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Dataset in Focus

Risk Hotspot Conceptual Space Characterized by Hexagonal Data Binning Technique: An Application in Albay, Philippines

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Abstract

Purpose – This study sought to develop a model to locate and visualize the risk hotspots and coldspots in Albay using the binning technique.

Method – Hexagonal binning technique leads to complexities in quantifying risk hotspots and coldspots. It is regarded as storing weighted values ranging from 1 which is the lowest to 5 which pertains to the highest value. The weights may be influenced by hazard return periods or proximity to the critical condition of the landscapes or seascapes that are highly prone or regularly impacted by hazards. The Binning Parameters following data binning parameters were created and applied to study variations of the six elements of risk reality.

Results –The hexagonal bin reveals that about 29,400 hectares in Albay are significant risk hotspots, with 99% confidence. Also, at least 7,100 hectares of land are significant risk hotspots, with 95% confidence, and 3,100 hectares are significant risk hotspots with 90% confidence.

Conclusion – The researcher concluded that disaster risk reduction entails interdisciplinary thinking to apply hexagonal to determine where the natural and man-made hazards, landscape vulnerable, and passive and active exposure hotspots or coldspots exist.

Recommendations – The researcher proposes applying hexagonal data mining techniques to dig deep into the risk realms to avoid unwanted effects in natural and built environments.

Keywords – hexagonal bin, risk hotspot, coldspot, risk reality quantity

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Introduction

Disaster risk reduction documentation started as early as 1814 after Mayon erupted disrupting people's lives and displacing them to look for lands suitable for planting crops far from the volcano, but located near rivers and access to outside assistance(Gerona, 1988, 2013). In 2018, the National Disaster Risk Reduction Management Council update on the situation per report number 57 re Mayon Volcano Eruption, there are 420 families were evacuated from Barangays "Matnog and "Budiao, Daraga" to evacuation centers in Anislag, Daraga (further south from the volcano) (NDRRMC, 2018). As multiple hazard events naturally re-emerge, the geospatial data on land morphology relatively implies physical and environmental modifications hint at residents around the Mayon Volcano are vulnerable to environmental changes(Usamah & Haynes, 2012). It allows visualization of location information analyzed as dangerous areas or hotspots(Abante & Abante, 2019a, 2019b). Geospatial modeling also mimics the undesired developments that were covered (using Open Street Map spatial data downloaded for free on the internet) inside the permanent danger zone(Abante, 2020; Abante & Abante, 2018; Abante&Balilo, 2018).

This study sought to develop a model to locate and visualize the risk hotspots and coldspots in Albay using the binning technique. To attain the research objective, the Open Street Map (OSM) datasets were used to disclose the uncontrolled construction of buildings along the old railroads and rights-of-way, near rivers prone to flash floods carrying lahar deposits(Abante, 2020; Abante & Abante, 2019a, 2019b). These data sets were used to analyze the variable for computing risk within the Mayon 6-Km Permanent Danger Zone in Albay Province. The paired risk variables as illustrated in Figure 1 carries the accumulated binned scores or risk location quotients that were stored and sorted in the 1,731 honeycomb-like hexagonal polygons arranged equidistantly to each other. The accumulated scores of the risk elements were categorized into five classes: very low, low, moderate, high, and very high numerical values and regarded as input data to process the risk hotspot and coldspots using the Getis Ord Gi* geostatistical tool. This statistical tool analyzedthe neighborhood of high and low values patterns. It is categorized into 7 levels of significance the input data sets (risk elements) that pinpoint the causes of specific geographical (spatial) patterns that interpret the risk reality interpreted as a hotspot and coldspots in ArcGIS Desktop 10.8 platform for easy visualization. The risk reality hotspot or coldspot spatial patterns were tested using Moran's I statistical tool covering the study area that was reckoned 25 km radial distance from the crater of Mayon.

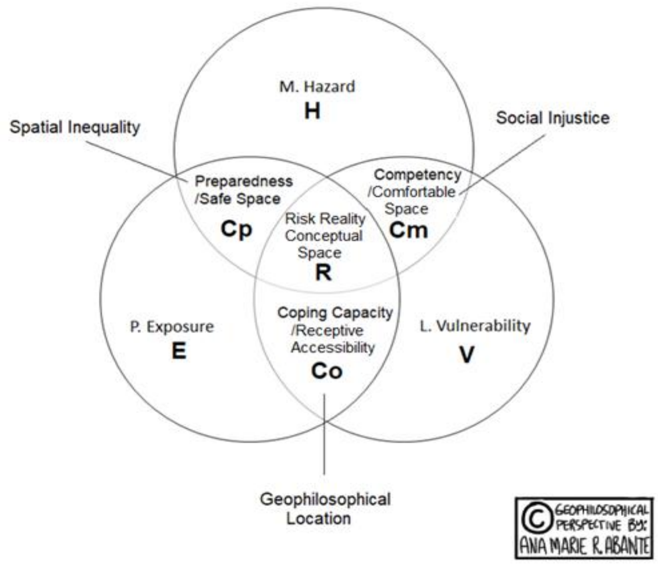

Figure 1 is a conceptual framework based on Gärdenfors' geometry of thought where the Y-junction of Gärdenfors-inspired conceptual spaces is attributed to three logical paired variables where R is expressed as Risk Reality

