GIS-based land suitability analysis for potential urban development sites in Diffun, Quirino, Philippines

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Abstract. As the world moves towards urbanization, the demand for land for urban land use increases. If left unmanaged, this might result in the wastage of land that could have been used for more productive purposes, such as agriculture. Other developments can also pose risks to the environment and to those who inhabit it. Therefore, land suitability analyses must be carried out before proceeding to urban planning. This study produced an urban suitability analysis of the municipality of Diffun in Quirino Province as a basis for future urban planning. Conducting this analysis will be very timely, considering that the revision of the municipality’s Comprehensive Land Use Plan (CLUP) will start in 2021. In this study, two methods of doing the analysis were integrated: Boolean overlay and weighted overlay. Using the gathered spatial data, a total of 18 factors and restrictions were produced for the analysis. Restriction layers used in the Boolean overlay method include existing built-up areas, erosion risk, flooding susceptibility, protected agricultural lands, other protected lands, Quirino Protected Landscape (QPL), slope, waterway buffers, and ecotourism site buffers. Meanwhile, the weighted overlay analysis used the following factors: elevation, land-use type, distance to ecotourism sites, distance to local roads, distance to national and provincial roads, proximity to the downtown, distance to protected agricultural lands, distance to waterways, and slope. The weights of the factors were calculated using a pairwise matrix. The study concluded that only 0.32% of the total land area of the municipality is most suitable for urban land-use, while 87.36% is considered not suitable for the development of built-up areas.

Keywords: land suitability analysis, weighted overlay, boolean overlay

1. Introduction
Throughout human history, the increase in population has brought about the development of built-up areas. With the Philippines having one of the highest population growth rates in ASEAN [1], urban areas in the country are expected to continue expanding. This expansion subjects agricultural land to urban pressures; such an example would be nearby provinces surrounding Metro Manila like Cavite [2]. If left unchecked, this might result in urban sprawl, eventually taking up too much prime agricultural land. Haphazard expansion can also mean that development may happen in areas that are unsuitable for built-up spaces. These areas may be vulnerable to different natural hazards that pose risks to those residing in them. Proper analysis for planning and enforcement must be done to avoid development that can negatively affect the environment and inhabitants of the areas.

Several studies have demonstrated the ability of GIS, and specifically the weighted overlay approach in being flexible enough in performing various kinds of spatial analyses. For example, the method of analyzing [3] as an improvement to the existing site evaluation
The technique used by the government, while [4] did an analysis of their study area for suitable areas for small farm reservoirs. Urban settlement analysis [5] and analysis for ecotourism [6] may seem vastly different at first, as one is more focused on developing built-up areas and the other is focused on preserving the natural environment. Nevertheless, the spatial factors that were used had a lot of similarities. These show that determining site suitability is mainly dependent on the relationship of the spaces adjacent to each other. The weighted overlay approach used by the studies was able to reflect the spatial relationships with the use of weights. Each study utilized various methods of determining the values. Riad [7] and Buncag, Santos, and Magpantay [8] gave weights based on previous literature, Şatir [9] assigned equal values to all factors. On the other hand, Kuru and Terzi [10] obtained the weights by surveying urban planners. Meanwhile, the others used the Analytic Hierarchy Process (AHP) in doing so [5, 6, 11]. Alongside the weighted overlay approach, Riad et al. [7] also integrated the Boolean overlay method into their study. The Boolean overlay method was used as an alternative way of determining suitable sites for artificial groundwater recharge.

Studies done in the Philippines that explore different methods on land suitability analyses for urban development seem to be limited, and most are focused on agriculture or siting facilities. [4, 8, 11] With the continued increase in population, the development of areas is sure to follow. Urbanization, as a phenomenon, inevitably needs to be managed through appropriate analysis and proper planning.

