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ORIGINAL ARTICLE

Multi-criteria evaluation of suitable locations for temporary disaster waste storage sites: the case of Cavite, Philippines

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Abstract

One of the problems that arise due to typhoon and flooding is the generation of large volumes of disaster wastes, which poses threats to the environment and human health when not managed properly. This study focused on the identification of suitable locations of temporary storage sites (TSS) for disaster wastes using geographic information system to address gaps in disaster waste management. A set of criteria for selection was established based on the guidelines of the United Nations Environment/Office for the Coordination of Humanitarian Affairs Joint Unit (UNEP/OCHA), with constraints set based on existing guidelines and past studies. Map layers were standardized using Boolean logic, and the criteria were analyzed using ArcGIS Pro and Google Earth Pro. Areas in the Province of Cavite having high disaster risks, particularly Cavite City, Noveleta, and Kawit, were selected as study sites. From the analysis, a total of 18 TSS candidates were identified. It was determined that land use and distances from fishponds and built-up areas were the most sensitive criteria as they cover large portions of the area. For each TSS candidate, a 15-min service area map was generated using the ArcGIS Pro Network Analyst which showed that selected locations may serve multiple cities/municipalities.

Keywords Disaster waste management · Temporary storage sites · Typhoons · Geographic information system · Cavite Philippines

Introduction

The Philippines' geographic location makes the country prone to different types of natural hazards. Situated along the typhoon belt of the Pacific Ocean, the country experiences an average of twenty (20) typhoons every year, five of which are disastrous, leading to the destruction of properties, injuries, and fatalities [1]. Typhoon is a term for tropical cyclones that form over the Western North Pacific [2]. It is one of the most frequent types of hazard that occur in the country, along with flooding or the overflow of water that submerges dry land. Flooding can result from heavy and excessive rainfall, storm surges, or from when dams and levees break [3]. The combination of these two hazards intensifies their devastating effects which may lead to disasters.

One of the biggest problems caused by typhoons and flooding, along with injuries, fatality, and damage to properties, is the generation of large volumes of disaster wastes. These disaster wastes are classified into types including green wastes, household materials, damaged vehicles, and mixed wastes [4]. These wastes, when not managed properly, increase environmental and public health hazards. They may also overwhelm existing solid waste management systems.

The Province of Cavite, which is the location of study, has high flooding risks in some of its cities and municipalities as shown in Fig. 1. Cavite has four kinds of physiographical areas, namely: the lowest lowland area, lowland area, the central hilly area and the upland mountainous area. Moreover, as a part of Luzon, Cavite is strongly affected by monsoon (rain-bearing) winds [5].

As a response to the generation of disaster wastes, the United Nations Environment/Office for the Coordination of Humanitarian Affairs Joint Unit (UNEP/OCHA) published the Disaster Waste Management Guidelines which covers the four phases of disaster waste management (DWM)—(1) Emergency phase, (2) Early recovery phase, (3) Recovery phase and (4) Contingency planning [6].

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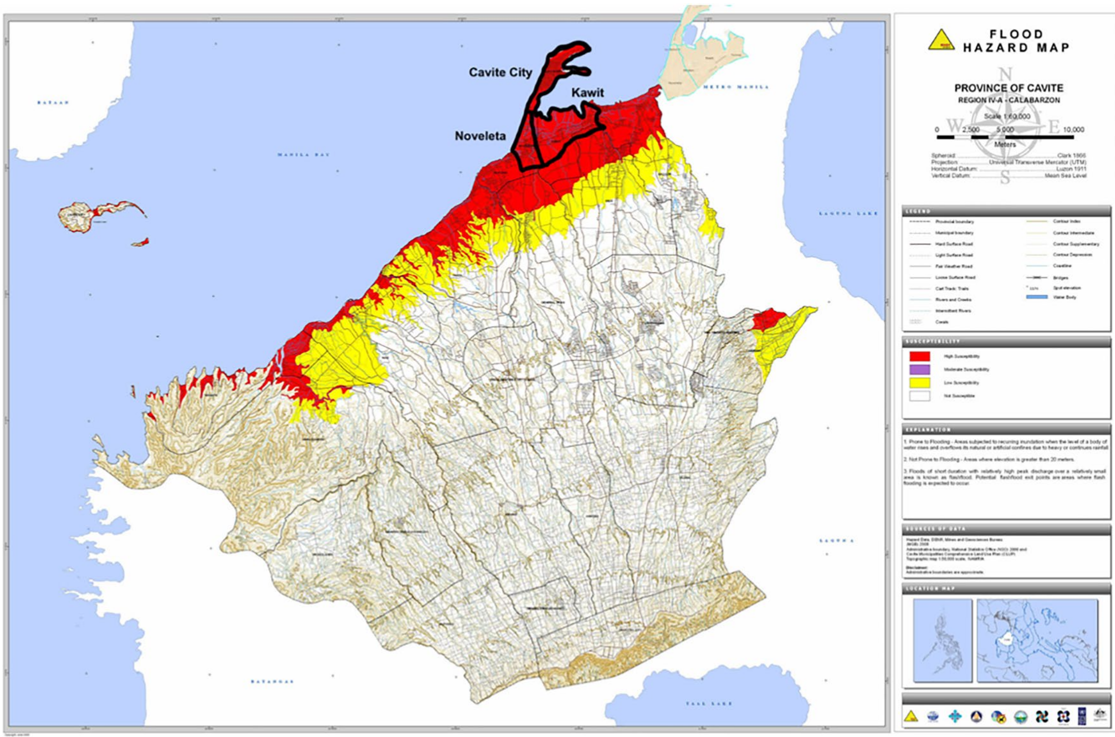

Fig. 1 Flood Hazard Map of Cavite (Reference: Philippine Atmospheric, Geophysical and Astronomical Services Administration, PAGASA). It is shown that some areas in the province, particularly those adjacent and near the coasts where the selected study sites are located, have high susceptibility to flooding

In the Philippines, studies revealed that there are gaps and issues in disaster waste management in different regions. Gaps in the disaster waste management practices performed by the local government units (LGUs) of selected cities in Metro Manila relative to the guidelines provided by UNEP/OCHA were identified [7]. Solid waste management guidelines are implemented in the country, but there are no established policies specific to disaster waste management.

