GEOGRAPHIC INFORMATION SYSTEMS

GEOGRAPHIC INFORMATION SYSTEMS MODULE explains the different techniques of spatial analysis in relation to CORE approaches and demonstrates the use of GIS in land use, land cover analysis and vulnerability assessment.

TRAINING MODULE FOR LOCAL PLANNERS

CLIMATE CHANGE COMMISSION

The Climate Change Commission, an independent and autonomous body that has the same status as that of a national government agency, is under the Office of the President of the Philippines. It is the lead policy-making body of the government which is tasked to coordinate, monitor, and evaluate programs and action plans of the government relating to climate change pursuant to the provisions of the Republic Act No. 9729 or the Climate Change Act as amended by Republic Act No. 10174 or the People's Survival Fund.

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The Global Green Growth Institute (GGGI) is a new international organization committed to strong, inclusive green growth. GGGI assists developing and emerging countries with integrating their ambitions for strong economic performance and environmental sustainability with the goal of bringing about poverty reduction, job creation, social inclusion, and climate change mitigation and adaptation. Headquartered in Seoul, GGGI was established by treaty in June 2012 at the United Nations Rio+20 Conference by an initial group of eighteen nations who share the organization's vision. To date, there are a total of 24 Member Countries who joined the organization. GGGI has a diverse portfolio of programs in developing countries around the world. These in-country programs, together with global products and services, focus on delivering results through an integrated approach of evidence based green growth planning and implementation aligned to countries' development priorities. The organization also focuses on knowledge development and management activities which build a strong theoretical and empirical basis for green growth, while providing concrete options and guidance for policymakers; as well as building the conditions for public and private green infrastructure investments.

PREFACE

The Philippines is highly vulnerable to the impacts of climate change. As witnessed through the devastation from typhoons Yolanda (2013), Glenda (2014), and Lando (2015), millions of Filipinos were affected and communities incurred costly damages and forced to rebuild. In anticipation of stronger typhoons hitting the country, climate change adaptation and mitigation is vital to the development and preparedness of Local Government Units (LGUs) and the people they serve.

The methodologies and tools offered in this publication are intended to raise national awareness and competence among national and local government institutions, civil society, private sector, and communities. This publication provides information outlining mechanisms on how to develop capacities of decision makers, local planners and trainers in integrating science-based assessments into policies, plans, and programs to make communities adaptive and resilient to climate risks.

This module is one of the many references that the users may utilize in developing their respective development plans.

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Disclaimer

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List of Acronyms

AHP	Analytical Hierarchy Process
B+WISER	Biodiversity and Watershed Improved for Stronger Economy and Ecosystem Resilience
CAD	Computer Aided Design
CLUP	Comprehensive Land Use Plan
CNCM3	Météo-France / Centre National de Recherches Météorologiques
CPDO	City Planning and Development Office
DEM	Digital Elevation Model
DENR	Department of Environment and Natural Resources
EDC	Energy Development Corporation
FAO	Food and Agriculture Organization
FMB	Forest Management Bureau
GIS	Geographic Information System
GCM	Global Climate Model
GPS	Global Positioning System
IPCC	Intergovernmental Panel on Climate Change
LCC	Land Capability Classification
LCE	Local Chief Executives
LCCS	Land Capability Classification Systems
LDRRMP	Local Disaster Risk Reduction and Management Plans
LGU	Local Government Unit
NAMRIA	National Mapping and Resource Information Authority
NDRRMP	National Disaster Risk Reduction and Management Plans
MPDO	Municipal Planning and Development Office
PHILVOCS	Philippine Institute of Volcanology and Seismology
POI	Point of Interest
PPDO	Provincial Planning and Development Office
PRECIS	Providing Regional Climates for Impacts Studies
RLPS	Rationalized Local Planning System
SEP	Soil Erosion Potential
SEI	Soil Erosion Index
USGS	United States Geological Survey
USLE	Universal Soil Loss Equation

Definition of Terms

Adaptive capacity – a determinant of vulnerability that refers to the general ability of institutions, systems, and individuals to adjust to potential harms such as climate change. It is largely influenced by the system's access to financial, institutional, and technological resources. It also refers to the potential for adjustments, processes (both natural and human), practices, or structures to moderate or offset the potential for damage, or take advantage of opportunities, created by variations or changes in the climate.

Exposure – a determinant of vulnerability referring to the extent of the ecosystem or human settlements as well as the types and value of assets that are at risk or most likely to be affected by climate change and its attendant hazards.

Hazard – a potentially damaging event or physical disturbance, which can be categorized as natural (*i.e.,* soil erosion, landslides, flood, drought) and man-made (*i.e.*, deforestation/biodiversity loss, forest fire, water pollution).

Geographic Information Systems – a computer system for entering, storing, naming, retrieving, transforming, analyzing, and displaying spatial data.

Geospatial technology – a technology that integrates remote sensing and global navigation systems.

Geomatics – a scientific approach to the fundamental issues raised by the use of GIS and related technologies.

Sensitivity – a determinant of vulnerability referring to the degree to which a system will respond to a change in climatic conditions. The sensitivity of an ecosystem or human settlements varies according to the type of hazards brought by climate change. It also depends on the state of quality and location of ecosystems and human settlements. In particular, the level of social and economic status of human communities, including their demographic features, determines their level of sensitivity.

Risk – the possibility or likelihood of danger, disaster, harm, or loss.

Standardized Precipitation Index – a tool developed primarily for defining and monitoring drought.

Vulnerability – the degree to which a system is susceptible or unable to cope with adverse effects of natural or man-made (anthropogenic) hazards.

Vulnerability Assessment – a profile discussing the relationship between natural and anthropogenic hazards and recipient subject (watershed).

I. Introduction

1.1. Overview of the Module for Local Planners

To help build the country's climate resilience and promote green growth, the Communities for Resilience (CORE) Capacity Development Project targets state universities and colleges (SUC) near the 18 major river basins in the country. Similar to the demonstration of the Ecotown Framework in 2014, the trainings aim to reduce the vulnerability of communities and ecosystems to climate change impacts and promote adaptation measures by building their capacities through a scientific approach.

In order to achieve these goals, appropriate data should be gathered and organized to determine the size of the locality, and the adaptation and mitigation activities that must be performed. This is done by utilizing Global Information Systems (GIS) that facilitate assessment and map generation of a given locality. Without this capability, a comprehensive risk and vulnerability assessment, land use zoning, and change modeling are impossible to identify.

This GIS module addresses the GIS users' domain focusing on local government unit (LGU) planners. Important aspects of GIS will be explained relevant to the CORE Initiative.

1.2. Objectives of the Module

By the end of the module, the local planners will be able to:

- Apply GIS in mapping their communities, specifically vulnerable areas;
- Explain the different techniques of spatial analysis in relation to CORE approaches;
- Demonstrate the use of GIS in land use and land cover change analysis, and vulnerability assessment; and
- Determine a method of land capability classification and zoning.

1.3. Brief Description

The GIS Module for Local Planners covers all the topics relevant to the CORE Initiative, as this module's target users will be responsible in mainstreaming the CORE approaches in building resilient communities and preparing for disasters. Local planners will learn data structure and spatial analysis, the role of GIS in hazards and disaster risk-reduction, how it is applied in land use decision-making and local governance, and how to analyze change and transition analyses.

1.4. Relevance of the Module for LGU Planners

Section 2 of Republic Act No. 10121, or the "Philippine Disaster Risk Reduction and Management Act of 2010" underlines the development, promotion and implementation of a National Disaster Risk Reduction and Management Plan that aims to "strengthen the capacity of the government and the local government units, together with the partner stakeholders, to build the disaster resilience of communities, and to institutionalize arrangements and measures for reducing disaster risks, including projected climate risks, and enhancing disaster preparedness and response capabilities at all levels." To ensure a multi-stakeholder participation, GIS-based maps should be used as policy, planning, and decision-making tools. Therefore, community-based action plays a great role in identifying, assessing, and managing the hazards that may occur in their localities. Therefore, knowledge of local planners in utilizing GIS is a command of the Act.

1.5. Summary of Topics

The Module for Local Planners covers almost all the topics relevant to the CORE Framework. The actual training focuses on the application of GIS and generation of maps, which they can use in their localities.