Diffun is a municipality located in the landlocked Province of Quirino, adjacent to the municipality of Cordon and Santiago City in Isabela Province. As it is nearer to the Pan-Philippine Highway, Diffun serves as the gateway to the province. The municipality prides itself as Quirino’s largest producer of rice and corn—with around 70% of the total households of the municipality depending on agriculture as a source of livelihood. [12] Despite being heavily reliant on agriculture, it also serves as the province’s center for trade and other economic activities. [13] Given its strengths in these areas, the municipality envisions itself to becoming a “prime agro-ecotourism center” in the province of Quirino.

According to the Local Government of Diffun [12], the municipality is experiencing positive economic spillover effects from its neighboring city, Santiago. As a result, population growth could surge as people migrate into the municipality. As established in the previous paragraphs, the development of built-up areas is brought about by population growth. Expansion of built-up areas without doing proper land suitability analyses can impede the municipality’s progress in achieving its long-term vision. Using GIS, the suitability of areas for urbanization within the municipality could be determined, which can then help in urban planning for the years to come.

1.1. Study area

Diffun (Figure 1) is a municipality located in the Province of Quirino in Region II (Cagayan Valley Region). It is located along the northeast edge of the province, bordering Cordon and Santiago City. Other municipalities within the Province of Quirino adjacent to Diffun are the Municipalities of Sagay day and Cabarroguis. Diffun is the second most urbanized municipality in Quirino, with its neighboring town, Cabarroguis, coming in first. [13] The downtown (locally known as población) of the municipality comprises four small administrative divisions, otherwise known as barangays: Andres Bonifacio, Rizal, Aurora West, and Aurora East.
2. Materials and methods

2.1. Spatial data

The spatial data used in the analysis were collected from Community Forestry Foundation-Quirino, Incorporated (CFFQI), a foundation under the government’s jurisdiction. A digital elevation model (DEM) was obtained from the United States Geological Survey (USGS). Below (Table 1) is a summary of all spatial data gathered before preprocessing.

| No. | Data                                      | File Format | Scale | Source       |
|-----|-------------------------------------------|-------------|-------|--------------|
| 1   | Digital Elevation Model (DEM)             | Raster (TIFF) | 30m   | USGS         |
| 2   | Waterways                                 | Shapefile (Line) | -     | CFFQI        |
| 3   | Ecotourism sites                          | Raster (JPG)  | -     | CFFQI        |
| 4   | Erosion hazard                            | Shapefile (Polygon) | -     | CFFQI        |
| 5   | Flood susceptibility                      | Shapefile (Polygon) | -     | CFFQI        |
| 6   | Land-use 2015                             | Shapefile (Polygon) | -     | CFFQI        |
| 7   | Local Roads                               | Shapefile (Line)  | -     | CFFQI        |
| 8   | National and Provincial Roads             | Shapefile (Line)  | -     | CFFQI        |
| 9   | Protection Agriculture                    | Shapefile (Polygon) | -     | CFFQI        |
| 10  | Quirino Protected Landscape (QPL)         | Raster (JPG)  | -     | CFFQI        |

2.2. Methods

The study utilized GIS methods, namely Boolean overlay and weighted overlay, in determining urban land suitability. To make the spatial data gathered useful, these were preprocessed and then processed into different thematic maps. ArcMap 10.2.2 with the Spatial Analyst extension was used in the preprocessing of spatial data and in performing the analyses. For the weighted overlay method, a pairwise matrix was created using Microsoft Excel was used to calculate the weights needed. To make the final suitability maps, the outputs of both methods, Boolean and weighted overlay, were combined through the
Raster Calculator tool. Figure 2 shows the steps that were undertaken to determine urban land suitability in Diffun.

2.3. Boolean overlay

The Boolean overlay method is a type of suitability analysis that uses Boolean algebra. Boolean algebra is a branch of algebra that uses only the truth values, true or false, represented as 1 and 0, respectively. In this study, the Boolean overlay method was used to create a restriction map, which determines areas barred from being developed for urban purposes. Thematic maps that represent restrictions to urban development were derived from Philippine laws, related literature, and environmental hazards that are present in the municipality [12, 14-20].