The Intergovernmental Panel on Climate Change (IPCC) is an intergovernmental body of the United Nations acknowledged the Risk (R)is a function of hazard, vulnerability, exposure, and capability where H is regarded as a hazard, V is regarded as vulnerability, E is regarded as exposure and C is regarded as Capability to withstand risk, mathematically written as

$$R = \frac{H \times V \times E}{C} \qquad \textit{Equation 1}$$

In this study, the risk math formula was based on equation 1 but harmonized with the conceptual framework as shown in Figure 1 where risk is treated as a function of the six paired elements of risk. It is understood as the function (multiple hazards, landscape vulnerability, passive exposure, preparedness, competency, coping capacity) where H is regarded as the multiple hazards, V is regarded as the landscape vulnerability, E is regarded as the passive exposure, Cp is regarded as the preparedness which is tied up with the safe conceptual space, Cm is regarded as the competency which is tied up with comfortable space, and Co is regarded as the coping capacity which is tied up with receptive accessibility is called the Abante Risk Formula. The Abante formula is equated 1 one unit. Her geophilosophical meta theorems on risk proved that when risk quantity is equal to one unit, it signifies stability reckoned from the vertex of resiliency that is orbiting from the risk reality spiral based on the Fibonacci golden ratio and Schoen golden triangle is true(Abante, 2020). Likewise, when risk is greater or less than one unit it signifies risk hotspot or coldspot respectively are true statements. (Abante, 2020) The Abante Risk Math Equations and Metatheoremapplied to pull off to answer the objective of this research to locate and visualize the risk hotspots and coldspots in Albay using the binning technique are written as follows:

(i) $$\text{Risk} = \frac{Multiple\ \ Hazards}{Preparedness} \times \frac{LandscapeVulnerability}{Competency} \times \frac{Passive\ \ Exposure}{Coping\ \ Capacity} = \qquad \textit{Equation 2}$$

(ii) $$\text{Risk} = \frac{Multiple\ \ Hazards}{Safe\ \ Space} \times \frac{LandscapeVulnerability}{Comfortable\ \ Space} \times \frac{Passive\ \ Exposure}{Receptive\ \ Accessib\ ility} \qquad \textit{Equation 3}$$

(iii) $$\text{Risk Reality Phi } \varphi = \frac{Risk\ \ Hotspot\ \ (Upper\ \ Limit\ )}{Risk\ \ Fuzzy\ \ Reality\ \left(\frac{125}{2Cosine\ \ 72}\right)} =$$

$$\frac{Risk\ \ Hotspot\ \ (Upper\ \ Limit\ ) + Risk\ \ Fuzzy\ \ Reality\ \ (Risk\ \ Hotspot\ \ Upper\ \ Limit\ /2Cosine\ 72^{\circ})}{Risk\ \ Hotspot\ \ (Upper\ \ Limit\ )} = 1 \qquad \textit{Equation 4}$$

The hexagonal bins' bell curve hinted at the data processing results labeled as follows: 99% significant hotspots (a bin belongs to a cluster of high value hinted at a disaster is imminent hinted at spatial inequality and social injustice; 95% hotspot significance hinted at-risk high to very high implying spatial inequality and social injustice are likely; 90% level of confidence hinted at moderate to high hotspot information that is attributable to spatial inequality and social injustice; -90% confidence level coldspot hinted at risk is impartial to marginal wherein spatial equality and social justice is likely; -95% coldspot's confidence level hinted at risk marginal to near insignificant social justice or spatial inequality; -99% confidence level coldspot hinted at risk is insignificant; and the neighborhoods of scattered and/or lowest numerical values were marked as 'Neutral' (Abante, 2020). Table 1 presents the risk reality standard deviations relative to the p-value and confidence level of the information binned in the tessellated hexagonal bins.

The study area is geographically located at 13° 15' 00'', 123° 45' 00'' northeast rim of the southernmost tip of Luzon in the Bicol Peninsula in the Philippines. The Hexagonal Bin in this study stands for a 500 m equidistant hexagonal polygon object to store information just like honey being stored in beehives. Bins are continuous hexagon-shaped cells and each centroid is arranged 1 km equidistant (Abante, 2019, 2020). It stores spatial data (pre-processed and weighted input data) extracted from different map layers to reveal the spatial and non-spatial (statistical) patterns (Abante, 2019, 2020). In this research, a user-controlled classification was set to define the five classes in which the parameters domain is continuously indicating value ranges to be mapped to the same categorical values (ordinal/nominal data) (Abante, 2019, 2020).