Data structure and spatial analysis

This section provides a brief discussion on the transformation of paper maps to digital themes with the advent of computers. A comparison is given between analytical cartography and spatial analysis. Discussions on common coordinate systems, datums and projections, data structures, and spatial analysis is explored.

GIS, Hazards and Disasters

This part describes a GIS-based mapping and assessment to determine the area's vulnerability to climate hazards. The assessment is undertaken by determining inherently sensitive areas brought by topography and its exposure. Vulnerability or hazard maps will be prepared to show which areas in a municipality are highly susceptible to the adverse impacts of changing climate.

Of the many different types of hazards related to climate change, 1) flood, 2) drought, and 3) landslides are selected for assessment in the CORE initiative. In addition, this section intends to present different steps in hazard mapping and assessment related to the determination of exposed elements, analysis of population exposed to hazards, and the spatial extent to hazards.

GIS for Land Use Decision Making

One of the objectives of this module is to describe the land capability classification and zoning, which can be used by LGUs in prescribing appropriate management prescriptions and activities. These become necessary when addressing continuously varying quantitative spatial properties, an issue typical to land use planning. The advantage of homogenous land units resulting from land classification procedure allows the land to be allocated in a rational manner. The allocation of land units depends on the capability as well as suitability to a specific land use. Land use zones are delineated based on land capability. Thus, the output zonation and the indicative land uses are intended to provide a scientific basis for allocating the lands in the municipalities for various uses.

GIS for Local Governance

Local government units are probably the most effective players in mainstreaming the CORE Initiative. LGUs are at the frontline owing to their presence in various activities and developments in the area. In addition, LGUs are the operative entities that can sustain efforts at protecting and restoring forests and natural resources. Compared to other government agencies with similar concerns, LGUs have the 'home advantage.' Thus, having a GIS unit to handle the spatial databank of the organization is desirable. It is important to emphasize that GIS is a tool for better decision-making.

This section describes a community-based GIS, and poverty mapping techniques in developing updated baseline information that can be used as basis for a systematic and organized rehabilitation and development of a certain locality.

Land Change Modelling

This part presents the different time window of land covers that are of interest in the change analysis conducted in the previous Ecotown projects. These are valuable take-off point in mapping and visualizing existing land covers, as well as transition from other categories. Determining the land use and land cover change provide the basis for formulating corresponding restoration or reforestation interventions in the communities in particular, and the ecosystem in general.

As such, this section shares a menu of viable land change modelling techniques, which participants can consider and use in mapping their localities.

II. Module Content

2.1. What is GIS all about?

1. Data Structure and Spatial Analysis

a. Georeferencing

Georeferencing is the process of aligning geographic data to a known coordinate system so it can be viewed, queried, and analyzed with other geographic data. The term is synonymous to geocoding or geo-locating. In transforming an analog map (or paper map), georeferencing also refers to map registration. Thus, data that have no location is termed non-spatial, non-locational or spatial.

Some commonly used georeferencing systems are: place name, postal address, postal code, linear referencing system, cadastral system, public land survey system, latitude/ longitude, universal transverse Mercator, and state plane coordinates. A place name is the simplest form of georeferencing and most likely developed by the early hunter-gatherers.

Using distinctive features of the landscape (*i.e.*, old tree, presence of a spring or waterfall, bridge crossing), a traveler can find his/her way towards a destination.

For a villager in remote areas, the concept of location is different from a person schooled in surveying. Directions are given using landmarks like a river crossing or a foot bridge and seldom in terms of the cardinal directions North, East, West or South. In some instances, landmarks have historical attachments and stories that only local residents are familiar. Even distance for a local resident is different – a certain distance is measured by the number of river crossings and hills traversed in order to reach the destination.

b. *Data and information*

Data may be defined as a body of facts or figures gathered systematically. In their raw form, data are mere numbers representing measurements from field surveys and inventories. However, it needs to be transformed in some way to be useful for decision-making and this transformation has to happen under a controlled situation. At the same time, feedback is necessary to ensure that the desired set of information is established.

c. *Data input*

Data come from two general sources: primary and secondary. Primary data usually refer to those that have been gathered by an on-going activity or project. These data may be results of field measurements (including sketches) from resource inventories and surveys, or from interviews (*i.e.,* focused group discussions, workshops, and meetings). Secondary data already exist in some form and only need to be collected, organized, and encoded into a text editor, spreadsheet, or database following some pre-determined format. Examples of secondary data are reports (monthly accomplishments, quarterly, semi-annual, annual) and compilations, watershed profiles, statistical reports, books and journals, satellite image/photograph, and analog maps.

Data input may be done from satellite imageries, existing maps, tabular data, field survey data, and data from other digital databases.

The process of data input consists of encoding the spatial (*i.e.,* digitizing) and non-spatial data (*i.e.,* digital encoding) and consequently linking these together. Basic encoding can be performed by the following:

- Digitizing of features from analog maps;
- Encoding of coordinates GPS readings either automatically or manually. Most GPS units enable easy downloading of waypoints to the computer.
- Automatic line following. GIS/ Computer aided design (CAD) software can be set to automatically digitize line features just by following the cursor (*i.e.*, stream-mode).
- Some GIS and CAD softwares contain functions that automatically digitize contours from elevation maps.
- Digital image processing of satellite images.

Data acquisition methods may be done through field surveys, digitizing of existing maps and aerial photographs, vectorization of remote sensing images, and existing digital databases.

Field survey methods include conventional position fixing systems like triangulation, traverse surveys and levelling techniques; and satellite-based positioning systems (*i.e.,* GPS). Image processing requires radiometric and geometric corrections, image enhancement and classification.

Data output from GIS can come in varied forms apart from the usual printed maps. These can be on-screen displays, graphs, tabular reports, and data files (as jpg image, database file or in map format). More importantly, data output should be presented in the most understandable manner and form to end-users.

d. Data quality

Data quality can be categorized into: positional accuracy, attribute accuracy, logical consistency, completeness and lineage.

Positional accuracy is commonly defined by the user depending on the level of detail that is required by the GIS project. Points derived from GPS measurements depends on the instrument (or quality of the GPS receiver), method of position acquisition, and the quality of the signal. In terms of map sources, positional accuracy is directly related to map accuracy.

Attribute accuracy likewise depends on the instrument used and the survey method. On the other hand, logical consistency has to do with logical organization of the data, while completeness points to the sufficiency of the results derived from the GIS analysis. In other words, depending on the objective of the GIS project, the results of the GIS analysis will reveal gaps in data collected.

e. Basic representations of spatial data

Earth features are encoded into GIS with three fundamental representations: points, lines, and area (or polygons). A point is described by its XY coordinate. In GIS, points, lines or arcs, and areas or polygons are structured such that relationships are established among them. Geometry tells where objects are located, while topology tells how objects are related. In other words, spatial relationships are established indicating adjacency (*i.e.,* A is adjacent to D), connectivity (*i.e.,* 1 connects with 2), and containment (*i.e.,* E is outside the boundary of the area of study. More importantly, with topology, the file size of the GIS theme is considerably reduced.

f. *GIS data model*

GIS uses two kinds of data: spatial (or locational) and non-spatial (*i.e*., non-locational or aspatial) data.

Spatial is described by:

- Where is it?
- Points/Lines/Polygons
- X,Y coordinates
- Latitude/Longitude
- Postcode

Non – spatial is described by:

- What is it?
- How much is it? (Quantities)
- What is its condition/status?(Qualities)

The vector data model shows features as points, lines, or areas (also polygons) based on their XY coordinates. Thus, a soil sampling pit would be represented by a point represented as a single coordinate pair; a river by a line which is represented by a string of coordinate pairs; and vegetation by an area represented by a string of coordinate pairs whose endpoints converge. These features are considered to be spatial data- which means that they all have a specific location on earth.

