A Localized GIS-Based Multi Decision Criteria Approach in Determining Suitable Sites for Community Toilet Facilities in BASECO Compound, Manila City

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Abstract

Access to sanitation remains a major concern in the Philippines due to the increasing population and growing demand for basic needs. This study addresses poor sanitary conditions in slum areas, specifically in BaSECo Compound, Manila, where informal settlers rely on shared toilets. Utilizing GIS and MCDA, the study identifies areas suitable for community toilet facility (CTF) development. The Modified Huff Three-Step Floating Catchment Area (MH3SFCA) method quantified spatial accessibility to existing toilets. The SPAI map shows low accessibility in blocks 15 and New Site, with Gawad Kalinga, Habitat, and Old Site (N) having none. The Analytical Hierarchy Process (AHP) prioritized six criteria, with accessibility being the most significant (33.18%), followed by proximity to water supply (31.76%), communal septic tanks (14.53%), land use (8.2%), flood-prone areas (7.44%), and ground slope (4.89%). The final suitability map identified 14.12% of the 0.6 sq. km. area as highly suitable, including Block 15, Gawad Kalinga, Habitat, and Old Site (N). Ground truth verification visited five candidate sites, which were tested for improved SPAI maps. The inclusion of facilities in Block 15, GK 2, OSN, and H improved accessibility in northern BaSECo. Significant service area improvements for each CTF were observed using Voronoi polygons. This study demonstrates the effectiveness of integrating GIS and MCDA methods for CTF site selection.

1. BACKGROUND

1.1. Rapid Urbanization and Informal Settlements

In developing countries like the Philippines, rapid urbanization, synonymous with economic growth, also presents various environmental challenges, including high population density, inadequate housing, and the proliferation of slums (Baker & Watanabe, 2017). Metro Manila, the country's only fully urbanized region, grapples with these issues, with the emergence of informal settlements being a primary concern (Raflores & Regmi, 2015).

Informal settlements, often referred to as slums or squatter areas, are impoverished residential zones lacking fundamental services such as safe water and sanitation, as per the United Nations' definition (UN-Habitat & ESCAP, 2015). Despite these challenges, the population of slum dwellers continues to grow rapidly due to urbanization. The 2018 Family Income and Expenditure Survey (FIES) indicates that around 2.45 million people (2.32% of the population) in the Philippines are informal settlers, with over 600,000 residing in Metro Manila (Navarro et al., 2021).

1.2. Sanitation and Access to Community Toilet Facilities

The rapid increase in population poses significant challenges to urbanization in many developing countries. Beyond the growing demand for basic needs like food and water, access to sanitation remains a major concern. According to the World Health Organization (2022), over 1.7 billion people lack access to basic sanitation, with 494 million still practicing open defecation.

In response to the global call to improve quality of life, "ensuring access to water and sanitation for all" is the sixth Sustainable Development Goal set by the United Nations for 2030. In the Philippines, the Department of Health (DOH) established new sanitation targets in 2019 under the Philippine Approach to Sustainable Sanitation (PhATSS) policy, aiming for Zero Open Defecation (ZOD) status in all barangays by 2025 (Department of Health and UNICEF, 2019). However, these targets are currently off-track (UNICEF, 2020a). The 2020 Annual Poverty Indicators Survey reports that around 24 million Filipinos (one in five families) still lack access to basic sanitation services, and seven million have no sanitation facilities and practice open defecation (Philippine Statistics Authority, 2021a).

The lack of access to improved sanitation leads to various health and environmental issues, particularly in urban poor communities. A 2019 Global Burden of Disease study found that approximately 756,585 people died due to unsafe sanitation (Murray et al., 2020). Health issues linked to poor sanitation include diarrhea, cholera, dysentery, hepatitis A, polio, and typhoid (World Health Organization, 2022).

Open defecation is common in slum areas like the Bataan Shipyard and Engineering Company (BaSECo Compound) in Manila, home to approximately 30,000 families, mostly informal settlers. These residents face limited access to basic healthcare and sanitation services, alongside other challenges such as low income and insecure jobs (World Vision Urban Programming, 2021). One solution to eliminate open defecation in slums is the provision of community toilet facilities (International Finance Corporation, 2017). Community toilets are shared sanitation facilities provided for groups of residents or entire settlements, particularly in low-income and informal areas where space constraints prevent individual household toilets (Ministry of Housing and Urban Affairs, 2017).