One of the gaps identified in the study areas of past research studies is the absence of temporary storage sites (TSS). A TSS is a temporary site where disaster wastes are stored before they are treated or disposed of. It serves as an area for the segregation of disaster wastes to separate the ones which can be recycled and/or treated from the ones that should be disposed of. Hence, it helps control the disposal of disaster wastes [8]. Establishment of TSS is under the early recovery phase in DWM [9]. Without TSS, there would be no centralized storage site for disaster wastes during the entire recovery phase which may result in secondary hazards, and the potential of disaster wastes to be recycled and reused may not be maximized due to inefficient segregation.

This study addresses an important component of disaster waste management – the identification and evaluation of TSS locations through a set of criteria established based on the guidelines from UNEP/OCHA using a geographic information system (GIS). It also aims to generate service maps of the identified potential locations. The presence of TSS can help minimize the environmental and health threats that can be caused by disaster wastes and will improve disaster response.

Literature review

Disaster waste management guidelines

DWM guidelines of UNEP/OCHA

The Disaster Waste Management Guidelines published by UNEP/OCHA provides detailed guidelines that are currently being adopted by different countries. This characterizes hazards and wastes generated by different disasters. The framework for disaster waste management which covers four phases of preparing and responding to disasters is discussed. This provides the tools necessary for disaster waste management including waste needs assessment, waste hazard ranking tool, and waste-handling matrix. It gives detailed general and operational considerations in developing temporary disposal sites, as well as a sample layout for a TSS and the environmental, safety, and logistical guidelines.

Based on the framework of disaster waste management, the establishment of TSS is under the early recovery phase, as well as the collection and transportation of wastes and debris to storage and disposal sites. The second phase also covers the preparation of practical advice and guidance for local authorities on tentative solutions for the minimization of negative environmental and health impacts of disaster wastes.

Since TSS is only for "temporary", UNEP/OCHA also provides the guidelines for the closure of TSS and restoration of the site to its original condition. According to UNEP/OCHA, a temporary storage site should be used for short periods of time, with an average from zero to 12 months.

The 3R International Scientific Conference on Material Cycles and Waste Management

Temporary storage site (TSS) was introduced and defined by Takai and Otsuka (2021) in their conference presentation as an area where disaster wastes are stored and separated before they are treated or disposed of [9]. A basic flow or transport scheme of DW treatment begins from collection in damaged areas and transportation to rough and advanced separations in the first and second TSS, respectively, to treatment, utilization, or landfill. Segregation of disaster wastes would help in reducing the disposed wastes.

According to the presentation by Tajima in 2021, the functions and designs of TSS may vary among countries, but the involvement of roles of the government in the operations is presented in the context of TSS in Japan [8]. The need to properly prepare TSS is discussed, wherein the consequences of opening a TSS without proper preparation, such as an opening in unsuitable land and opening before sufficient staff and equipment are readied, were emphasized. A summary of the criteria for the conditions of TSS was provided, including the reasons behind each criterion. These are necessary to be able to identify potential areas for TSS. Moreover, the components that must be prepared, including TSS layout plan, procedures, and resources, were also mentioned. The presentation also included the equation to estimate the total TSS area under three assumptions: (1) DW collection is done in some specific time frame, (2) DW are carried into and out of TSS in parallel, and (3) DW are transported from TSS to disposal sites since the TSS is opened. This equation was adopted in this study to analyze the site capacity (Eq. 1).

Disaster waste management in the Philippines

National Capital Region

The study by Osorio and Tandoc (2016) contains quantitative and qualitative data on disaster waste management in seven cities in the National Capital Region—Malabon, Manila, Marikina, Navotas, Pasig, Quezon City, and Taguig [7]. Responses of each city to disaster waste generation were assessed through site visits and ocular inspections, as well as coordination with stakeholders. Shown in their paper are the recorded amounts of wastes generated due to specific typhoons in each city, and the locations of temporary storage sites. Based on the study, not all of the cities studied have established TSS, directing disaster wastes to landfills without proper segregation and treatment. Some of the cities also did not have proper documentation of their disaster-related operations. It was recommended that a disaster waste management plan should be established with the help of useful tools such as a waste map, waste hazard ranking tool, and waste handling matrix.

DWM in other regions

Barriga assessed the disaster waste management practices as a response to the generation of disaster wastes caused by the typhoons that hit the Bicol region [10]. The assessment was based on international guidelines as there were no management plans and practices that had been established in the Philippines for the provinces to use. Data were analyzed quantitatively, along with waste characterization, identification and mapping of disposal sites and waste facilities, and documentation and assessment of the entire disaster waste management in the region. The assessment was done according to the four phases—(1) Emergency Phase, (2) Early Recovery Phase, (3) Recovery Phase, and (4) Contingency Planning—of response to and preparedness for disaster waste management. It was observed that many of the DWM guidelines have been practiced in the study area. It was shown that the cities and municipality studied (Legazpi, Naga, and Sto. Domingo) had specific guidelines for temporary disposal sites and transportation of wastes to the sites, but these sites were not outside the materials recovery facilities (MRF), and waste maps were not generated. Essentially, MRFs are solid waste management facilities where recyclables are sorted and recovered. Generally, it was stated that Bicol Region is ahead in terms of disaster waste management in the country, but there is still a need to fill in the gaps identified, including the need to establish further guidelines on contingency planning.

According to a 2015 study on how disaster wastes caused by Typhoon Yolanda were managed in Tacloban, Leyte, there were no proper documentations and records on the wastes generated; hence, data were based on news reports, satellite imagery, interviews three months after the disaster, and ocular inspection in the disposal site [11]. The paper provided the timeline of the responses of the authorities to the damages due to the typhoon. It was stated that three temporary dumpsites were set up to aid in the clean-up operation to hasten the immediate relief operations for the survivors. It was also noted that there was no processing of waste materials implemented on the entire island and that the wastes to be recycled had to be transported to neighboring areas or even to Manila. In general, the study states that due to a lack of disaster waste management plan, (1) the clean-up operation after Typhoon Yolanda did not start immediately; (2) there was no proper waste segregation and recycling done; and (3) waste management practices were not documented. The siting of TSS prior to the occurrence of disasters could help address these problems.