The raster approach, on the other hand, has a simple data structure which makes spatial analysis more straightforward. The area of study is subdivided into a mesh of cells (or pixels – picture elements) or grids of pre-determined size. Each cell is assigned a numeric value which may represent a feature identifier, a qualitative, or a quantitative attribute (Eastman, 1997). Normally, only one attribute per raster unit (*i.e.,* square or rectangle) is possible for every layer. And if the raster unit is too large, smaller features are missed and thus remain unmapped. Thus, the quality of the analysis depends on grid size or raster resolution. Rasterization is the conversion of a vector GIS theme into raster format.

g. *Spatial analysis*

The easiest way to understand cell-based modelling is from the perspective of an individual cell (the worm's-eye approach) as opposed to the entire raster (the bird's-eye approach). To do so, think of yourself as a cell in a raster dataset. You represent a location, and you have a value.
There are six categories of spatial analytical techniques in GIS: 1) topological overlay, 2) proximity analysis, 3) feature extraction, 4) feature merging, 5) join and 6) relate. The last two refer to relational database operations. Topological overlay combines GIS themes in a pairwise manner to form new themes with a new set of attributes and a resultant GIS theme. In vector data model, there are three situations that arise when conducting overlay analysis: point in polygon, line on polygon, and polygon on polygon.

Boolean algebra is a useful topological overlay operation that can be implemented in both vector and raster environments. This operation uses Boolean logic and may be applied to all data types: binary, nominal, ordinal, interval, and ratio. It uses the logical operators AND, OR, NOT, and XOR.

Proximity analysis can be visualized by creating a new polygon with a specified distance around a point, line, or area. In raster analysis, the technique is called buffering. The buffer distance need not necessarily be a fixed distance as these distances can be specified in an attribute table.

After executing the buffer operation, overlaps are intersected and dissolved to generate a single polygon. Line buffering is executed at right angles to each line segment comprising the line feature. Similarly, overlaps are intersected and dissolved to generate a single polygon. In buffering a polygon, the same operation is done as line buffering. The resulting polygon is usually outside the original polygon creating an envelopment. It is also possible to invoke the operation to generate a buffer zone from both sides of the polygon perimeter as in line buffering. Applications of buffering include buffer zones for protected areas; lakes and rivers (*i.e.,* 20 m on both sides to be slated for protection purposes); noise pollution; waste disposal sites; right of way among others.

h. *Spatial Interpolation*

Spatial interpolation seeks to generate a complete picture of the area of study by estimating the values of unsampled areas from sampling points. The basic premise in interpolation (including extrapolation) is that points that are closer together in space are more likely to have similar properties than those farther apart (Burrough, 1986). The quality of the result of spatial interpolation is dependent on the mathematical function, degree of certainty on the sampling points, and quality of the output or product.

There are two main groupings of interpolation techniques: deterministic and geostatistical. Deterministic interpolation techniques create surfaces from measured points, based on either the extent of similarity (inverse distance weighted) or the degree of smoothing (radial basis functions). Geostatistical interpolation techniques (kriging) utilize the statistical properties of the measured points. Geostatistical techniques quantify the spatial autocorrelation among measured points and account for the spatial configuration of the sample points around the prediction location.

Deterministic interpolation techniques can be divided into two groups: global and local. Global techniques calculate predictions using the entire dataset. Local techniques calculate predictions from the measured points within neighborhoods, which are smaller spatial areas within the larger study area. Geostatistical Analyst provides global polynomial as a global interpolator while inverse distance weighted, local polynomial, radial basis functions, kernel smoothing, and diffusion kernel as local interpolators.

A deterministic interpolation can either force the resulting surface to pass through the data values or not. An interpolation technique that predicts a value that is identical to the measured value at a sampled location is known as an exact interpolator. An inexact interpolator predicts a value that is different from the measured value. The latter can be used to avoid sharp peaks or troughs in the output surface. Inverse distance weighted and radial basis functions are exact interpolators, while global polynomial, local polynomial, kernel interpolation with barriers, and diffusion interpolation with barriers are inexact.

2.2. Importance of GIS in the CORE Framework

GIS is designed as a generic system for handling any kind of spatial data. This technology can be used for scientific investigations, resources management, environmental monitoring and modelling, habitat assessment, vulnerability assessment, decision support systems, development planning, urban planning, and mapping among others.

Similarly, GIS provides techniques of investigation and knowledge of the watershed characteristic values, and to generate land use zone based on topography, land use and precipitation factors. It can apply in land-use planning to classify a whole watershed area, which is heterogeneous in nature, into different homogeneous groups through the land capability classification technique. It can also be used to develop a model for land-use optimization in the watershed, investigate the effects of slope information on soil erosion estimates, and identify areas at risk of visual degradation.

For instance, GIS might allow planners to easily calculate emergency response times in the event of a natural disaster, or be used to find areas that need protection and rehabilitation.

In particular, GIS technology is often used in climate change vulnerability and impact assessment. GIS-assisted integration with climatic and biophysical information in other communities (i.e., barangay, municipality, and region) is possible. Mapping can be done through the use of computer with GIS. Hence, training on use of GIS is necessary.

2.3. Application of GIS

1. GIS, Hazards and Disasters

Hazard assessments can be conducted based on different factors and their relative weights. Vulnerability maps to climate hazards for a climate scenario based on future with time periods of 2020 (base year 2006-2035) and 2050 (base year 2036-2065) can be developed following the processes as illustrated below (Figure 1).

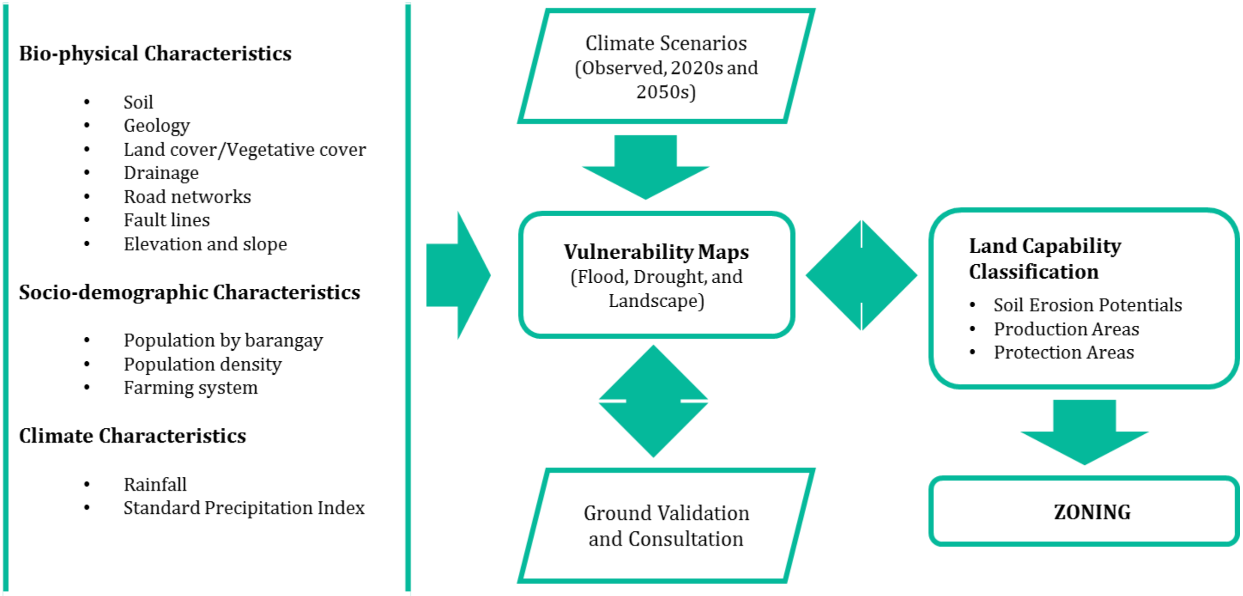

Figure 1 Vulnerability assessment structure for flood, drought and rain-induced landslide (CFSHD, 2015; USAID-DENR, 2015)

a. *Concept of ranking and ratings*

Ranking and rating is a technique that provides a mathematical method to analyze and construct a map from overlays or data from other related maps. Each parameter is given a rating, which represents the relative weight of these parameters. The ranking assessment method can be incorporated into GIS-based, multi-criteria decision analysis. There are several ways to deal with the uncertainty about the relative weight of rankings. Assigning ranking to parameters by direct *i.e.,* arbitrary means is likely to induce subjectivity in their rankings, which must be removed in order to eliminate bias in assigning rankings.