Proper planning and distribution of community toilets are crucial to balance supply and demand. Geographic Information System (GIS) technology can address sanitation infrastructure planning issues in informal areas, especially for site selection of community toilet facilities. GIS enables spatial analysis to identify areas lacking community toilets. Additionally, the absence of national standards for the location of sanitation facilities allows Multi-Criteria Decision Analysis (MCDA) to support decision-making. By integrating GIS and MCDA-based tools, effective site selection for community toilets can be achieved.

1.3. Objectives and Significance

The objective of this study is to identify suitable areas for the development of community toilet facilities in a slum area using GIS and Multi-Criteria Decision Analysis (MCDA). This methodology aims to assist stakeholders in addressing poor sanitation in slums. The MCDA approach involves engaging local officials and stakeholders to gather feedback, which will then be used as inputs in determining suitable sites. This ensures stakeholder inclusion in the decision-making process and ensures that each criterion considered is aligned with local needs.

Specifically, the study aims to analyze the availability and accessibility of community toilets using Modified Huff Three-Step Floating Catchment Area (MH3SFCA) method, determine the significance of different factors in identifying community toilets sites using the Analytic Hierarchy Process (AHP) method, and perform suitability analysis using GIS-MCDA techniques.

This study will provide significant benefits to the BaSECo community by serving as a campaign for residents, who are the primary stakeholders in the establishment of community toilet facilities. Additionally, this research will benefit local health departments and other affiliated agencies by sharing the responsibility for prioritizing sanitation to achieve sustainable development goals. The study results will also aid in identifying gaps in the geographic coverage of community toilets and improving existing policies by integrating GIS technology to address issues related to poor sanitation.

2. MATERIALS AND METHODS

2.1. Study Area

The study was conducted in Barangay 649, Zone 68, Port Area, Manila, also known as BaSECo Compound. BaSECo, or Bataan Shipyard and Engineering Company, is an urban poor community and one of the largest informal settlements in the Philippines. The total area of BaSECo covers about 0.6 sq. km of poorly reclaimed land around Manila Bay, with an official population count of approximately 65,000 individuals (or around 13,000 families) as of 2020 (PSA, 2021b). Due to its proximity to the bay and being a reclaimed area, BaSECo is highly vulnerable to both natural and man-made disasters, including flooding, tsunamis, and others (Rossini, 2021).

The residents of BaSECo are mostly informal settlers with limited access to basic services, including education, healthcare, and sanitation (World Vision, n.d.). Poor sanitary conditions are very evident in the community, where open defecation is prevalent, especially among children. According to the DOH, open defecation is a risk factor in the spread of polio (Bagaoisan, 2019), and children in slums are particularly vulnerable to this disease, as well as urinary tract infections and worm infestations (World Vision, n.d.).

In 2020, almost half of the households in BaSECo did not own household toilets and relied solely on community toilets (Senate of the Philippines, n.d.). When the distance to the nearest community toilet is too far, residents often relieve themselves in the open, in the bay/river, or nearby esteros (Rossini, 2021). To address the lack of basic household sanitation, the development of community toilet facilities can be a viable solution (Schouten & Mathenge, 2010).