Application of GIS in DWM

GIS has been widely used in siting waste treatment sites concerning multi-criteria analysis as it reduces the time and cost required [12]. Many studies used Boolean logic, along with fuzzy logic as methods to standardize the criteria. In the study of Cheng and Thompson, ArcGIS Pro was utilized in identifying temporary storage site locations for disaster waste management for bushfires in Victoria, Australia [12]. They established a set of criteria for identification with constraints based on multiple studies. The set of criteria requires to be modified based on the characteristics of the study sites and disasters, following the guidelines from UNEP/OCHA. To identify potential locations, they created a siting model using the ModelBuilder in ArcGIS Pro which was incorporated in this study. Furthermore, GIS is also used in the analysis of road networks which helps determine the serviceability of a facility. In the case where a facility is known but other location points are not identified, service maps may be generated.

Methodology

Study site

This study focused on disaster waste management in the Province of Cavite, particularly in Cavite City and municipalities of Noveleta and Kawit. Cavite Province is part of Region IV-A CALABARZON in Luzon and is located on the southern shores of Manila Bay and southwest of Manila. Due to its location relative to the National Capital Region (NCR), it is one of the most industrialized and fastest-growing provinces [13]. According to the 2020 census from the Philippine Statistics Authority (PSA), the province has a population of 4,344,829. It has seven (7) cities and 16 municipalities, and a total land area of 1427.06 km^2 [14].

Despite the high industrialization in the province, it still remains as an agricultural area. Farming, fishing, and mining are the primary industries in its local economy, sharing the production lands of the province [15]. With a stretch of about 122.574 km of shoreline, coastal resources contribute to the economic activities in the province. This production area accounts for 50.09% of the total land area of the province, while the built-up areas covering residential, commercial, industrial, and tourism zones account for 40.58% of the total land area [16].

The three selected areas of interest are among the zones with high flooding risk in the province. The Provincial Planning and Development Office stated that Cavite City, Noveleta and Kawit are in coastal plains, with some parts covered by coastal and alluvial plains. Figure 1 displays the boundaries of the selected sites. From the map, it can be seen that Cavite City is mostly bounded by coastline, while Noveleta and Kawit are bounded by the coastline in their northern areas. Based on the 2020 census of PSA, it can be observed that Noveleta has a relatively lower population (49,452) compared to Cavite City (100,674) and Kawit, (107,535). According to data from PhilAtlas, it can also be noticed that Cavite City has a high population despite having a relatively small area of 10.89 km^2 compared to that of Noveleta (16.43 km^2) and Kawit (25.15 km^2) [17].

Data gathering on disaster waste generation and management

Data on disaster waste generation and management of the selected study sites were obtained from the City/Municipal Environment and Natural Resources Offices (CENRO/MENRO). The collected data included the estimated volumes of disaster wastes generated that were available in the offices, documentation of disaster waste management, and locations of existing temporary storage locations for disaster wastes. The list of MRFs within the Province of Cavite, including their lot areas and conditions, was obtained from the Provincial Government-Environment and Natural Resources Office (PG-ENRO). Representatives from PG-ENRO were interviewed regarding disaster waste management guidelines in the province through a virtual meeting.

The maps and shapefiles that were used in this study were obtained from the sources shown in Table 1.

Establishment of criteria for identification of suitable TSS locations

The criteria were established based on the guidelines from UNEP/OCHA. It was divided into two categories—(a) proximity and position, and (b) size and condition. The former includes the buffer distances of the zones specified in Table 2, as well as suitable type of land use, while the latter covers the other necessary requirements for a TSS location.

Table 1 Obtained maps of the study sites

Data	Data type	Source
Topographic map	Raster, vector	Philippines' National Mapping and Resource Information Authority (NAMRIA)
Land cover	Vector	NAMRIA
Flood hazard map	Raster	PAGASA
Philippine main road network	Vector	WFPGeoNode
Philippines municipal boundaries	Vector	ArcGIS Living Atlas

Table 2 Established criteria for identification of suitable locations of temporary storage sites with assigned features

Criteria	Constraints	Features	Weight
A. Proximity and position			
C-A.1. Distance from rivers	≥ 100 m	River 1, River 2	2[a]
C-A.2. Distance from fishponds	≥ 200 m	Fishpen	1
C-A.3. Distance from coastline	≥ 200 m	Coastline	1
C-A.4. Distance from built-up area (residences, infrastructures, and businesses that could be affected by site operations)	≥ 100 m	Built-up, School	2[a]
C-A.5. Distance from roads	≤ 100 m	Road	1
C-A.6. Land use	Not located in floodplain or wetland and agriculture land	Land cover	1
B. Size and condition			
C-B.1. Land slope	≤ 8%	Slope	1
C-B.2. Distance from obstructions such as power lines and pipelines	No power lines and pipelines in the area	–	1
C-B.3. Size	Equation (1)	–	1
C-B.4. Ownership	Public land is prioritized	–	–
Total			11

[a]One point corresponds to each feature

The minimum allowable buffer distances were considered when setting constraints for items under proximity and position, considering that the study sites have large built-up areas and agricultural land. Currently, there is no existing set of guidelines on buffer distances from different zones for TSS for disaster waste management in the Philippines. Hence, the constraints set in this study were mainly based on international guidelines and past studies.

Calculation of required area

The required TSS area for each city/municipality, based on the collected data on amounts of disaster waste generated, were calculated to ensure that the TSS candidates to be selected are able to accommodate the disaster wastes, the required area for TSS is calculated using the Eq. (1) [4, 8],

$$TSS\ Area\left(m^2\right) = \frac{\frac{maximum\ amount\ of\ DW\ in\ TSS\ (t)}{apparent\ specific\ gravity\ \left(\frac{t}{m}^3\right)}}{height\ of\ DW\ pile\ (m)}(1 + working\ space\ area\ ratio), \tag{1}$$

under the assumptions that:

a. Collection of disaster waste is completed in some specific time frame;
b. Disaster wastes are carried into and out of TSS in parallel; and
c. Disaster wastes are carried from TSS to disposal sites or other treatment/recycling facilities since the TSS is opened.

Tajima [8] presented the acceptable values of variables for the estimation of total TSS area such as the apparent specific gravity which are 0.4 t/m^3 and 1.1 t/m^3 for combustibles and incombustibles, respectively. The maximum height for a disaster waste pile is 5 m and the working space area ratio is from 0.8 to 1. Increasing the working space area ratio and reducing the maximum allowable height of the waste pile would maximize the calculated required area, thus the values of 1 for the working space area ratio and 1 m for the height of the disaster waste pile were used in the calculations.