Assignment of weights for each susceptibility factor is done using the analytic hierarchy process (AHP) method or the statistical/heuristics approach (Saaty, 1980; Saaty and Vargas, 2001), a theory of measurement for dealing with quantifiable and intangible criteria that has been applied to various problems, including decision theory, conflict resolution (Vargas, 1990), and land use decision-making (Bantayan and Bishop, 1998). It is a multi-objective, multi-criteria decision-making approach that enables the generation of a scale of preference drawn from a set of alternatives.

Using this method, each layer or factor is compared with other layers based on their importance. For comparison of importance of factors relative to each other, each factor is rated against every other factor by assigning a relative dominant value between 1 and 9, with 1 being of equal importance and 9 of extreme importance. The complete table of Saaty Rating Scale is outlined in Table 1.

Table 1. The Saaty Rating Scale (Saaty, 2008)

Intensity of Importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective
3	Somewhat more important	Experience and judgment slightly favour one over the other
5	Much more important	Experience and judgment strongly favour one over the other
7	Very much more important	Experience and judgment very strongly favour one over the other. Its importance is demonstrated in practice.
9	Absolutely more important	The evidence favouring one over the other is of the highest possible validity.
2,4,6,8	Intermediate values	When compromise is needed

Pairwise comparison files can be made in spreadsheet or Microsoft access format. The first line contains the number of factors being compared, then each factor name follows, one per line, in the order they appear in the matrix. The lower left portion of the pairwise comparison matrix is then entered, with one or more spaces separating each cell entry on a line. Fractions or decimals may be entered (*i.e.,* entering 1/2 is the same as entering 0.5).

Details of various parameters and weights are presented in Figure 2. The weights assigned to reflect importance of each parameter are shown together with the rating for individual classes (***5*** being the highest and ***1*** the lowest drought influence). The severity of an area depends on the cumulative effects of individual classes. The identification of risk areas requires the factors considered to be combined in accordance with their relative importance. This can be achieved by developing a rating scheme in which the factors and their classes are assigned numerical values. A rating scheme may be developed based on the associated parameters triggering drought, field observations, previous experience, and knowledge of the localities.

A typical pairwise comparison of factors

	SPI	Elevation	River/ Spring	Soil	Vegetation	Populatio n Density
SPI	1					
Elevation		2				
River/Spring			3			
Soil				4		
Vegetation					5	
Population Density						6
Total						

Standardized ratings

	SPI	Elevation	River/ Spring	Soil	Vegetation	Population Density	Average
SPI							
Elevation							
River/Spring							
Soil							
Vegetation							
Population Density							
Total	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Figure 2. A pairwise comparison matrix

b. Hazards assessment

A GIS-based mapping and assessment can be conducted to determine the area's vulnerability to climate hazards. The assessment can be undertaken by determining inherently sensitive areas due to topography and its exposure. Vulnerability or hazard maps are prepared to show which areas in the watershed or even municipality require immediate attention to minimize the adverse impacts of changing climate. Projected hazard maps may be simulated using overlay analyses associated with different variables based on the observed and projected climate scenarios. Of the many different types of hazards related to climate change, 1) flood, 2) drought, and 3) landslides are selected for assessment in the CORE Initiative. The selection is founded on the understanding that the projected climatic changes in the area involve significant variations in the amount, and seasonal pattern of rainfall. With shorter/ drier dry seasons and longer/ wetter wet seasons expected to become more prevalent, more frequent flood and drought events are expected to affect the activities of local communities.

The determinants of vulnerability are sensitivity, exposure, and adaptive capacity.

$$\boldsymbol{Vulnerability = Sensitivity + Exposure + Adaptive\ Capacity}$$

i. Rain-induced landslide

Landslide is essentially described as the downward movement of a relatively dry mass of earth and rock. It is a process where soil particles are detached, transported, and deposited from one place to another. It is usually triggered by excessive rainfall or the occurrence of an earthquake strong enough to cause instability in the underlying rock layer. The rain-induced landslide hazard maps are assessed and generated based on physical conditions, vegetated factors, and climate change influences given the Global Climate Model (GCM) and scenarios.

The vulnerability to landslide is a function of different physical factors, and the different thematic maps (slope, soil, geology [geo-hazard], land cover, and climate). Essentially, each factor is assigned a relative weight according to its influence in landslide occurrence. Each factor, with the specific hazard values, can be prepared and analyzed for simulation. All physical factors follow the same scaling factor procedures. Degrees within each factor is given relative weights (from low to high) depending on the degree by which these could influence landslide susceptibility (Table 2). The different susceptibility factors are described below:

Elevation: It is normally associated with the change in relief. The DEM will serve as the main data source for extracting topographic factors. From the Digital Elevation Model (DEM) elevation and slope gradient can be derived. To keep the data manageable, elevation breaks are assigned as low (<200 m elevation), moderate (200 to 800 m), and high (>800 m).

Slope: The steeper the slope is, the higher the risk for landslides to occur. Slope gradients canl be broken down into low (<8% slope), moderate (8-50%), and high (>50%).

Rainfall: Amount of total monthly rainfall can be broken down into low (<100 mm rainfall), moderate (200 – 300 mm), and high (>500 mm).

Geology and rock type: The kind of underlying geological materials can have direct impacts on the propensity for mass movements to occur. Categories based on age, rock type, and induration can be devised resulting into three grades: low for Upper Miocene to Pliocene igneous rocks, moderate for Upper Miocene to Pliocene sedimentary rocks, and high for exclusively Plio-Pleistocene rocks.

Land cover: Different types of land uses have different effects on the susceptibility for slopes to fail. Generally, the less forest cover present, the higher the chances for landslides to happen. The wider the area affected by anthropogenic disturbances, the more likely for landslides to occur. This association is linked to the changes in hydrological regimes such as infiltration, runoff, and water-holding capacity of the ground. As a substitute to land use information, the type of land cover can be used as proxy. Forest, grassland, and developed areas can be assigned as having low, moderate, and high impacts on landslide susceptibility.

Distance from geologic structures: The presence of fractures and lineaments, more so of active fault lines, decreases the overall engineering strength of underlying rocks through mechanical action along these planes of weaknesses. For this data, proximity to the structures dictates the level of importance to landslide susceptibility evaluation. Zones closest to the structure (<8000 m) are ranked with the highest susceptibility to failure; between 500-8000m is moderate, and >500, low.

Road networks: Project developments in the form of slope changes or road cuts have significantly destabilized these areas. As such, a separate layer for the road cuts have been introduced in the susceptibility modelling to account for this factor. Buffer classes can be assigned as high (<150 m), moderate (150 to 1000 m), and low (>100m).

Table 2. Summary of the classified ranges for the different layers/ factors considered in the landslide susceptibility modelling

Layer/ Factor	Classes/Ranges	Relative weights
SENSITIVITY		
Elevation (ranges in m asl)	<200	1
	200 – 400	2
	400 – 600	3
	600 – 800	4
	>800	5
Slope (% ranges)	<8	1
	8 – 18	2
	18 - 30	3
	30 - 50	4
	>50	5
Rainfall (buffer ranges in mm)	<100	1
	100 – 200	2
	200 – 300	3
	300 – 500	4
	>500 mm	5
Soil Morphology (categories)	Tropaquepts w/ Entropepts; Udorthents & Tropepts	1
	Tropopsamments w/ Troporthents; Eutrandepts w/ Eutropepts	2
	Tropudalfs w/ Tropepts	3
	Entropepts w/ Dystropepts	4
	Tropudults w/ Tropudalfs; Mountain soils w/ Entisols, Inecptisols, Ultisols and Alfisols	5
Land cover (categories)	Closed forest; Mangrove forest	1
	Open forest; Plantation	2
	Shrubs; Natural grassland	3
	Agricultural/Cultivated; Pasture land	4
	Built-up; Bare	5
Fault lines (proximity range, in meters)	<500	5
	500 - 2000	4
	2000 - 5000	3
	5000 - 8000	2
	>8000	1
Road Network (buffer ranges in meters)	<150	5
	150 - 300	4
	300 - 500	3
	500 - 1000	2
	>1000	1
EXPOSURE		
Annual forest loss (ha/yr)	Loss >10	5
	Loss 5 - 10	4
	Loss 1 - 5	3
	Gain 0 - 5	2
	Gain >5	1
	>50	5

Extent of cultivated areas within the forestlands (in %)	40 - 50	4
	30 - 40	3
	20 - 30	2
	<20	1
ADAPTIVE CAPACITY		
Extent of soil conservation practices in upland areas	Available	1
	Partially available	3
	Not available	5
Reforestation efforts (in %)	>30	1
	20 - 30	2
	10 - 20	3
	<10	4
	None	5

The vulnerability can be described in three (3) categories: low, moderate, and high. Areas that are assessed prone to geologic hazards have high exposure to impact of extreme climate variability. This can primarily be associated with the fluctuating pattern and trend of monthly rainfalls.