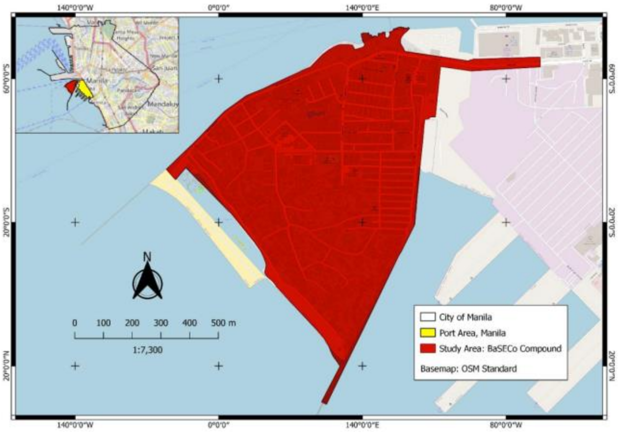

Figure 1. BASECO Compound, Manila

2.2. General Methodology

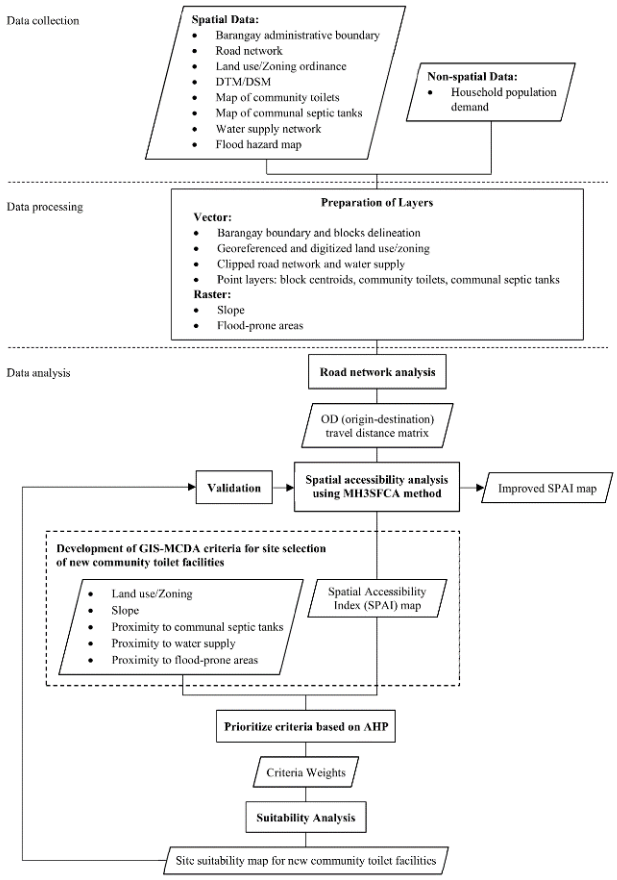

Figure 2. General Methodology

The methodology in this study comprises three main stages: data collection, processing, and analysis (Figure 2). Data collection involves identifying and obtaining relevant datasets based on literature and local stakeholder input, including administrative boundaries, road networks, land use/zoning ordinances, topography (DTM/DSM), population counts, water supply lines, flood hazard maps, and existing community toilet and communal septic tank locations in BaSECo.

Data processing involves preparing layers required for analysis. Some data are georeferenced and digitized, while others are further processed to derive additional inputs. For data analysis, three key steps are undertaken: (1) road network analysis using OD (origin-destination) travel distance matrices, (2) spatial accessibility analysis using the Modified Huff Three-Step Floating Catchment Area (MH3SFCA) method, and (3) suitability analysis using GIS and Multi-Criteria Decision Analysis (MCDA). The MCDA technique employs Analytic Hierarchy Process (AHP) to obtain criteria weights through pairwise comparisons by experts or stakeholders. Aggregating the criteria using weighted overlay analysis determines suitable sites for new community toilets.

A total of ten (10) spatial data layers are used in the conduct of the study. Table 1 lists down the data used along with its corresponding format and source

Data	Format	Source
Barangay Administrative Boundaries	.shp / vector	Philippines PSGC Administrative Boundaries Shapefiles
District Boundaries	.pdf	Barangay of BaSECo; Di Pinto et al., 2021
Census of population	.jpg / image	Barangay of BaSECo
Community toilet facilities (CTFs)	coordinates / points	Barangay of BaSECo
Road network	.osm / vector	OpenStreetMap (OSM)
Land use/Zoning ordinance	.pdf	Manila City Planning and Development Office (MCPDO)
Topographic map/DTM/DSM	.tiff / raster	National Mapping and Resource Information Authority (NAMRIA)
Communal septic tanks	coordinates / points	Barangay of BaSECo
Water supply network	.shp / vector	Maynilad Water Services, Inc.
Flood hazard map	.shp / vector	LiDAR Portal for Archiving and Distribution (LiPAD)

Table 1. List of acquire datasets

2.3. Road Network Analysis

Using the OD (origin-destination) Matrix from Layers as Lines (m:n) algorithm of QNEAT3 (QGIS Network Analysis Toolbox 3), the network route-based cost from each block centroid to the community toilet facilities (CTFs) was calculated. In the algorithm, the block centroids were set as the origin (layer m) and the locations of the CTFs were set as the destination (layer n). The output of the network analysis is an OD travel distance matrix containing cost components such as entry-cost, network-cost, exit-cost, and total cost.