Distance from rivers, fishponds, and coastline

Temporary storage sites must be located at certain distances from surface waters to prevent secondary hazards from occurring in bodies of water. According to Cheng and Thompson, whose study area was the state of Victoria in Australia, the buffer zones for surface waters vary from case to case, with most past studies on landfill siting setting 500 m as a buffer distance from rivers [12]. Based on the Amended Guidelines on the Provision of Buffer Zone around Waste Processing and Waste Disposal Facilities, the minimum siting distance from rivers for identifying suitable land for sanitary landfill sites is 100 m, while a 200-m buffer zone is recommended for lakes, ponds, and other water bodies [18].

Since the areas of interest in this study are municipalities and a city that are relatively smaller than a state in terms of land area, and the locations being sited are for temporary storage sites and not a landfill, the minimum buffer zones were used—100 m for rivers, and 200 m for fishponds and coastline. Two separate shapefiles which are contiguous were available for rivers in the selected study sites and were labeled "River 1" and "River 2" for easier identification.

Distance from built-up areas

Similarly, TSS should be located away from built-up areas that include residential zones, schools, infrastructures, and buildings that could be affected by site operations. Since the study sites have large built-up areas occupying the total land area, especially Cavite City, the minimum value was considered. According to the Materials Recovery Facility (MRF) Tool Kit of the Asian Development Bank, a minimum buffer zone of 100 m is used for the areas mentioned above for MRFs [19], which also serve as TSS in the Philippines.

Upon checking the available shapefiles for the study sites, it was observed that there were school points that were located outside the built-up area. Hence, analysis for school points was performed separately.

Distance from roads

Accessibility is important to reduce the cost of transportation of disaster wastes to temporary storage sites. The study sites have a high density of housing and high accessibility to roads; hence the locations of temporary storage sites were set to be within 100 m from the road network based on the options mentioned by Cheng and Thompson [12], wherein 500 m was used as inclusion zone since their study site was located in a rural area with less road accessibility.

Land use

TSS should not be located in specific types of land uses that are productive and critical. UNEP/OCHA specifically mentioned that TSS must not be located in floodplains or wetlands and agricultural land. Basing on the available data on land use, only grassland and open/barren areas were considered as suitable options, while annual crop, brush/shrubs, built-up, fishpond, inland water, mangrove forest, and perennial crop were avoided. However, potential locations that were generated were still inspected via Google Earth to confirm that the selected sites were not productive or critical.

Since the land use/land cover map also contains fishpond and built-up areas, there was an overlap between the land use/land cover map and two other criteria—C.A-2 Distance from fishponds and C.A-4 Distance from built-up in the generated map. This was addressed by specifying the relaxed criterion/a or the criterion/a in which each selected site failed.

Slope

To reduce excavation costs and avoid problems of slope stability, MRFs should be located in relatively flat or gently sloping land [19]. The slope requirement was set to no more than 10% in the study of Cheng and Thompson [12]. However, in the slope map available in the study sites, slopes of land were classified as 0 to 8% (level to undulating), followed by 8 to 18% (undulating to rolling), and so on. In this study, the constraint for the criterion on the slope was set to 0 to 8%.

Identification of potential TSS locations

The suitable regions for locations of TSS candidates were first identified using ArcGIS Pro where criteria under proximity and position, and land slope were analyzed. Google Earth Pro was then used to locate specific sites based on the suitability map and analyze distance from obstructions and the size of the sites. Finally, the land ownership classification was determined through confirmations with City/Municipal Planning and Development Offices (CPDO/MPDO). To determine the final value (V) of each point, the summation of the value from each criterion layer was obtained as shown in Eq. (2).

$$V = \sum v_i, \qquad (2)$$

where $v_i = value\ of\ each\ criterion\ layer$

Identification of suitable regions using ArcGIS Pro

The Philippines Municipal Boundaries shapefile was first clipped into the areas of interest to be used as a guide in the analysis. This would ensure that only the selected sites were being analyzed. The ModelBuilder tool in ArcGIS Pro was used to analyze the criteria through the development of a TSS siting model shown in Fig. 2. The model was adopted from the flowchart created by Cheng and Thompson [12]. Sequences of geoprocessing tools were built and managed, where the output of one tool was fed as the input of another tool. The first geoprocessing tool used was the Euclidean Distance where buffer distances were the inputs for C-A.1 to C-A.5. After obtaining the buffer zones, the layers were standardized using Boolean Algebra with the assigned values—suitable (1) and unsuitable (0). The criteria maps were overlaid, and the sum of values was obtained. A land suitability map was then generated based on the results of the weighted sum.