Using the tools in ArcMap’s Spatial Analyst toolbox, the raster thematic maps were reclassified into having two classes, with either a value of 1 or 0, depending on different conditions (Table 2). A value of 0 means an area is unsuitable for urban development, while 1 allows development.

The Boolean overlay operation was then done using the Raster Calculator. In place of the Boolean AND operation, overlaying was done by multiplying the restriction layers using the Raster Calculator.

| No. | Restriction Layer | Value |
|-----|------------------|-------|
| 1   | Agricultural protection | Not considered as protected agricultural areas | Protected agricultural lands |
| 2   | Built-up areas | No existing built-up spaces | Existing built-up areas |
| 3   | Erosion risk | Minor risk of erosion | Prone to severe erosion |
| 4   | Ecotourism sites | Outside the vicinity of ecotourism sites | Ecotourism sites and areas within a 1 km buffer around these sites |
| 5   | Flood risk | Less risk of flooding | Highly susceptible to flood |
| 6   | Protected land | Alienable and disposable (A&D) land | Forest land |
| 7   | Quirino Protected Landscape (QPL) | Areas outside the QPL | Areas within the QPL |
| 8   | Slope | <18% slope | >18% slope |
| 9   | Waterways | Areas outside waterways | Water networks and areas within a 100-meter ecological buffer |
2.4. Weighted overlay

A common and straightforward approach to weighted overlay is by doing weighted linear combination (WLC), also called weighted linear summation. [21, 9] It involves the standardization of criteria scores and the weighing of factors. Factors used for the weighted overlay analysis were determined by comparing the factors used in other studies and the availability of data. [5, 6, 9, 22-25] The data in each factor must be standardized to a specified range or scale because it will not make sense to calculate using different measurement scales. [21] In this study, scores of 1-10 were used to standardize the input values, with higher scores representing “high suitability.” For instance, areas near waterways and are within the riparian buffer are unsuitable for development and thus are assigned a value of 1. Scoring was based on other literature and observations of the site. The reclassify tool was used to assign new cell values to the input data. The following conditions were considered to determine if an area is most suitable for development: proximity to ecotourism sites, road networks, protected agricultural land, the downtown and water systems, slope, elevation, and existing land use. In the layer maps, darker shades represent higher values or high suitability. Figure 3 below shows the reclassified factor maps for weighted overlay analysis.

![Factor maps used in the weighted overlay method](image)

**Figure 3** Factor maps used in the weighted overlay method

For the calculation of weights, the initial plan was to gather inputs from government officials, urban planners, and locals through questionnaires and field interviews. However, due to the COVID-19 and lockdowns imposed in the country during the time this study was undertaken, it was difficult to establish proper communication with the stakeholders. Thus, the study relied on the study area's existing conditions, the municipality's vision, and related literature [5, 6, 11-13].

Derived from the Analytic Hierarchy Process (AHP) [21], using a pairwise comparison matrix is a popular method in multi-criteria decision making (MCDM). [5] Therefore, it is used to determine the relative importance of the nine factors. In this study, Saaty's comparison scale [26] was used for pairwise matrices. As seen in Table 3, priority was given to the preservation of ecotourism sites and prime agricultural land as a reflection of the municipality’s vision. Preservation of these areas is essential in the determination of
potential urban development sites. This resulted in both being the top two factors with the highest level of importance with 24.72% and 29.52%, respectively.

To produce the weighted overlay output, the factors and their corresponding weights were then inputted into ArcMap’s weighted overlay tool.