2.4. Spatial Accessibility Analysis using MH3SFCA

The total cost from the OD matrix represents the travel distance from each origin to each destination. This data was used to analyze the spatial accessibility of community toilets using the Modified Huff Three-Step Floating Catchment Area (MH3SFCA) method. Although typically used for healthcare facilities (Luo, 2016), this method was modified to consider the number of individual toilets as the supply capacity.
The MH3SFCA method involves three steps:

1. Calculating the probability of interaction between block centroids (population location) and community toilet facilities (CTFs) to quantify accessibility based on competition.
2. Calculating the supply-demand ratio to assess the sufficiency of CTFs.
3. Calculating the spatial accessibility index (SPAI) for each block.

A travel distance threshold of 500 meters defined the catchment area for each block. The probability of interaction was calculated using the OD matrix data. The supply-demand ratio was determined by dividing the supply capacity (number of individual toilets) by the sum of the products from the first step and the number of household users for each block. The SPAI for each block was then calculated by summing the products of the first two steps and the Gaussian weights for all CTFs within the 500-meter catchment.

The resulting SPAI map shows the spatial accessibility indices for the 12 blocks of BaSECo. Areas with higher indices indicate better accessibility to community toilets, while lower indices highlight areas deprived of such facilities

2.5. Site Selection Factors / Criteria

The factors influencing the site selection of community toilets were determined based on literature and available data for the study area. Each criteria map corresponding to each factor were prepared and normalized to transform values to a common scale. The key factors considered are:

1. *Land Use/Zoning:* Land use is crucial for determining suitable locations for sanitation facilities (Nega et al., 2021). Since BaSECo is classified as built-up, the zoning ordinance was used to identify areas based on land purpose.
2. *Accessibility:* Accessibility is significant for site selection as it considers the spatial distribution of facilities relative to population demand (Yin et al., 2020).
3. *Slope:* Safety of public toilet locations requires avoiding steep slopes and hazardous traffic areas (Greed, 2006). The slope factor was derived from the Digital Terrain Model (DTM) dataset of Manila.
4. *Proximity to Communal Septic Tanks:* Public toilets should be close to the urban sewage network (Yin et al., 2020). As BaSECo lacks a sewer system, proximity to newly built communal septic tanks were used.
5. *Proximity to Water Supply Lines:* Sanitation facilities need to be near clean water sources. This factor was represented by proximity to existing water supply pipelines in BaSECo.
6. *Proximity to Flood-Prone Areas:* Avoiding flood-prone areas is crucial for implementing sanitation facilities in urban slums. Identifying non-flood-prone areas was essential for site selection.

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3. RESULTS AND DISCUSSION

3.1. Spatial Accessibility Indices

The final result of the MH3SFCA method is the spatial accessibility indices (SPAI), which indicate the spatial accessibility of each block to the community toilet facilities (CTFs). The SPAI map of BaSECo shows green areas with high accessibility and red areas with low accessibility.