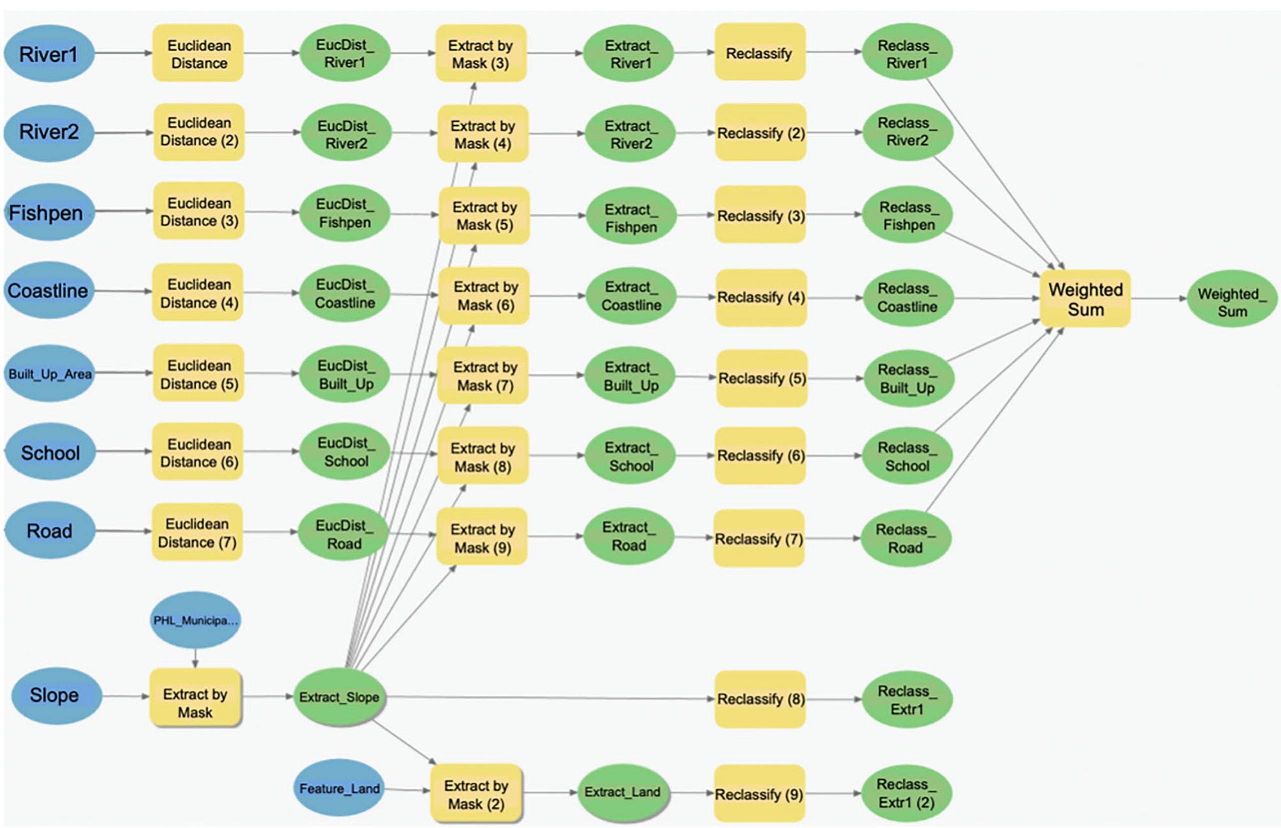

Fig. 2 Temporary storage siting model generated. ModelBuilder in ArcGIS Pro was used to create a series of procedures to generate results

Selection and evaluation of TSS candidates using Google Earth Pro

Based on the values in the map, the most suitable areas were examined using satellite imagery and street view. Potential TSS candidates were located considering that the study areas have large built-up areas, and the municipalities of Noveleta and Kawit have large agricultural lands. The presence of obstructions was also examined. TSS sizes were then estimated and compared with the calculated required total TSS areas. However, in general, since only Google Earth Pro was used to analyze C-B.2 and C-B.3, the obtained information could have differences from the actual sizes and conditions.

A summary table was created to show the information on the selected TSS candidates including the value, coordinates, area, absence of obstructions, land ownership, and failed criteria if there were any. The existing MRFs in the study sites serving as TSS were also evaluated using the same set of criteria.

Evaluation of MRF locations using Google Earth Pro

The generated suitability map was investigated in Google Earth Pro. The layer for locations of MRFs of Cavite City and Noveleta was overlaid on the suitability map to determine the number of points that correspond to their values. The reclassification maps were used to identify in which criterion/a the MRFs did fail. Then, using the satellite imagery and street view of Google Earth Pro, the presence of obstructions was inspected. The MRF sizes provided by PG-ENRO were then compared to the calculated required areas of TSS in the respective city/municipality.

Generation of service area maps using Network Analyst

Service area maps show the regions covering road networks that can be reached by one or more facilities at a given travel distance or time. The service areas of the selected TSS candidates were generated using Network Analyst under the following assumptions:

1. The road network considered in the study consisted of the Philippine main roads only.
2. Driving speeds of vehicles were assumed to be equal to the input speeds. The input speeds were defined as the following:
   a. The general speeds for specific roads provided in the shapefile from WFPGeoNode were used [20].
   b. For the roads with no given speeds, the speed limits according to road type as shown in Table 3 were assigned.

Table 3 Speed limits according to road classification

Road classification	Speed (kph)
Trunk	60[a]
Motorway	80
Primary	40
Secondary	40
Tertiary	30
Track	20
Service	20
Trunk_link	60
Primary_link	40
Motorway_link	20
Unclassified[b]	20

[a]from WFPGeoNode [20]

[b]unclassified roads were only assumed to have speed limits of 20 kph

3. Roads were assumed to be clear of barriers (e.g. flood, construction) during transport of disaster wastes to the TSS sites.

The study sites were clipped from the entire municipal boundary map as a guide to reduce the roads in the network into the ones that were only required. The road network was then clipped based on the study sites. All intersections were inspected, and it was ensured that the roads were cut at every junction to allow travel in all directions.

Based on the road classification of the Philippine Main Roads, speed limits were determined [20]. The speed limits were based on Joint Memorandum Circular (JMC) 2018-001 launched by the Department of Transportation (DOT), together with the Department of Interior and Local Government (DILG) and the Department of Public Works and Highways (DPWH) [21].

From the input speeds and given lengths of roads in the shapefile, the travel time in minutes for each road was calculated using Eq. (3).

$$T = \frac{d}{1000s}(60), \tag{3}$$

where $T = time$ (min), $d = length\ of\ the\ road$ (m), and $s = input\ speed$ (kph).

A network dataset was built from the fixed road network. Before performing the network analysis, the cost was set to time in minutes. Cost attributes in ArcGIS are "used to measure and model impedances" [22]. These include distance and travel time.

For the network analysis, the break was set to 15 min to generate service area polygons within 15-min driving times. In every run of the analysis, a TSS candidate was inputted as a facility. There were no barriers set as stated in the assumption. The service area for each TSS candidate was then generated.

Results and discussion

Disaster waste estimation and management

This section discusses the disaster waste management practices in the province, specifically in the study sites, as well as the estimated amounts of generated disaster waste. The data were obtained through online interviews and email correspondence with government agencies.

Based on an interview with a representative from Cavite Provincial Government-Environment and Natural Resources Office (PG-ENRO), the province has no definite guidelines on disaster waste management, that are separate from guidelines on solid waste management, that the cities/municipalities can follow. The study sites implement their own practices to handle wastes generated after typhoons and flooding.

Cavite City

According to Cavite City CENRO (personal communication, September 28, 2021), their available data on disaster waste estimation is the recorded average amount of disaster wastes in the year 2019 amounting to 20.22 tonnes. They stated that the disaster wastes generated in the city are temporarily stored in their MRF located at Barangay 48A, San Antonio, Cavite City.