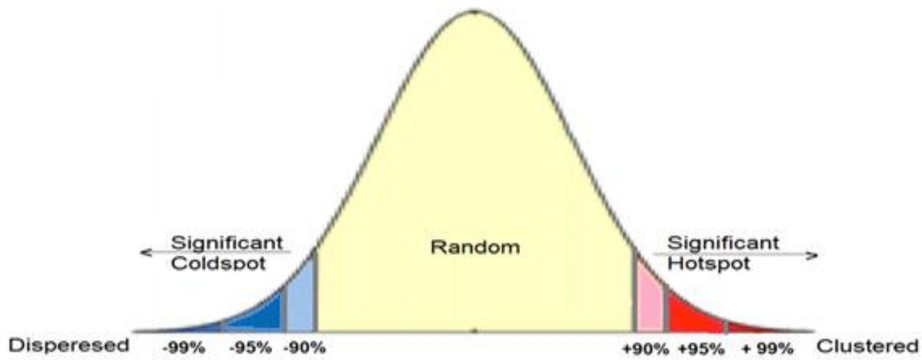

Figure 2. Risk Spatial Pattern Bell Curve disclosed the risk hotspots and coldspots resulted from analyzing the geographical aspects of georeferenced hexagonal tessellated bins' using the Getis Ord Gi* statistical tool to examine the neighborhood of clustered high numerical values and dispersed low numerical values regarded as hotspots and coldspots levels of significance.

Table 1. Risk Reality Std. Deviations, P-values and Confidence Level

Risk Reality	Risk Reality z-score *(Standard Deviations)*	P-value *(Probability)*	Confidence level
Significant Risk Hotspot	> +2.58	< 0.01	99%
	> +1.96	< 0.05	95%
	> +1.65	< 0.10	90%
Insignificant	Random	Random	Random
Significant Risk Coldspot	< -1.65	< 0.10	90%
	< -1.96	< 0.05	95%
	< -2.58	< 0.01	99%

Almost every attempt to understand the geophysical space begins with uniformly defining or measuring the physical world. As said by Christaller urban features (minimum and maximum range) can be represented as a circle emanating from its location. According to him, a lattice of hexagons is a better model to represent the geophysical space because it has no overlaps compared to a circular model. Efficient spatial binning is a technique for sorting data into spatial bins taking points in sorted order into a set of bins. (Oat, Barczak, &Shopf, 2008) The binning principle is a way to understand the uncertainty of spatial data. (Oksanen, 2013) It is like what the researcher had investigated to analyze the topographic (spatial) features of a local setting (landscape) for each cell. The hexagon binning technique in this study was based on Walter Christaller's Central Place Theory where his notion on the overlaps and non-coverage caused by a circular model, brought a lattice of hexagons as a better model to represent the geophysical space. Hexagons reduce sampling bias due to edge effects of the grid shape that is related to the low perimeter-to-area ratio of the shape of the hexagon (Abante, 2019, 2020; Abante & Abante, 2019a, 2019b;Worboys, 2004). While the circle has the lowest ratio but cannot tessellate to form a continuous grid, the hexagons are the most circular-shaped polygon (based on Christaller's Central Place Theory) that can be tessellated to create and arranged evenly spaced grid (Abante, 2020; Gold, 2016; Worboys, 2004; Getis& Getis, 1966). Figure 3 illustrates how an average person with a 0. a 50-meter pace factor can walk a 500-meter radius (distance) or take 1,000 steps with 3-meter/second speed can measure the one-side of the hexagon in just 3-minutes or it takes 18 minutes to walk around a flat physical space regarded as a hexagonal bin. Data collection, updating, and assessing the situation in the ground within a hexagonal bin is doable manually or equipped with a handheld GPS to collect data.

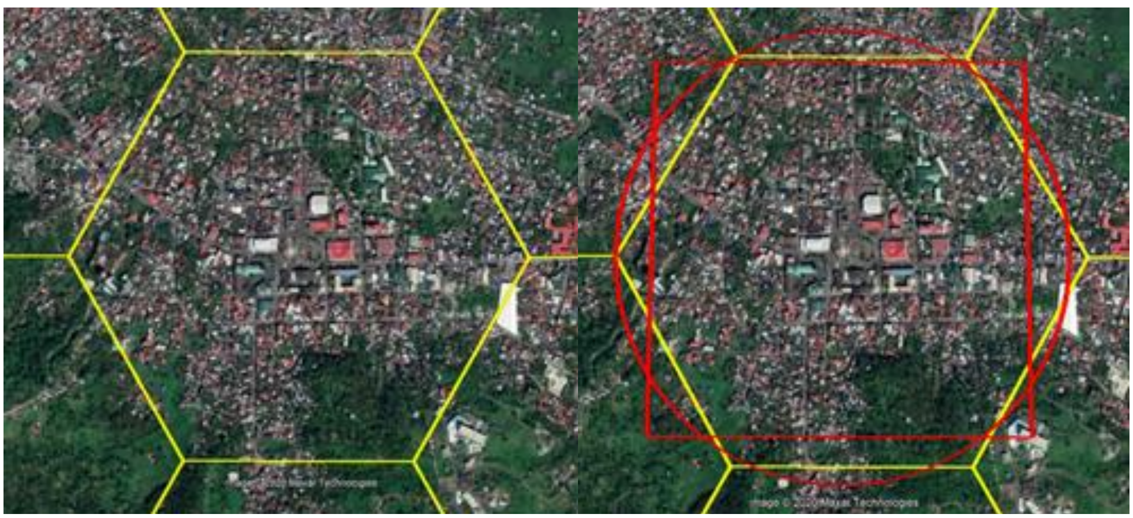

Figure 3. is a Google image showing hexagonal bins designed to collect data naturally compared to square grids or circles