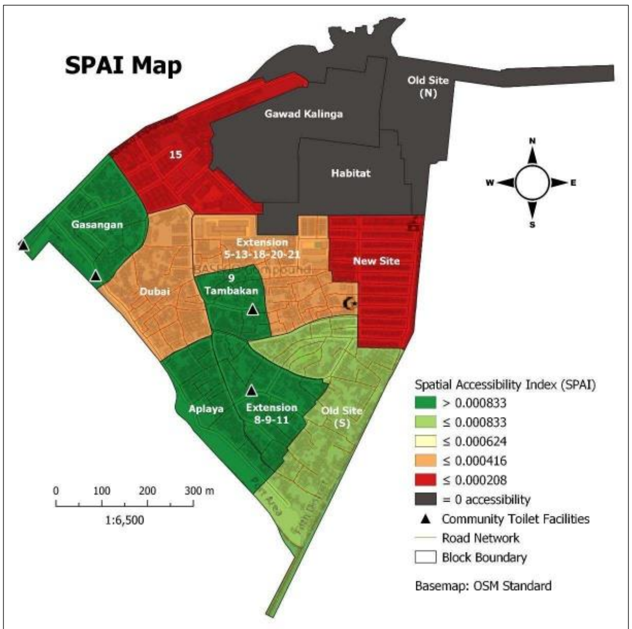

Figure 3. Initial Spatial Accessibility Index Map of BaSECo

Green areas include blocks Gasangan, 9 Tambakan, Extension 8-9-11, and Aplaya with accessibility indices higher than 0.000833. Whereas the red areas which are deprived of community toilet facilities are blocks 15, and New Site while the excluded blocks from the MH3SFCA method such as Gawad Kalinga, Habitat, and Old Site (N) automatically have zero (0) indices indicating no accessibility at all.

The indices align with values from other MH3SFCA studies (Subal et al., 2021; Lao et al., 2022). The analysis reveals a significant lack of access to community toilets in BaSECo, especially in the northern communities. The low accessibility indices for blocks like Dubai and Extension 5-13-18-20-21, despite their proximity to existing facilities, are due to low toilet capacity and high demand. This indicates an imbalance in the supply and demand of CTFs, particularly in the south of Gasangan and 9 Tambakan.

3.2. Suitability Criteria Weights

Eight experts participated in the decision-making process. The completed questionnaires were processed using the Analytic Hierarchy Process (AHP). Table 2 shows the consolidated weights and ranks of six factors from the group comparison matrix. According to the experts' judgments, the most significant factor in the site selection of new community toilets is accessibility, with a 33.18% significance level, followed by proximity to water supply at 31.76%, and proximity to communal septic tanks at 14.53%. The ground slope was deemed the least significant at 4.89%, followed by proximity to flood-prone areas at 7.44%, and land use at 8.2%. 1.2%, which is less than the required maximum threshold of 10%. Therefore, the experts' judgments were found to be adequately consistent.

	Criterion		Weights (%)	Rank
1	Land use/zoning	LU	8.20	4
2	Accessibility	AC	33.18	1
3	Slope	SL	4.89	6
4	Proximity to communal septic tanks	ST	14.53	3
5	Proximity to water supply	WS	31.76	2
6	Proximity to flood-prone areas	FP	7.44	5
	Total		**100**	

Table 2. Summary of Criteria Weights

The obtained final Consistency Ratio from the group comparison matrix is 1.2%, which is less than the required maximum threshold of 10%. Hence, the experts’ judgments were found to be adequately consistent.

3.3. Suitability Map for CTFs

The final weights from Table 2 were used in the weighted overlay analysis to identify suitable areas for developing new community toilet facilities. Normalized raster layers were overlaid using the raster calculator, where each factor or criterion was multiplied by its respective weight based on the results of AHP. These values were then summed to produce a suitability scale from 0 to 1. The suitability was further reclassified into five classes with equal intervals: very high suitability, high suitability, moderate suitability, low suitability, and very low suitability. The generated suitability map is shown in Figure 4.