In addition, it was shared that the city does not perform segregation of disaster wastes since they consider the disaster wastes as residual wastes. After holding the wastes, they are disposed of at the landfill. The landfill that serves Cavite City is the Rizal Provincial Sanitary Landfill operated by International Solid Waste Integrated Management Specialist, Inc. (ISWIMS) located in Rodriguez, Rizal [23]. Based on the estimation through satellite imagery, it would take more than two (2) hours to travel the shortest distance of 68.3 km from the city, specifically from the MRF, to the landfill. Since it could take that much amount of time, the temporary storage of disaster wastes is necessary to accommodate the volumes prior to transportation.

Municipality of Noveleta

The Noveleta MENRO (personal communication, August 19, 2021) provided the amounts of disaster waste generated by Typhoon Fabian in July 2021, as well as how these were managed, as summarized in Table 4. It can be observed that the disaster wastes are classified according to type, and are handled depending on their classification. From this documentation provided by Noveleta MENRO, the disaster wastes were not directly disposed of as their uses were maximized. The involvement of the residents in disaster waste management was also observed.

According to the Noveleta MENRO, flooding in their town is frequent due to the fact that the municipality of Noveleta is a catch basin of rainwater from the upland with two river systems—(1) Ylang-Ylang River that traverses from

Table 4 Summary of disaster waste generation and management of Noveleta after Typhoon Fabian

Type of waste	Description	Estimated weight (tonnes)	Management
Biodegradable	(a) Construction materials, bamboos, logs, branches of trees	> 30	Sold by the locals to those who had smoke fish (*tinapa*) business
	(b) Water hyacinth water lilies, fallen leaves, kitchen left over	–	Dried up
Non-biodegradable	(a) Plastic bottles of any kind, glass bottles, *sibak*, pvc, metals, electrical appliances	2	Collected by households and given to the garbage collectors; some are sold to the nearest junk shops for equivalent money
Residual		–	Collected regularly through *bayanihan* style clean-up activity with the help of volunteers from barangay, civil society organization, schedule department of the LGU, and other public organizations during friday, saturday or sunday in all barangays
Others: mud after flooding	Almost one foot in height	–	Dumped at vacant lots, and at materials recovery facility to dry

Tagaytay City-Silang-Dasmariñas City-Imus City-Kawit-Noveleta, and (2) Rio Grande River that traverses from Tagaytay City-Silang-Amadeo-Trece Martires City-General Trias City-Noveleta. Since the locations of the mouths of the rivers are located in the municipality, there is a great volume of water that accumulates in the area. Moreover, the occurrence of wave inundation from storm surges and southwest monsoons (*Habagat*), as well as high tides, destroys houses made of light materials that are situated along the coast.

On disaster response, Noveleta MENRO primarily performs the environmental impact assessment after a calamity. It cooperates with the municipality's Local Disaster Risk Reduction and Management Office (LDRRMO) for the evacuation of the residents, and the Office of the Mayor and the Municipal Engineering Office for the assessment and evaluation of the damaged houses, businesses, and infrastructures. Among the agencies involved in disaster response are the Municipal Social Welfare and Development Office (MSWDO), Philippine Coast Guard (PCG), Philippine National Police (PNP), Bureau of Fire Protection (BFP), and other civil society organizations (CSO) volunteers.

All the wastes hauled or collected during times of flooding are temporarily stored at the transfer station located at their municipal MRF which is situated at Poblacion, Noveleta. The final disposal site is at Navotas Sanitary Landfill operated by Phil. Ecology Systems Inc. located in Navotas in Metro Manila. It would take around two (2) hours to travel the shortest distance of 42.4 km from the Noveleta MRF to the said landfill.

Municipality of Kawit

For the municipality of Kawit, Kawit MENRO (personal communication, September 16, 2021) stated that they do not have any available data regarding disaster waste management. Disaster wastes hauled are mixed with household wastes. They only record the amount of daily collected wastes using garbage trucks, and not specifically the disaster wastes. The MRF of the municipality is located at Brgy. Aplaya, Binakayan, Kawit. The solid waste disposal site of Kawit is the Suri Waste Management Landfill operated by Suri Waste Management and Disposal Services in Calamba City, Laguna which is more than one (1) hour of travel from the municipality [15].

From the collected data on disaster waste management of the three study sites, it was observed that there are big differences in how each city and municipality recognizes the need to manage disaster wastes and in how they handle them. Another factor that might have led to the differences in DWM practices is the lack of national guidelines on how to properly manage disaster wastes. Generally, it was observed that there is a lack of attention and action with regard to disaster wastes, and the study sites do not have temporary storage sites specifically for disaster wastes. Moreover, disaster waste management in the city/municipality is also affected by the implementation of the city/municipal solid waste management, as the two are connected, and they could have similarities in handling procedures (e.g. segregation and storage).

Established criteria for identification of TSS

Calculation of required TSS area

To set the constraint for C-B.3. Size, the required total area for each study site was calculated using Eq. (1). A sample calculation is shown below. The calculated values are summarized in Table 5.

Required TSS area for Cavite City:

$$TSS\ Area\left(m^2\right) = \frac{20.22\ (t)}{\frac{0.4\ (t/m^3)}{1\ (m)}}(1+1) = 101.1m^2.$$

Table 5 shows that in the calculation of the required TSS area for Cavite City, it was assumed that the total wastes were combustibles since there were no specified amounts for different classifications of wastes. This was done to obtain a larger value of the required area since combustibles have

Table 5 Summary of calculation of required area of temporary storage sites

City/Municipality	Amount of DW in TSS (t)	Apparent specific gravity (t/m^3)	Height of DW pile (m)	Working space area ratio	TSS Area (m^2)	
Cavite City (2019)	20.22[a]	0.4[b]	1	1	**101.1**	
Noveleta (Typhoon Fabian, 2021)	30.00	0.4	1	1	150	**153.64**
	2.00	1.1	1	1	3.64	
Kawit[c]	–	–	–	–	–	–

The bold highlights the total calculated values using Eq. 1

[a]Average total wastes generated during typhoons/flooding

[b]Assuming that combustible make up the volume

[c]No available data on the estimated amount of generated disaster wastes due to typhoons/flooding

lower apparent specific gravity. Meanwhile, two amounts were considered for Noveleta to account for the different apparent specific gravities of different types of wastes: biodegradable for combustibles, and non-biodegradable for incombustibles. This was based on the descriptions of types of waste displayed in the table. For Kawit, since there was no available data on the amounts of generated disaster wastes, the TSS candidates selected in the municipality were exempted from C.B.3 Size.