<u>ii. Flood</u>

Flood is commonly defined as an overflow of water onto normally dry land. It is also described as the inundation of a normally dry area caused by rising water in existing river networks and waterways. In flood assessment, scenarios can be generated given physical factors, vegetative conditions, and rainfall amounts based on the GCM with a scenario during the 2020s and 2050s periods.

The susceptibility flood hazard map can be generated based on different factors and its relative weights. The flood modelling is based on the overlay of contributing factors namely slope, land cover/land use, soils, elevation, sub-watershed shape, and stream buffer. Each factor is classified into five (5) categories ranging from very low to very high classes (Table 3). The different factors are described below:

<u>*Elevation*</u>: Elevation can be generated from the DEM. Higher elevations are considered to be resistant to flooding and these are classified to have normal susceptibility, while lower elevations are regarded as areas with very high susceptibility to flooding.

<u>*Slope*</u>*:* The slope of different sites can be generated using a DEM with a resolution of 30 m. A slope of >30% is considered to have very normal susceptibility and a slope range of 0-3% as highly susceptible to flood.

<u>*Soils*</u>*:* The different soil textural classes, more commonly known as the soil series, mainly describe the soil factors. These textural classes range from clay to sandy types. Water-holding capacity of soils at field capacity and wilting point of different soil textures are

considered in the classification. Hence, clay types are deemed to be highly susceptible and sandy types as having normal susceptibility to flood.

Land Cover: The land cover data can be used for this factor. Water bodies and open areas are classified as highly susceptible to flood because these can generate high surface runoff, while forested areas are considered to have low susceptibility to flooding.

Watershed Shape: Shape of different sub-watersheds with the watershed can be interpolated from the DEM. Almost elongated watershed is classified to be less susceptible, while a watershed with nearly circular in shape is highly susceptible to flood.

Stream Buffer: Streams can be generated from the 30 m DEM and then buffers can be interpolated. Distance within 30 m from the stream is classified to be highly susceptible to flood, while buffers with >1000 m distance from the stream is regarded to have very normal susceptibility.

Table 3. Summary of the classified ranges for the different factors considered in the flood susceptibility

Layer/ Factor	Classes/Ranges	Relative weights
SENSITIVITY		
Elevation (ranges in m asl)	>150	1
	80 - 150	2
	40 - 80	3
	20 - 40	4
	<20	5
Slope (% ranges)	>30	1
	18 - 30	2
	8 - 18	3
	3 - 8	4
	0 - 3	5
Soil textural class	Fine sand	1
	Sandy loam; Fine sandy loam	2
	Loam; Sandy clay loam; Sandy clay; Silty clay; Silty loam	3
	Silty clay loam; Clay loam;	4
	Clay	5
Land cover (categories)	Closed forest	1
	Open forest; Plantation	2
	Shrubs; Natural grassland	3
	Agricultural/Cultivated; Pasture land; Built-up	4
	Bare; Water bodies; Inland water; Mangrove forest; Marsh land	5
Rainfall (Annual, mm)	<1500	1
	1500 - 2000	2
	2000 - 2500	3
	2500 - 3000	4
	>3000	5

EXPOSURE		
Proximity to streams and rivers (buffer ranges in m)	<100	5
	100 – 200	4
	200 – 300	3
	300 – 500	2
	>500	1
Watershed shape (ratio; description)	<0.25 (almost elongated)	1
	0.25 – 0.40	2
	0.40 – 0.60	3
	0.60 – 0.80	4
	>0.80 (almost circular)	5
Frequency of flooding	None	1
	Once	2
	2x	3
	3x	4
	>4x	5
ADAPTIVE CAPACITY		
Updated maps of flood-prone areas	Fully updated	1
	Partially updated	3
	Not updated	5
Availability of annual historical flood data	Available	1
	Partially available	3
	Not available	5
Access to flood forecasting information	Accessible	1
	Partially accessible	3
	Not accessible	5
Warning system and evacuation routes	Warning system operational and evacuation routes identified	1
	Warning system operational and evacuation routes partially identified	2
	Warning system not fully operational	3
	Warning system not operational	4
	None	5

Based on the overlay analyses of these factors, different flood vulnerability models can be generated. Assigned or standard colors represent specific categories and translate into susceptibilities. In short, it is the possibility of floods covered by each colored representation. However, vulnerability flooding, at any rate cannot be equated with floodwaters. In particular, the blue color suggests that the areas covered are highly vulnerable to flooding at any given event. Although it can be categorized in one single category, this does not mean that the entire town will be flooded all at the same time at any given event, but rather depending on the magnitude of rainfall and influence of associated factors. In any given tropical storms and extreme rainfall events, some parts will be highly affected, others moderately affected, and some low at all.

iii. Drought

Drought is described as the unavailability of water due to extreme weather conditions such as long periods of abnormally low rainfall.

It is also a condition of moisture deficit sufficient to have an effect on vegetation, animals, and man over a sizeable area. Basically, a drought-related hazard is an event in which a significant reduction of water brings about severe economic, social, and environmental hardships to the population.

Vulnerability to drought is the relationship of susceptibility to physical factors, exposure to climatic factors, and adaptability to anthropogenic factors. Basically, each factor can be assigned a relative weight according to its influence. Each factor, with the specific hazard values can be prepared and analyzed for simulation. All factors follow the same scaling factor procedures to assess and map out vulnerable areas. Overall, drought hazard maps for observed, 2020s, and 2050s periods may be produced based on different factors and its relative weights (Table 4). Different factors are described below:

Standardized Precipitation Index: The Standardized Precipitation Index (SPI) is a tool developed primarily to define and monitor drought. It determines the rarity of a drought at a given time scale of interest for the given station. It can also be used to determine periods of anomalously wet events. It must be noted that the SPI is not a drought prediction tool. Mathematically, the SPI is based on the cumulative probability of a given rainfall event occurring in the station.

Elevation: The elevation can be generated using the digital elevation model. Higher elevations are classified as resistant to drought and have low susceptibility, while low elevations are regarded as areas with severe susceptibility to drought.

Soils: The different soil textural classes, more commonly known as the soil series, describe the soil factors. These textural classes rangd from fine sand to clay types. Water retention of several soil textures is already reported in literature (Plaster, 2003). Hence, fine sand types are deemed to be highly susceptible and silty loam types are classified to have low susceptibility to drought.

Irrigation Canal and River: Streams and canals assessment are based on available datasets and then buffers can be interpolated. Distance less than 250 meters from the stream and canal is classified as not susceptible to drought, while buffers with >5000 meters distance from the stream is regarded to have high susceptibility.

Population Density: Population density can be estimated based on population and area per barangay. Barangays with more than 500 person/ha are classified to be severely susceptible to drought, while barangays with less than 10 person/ha are assigned to have low susceptibility.

Land Cover: The influence of water bodies is considered normal. Open and built up areas are classified as severely susceptible to drought because these can generate high soil and surface evaporation losses.