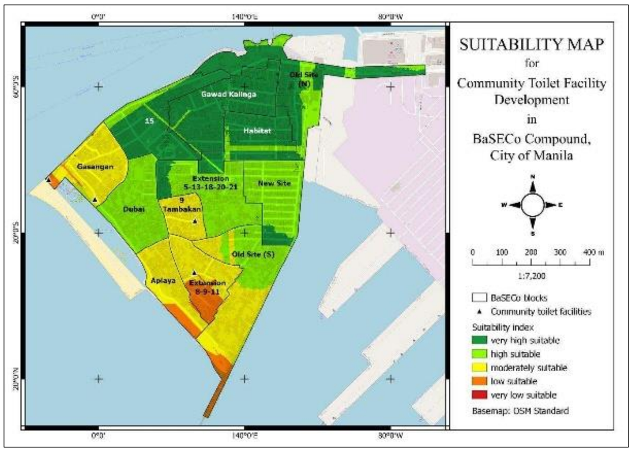

Figure 4. Suitability Map of CTFs in BASECO

High to very high suitable areas for developing new community toilets in BaSECo include blocks 15, Gawad Kalinga, Habitat, Old Site (N), New Site, Dubai, Extension 5-13-18-20-21, and a portion of Old Site (S). Moderately suitable areas include blocks Gasangan, 9 Tambakan, and portions of Aplaya, Extension 8-9-11, and Old Site (S). Low suitability areas include the remaining portions of Aplaya, Extension 8-9-11, and Old Site (S). The map shows no red areas, indicating that BaSECo does not have any regions with very low suitability for community toilet facility development. To further refine the suitability map, building footprints from OpenStreetMap (OSM) and the road network buffer were considered. The improved suitability map, identifying potential sites with available land/space, is shown in Figure 5.

Since accessibility is the most significant factor in the site selection process, the generated suitability maps highlight suitable areas in blocks with lower accessibility indices. The initial suitability map identifies the blocks or portions of blocks where new community toilets should be developed based on the criteria weights set by the experts. By incorporating building and road shapefiles into the analysis, the final suitability map has significantly improved, though it is subject to validation.

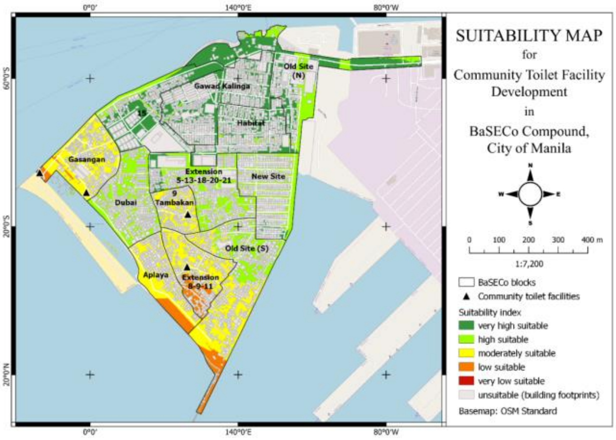

Figure 5. Final Suitability Map for CTFs in BASECO

To assess the reliability of the generated suitability maps, ground truth verification and test points were used for validation. A site visit in BaSECo was conducted to verify potential sites in blocks with very high suitability for new community toilet facilities. With the assistance of barangay officials, five areas, all situated on public property, were visited, as shown in Figure 6.

Figure 6. Candidate sites: (a) beside parking lot in Block 15, (b) open space in Gawad Kalinga, (c) open space in Old Site (North), (d) in a public property in Gawad Kalinga, and (e) in a public property in Habitat

Each of the five candidate sites was considered as a test facility, featuring similar characteristics to the one located at BaSECo Beach Esplanade. The test facility would include two separate doors for men and women, with a toilet capacity of eight. Different combinations of candidate sites were also included in the network to determine whether adding more than one community toilet facility is more optimal than adding only one. By running the MH3SFCA method, new accessibility indices were obtained for each test scenario and mapped to produce the improved SPAI maps. Figure 7 shows a smaple updated SPAI map for test scenarios involving a single added CTF and when all CTFs are included. The choice of combinations was based on the resulting SPAI map of individual candidate sites and the spatial distribution of test community toilet facilities (CTFs).

