Percentage UGS abundance (%UA)	The percentage of total area (TA) comprised of UGS (unit: %)
Proportional UGS abundance (PUA)	Percentage of total area (TA) comprised of a specific class of UGS (%)
Diversity of UGS (DU)	Number and classes of UGS identified
Proportional diversity of UGS (PDU)	The percentage area of UGS occupied by a specific class (unit: %)
Landscape shape index (LSI)	Perimeter-to-Area (PA) ratio
Mean Patch Shape Index (MPSI)	Patch level shape index averaged over all patches of the UGS
Isolation/ proximity/ nearest-neighbour	Distance to the nearest green space of the same class (unit: km)
Largest patch index (LPI)	Percentage of the landscape occupied by the largest patch (unit: %)
Mean patch size (MPS)	The average area of all patches in the study area (unit: ha)
Patch size standard deviation (PSSD)	The standard deviation of patch size in the entire study area (unit: ha)

Site suitability assessment involves the creation of suitability maps that identify areas most suitable for a certain activity (Hopkins, 1977). Elements such as rivers, roads, railway lines and utility corridors were traced, verified, classified and digitized. Viable areas to receive UGS were also traced, digitized and their attributes described in a separate layer. The authors developed an Urban Green Space Suitability Checklist, that entailed variables or parameters used to evaluate the suitability of an area to be converted and developed as UGS. The following variables were evaluated and assigned values based on Analytical Hierarchy Process (AHP) and pair-wise comparison. (i) Areas within 100m proximity of existing UGS (ii) wetlands (iii) riparian areas (iv) bare soil or open grounds (v) demand areas (vi) transportation and or infrastructure corridors (vii) friendly land use planning (viii) those with unfriendly land use planning. We set a goal 'to select potential sites for expansion of UGS', using the variables above as alternatives for reaching that goal, and four factors or criteria to relate the alternatives to the goal. These included; influence on ecological processes, curb pollution or protect resource, extend BUGS, and easy to acquire or convert to UGS. Experts interviewed provided priorities (numerical values representing relative weights for each variable derived from pair-wise comparison in relation to the goal). Consequently, the priorities with resultant weights for each variable were analyzed as follows. Areas within 100m proximity of existing UGS (0.115), wetlands (0.154), riparian areas (0.151, bare soils or open grounds (0.139), demand areas (0.112, transportation and or infrastructure corridors (0.138), friendly land use planning (0.118), and unfriendly land use planning (0.074). The checklist included eight variables, their descriptions and weights. We evaluated each space identified as a potential area for expansion of UGS using the checklist. If, the space possessed any of the variables, it was accorded full weight or zero weight where it did not. This was done for all the variables against all the identified spaces, and a total score recorded for each. Each space got this score as a new field in its attributes, symbolized into three classes expressed in the resultant map based on their value through a colour gradient as High, Mid and Low Potential. Normalization process was carried out in a separate field, where areas of high potential were assigned a value of 30, mid potential 20, and low potential 10, a step to ensure compatibility during map overlay. The authors employed a second process to reduce bias in identification of potential expansion areas of UGS within the study area. Various variables compatible with UGS were identified, digitized and their attributes described. They included existing UGS, rivers and streams, wetlands as well as transportation and infrastructure. Subsequently, relative weight for each variable was derived using Analytical Hierarchy Process (AHP) with the resulting figures as follows. Existing UGS (0.197), rivers and streams (0.274), wetlands (0.281) transportation and infrastructure (0.248). Buffer boundaries were determined as: existing UGS (200m for green space and 100m for sports fields), rivers and streams (60m for rivers and 30m for streams), wetlands (50m), transportation and infrastructure (highway 60m, main road 30m, feeder roads 15m, and railway 50m). Using GIS spatial analyst, a buffer was created for each variable, and each map assigned a colour gradient commensurate with its weight. Eventually, the resulting single variable maps were overlaid to create a single map of 'potential areas through proximity buffering'. They exhibited three varying colour gradients of high, mid and low potential areas. Normalization process for compatibility was done during map overlay. High potential areas were assigned score 15, mid potential 10 and low potential 5, as the authors considered this process less weighty and accurate than that of checklist application. Map overlays are a common method for delineating suitable areas (McHarg, 1969). To get a final potential map, the output maps of Suitability Checklist and that of Proximity Buffering processes were overlaid. After overlay, a value for each of the areas was derived, whether existing independently or overlapping with another potential area. The sum of these values was expressed numerically and in colour gradient on the Final Potential Map showing the most to the least potential areas for expansion of UGS.