### Table 3 The pairwise matrix used in calculating the weight of each factor

| Factors (F)                              | Factor j | Weights (%) |
|------------------------------------------|----------|-------------|
| Ecotourism Sites (F1)                    | 1 5 5 9 5 9 1/3 3 7 | 24.72%     |
| Elevation (F2)                           | 1/5 1 1 3 2 3 1/3 1/5 3 | 7.65%     |
| Land Use (F3)                            | 1/5 1 1 3 1/3 1 1/3 1/9 1/2 | 4.57%     |
| Local Roads (F4)                         | 1/9 1/3 1/3 1/3 1/2 1/9 1/9 1/3 | 1.99%     |
| National Roads (F5)                      | 1/5 1/2 3 3 1 1/3 1 3 | 6.44%     |
| Downtown (F6)                            | 1/9 1/3 1 2 1 1/9 1/3 1 | 3.72%     |
| Protected Agricultural Land (F7)         | 3 3 3 9 5 9 1 4 5 | 29.52%     |
| Slope (F8)                               | 1/3 5 9 9 3 3 1/4 1 3 | 16.96%     |
| Waterways (F9)                           | 1/7 1/3 2 3 1/3 1 1/5 1/3 1 | 4.42%     |

### 3. Results and discussion

#### 3.1. Restriction map (Boolean overlay output)

The Boolean overlay method was able to produce a restriction map (Figure 4a), defining areas that are unsuitable or prohibited from being developed. According to the output, around 87% (≈26,345.89 ha) of the municipality’s land area is restricted for development, leaving only 13% (≈3,936.74 ha) available for possible expansion. The bulk of the restricted areas come from protected areas as around 65% of Diffun is considered as forest land. These are the mountainous areas on the western side of the municipality. Adding other factors such as flood risk, ecotourism site buffers, erosion risk, existing built-up areas, prime agricultural land, slope, and waterways further decreased the area available for development.

Most of the areas available for development are on the eastern side of the municipality, located near the downtown barangays. These areas have a slope of not more than 18%, which also makes them suitable for paddy fields. Hence, most of the available areas for development seen in the restriction map are adjacent to prime agricultural lands.

#### 3.2. Weighted overlay output

Distinct levels of suitability from least suitable to the most suitable areas were determined using the weighted overlay approach, unlike in Boolean overlay, where the suitability values are binary. In this study, the suitability scale of 1-10 was further simplified and categorized into five (5) classes: least suitable, not very suitable, moderately suitable, highly suitable, and most suitable. Areas with a final score of 9 to 10 are the most suitable areas for urban development, while areas with the values 1 to 2 are deemed least suitable.

According to the weighted overlay map (Figure 4b), only 8.09% (≈2,449.86 ha) of the municipality is deemed most suitable. These areas are mostly located in the western barangays of Pimentel and Magsaysay. Large portions of the municipality are highly and moderately suitable for urban development, making up 46.07% (≈13,951.21 ha) and 33.09% (≈10,020.52 ha) of the total land area respectively. Not very suitable areas take up 12.31% (≈3,727.79 ha) and are located near the downtown (Aurora West, Aurora East, Rizal, and Andres Bonifacio) where the suitability scores are generally low. Lastly, the least suitable
areas only take up 0.44% (≈133.24 ha) of the municipality’s total land area.

![Figure 4 Maps produced using Boolean and weighted overlay output](image)

**Figure 4** Maps produced using Boolean and weighted overlay output

### 3.3. Comparison of the restriction map and the weighted overlay output

As seen in Figure 5, there are significant differences between the restriction map and the weighted overlay output. According to the weighted overlay output, many of the most suitable areas are on the western side of Diffun. However, according to the restriction map, most of these areas are unavailable for development. The reason is that most of the sites are located in or are adjacent to protected areas such as forest land. Meanwhile, barangays surrounding the downtown received low suitability scores in the weighted overlay output despite being available for development in the restriction map. The low suitability rating can be attributed to the sites’ proximity to prime agricultural areas. Notwithstanding the differences, Figure 5 also shows that there are areas that satisfy the urban suitability criteria of both methods.