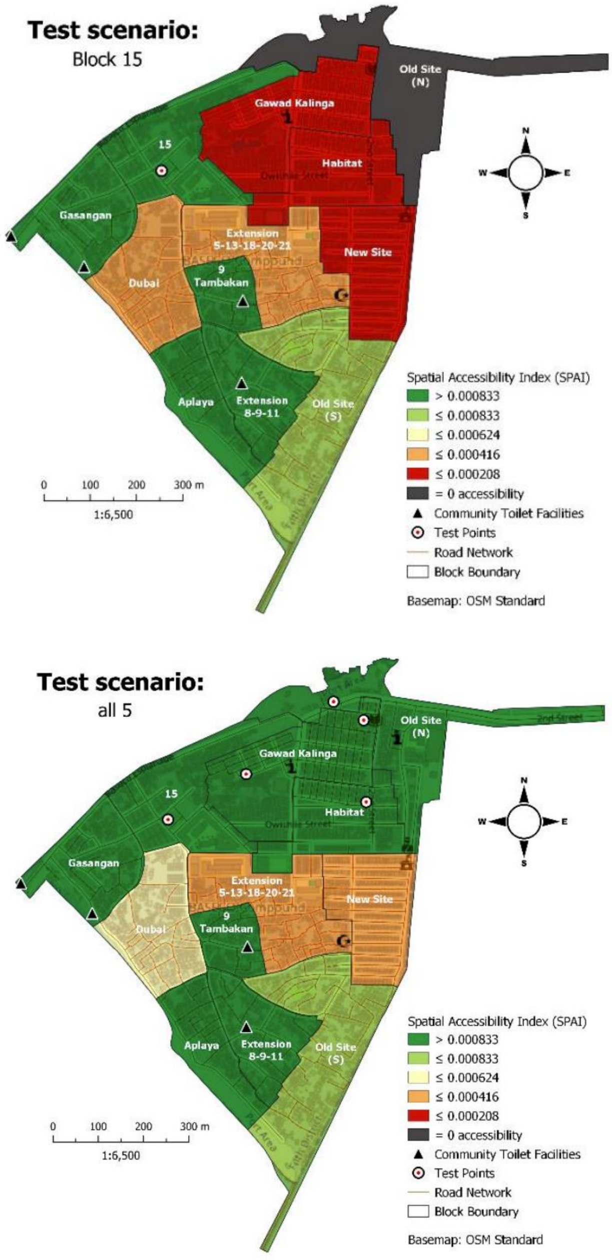

Figure 7. Updated SPAI map with test scenario of 1 CTF at Block 15 and a test scenario when all CTFs are included

For each test scenario, the generated SPAI map shows significant improvement in accessibility within the communities of BaSECo compared to the base scenario (Figure 3). The summary of the catchment results based on the MH3SFCA method is shown in Table 3.

Out of the 12 blocks in BaSECo, it was determined that only 9 have access to at least two CTFs within a 500-meter walking distance in the base scenario. In the test scenarios, 11 blocks will have accessibility after adding a CTF either beside the parking lot in Block 15 or at an open space in Gawad Kalinga. Among the individual test scenarios, the inclusion of a test facility in Habitat produces the best result, with five blocks having access to three CTFs. This is followed by the inclusion of test facilities in Gawad Kalinga 2 and Old Site (N), with the same number of blocks having access to every classified number of community toilets.

		4 or more	**3**	**2**	**1**	**Total**
Number of blocks	Base scenario	1	3	5	0	**9**
	Test scenarios:					
	Block 15	3	3	3	2	**11**
	Gawad Kalinga 1	1	4	4	2	**11**
	Gawad Kalinga 2	1	3	5	3	**12**
	Old Site (North)	1	3	5	3	**12**
	Habitat	1	5	3	3	**12**
	Old Site (North) and Habitat	1	5	6	0	**12**
	Block 15, Old Site (North), and Habitat	4	5	3	0	**12**
	Block 15, Gawad Kalinga 2, Old Site (North), and Habitat	6	4	2	0	**12**
	All 5	6	4	2	0	**12**

Table 3. Summary of MH3SFCA Catchment Results with CTF reaching 500m considering blocks as origin

For the remaining test scenarios, the combinations of two, three, four, and five test facilities included the candidate site in Habitat to find the most optimal number of community toilet facilities to develop that will better serve the community of BaSECo. Based on the table, the lowest number of CTFs to reach within 500 meters is 2, with all 12 blocks having access to CTFs. However, the combination of two test facilities (i.e., OSN and Habitat) will only have 1 block with access to 4 or more CTFs.

In this study, the most optimal combination of new community toilet facilities is defined as having the greatest number of blocks with access to 4 or more CTFs. Thus, the combination of four test facilities (i.e., Block 15, GK 2, OSN, and Habitat) provides the optimal or sufficient accessibility for the community of BaSECo.