In comparison with the rule from Tajima's presentation which requires TSS area to be more than 3000 m^2 to accommodate machineries, the calculated areas for the study sites were significantly smaller [8]. While the value presented by Tajima was based on the experiences in Japan, the Philippines does not have established guidelines on the required TSS size. Despite the big difference, the calculated areas were still considered due to existing local situations. Based on the list of Material Recovery Facilities provided by PG-ENRO, the sizes of MRFs in the province have large differences, varying from 68 to 47,000 m^2. The calculated required TSS areas are within the range but are relatively smaller compared to most of the existing MRFs. It is important to note that the input data on the amounts of disaster wastes generated depend on their availability in LGUs. Hence, these data do not equate to the maximum amount of disaster wastes generated as there could be deficiencies in documentation of the effects of typhoons and flooding. Moreover, the selected study sites have large built-up areas, being mostly occupied by residential, agricultural, and aquacultural zones which makes it unworkable to identify potential locations of size greater than 3000 m^2. Lastly, the presence of heavy machinery was not assumed to occupy spaces inside the TSS.

Assignment of features and reclassification values

The features were assigned to each criterion as shown in Table 2. There were multiple features placed under C-A.1 and C-A.4 since they were unable to be merged due to differences in geometry types. For C-A.4, upon looking at the shapefiles, it was observed that there were schools that were not included in the built-up areas, hence it was analyzed separately. In calculating the sum of the weights of the criteria, C-B.4 was not taken into account since the criterion is not strict to only public land ownership despite it being a priority.

Table 6 specifies the reclassification values for each criterion considered, and the suitable and unsuitable regions were defined. Since there were nine (9) layers, 9 out of 11 points from Table 2 were obtained in ArcGIS Pro.

Identified TSS candidates

This section presents the suitability map and identified locations of TSS candidates after performing analyses in ArcGIS Pro and Google Earth Pro.

Table 6 Reclassification values

Criteria	Constraints	Value	
		0	1
A. Proximity and position			
C-A.1. Distance from rivers	≥ 100 m	Within 100 m from rivers	Other areas
C-A.2. Distance from fishponds	≥ 200 m	Within 200 m from fishponds	Other areas
C-A.3. Distance from coastline	≥ 200 m	Within 200 m from coastline	Other areas
C-A.4. Distance from built-up area (residences, infrastructures, and businesses that could be affected by site operations)	≥ 100 m	Within 100 m from built up area	Other areas
C-A.5. Distance from road	≤ 100 m	Other areas	Within 100 m from road
C-A.6. Land use	Not located in floodplain or wetland and agriculture land	Annual crop, brush/shrubs, built-up, fishpond, inland water, mangrove forest, perennial crop	Grassland, open/barren
B. Size and condition			
C-B.1. Land slope	≤ 8%	Other values	≤ 8%
C-B.2. Distance from obstructions such as power lines and pipelines	No power lines and pipelines in the area	–	–
C-B.3. Size	Equation (1)	–	–
C-B.4. Ownership	Public land is prioritized	–	–

Fig. 3 Reclassification Maps (generated using ArcGIS Pro). The value of one (1) corresponds to areas that are suitable in terms of the criterion, while the value of zero (0) corresponds to areas that are unsuitable

Generated maps using ArcGIS Pro

Figure 3 displays the reclassification map of each criterion analyzed in ArcGIS Pro. The areas with a value of 1 are the suitable areas according to the constraints set while the value of 0 indicates unsuitable land. As seen in the figure, C-A.6 Land Use is the most sensitive criterion since most of the land is not suitable under it. Included in the sensitive criteria are C-A.2, C-A.4, and C-A.5.

Because of the location of the study sites relative to Manila Bay, it can be observed from the figure that the entire study area is largely bounded by coastline and that there are rivers within the study area connecting to Manila Bay. The geographic location of the province allows agriculture and fishing to become the leading industries in its local economy, hence the large areas for fishponds located near the coastline, and agricultural land making up the production area. This can also be observed in the reclassification map for land cover which is mostly made up of production and built-up zones.

Observing the reclassification map for the built-up area, it can be seen that comparing the suitable and unsuitable lands in each city/municipality, Cavite City has relatively larger unsuitable lands because of its urbanization and greater infrastructure. Meanwhile, since the study sites are located in coastal plains, the slope of the land is not much of an issue among the criteria.

Shown in Fig. 4 is the resulting suitability map after overlaying all the layers and getting the weighted sum. The higher the value of the area, the more suitable it is. As observed in the figure, only small portions of land reached the maximum value, or satisfied all the criteria, due to the sensitive criteria. Hence, for the selection of TSS candidates, relaxation of criteria was allowed to be able to identify candidates in each city/municipality.

Identified sites using Google Earth Pro

Overlaying the generated suitability map in Google Earth Pro, TSS candidates were located in areas with values of 7 to 9. The Street View was used to verify the reliability of the values obtained from ArcGIS Pro. Then, the sites were inspected using Google Earth Pro in terms of C-B.2 Distance from obstructions and C-B.3 Size. The final candidates are shown in the appendix table. The codes used to refer to each TSS are as follows: CC for Cavite City, N for Noveleta, and K for Kawit. The table also shows the land ownership classification of each TSS location.

It can be observed from the table that the criteria permitted to relax were the distance from built-up areas and the land use, also due to built-up zones in the land cover of the sites. Observing the selected TSS candidates, it is noticeable that the identified TSS in Cavite City are all open lots located in built-up areas, adjacent to residential and/or commercial structures. For Noveleta, the TSS candidates are also located near built-up areas, but the majority are in grasslands. Finally, for Kawit, vacant lots