4. Results and Discussion

The total area (TA) for Central Nairobi was approximately 41.75km2 or 4175 ha. Green space abundance total was 4.12km2 or 415.7 ha, with percentage abundance for UGS at 9.86%. This shows Central Nairobi is under endowed since various cities have set much higher thresholds. Hanoi in Vietnam as an example has set its minimum at 18% (Uy, 2006). Low abundance indicates a city that could be facing ecological, environmental and social difficulties. Urban parks, mostly utilized and accessed by urban dwellers for their recreational needs cover just 0.78% of the total study area, or 7.89% of the existing UGS. Urban forests with their bigger role as carbon and dust sinks, as well as biodiversity hosts than any other class occupy only 0.83% of the total study area or 8.39% of UGS cover. Classes occupying the largest portions of UGS includes institutional green space (PUA 2.55% or PDU 25.89%), golf courses (PUA 2.44% or PDU 24.72%), and residential green space (PUA 2.11% or PDU 21.38%). These indicate that most of the UGS is not accessible to the public, but only members of these institutions. They include those that can afford membership fees in the case of golf courses, and homeowners and their families in the case of residential green space. This leaves residents living in apartments, small lot town houses and in the crowded slums of Nairobi having little or no opportunities in accessing green spaces. The proportional UGS abundance (PDU) that is the percentage of the total area (TA) composed of each class of UGS is as shown on Table 2. In terms of diversity, we identified nine classes of UGS. Residential green space had the most patches at 34, while urban forest had the least with one patch as also summarized on Table 2. Their composition shows low diversity, lack in essential UGS classes such as neighbourhood parks, children play parks, thematic gardens and agricultural areas among others. All the above provide avenues for play, recreation, socializing, therapeutic functions, city aesthetics, supplement food supply and expand ecological catchment. The number of patches per class also shows inequalities. Urban parks have just five patches indicating that even if they were evenly spread throughout the study area, they could be far and wide hence inaccessible to most residents.

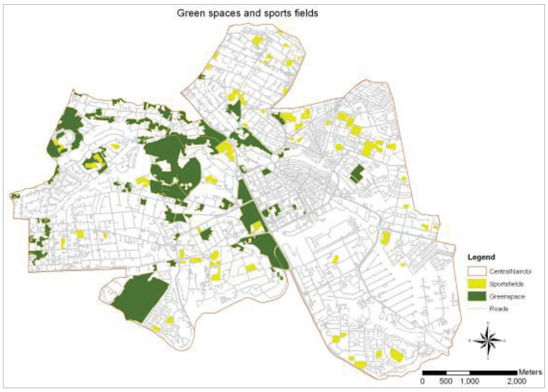

Fig. 2. Existing UGS and sports fields' patches after trace over and digitization

Landscape shape index (LSI) establishes whether a landscape patch shape is compact or not, irregular or convoluted. We calculated it using perimeter-to-area (PA) ratio that established a maximum LSI for green spaces at 0.1035, minimum at 0.0056 and a mean of 0.0471, as well as the standard deviation of 0.0235. It also indicated that the larger patches had a lower PA ratio (more compact) than smaller ones that are more convoluted and irregular. This can be attributed to the fact that larger patches could be products of whole lots or combination of lots with regular geometry predetermined through planning and designated for UGS. Smaller patches could be products of leftover or incidental spaces within lots or across lots. The largest patch measured 0.73km2 or 73.19ha, big enough to host a credible ecosystem, as well as dispense adequate BUGS to the residents if well planned and managed. This makes the largest patch index (LPI) to be 1.75%. The mean patch size (MPS) for green spaces was 0.058km2 or 5.80ha, with a patch standard deviation (PSSD) of 0.101km2 or 10.09ha.