Figure 4shows the Hexagonal bins better represent the thematic data sets. It allows the presentation and visualization of weighted spatial information in analyzing location x and y or sorting local knowledge. The yellow dots symbolize the barangay halls that characterize the community locations. The bins are designed to store and sort hazard events, passive exposure happenings or coincidence, topographical spatial properties, and aspatial data in the 2,785 hexagonal lattice-shaped cells to cover Albay. Each hexagon has an area of 100 hectares. It is also a tessellated polygon features geometry is projected in WGS 1984; UTM; Zone_51N; False_Easting: 500000.00; False Northing: 0.00 ; Central Meridian: 123.0; Scale Factor: 0.9996; Latitude_of_Origin: 0.00; Linear Unit: Meter; Geographic Coordinate System:GCS_WGS_1984; Datum: WGS_1984; Prime Meridian: Greenwich and Angular Unit: Degree.

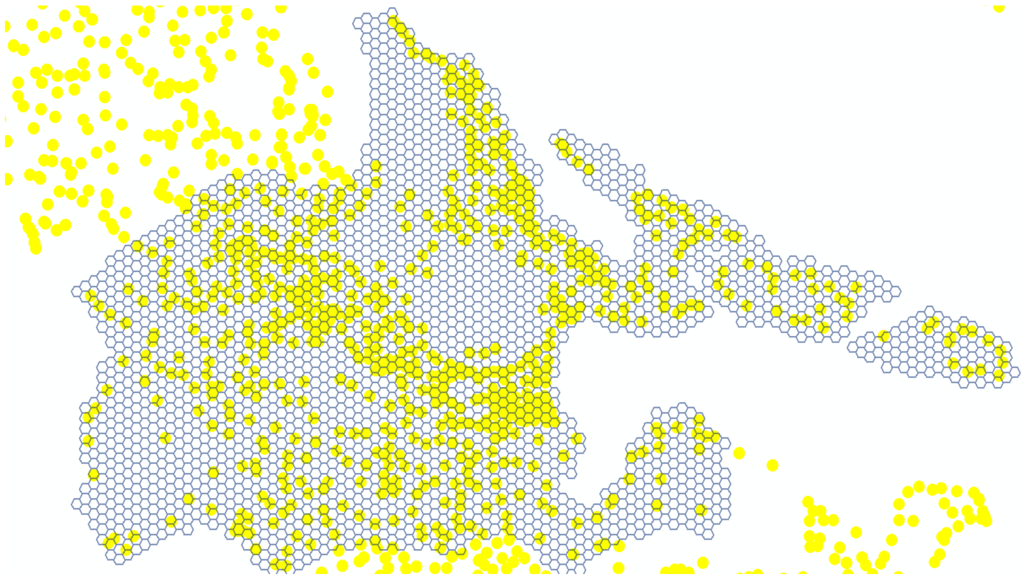

Figure 4. Hexagonal Bins mimics how data are stored in hexagon-shaped (beehive) to store honey (depending on the volume of honey in each cell represents the weights assigned to measure hazards, vulnerability (extrinsic), and passive exposure.

RESULTS OF DATA ANALYSIS

Pre-processedSpatial Datasets (Input)

Multiple Hazards (H)

Albay is affected by tropical cyclones, aggravated by natural catastrophes such as volcanic eruptions, flash floods, and eruptions, flash floods and mudslides, the spirits of the mudslides, the spirits of the Albayanos (Abante & Abante, 2018; Lasco, et al., 2008). This natural calamity resulted in hundreds of deaths and several communities buried by the debris. (Lasco, et al., 2008). The flash flood triggered by volcanic debris deposited on the slope of Mayon Volcano foot slopes in 2006 carried by heavy rain runoff due to typhoon Reming (Durian) (Luna, 2009; Bankoff&Hilhorst, 2009). This natural calamity resulted in hundreds of deaths and several communities buried by the debris. (Luna, 2009) Landslide (rain-induced) is a downward movement of a mass of earth, rock, or debris due to gravity and triggered by rainfall. Natural hazard susceptibility maps such as lahar, flood, landslide, erosion, were rated and stored and sorted to outline multiple hazard events impacting the hexagonal bins (Fano, etal., 2007; Paguican, et.al, 2009). Figures 5 and 6 show the volcanic and hydro-meteorological hazards in which the process or phenomenon of atmospheric, hydrological, or oceanographic nature that may cause loss of life, injury or other health impacts, property damage, loss of livelihood and services, social and economic disruption, or environmental damage due to floods, storm surge, and rainfall-induced landslides.