Table 4 . Summary of classified ranges for the different factors considered in the drought susceptibility

Layer/ Factor	Classes/Ranges	Relative weights
SENSITIVITY		
Annual Rainfall	>2000	1
	1600 – 2000	2
	1200 – 1600	3
	800 – 1200	4
	<800	5
Number of dry months (Alternate indicator)	1	1
	2	2
	3	3
	4	4
	>4	5
Number of dry days (dry spell/drought) (Alternate indicator**)**	<3 days	1
	4 – 6	2
	7 – 9	3
	10 - 12	4
	>12 days	5
Proximity within the existing irrigation canals and rivers (buffer ranges in m)	0-250	1
	250-500	2
	500-1000	3
	2000-3000	4
	>3000	5
Types of rivers and streams	None	5
	Ephemeral	4
	Intermittent	3
	Semi-perennial	2
	Perennial	1
Number of hot days (max temperature with >35 ºC	<1 day	1
	1 – 7	2
	8 – 14	3
	15 – 21	4
	>21 days	5
EXPOSURE		
Population Density (person/ha) by barangays	<10	1
	10 -50	2
	50 - 100	3
	100 - 500	4
	>500	5
Extent of production areas/SAFDZs over total land areas (%)	<10	1
	10 -20	2
	20 - 30	3
	30 - 40	4
	>40	5

ADAPTIVE CAPACITY		
Availability of small – scale irrigation program	Available	1
	Partially available	3
	Not available	5
Water impounding or rain harvesting facilities	Available	1
	Partially available	3
	Not available	5
Maps of drought prone areas	Available	1
	Partially available	3
	Not available	5
Access to drought forecasting information and early warning system	Available	1
	Partially available	3
	Not available	5

Climate-related droughts given three different periods can be generated and labeled as high (yellow), moderate (gray), and low (green). The attribute table can be then generated to determine a barangay's exposure to drought. The spatial assessment indicates the total number of barangays that are highly vulnerable to drought.

c. *Validation on the ground*

Ground validation or ground-truthing is one of the components of the simulation and modelling. The product of simulation based on physical, demographic, vegetative, and climate data can be validated on a given site. Basically, stakeholders within the areas (*i.e.,* various municipalities) who are familiar with the physical conditions are considered key informants. Each informant will be asked of his/her observation on the degree of hazard susceptibility for each barangay. Normally, highly susceptible barangays are considered to have previous experiences of landslides, droughts, or floods.

2. GIS for Land Use Decision Making

a. *Defining the landscape*

A landscape may mean many things to a person depending on tradition and perhaps more validly, disciplinary bias. To a person schooled in landscape architecture and design, a landscape consists of people, softscapes, and hardscapes. Softscapes referring to the biological component – the people, plants, and animals that hold the landscape as their home and source of food. Hardscapes, referring to the built environment – the pavements, light posts, and other man-made structures built of metal cement, wood, and other materials. To an engineer, a landscape or a site is something that you build on, be it a skyscraper, a pavilion, or as grand as holiday resort or as simple as a sitting bench (Bantayan *et al.*, 2000; Bantayan *et al.,* 2015).

b. *Land evaluation*

Land evaluation is a process whereby the potential of land for a particular use is estimated. It may be categorized as qualitative, quantitative, or economic evaluation. A qualitative evaluation is limited by its description of the landscape where land for alternative uses are expressed in terms of highly suitable, moderately suitable, or not suitable. Mabbutt (1968) discusses two types of qualitative evaluation: the generic and landscape approaches. The generic approach uses so-called natural regions based on climate, particularly precipitation. The landscape approach, on the other hand, is based on the analysis of the visible features of the area.

c. *Land classification*

Land classification becomes necessary when addressing continuously varying quantitative spatial properties, an issue typical to land use plannings. Because data are usually closely related, it is easier to simplify these without sacrificing the results. An important first step in classification is to have a good working knowledge of the characteristics of the data set. This is to avoid classes that do not exhibit similar characteristics. According to Burrough (1989), a good classification system is one which takes up as much of the variation in the data set as possible. In addition to the homogeneity of the resulting class intervals, arbitrary decisions should be minimal in the designation of land classes.

The advantage of homogenous land units resulting from a land classification procedure allows the land to be allocated in rational manner. The allocation of land units depends on the capability as well as suitability to a specific land use – which is a classification on land capability and land suitability.

d. *Land capability classification*

Land capability refers to the inherent capacity of land to support, on a sustained basis, a particular use or a set of uses. One may look at land capability as the carrying capacity of the land in terms of the uses that may be allowed in an area without leading to the degradation of the land and the resources found therein. In effect, land capability sets the limit to which a particular use of the land can be carried out safely beyond which the sustainability of the land and other resources suffer serious jeopardy. It is generally determined by the biophysical attributes of the area.

The concept of land capability has been widely used in land use planning as a tool for ascertaining the uses that are most suited to an area without resulting to land resources degradation. Land capability evaluation, defined as the subdivision of large tracts of land into capability classes each consisting of biophysically homogenous areas with distinct ability to accommodate a set of uses (*i.e.,* forest protection, forest production, agroforestry, agriculture, residential, commercial and industrial) on a sustainable basis, can be used in identifying the best development options for the project area. Specifically, the result of land capability classification is used to define the different land use zones in the municipality or project site in particular, and in the watershed in general.

e. *Method of land capability classification*

Land capability evaluation process looks at the characteristics of each factor and how it affects the land's capability to sustain the forest ecosystem. This process can be applied as a product of land capability classification, which is undertaken using the potential soil erosion of an area as basis.

Figure 3 shows the structure derived from the erosion-based land capability classification system (LCCS) developed by Warren *et al*. (1989) in the United States and applied by Cruz (1990) in Ibulao Watershed, by De Asis (1998) in UP Land Grant, Quezon-Laguna, by EDC (2012) in five (5) geothermal project sites, Department of Environment and Naural Resources (DENR)-Region 4 (2013) in San Juan River Watershed, and DENR- United States Agency for International Development (USAID) (2015) in four (4) B+WISER program sites.

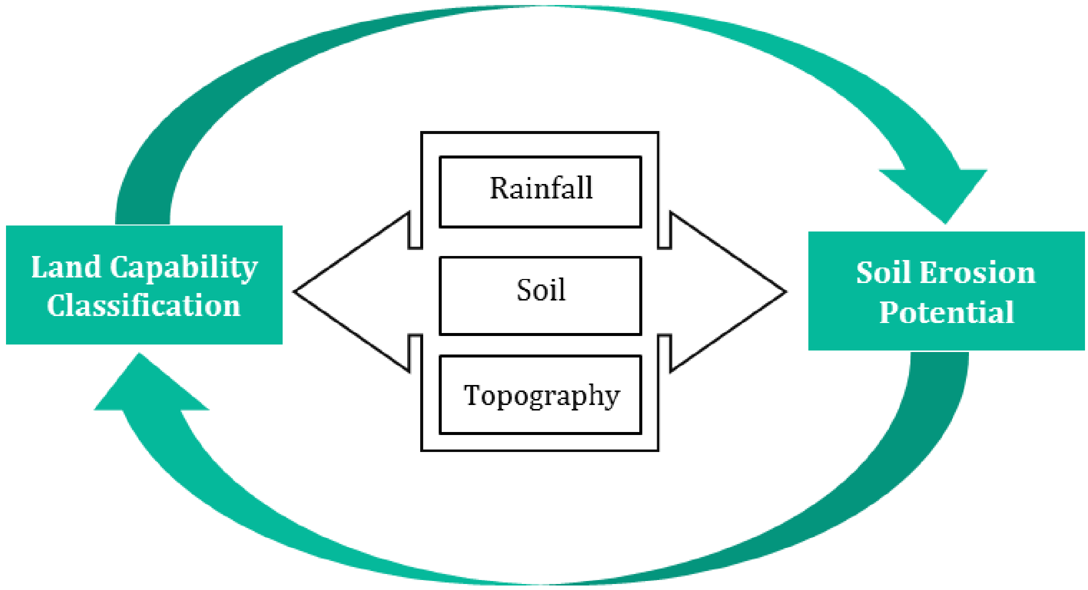

Figure 3 . Erosion-based land capability classification associated with biophysical factors (EDC, 2012; DENR-R4, 2015; CFSHD-DAP, 2015; USAID-DENR, 2015*)*

f. *Land use modelling*

Modelling soil erosion is the process of quantitatively describing soil particle detachment, transport, and deposition on land surfaces (Nearing, *et al.*, 1994). These models are useful tools for understanding the erosion process and the interactions of the factors affecting soil loss. From this information, appropriate measures can be taken to reduce the negative impacts and also prescribe proper land use management strategies.