Table 2. UGS diversity, proportional UGS abundance (PUA), and proportional diversity of UGS (PDU)

	Class	Number of patches per class (No.)	Proportional UGS abundance (PUA) (%)	Proportional diversity of UGS (PDU) (%)
1	Urban forest	1	0.83	8.39
2	Urban park	5	0.78	7.89
3	Residential green space	34	2.11	21.38
4	Institutional green space	15	2.55	25.89
5	Commercial area green space	7	0.19	1.97
6	Riparian green space	3	0.80	8.08
7	Golf course	3	2.44	24.72
8	Cemetery green space	3	0.17	1.69

The study area total population in 2010 as per the Kenya National Bureau of Statistics (KNBS, 2008) estimates was 438,376 people. Thus, green space per capita at that time was 9.38m2/person. The western half of the study area contained most of the patches, with the eastern half having just but few patches.

This indicates unequal distribution of UGS that affords advantage to the western residents over the eastern counterparts in access, recreation, and contact with nature. The green spaces in the north western part, exhibited a high degree of contagion, with proximity to neighboring patches minimum. They were also irregular and large, which is conducive for a vibrant ecosystem, and accords residents within their catchment areas a better chance to enjoy recreational and other benefits. The patches found in north eastern and south eastern areas are small, with little or no contagion and have large distances to the nearest neighbor. They also showcase a high level of compactness, which can signal reduced ecological processes and BUGS. UGS patches in the entire study area do not show any pattern in planning or formation. They appear arbitrary in space and place, indicating piecemeal planning or natural occurrence.

4.1. Identification of potential expansion areas through UGS suitability checklist

We identified and digitized 129 patches that we considered as raw spaces before application of the UGS suitability checklist. The spaces spread throughout the study area in varying sizes, shapes, and locations. We applied the UGS suitability checklist and computed the cumulative weight for each patch. The least potential patch scored a total weight of 0.1610; the most potential scoring 0.6680 out of the maximum weight score of 1 and mean potential of 0.4098. Identified potential areas after application of UGS suitability checklist are as shown on Figure 3. Colour gradation symbolizes areas with high potential normalized with score 30, mid potential normalized with score 20 and low potential normalized with score 10 as shown on the map's legend. The high potential patches are large enough and are all over the study area, especially to the eastern half which has few existing UGS.

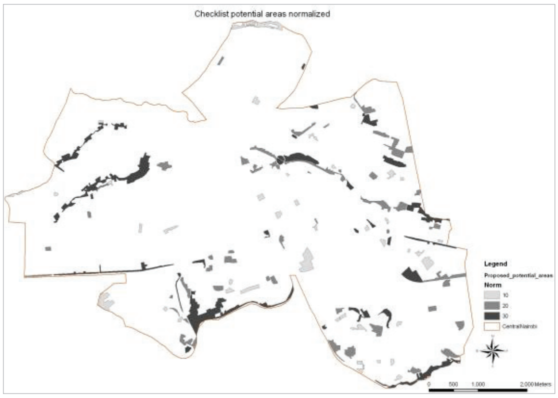

Fig. 3. Potential map after UGS checklist application and normalization

4.2. Identification of potential expansion areas through proximity buffering

We generated a potential map for each variable included in proximity buffering based on their derived weights. They included potential areas after transportation and infrastructure buffering, rivers and streams buffering, wetlands buffering as well as existing UGS buffering. We then overlaid them to produce a resultant map containing potential areas after proximity buffer overlays as shown on figure 4. The map indicates colour gradation denoting high potential areas normalized with score 15, mid potential normalized with score 10 and low potential areas with score 5. Proximity buffering resulted in a network of possible linear green spaces that transect through the entire study area. Such buffer zones a long transportation corridor can reduce dust and smoke which are prevalent in Nairobi, screen off eyesores and reduce traffic noise among other benefits. Rivers within the study area are part of Nairobi River Basin, currently under restoration after years of heavy pollution and encroachment. Buffering their corridors with UGS as indicated in Figure 4, can enhance their quality and consequently their service to the residents, the environment and restore riparian ecosystems.