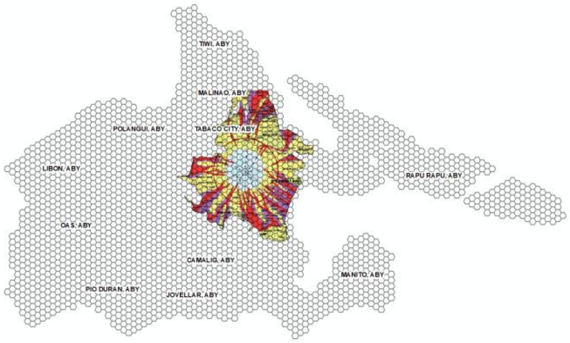

Figure 5. Lahar Bin Map shows where and which bins store the lahar attributes and weights

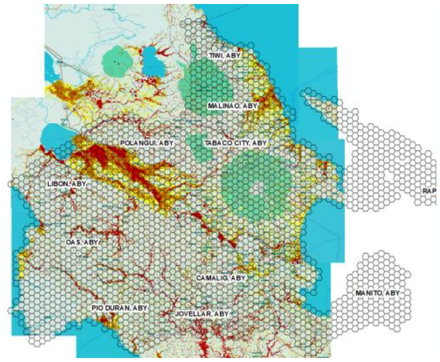

Figure 6. Flood Bin Map shows where and which bin store the flood susceptibility attributes and weights

The multiple hazards in this study refer to the combined scores of natural or environmental hazards impacting Albay based on the definition of the Joint DENR-DILG-DND-DPWH-DOST Memorandum Circular NO. 2014-01. This study revealed the multiple hazards hotspots with a 99% level of confidence are located within the Mayon 6 km permanent danger zone, between the 6 to 8 Km extended Mayon danger zone covering Tabaco City and Malilipot. It also includes areas near the Albay Lineament fault line crossing the town of Libon, Oas, Ligao City, Guinobatan, Camalig, Daraga, ending in Legazpi City. Figure 7 shows the multiple hazard bin counts that disclosed the 134 hexagonal bins or 13400 Ha where 91 hexagonal bins are labeled as 99% hotspots level of confidence, 29 hexagonal bins are labeled as 95% hotspots level of confidence, and 14 hexagonal bins are labeled as 90% hotspots level of confidence (Abante, 2020).

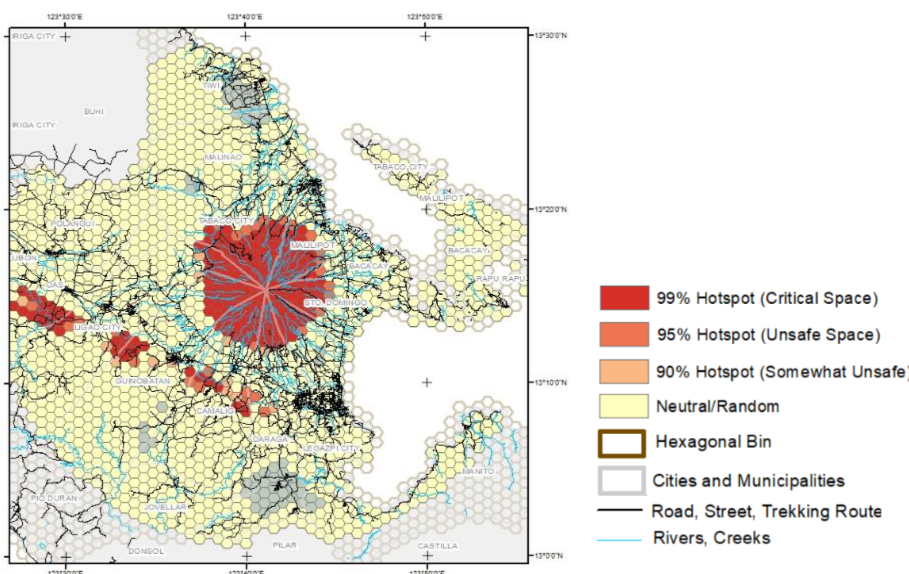

Figure 7. Multiple Hazards Bin Map is a presentation of the multiple hazards bin using Getis Ord Gi* statistical tool in ArcGIS Platform that characterizes the result after combining the data inputs in terms of elevation, slope, soil erosion, rainwater, and runoff.

Landscape Vulnerability (V)

In terms of the landscape vulnerability, hotspots with a 99% level of confidence greatly cover the 4 Km buffer area reckoned from the 6 km permanent danger zone. Measuring Passive Exposure relies on the location of the building and road network where the said multiple hazards and passive vulnerable hotspot areas exist. Landscape Vulnerability is defined as the physical potential (negative) impact or degree of loss in a built environment. In this study, this refers to the condition (quality of built environment) of lowland: coastal, broad, and minor alluvial plains, hilly land, terrace or residual slope, foot slope, plateau, sedimentary hills, volcanic hills, metaphoric hills, mountain, a volcanic cone, beach sand, sand bars, creek, terrace escarpment, plateau escarpment, major rivers, lakes, and urban of geographically enclosed land ajar to alteration (physical changes) ajar to the effects of floods, bank erosion and other hydrological related hazards that may occur when river discharge exceeds its channel's volume, causing the river to overflow onto the downstream alluvial flats as well as the coastal area that conveys different states of discomfort, security, worries, distress, angst, and more(Abante, 2019, 2020). Figure 8 and Figure 9 show the landslide and soil erosion susceptibilities due to steep to very steep slopes and underlain by weak materials, recent landslides, escarpments and tension cracks, as well as numerous old/inactive landslides; also includes areas that can be affected by landslide debris (debris flow path/possible accumulation zones). Moderate landslide susceptibility is areas with moderately steep slopes. Soil creep and other indications of possible landslide occurrence are present. Low landslide susceptibility is gently sloping areas with no identified landslide.