Soil erosion is a suitable indicator of land capability because of common key determinants (*i.e.*, rainfall, soil, and topography). Soil erosion is also a good measure of the sustainability of land productivity, which is the primary success indicator of land capability. The premise of an erosion-based LCCS is that any use compatible with a specific land capability class (LCC) or zone will not cause significant soil erosion that leads to the deterioration of land productivity, soil, and water resources. Further, the planned use should not bring about adverse offsite impacts. Climate change related hazards, such as floods, rain-induced landslides, and other natural hazards, impose limitations on the potential uses of LCC.

Following the procedure described by Warren *et al.* (1989) and with the aid of GIS analytical techniques, erosion index can be developed and used for land capability classification.

<u>Generation of Soil Erosion Potential</u>

Soil erosion potential (SEP) can be estimated given the relationship of rainfall (*R*), soil (*K*), slope (S), plant cover and farming techniques (*C*), and erosion control practices (*P*). SEP is computed using the equation below. The *C* will be excluded because it can easily be altered by the human activities.

$$SEP = R \times K \times S$$

<u>Creation of Soil Loss Tolerance</u>

Soil loss tolerance limit is a common expression of the SEP estimates (Table 5). The *T* value is an expression of the maximum soil loss that an area can sustain without regressing in productivity permanently or temporarily. It is a function of the rate of soil accumulation in an area that is dependent on the slope of an area. Hence, the slope might be reclassified according to its soil loss tolerable limits.

Table 5 . Prescribed soil loss tolerance

Slope	Soil Loss Tolerance (ton/ha)
0 – 3	12
3 – 8	10
8 – 18	8
18 – 30	6
30 – 50	4
>50	2

<u>Determination of Soil Erosion Index</u>

The computation of soil erosion index (SEI) is essential to standardize SEP estimates. As it is, the SEP per se when directly used as indicator of sensitivity or susceptibility of an area to soil erosion, does not capture the full weight of slope as a determinant of soil erosion in an area.

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g. Land use allocation

Land use zones can be delineated based on land capability as indicated by soil erosion index and other criteria as shown below (Table 6). Two (2) major zones, namely protection and production, are identified. Each major zone can be further classified into subzones. It is noted here that the output zonation and the indicative land uses in the area are intended to provide a scientific basis for allocating lands in the municipalities to various uses.

Table 6 . Land capability classification criteria

Class	Land Classification	SEI	Considerations
I	**PROTECTION AREAS**		
IA	***Strict Protection Zone***	>3	All remaining natural forests; Areas with high erosion potential; Slope >50% All key biodiversity areas; All areas categorized as SAFDZ; All areas above 1,000 masl (DENR, 1991)
IB	***Protection Buffer Zone***		Banks of rivers and streams and the shores of the seas throughout their entire length and within a zone of 3 m in urban areas, 20 m in agricultural areas, and 40 m in forest areas, along their margins. (Section 17, Pres. Decree [PD] 705, and pursuant to the provisions of the Water Code)
II	**PRODUCTION AREAS**	0 - 3	
IIA	***Unlimited Production Zone***	0 - 1	Built-up areas; Slope less than 18%
IIB	***Multiple Use Zone***	1 - 2	Open brushland and grass land areas; Slope less than 18%
IIC	***Limited Production Zone***	2 - 3	Slope less than 18%

A GIS analysis generates management zones, namely: strict protection zone, restoration zone, buffer zone, limited production zone, multiple-use zone, and unlimited production zone. Management prescriptions of the land capability classes are the following:

<u>Protection Areas</u>

Protection areas are designated mainly for the conservation of biodiversity; conservation of soil and water; protection of unique habitats, vegetation, geologic formation and landscape, and areas of sociocultural values; and minimization of climate-related and other natural risks and hazards associated with soil erosion, landslides, and floods.

Strict Protection Zone

Strict Protection Zone, as defined in Section 5.23, DENR Administrative Order (AO) 2008-26 Section 5.23, pertains to management zones of protected areas consisting of natural areas with high biodiversity value closed to all human activities except for scientific studies and/or ceremonial or religious use. It may include habitats of threatened species, or degraded areas that have been designated for restoration and subsequent protection, even if these areas are still in various stages of regeneration.

Stream Buffer Zone

The banks of rivers and streams and the shores of the seas throughout their entire length and within a zone of 3 m in urban areas, 20 m in agricultural areas, and 40 m in forest areas, along their margins, are subject to easement of public use in the interest of recreation, navigation, float age, fishing and salvage. This provision is mandated by law (Section 17, PD 705) and pursuant to the provisions of the Water Code. These areas are essential buffers for rivers that serve as filters to incoming sediments and other pollutants. These buffers that are supposed to be covered with vegetation, are also excellent protection of the streamflow against excessive solar exposure to keep water temperature at ideal level.

Production areas

The production zone is made up of lands that are suited for intensive land uses such as farming, multiple use forestry, and other uses requiring disturbance of the soil and other resources found in the area. This zone also includes areas that are used for settlement and urbanization and other built up purposes.

Multiple Use Zone

Multiple use zone, as defined in Section 5.10 of DENR AO 2008-26, pertains to the management zone of protected areas where settlement, traditional and/or sustainable land-use including agriculture, agro-forestry, and other income-generating or livelihood activities may be allowed consistent with the Management Plan. It also includes, among others, areas of high recreational tourism, educational or environmental awareness values, and areas with existing installations of national significance or interest such as facilities or structures for renewable energy, telecommunication, and hydro-electric power generation, among others. However, the land capability classification of the multiple use zone is placed under production areas since it requires intensive management requiring soil disturbances.

Limited Production Zone

Limited production zones can be allocated as agricultural areas that are classified within the alienable and disposable lands.

Unlimited Production Zone

Areas for settlement and commercial purposes consist mostly of areas that are currently used for the same purposes. As the town's population continuously grows, the settlement and community areas may expand only to production areas immediately adjacent to existing areas. By no means, the areas for settlement and community purposes should be permitted to extend in multiple use or even in the protection areas, as this will likely compromise the ecological and environmental integrity.

3. GIS for Local Governance

a. Integrating GIS in natural resource organizations

In the Philippine context, local government units are the most potent instruments for sustainable forest and natural resources management. Several reasons point to this observation:

- LGUs are at the 'frontline,' owing to their presence in all areas of the country especially where forest destruction occurs;
- LGUs have jurisdiction over upland dwellers, especially those at the boundary of forestlands and private lands (*i.e.,* 'forestline'), where conversion and resource extraction is apparent;
- LGUs are the most potent entities that can sustain efforts at protecting and restoring forests and natural resources. Compared to other government agencies with similar concerns, LGUs have the 'home advantage.'

For a natural resource manager, having a GIS unit to handle the spatial databank of the organization is desirable. In most cases however, GIS activities are ad hoc, and once the GIS has been plotted and printed, the GIS unit ceases to exist. More often than not, these activities are contracted out to GIS companies. Thus, the use of GIS must be institutionalized within the organization and not just an ad hoc activity.

b. Community-based GIS

Community-based GIS can be seen in terms of utilizing GIS technology in enhancing the capability of upland communities to better manage the natural resources around them. The process consists of the following:

1. Preparation and plotting of the GIS themes.
2. Conduct of an appreciation workshop on participatory mapping using GIS and 3D relief modelling.
3. Construction of the 3D relief model per barangay.
4. Transferring of 'mental maps' onto the 3D model.
5. Ground verification
6. Updating of the land use on the 3D relief model.

c. Poverty Mapping

Poverty stems from the lack of access to resources and opportunities that would enable a human being to a level of well-being. Thus, lightly defined, poverty is the ability (or inability) to attain a minimal standard of living. This minimum level is usually called the ‘poverty line.’

Integrating GIS in mapping poverty, therefore, is a necessary task. A poverty map is a geographic profile indicating concentrations of well-being. Such maps are useful, for instance, in targeting interventions and policies geared towards alleviating poverty.