![Figure 5 Comparison map](image)
3.4. Urban suitability map

The final suitability map for the municipality of Diffun was created by combining the output maps of the Boolean overlay and weighted overlay analyses. The maps were consolidated into one with the use of the Raster Calculator tool in ArcMap. The final suitability map (Figure 6) shows the levels of suitability in different areas of the municipality with the added layer of development restrictions. It can be seen in the output map that areas near the urban core have medium suitability scores. Because of the added restriction map, the percentage of area covered by suitable areas were greatly diminished (Table 4). Areas that are considered most suitable now only consists of around 0.32% of the total land area of Diffun (=96.90 ha) from the previously calculated 8.09% (=2,449.86 ha) in the weighted overlay output. The area covered by highly suitable areas also decreased, now only making up 5.84% (=1,768.51 ha). As seen in Table 5, Barangay Magsaysay has the largest area in the municipality that is most suitable for urban development. However, the area covered by these suitable sites is small relative to the size of the entire municipality.

![Final urban suitability map](image_url)

**Figure 6** Final urban suitability map

| Suitability Level       | Approx. Area (ha) | Percent Area |
|------------------------|-------------------|--------------|
| Most Suitable          | 96.90             | 0.32%        |
| Highly Suitable        | 1,768.51          | 5.84%        |
| Moderately Suitable    | 1,907.82          | 6.30%        |
| Not Very Suitable      | 54.51             | 0.18%        |
| Least Suitable         | -                 | 0.00%        |
| Unsuitable             | 26,454.95         | 87.36%       |

Table 4 Percent area covered by each suitability level in the urban suitability map
Table 5 Barangays with the most suitable areas for urban development

| Barangay     | Approx. Size of Most Suitable Area (ha) | % Area Relative to Diffun |
|--------------|----------------------------------------|---------------------------|
| Magsaysay    | 47.9274                                | 0.1583%                   |
| Pimentel     | 18.1347                                | 0.0599%                   |
| Rafael Palma | 12.5833                                | 0.0416%                   |
| Isidro Paredes | 3.7935                               | 0.0125%                   |
| San Isidro   | 3.5159                                 | 0.0116%                   |
| San Pascual  | 2.6832                                 | 0.0089%                   |
| Villa Pascua | 2.2206                                 | 0.0073%                   |
| Gulac        | 1.2028                                 | 0.0040%                   |
| Bannawag     | 1.1103                                 | 0.0037%                   |
| Ricarte Sur  | 0.7402                                 | 0.0024%                   |
| Dumanisi     | 0.7402                                 | 0.0024%                   |
| Diego Silang | 0.6477                                 | 0.0021%                   |
| Maria Clara  | 0.4626                                 | 0.0015%                   |
| San Antonio  | 0.1850                                 | 0.0006%                   |
| Luttuad      | 0.1850                                 | 0.0006%                   |

4. Conclusion

As the population increases, the development of built-up areas is expected to follow. Diffun, being situated near important economic centers of the region, is foreseen to receive an influx of people from other places which can spur development. With proper planning, the adverse effects of urbanization can be mitigated. Conducting land suitability analyses is a part of the overall planning process. Without it, land use plans and policies may be more detrimental to the development of an area, hence, unsustainable.

Having used both Boolean and weighted overlay methods in the study, integrating the weighted overlay method into the former could provide more information about the suitability level of each area. The Boolean overlay method could only determine whether the land is suitable through binary values, 1 (true) or 0 (false). In contrast, in weighted overlay, an area can be more suitable than the other according to a specified numeric scale. Moreover, weighted overlay treats the factors with varying levels of importance, which is the same as in real-life decision-making processes. A total of 18 factors and restrictions were identified and used in the study in determining urban land-use suitability. After performing the analysis, it was found out that only 0.32% of the total land area of the municipality is most suitable for urban land-use, while 87.36% is considered not suitable for the development of built-up areas. The researcher recognizes that the study alone should not be the sole basis in planning as the dynamics of development is much more complex. The study can still, nonetheless, be a guide in carrying out future studies or analyses.

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