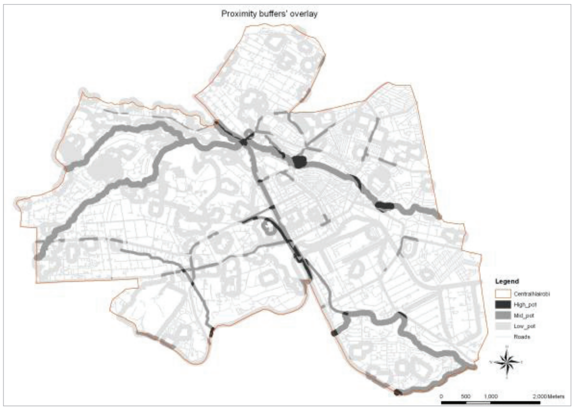

Fig. 4. Potential map after proximity buffers overlay and normalization

4.3. Final potential map

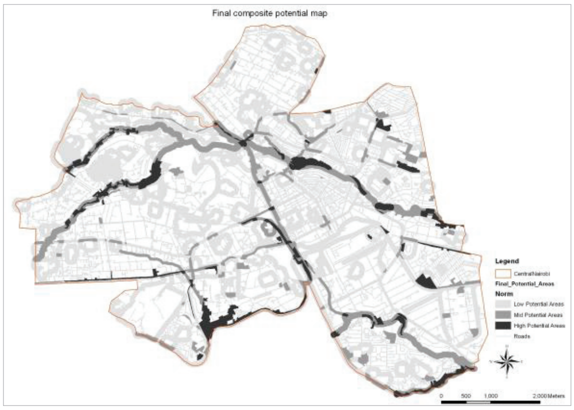

Fig. 5. Final composite potential map for UGS expansion in Central Nairobi

Finally, we overlaid resultant maps from the two methods 'UGS suitability checklist application potential areas after classification and normalization' (Figure 3), and 'Potential areas after proximity buffers overlay and normalization' (Figure 4). We calculated the sum of normalization score where they overlapped, and where they did not overlap we used the single normalized score. This resulted in the final composite potential map for Central Nairobi (Figure 5). It had three levels of potentiality represented through colour gradation as high potential areas, mid potential areas and low potential areas. This map clearly shows in the study area, where green spaces can be easily expanded. We considered this map realistic in pinpointing where to develop new UGS because it is a result of two complementing processes.

The Final Potential Map shows a series of spaces following a pattern and connectivity. These can be adopted to form green infrastructure system, complete with corridors and hubs within the study area. This can increase opportunities for residents and biodiversity to enjoy nature and benefits of UGS.

5. Conclusion

This study contributes a successful method for analyzing UGS and prioritizing possible expansion areas in a GIS environment. Concerning UGS it showed the shortcomings of Central Nairobi UGS on various landscape metrics and identified the least to the most potential areas for UGS expansion. Central Nairobi UGS lacks in size, composition, distribution, and character but has a high potential for expansion. Most available spaces are out of public access and utilization due to their ownership or management regimes. The composite potential map generated can be used as a basis for future selection of areas to develop UGS. The map can also be used to indicate where not to develop other physical infrastructure, if such areas are found to have high potential for development of UGS. Such developments can be allocated areas found to have low potential for development of UGS. Conclusion concerning quality of life and behavior is that: UGS in Central Nairobi as presently constituted cannot provide adequate benefits that can positively influence residents' quality of life and behavior. The residents have limited access to UGS because of long distances they travel to access them. Lack of diversity in UGS reduces the number of activities (social, cultural, economic, recreational, and therapeutic) they can engage in, which in turn affects their quality of life and behavior. If identified potential areas are exploited, they can ensure adequacy, even distribution, and performance to grant residents maximum UGS benefits hence a more livable city. Authority in charge (City Council of Nairobi) should establish UGS targets and various standards to guide green space allocations and distribution. These can include; a green master plan, distance limits for green space catchment areas, green space per capita and UGS classes' composition and distribution among others. Planning within the city needs a holistic approach with a paradigm shift that gives UGS the same or more weight than other physical development undertakings and policies. This can improve the city's obligations in providing environmental, socio-cultural, and economic benefits to its citizenry. Finally, the methodology used in this study can be applied in other parts of Nairobi City or other cities with similar characteristics as central Nairobi. It can also be modified to suit conditions of dissimilar cities to analyze their UGS or prioritize which areas are best suited to be acquired, utilized, or converted to UGS. The methodology can also be used in site analysis during planning for new towns or new neighborhoods. This can prioritize areas to be zoned for UGS, and those to be zoned for other physical infrastructure in such new developments.

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