For instance, GIS-assisted poverty mapping, therefore, may be implemented based on the following:

- Accessibility to resources and services
- Biogeographical mapping
- Vulnerability mapping

d. LGU and Land Use Planning

The concept and interpretation of the comprehensive land use plan as embracing the entire LGU territorial jurisdiction derive from the reality that in any LGU territory there exists two, possibly three, property domains such as private, public, and ancestral.

- The private domain includes areas that had earlier been classified as alienable and disposable, and have since been titled to private owners or claimants. The private domain is completely under the authority of an LGU to regulate.

- Public domain lands such as forests, national parks and similar reservations, which are within the territorial limits of an LGU are traditionally the preserve of the national government. LGUs usually do not have anything to do with those areas. But now the national government intends to involve LGUs in the management of these areas and resources.

- Another domain that may occur within a territory of an LGU is the ancestral domain. The Indigenous People’s Rights Act (RA 8371) declares these areas as exclusively for the use and occupancy of the particular ethnic and cultural group that had occupied the area since time long-established.

Management plans of ancestral domains/lands, nevertheless, shall be integrated into the Comprehensive Land Use Plan (CLUP) of the LGU having territorial jurisdiction (Figure 4).

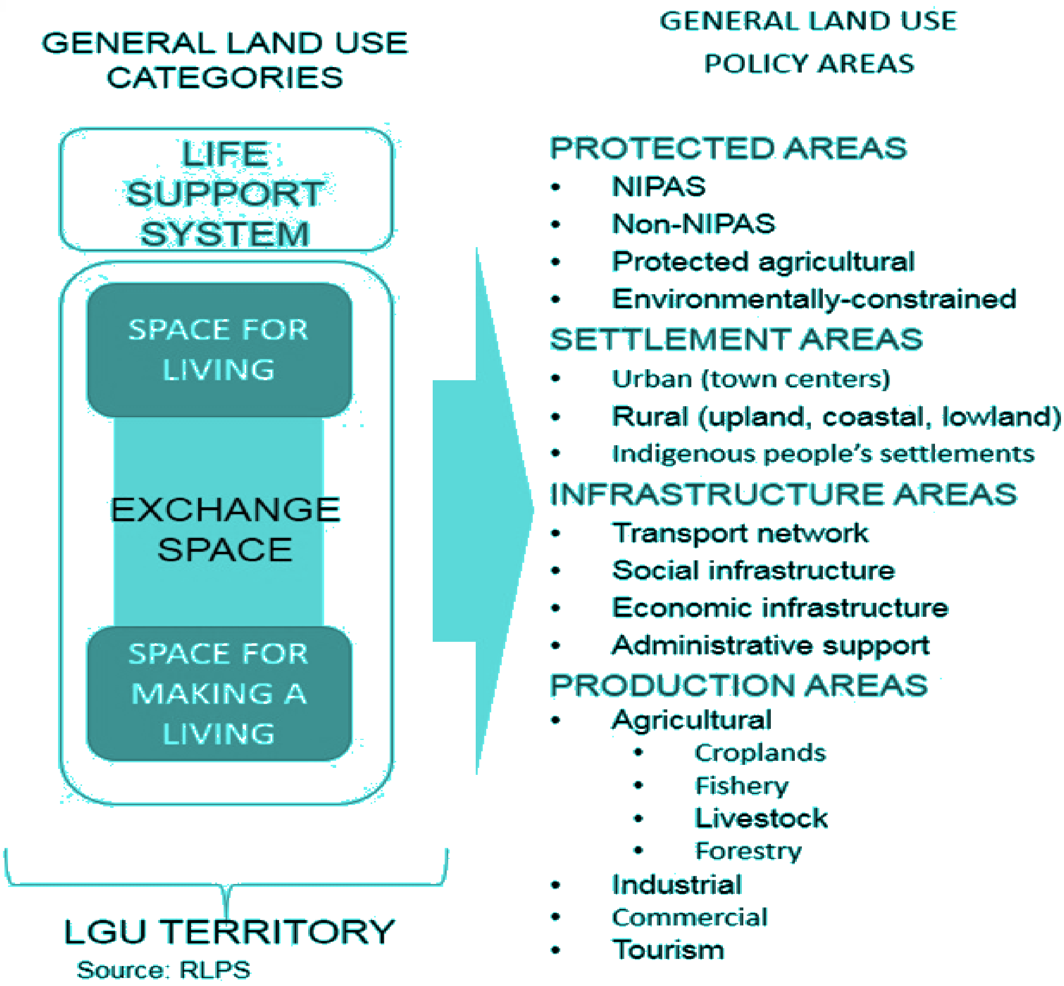

Figure 4. LGU basis for land use planning (Source: LGA-DILG, 2015)

Through GIS technology, intervention options or management prescriptions may be developed on the basis of the major strategies: protection, production, and intensive use. GIS can be used to assist the community transform their mental maps into tangible forms that can allow georeferencing and spatial analysis. GIS can help communities plan out the most appropriate farming system (*i.e.,* agroforestry) design. Implementation may be done by visualizing the land use location and allocation problem as a set of map layers or themes representing earth features. Generating thematic layers allows for selective combination that answers specific questions. Thus, GIS technology has allowed many LGUs to better manage their activities as well as identify solutions to pressing problems in a more responsive way.

4. Land Change Modelling

a. Change analysis

Change Analysis is a set of tools for the rapid assessment of change, allowing one to generate one-click evaluations of gains and losses, net change, persistence, and specific transitions both in map and graphical form. Using land change modelling, users are allowed to specify the essential files associated with the land cover change analysis of a specific area, as well as a project name. For the change and prediction analyses, a minimum requirement is the specification of two land cover maps that can be used as the basis of understanding the nature of change and the means of establishing samples of transitions that should be modelled. The two land cover maps must have matching backgrounds, legends, and spatial characteristics.

This analysis has the ability to create a variety of change maps, including maps of persistence, gains and losses, transitions, and exchanges.

Changes in land use and land cover detected through GIS analysis can be validated through limited ground verification surveys and interviews with key informants and members of local communities.

b. Transition analysis

Two main types of forest change are of interest in the land use change analysis: forest to non-forest (forest loss) and non-forest to forest (forest gain). Forest loss (deforestation) is defined as the direct human-induced conversion of forested land to non-forested land or more specifically, as the conversion of forest to other land use or the long-term reduction of tree canopy cover below the minimum 10% threshold (Food and Agriculture Organization [FAO], 2010). Deforestation falls under the category on forestlands converted to other land uses based on the Intergovernmental Panel on Climate Change (IPCC) Good Practice Guidance on Land Use, Land Use Change, and Forestry (LULUCF). Other land uses as defined in this same framework include the following broad land use/cover categories, particularly: cropland, grassland, wetlands, settlements, and other land.

On the other hand, forest gain (forestation) is defined as non-forestlands converted to forestlands and is reflected in new forests being established (*i.e.,* afforestation and reforestation). According to the IPCC Good Practice Guidance on LULUCF, “afforestation” is the direct human-induced conversion of land that has not been forested for a period of at least 50 years to forested land through planting, seeding and/or the human-induced promotion of natural seed sources. On the other hand, “reforestation” is the direct human-induced conversion of non-forested land to forested land through planting, seeding and/or the human-induced promotion of natural seed sources, on land that is forested but has been converted to non-forested land.

For instance, land cover assessment can be utilized (2003 and 2010 land cover data produced by the National Mapping and Resource Information Authority [NAMRIA]) for generating activity data and analyzing forest cover change. Both the 2003 and 2010 land cover data can be generated using visual interpretation and manual editing of the from 30m-resolution Landsat data categorized into the FAO land use classes, which consist of: nine (9) forest classes, two (2) agricultural classes, three (3) wetland classes, four (4) grassland classes, and two (2) other-land classes

III. Reading Materials/References

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Address: Bulwagan Ninoy, Ninoy Aquino Parks And Wildlife Center, North Avenue, Quezon City, Philippines

Tel/FaxNo.: (02) 925-8954
Website: www.climate.gov.ph

Address: 19F Jeongdong Bldg.
21-15 Jeongdong-gil
Jung-gu Seoul 04518
Republic of Korea

Tel. No. +82-2-2096-991
Website: www.gggi.org