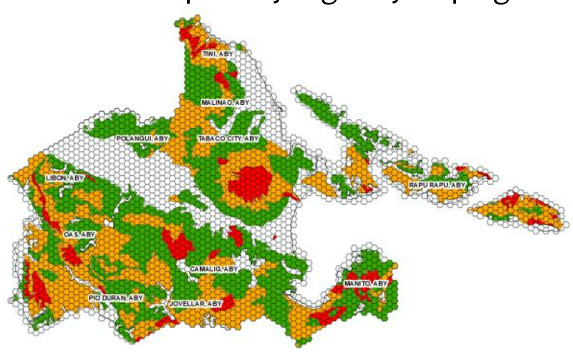

Figure 8. Landslide Bin Map shows where and which bins store the landslide attributes and weights

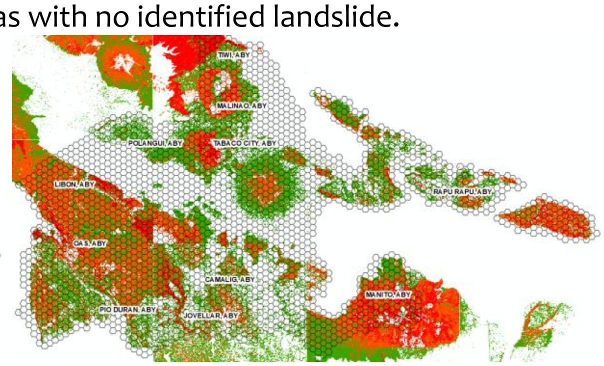

Figure 9. Erosion Bin Map shows where and which bins store the erosion attributes and weights

According to Gerona (2013), archive records in the 1800s or earlier describing the Mayon lava reached the Pueblo de Guinobatan located 12-kilometers from the crater. (Mirabueno, 2001; Tabayag, 2010) Landscape vulnerability is extrinsic to landforms and characteristics such as slope and elevation stored and sorted to picture the critical areas and prone to geomorphological changes brought by multiple hazard events. Figures 10and 11 show critical (1000 meters above) elevations, Mayon Volcano, Mt. Malinao, and Mt. Maharaja.

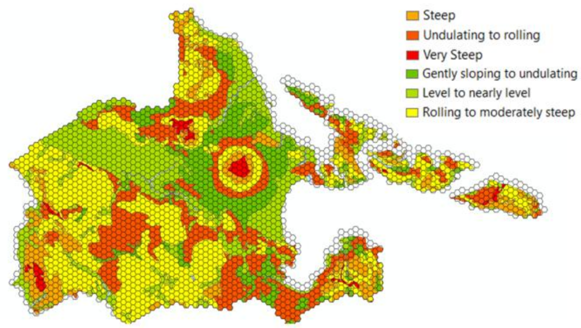

Figure 10. Slope Bin Map shows where and which bins store the slope attributes and weights

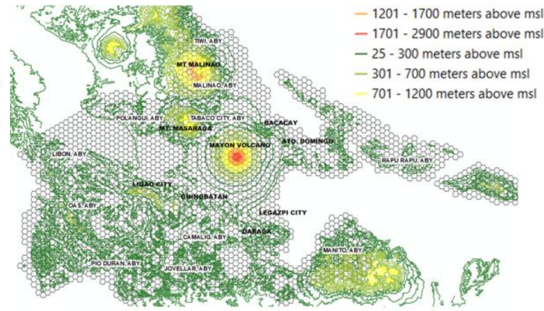

Figure 11. Elevation Bin Map shows where and which bins store the elevation attributes and weights

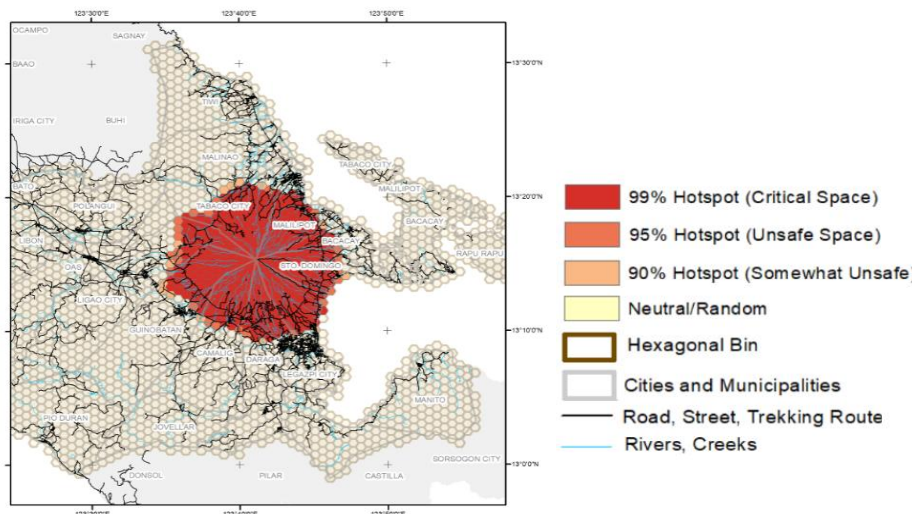

Figure 12. Landscape Vulnerability Bin Map is a presentation of the landscape vulnerability using Getis Ord Gi* statistical tool in ArcGIS to characteristics the slope, geomorphological characteristics, and soil erosion.