Furthermore, the delineation of service areas for each test scenario, including the base scenario for comparison, was estimated using Voronoi polygons. For all scenarios, the map of the study area was divided into polygons such that each polygon contains exactly one generating point (either a CTF or a test point), and every point within a given polygon is closer to its generating point than any other point on the map. In simple terms, each Voronoi polygon represents the area on the map that is closest to the community toilet facility or test CTF it contains, rather than any other CTFs or test CTFs on the map.

The generated Voronoi diagrams were overlaid with the building footprints from OSM to count the number of buildings within each polygon. Assuming that every building is inhabited, each building served as a demand point representing the households being supplied by the community toilet facilities. Based on the generated Voronoi polygons, adding more facilities within the northern communities of BaSECo results in a better distribution of the service area. Essentially, the more facilities there are, the better the distribution and higher the accessibility. With an adequate number of community toilet facilities in BaSECo, the sanitation issue can be significantly improved.
A bar graph shown in Figure 8 illustrates the standard deviation of different test scenarios, including the base scenario, based on the number of buildings within each service area of CTFs. Although the computed standard deviations are large, we can still compare this parameter across scenarios to determine how well-distributed the service areas are relative to the demand points. As mentioned earlier, the demand is represented by each building on the map.

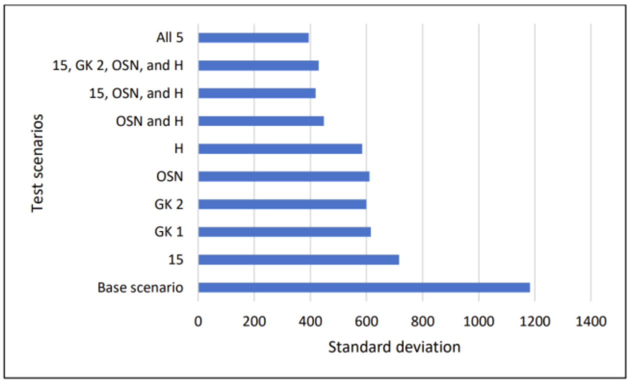

Figure 8. Bar graph of standard deviations for distributed service areas of each CTF test scenario

Based on the graph, the inclusion of all five test facilities produces the lowest standard deviation, indicating that the service areas of those five facilities are well allocated and distributed within the study area. Furthermore, it can be inferred that all test scenarios show a significant improvement in distribution compared to the base scenario.

4. CONCLUSIONS

The identification of suitable sites for new community toilet facilities was effectively addressed through Multi-Criteria Decision Analysis (MCDA), specifically the Analytical Hierarchy Process (AHP). By applying Saaty’s 9-point scale for the pairwise comparison matrix, the final weights for six criteria were determined. Expert judgments revealed that accessibility was the most significant criterion for site selection, with a significance level of 33.18%. This was followed by proximity to water supply at 31.76%, proximity to communal septic tanks at 14.53%, land use at 8.2%, proximity to flood-prone areas at 7.44%, and ground slope at 4.89%.

Both initial and final suitability maps were generated based on these criterion weights. Suitability levels were classified into very high, high, moderate, low, and very low. The initial suitability map identified potential blocks for new community toilets without considering existing land cover. In contrast, the final suitability map incorporated building footprints and road shapefiles from OpenStreetMap (OSM), clearly depicting suitable sites. Of the study area (0.6 sq.km.), 14.12% was classified as very high suitability and 0% as very low suitability. Areas of very high suitability included Blocks 15, Gawad Kalinga, Habitat, and Old Site (N). The most suitable areas for new community toilets were those with low accessibility to existing facilities, emphasizing the importance of the accessibility criterion.

Ground truth verification involved visiting five candidate sites within blocks identified as having very high suitability. Each site, along with various combinations, was tested to produce improved SPAI maps using the MH3SFCA method. The optimal accessibility for the northern communities of BaSECo was achieved by including four test facilities in Blocks 15, GK 2, OSN, and H. Voronoi polygon analysis further demonstrated significant improvements in the distribution of service areas, with all five test facilities showing better allocation.

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This study demonstrates the effectiveness of integrating GIS and MCDA methods for the site selection of community toilet facilities. Expert opinions on influencing factors were crucial, as criteria weights significantly impacted the suitability analysis.

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