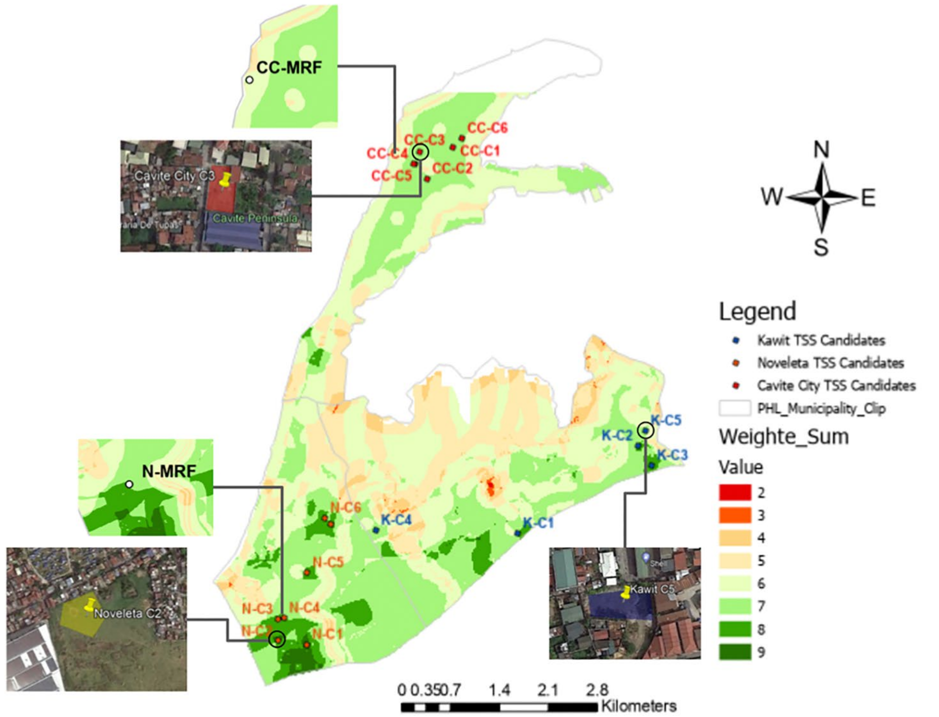

Fig. 4 Selected locations of temporary storage sites and existing MRFs on the generated suitability map. A total of 18 candidates for temporary storage locations were mapped in areas with higher values, as they correspond to a relatively more suitable location based on the established criteria. Seven (7), six (6), and five (5) locations were identified for Noveleta, Cavite City, and Kawit, respectively. The locations of existing MRFs in Cavite City and Noveleta are also shown

in built-up areas and grasslands were the typical location of selected TSS candidates.

The plot of the candidates on the suitability map is also shown in Fig. 4, along with the satellite images of some of the TSS candidates. Based on the suitability map, other areas may be considered in the selection and inspection of TSS candidates. A total of 18 TSS candidates were identified. Seven (7), six (6), and five (5) TSS candidates were selected for Noveleta, Cavite City, and Kawit, respectively.

Evaluation of existing MRFs

Figure 4 also displays the location of the MRFs of Cavite City and Noveleta over the suitability map.

From the analyses, it can be observed that CC-MRF failed the criteria on distances from built-up areas and coastline, and land use, while N-MRF failed in distance from built-up areas, land use, and size. Both comply with eight (8) out of 11 criteria points. It is important to note that upon locating the said MRFs, it was discovered that they were located within the proximity of cemeteries, which were included in the built-up areas as observed in the gathered shapefiles, and they were not necessarily very close to the residential areas. However, during the inspection of the areas using Street View in Google Earth Pro, it was observed that there were people residing in informal houses inside the cemetery, specifically in Cavite City. Still, it should be noted that this situation may not be exactly the same in actual conditions and current time.

Generated service maps

A sample service area map of a TSS candidate is displayed in Fig. 5. It can be observed that under the assumption that there are no barriers present, and that vehicles travel at speed limits, the service area of the facility within 15 min of driving reaches the adjacent cities/municipalities shown in green shading. It can be suggested that in the case where there is difficulty securing a TSS location for each city/municipality, a specific TSS candidate may serve multiple cities/municipalities.

It was observed that the TSS candidates in Noveleta, together with K-C2 in Kawit, have service areas also covering large parts of Cavite City and Kawit. Meanwhile, TSS candidates located in Cavite City cover large areas of the city and the municipality of Noveleta. For TSS candidates in Kawit, the service areas also reach Noveleta and the city to the south of Kawit which is Imus City. Generally, the selected TSS located in Noveleta has greater coverage when considering only the study sites.

Conclusions

This study recognized the gaps in disaster waste management in the Philippines, particularly in temporary storage which helps minimize the secondary hazards that could potentially develop and affect public health and the environment. This aimed to strengthen the response to the generation of disaster wastes by identifying suitable locations of

Fig. 5 15-min service area of CC-C2. The location of one of the selected temporary storage sites in Cavite City is represented by the circle and the areas it could serve by the shaded regions. Within 15 min, considering the assumptions, the site could serve portions of adjacent towns

temporary storage sites (TSS) using GIS in Cavite Province, particularly in Cavite City, Noveleta, and Kawit. This study adopted procedures from published guidelines and studies, but incorporated other applicable methods and local conditions, and extended its scope to the generation of service area maps for disaster waste transportation.

It was determined that distances from fishponds and built-up areas, and land use were the most sensitive criteria as large parts of the lands were not suitable under them. From the suitability map, a total of 18 TSS candidates were identified. Seven (7), six (6), and five (5) TSS candidates were selected for Noveleta, Cavite City, and Kawit, respectively.

The existing MRFs of Cavite City and Noveleta were also evaluated using the established criteria since their CENRO/MENRO stated that the MRFs also serve as their TSS for disaster wastes. The results showed that both the Cavite City and Noveleta MRFs comply with eight (8) out of 11 criteria points. Other potential sites in the suitable areas may also be selected as TSS based on the generated reclassified maps and suitability map.

The generated maps from this study may be of significance to the LGUs in terms of selecting land area potential to serve as TSS. The established criteria may also be used in different study sites that are prone to typhoons and flooding. Moreover, while this study focused on the mentioned hazards, the same procedure may be performed for other disasters by modifying the set of criteria and constraints appropriately, as well as the assumptions for the generation of service areas.

While this study paved the way to discover the current state of disaster waste management in the study sites, as well as it provided a TSS suitability map, it also has its limitations. This study was highly dependent on the available data from local government units and agencies, and the insufficiency of information on disaster waste management might have affected the results. In addition, the procedure in this study was mainly performed using different software, and minimal site investigation was performed. The lack of local disaster waste management guidelines also required this study to put together international references to establish a set of criteria for analysis.

Generally, this study can contribute to more efficient preparation to respond to disaster waste generation in terms of suitability and serviceability of temporary disaster waste storage sites, as well as in more detailed and orderly documentation of disaster events and their impacts.

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