The landscape vulnerability bin count as shown in Figure 12 disclosed the 376 hexagonal bins or 37,600 Ha where 337 hexagonal bins are labeled as 99% hotspots level of confidence are located more or less within the 12-km radius from the crater of Mayon Volcano. Similarly, the 29 hexagonal bins that are labeled as 95% hotspots level of confidence, and the 14 hexagonal bins are labeled as 90% hotspots level of confidence are located near the 12-km ring. (Abante, 2020) Among the Poblacion areas (urban centers) of the cities and municipalities, Camalig is the most vulnerable because of its geographical location.

Passive Exposure (E)

The passive exposure in this case study is defined as the points or polygon centroids (represented by OSM building footprints location x and y that are coinciding with danger zones or as near as 100 meters volcanic related natural hazards. (Abante, 2020) Structures sited within the 6 km declared Mayon Permanent Danger Zone is highly exposed or moderate to high exposure when located within the 6 to 8 km extended danger zone(Abante, 2019, 2020; Abante&Balilo, 2018). Also, structures sited within the 8 to 10 km range are regarded as moderately exposed(Abante, 2019, 2020). A 100-meter buffer for building and road-network was created to analyze the extent of exposure in the ArcGIS platform. (Abante, 2019, 2020)The passive exposure is hinted at a location x and y. (Abante, 2017, 2018, 2019, 2020) Risk cannot exist in bins when passive exposure is nil. Since the passive exposure is involved as an independent variable when paired with coping capacity hinted at the geo-philosophical location as a conceptual space is the most important information that connotes land utilization and zoning (Abante, 2020). The passive exposure carried five and one numerical value that characterized very high and very low passive exposure respectively. Figure 13 shows the 623 hexagonal bins are regarded as exposed physical structures combining building and road incidences where nearness is measured 100 m (Abante, 2020).

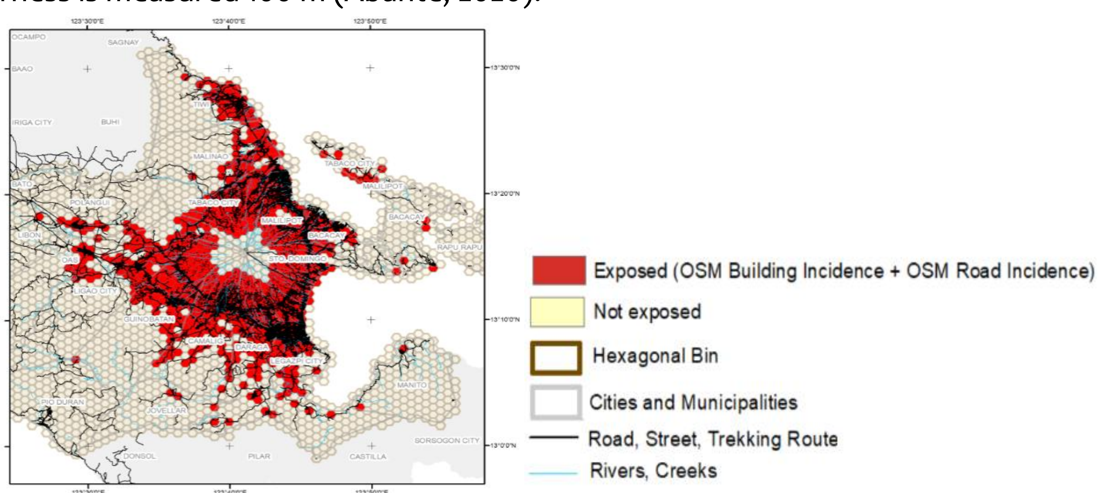

Figure 13. presents the passive exposure characterizing the locations relative to their nearness to the OSM buildings and roads.

Capability

Unlike the first three risk elements, capability as shown in Figure 14 is non-spatial information representing the attributions that characterized the factor to cut risk(Abante, 2020). The capability in this study is understood as the non-spatial aspects that encompass the preparedness that is correlated with safe space (hexagonal bin), competency that is correlated with comfortable space (hexagonal bin), and coping capacity that is correlated with the provision of receptive accessibility of the local government units around Mayon Volcano. These variables were based on the income class as well as the 5% mandatory fund for prevention, mitigation, preparedness, response, and recovery per Republic Act No. 7160 which allows every local government unit to exercise the powers to appropriate to promote the general welfare by recognizing and strengthening the capacities of LGUs and communities in mitigating and preparing for, responding to, and recovering from the impact of natural and man-made disasters such as the COVID-19, terrorism and so on. The preparedness, competency, and coping capacity variables have their respective consequences on outlining the risk reality in LGUs to either boost their local development (if the risk is reduced to bearable quantity) or to a worsened state if risk realities continue accruing. A worsened risk reality implies that the capability of the local government units is unstable to withstand natural calamities resulting in the inability to fully recover and/or reduce the accumulated risk residuals past disasters (Abante, 2020).

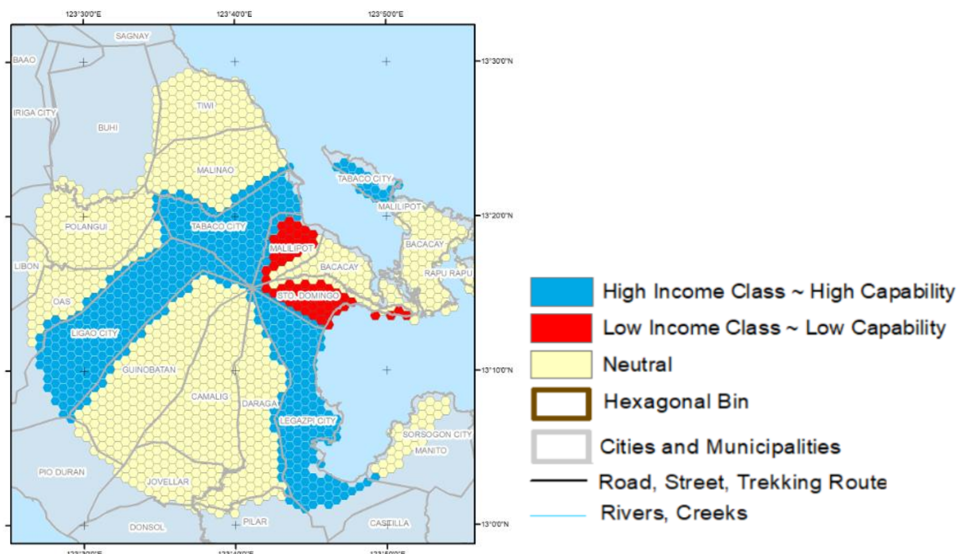

Figure 14. Capability Bin Map presents the capability as a function of preparedness, competency, and coping capacity

Binned and Stacked Risk variables

The risk elements scores that were stored in the hexagonal bin(each hexagonal bin is annotated with a chart)are presented using stacked charts to display the scores broken down by the 6 elements of risk: red to view multiple hazards binned scores, brown to view landscape vulnerability binned scores, and yellow to view exposure binned scores relative to cyan to view preparedness binned scores, blue to view competency binned scores, and grayish blue to view coping capacity binned scores. The stacked label tool in ArcGIS automatically chooses the best location of the feature. This labeling tool is beneficial to picture the variating (spatial) risk elements compared to traditional tabular information.

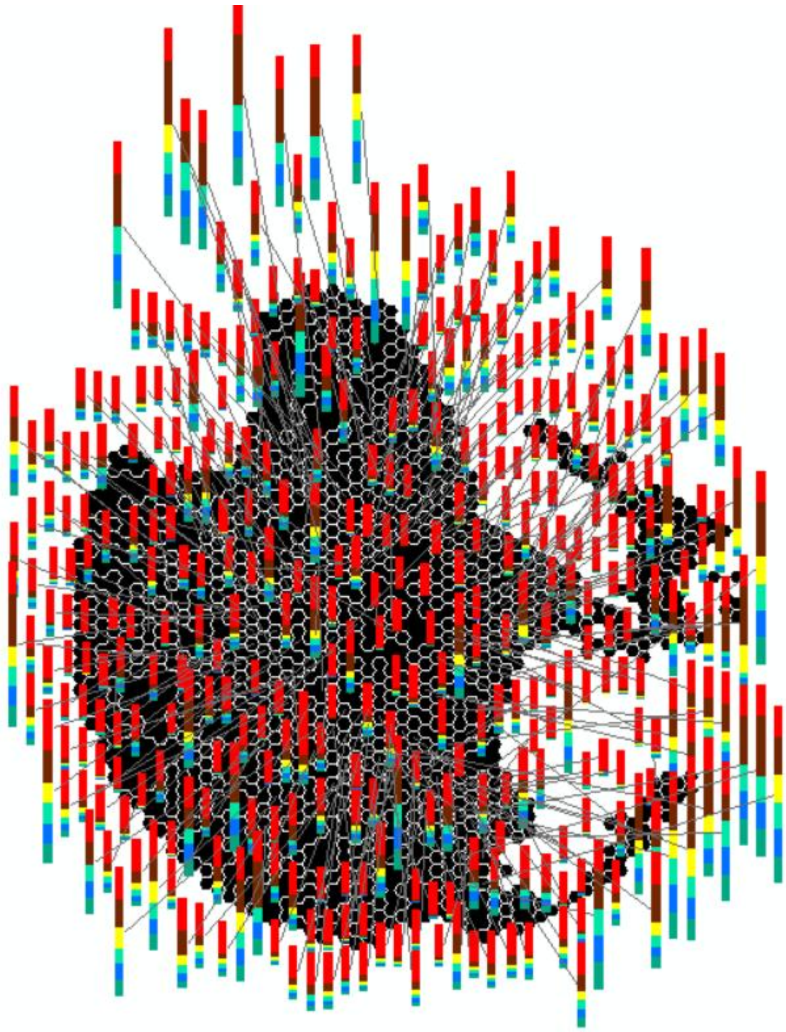

Figure 15. Risk Elements Bin Map presents the placement of scored staked risk elements that were binned in every hexagonal polygon (cell) in the ArcGIS 10.8 platform

Risk Spatial Pattern Analyses and Quantification (Result)

The risk reality sampling covers the 25 km radial distance measured from the crater of Mayon, Albay. It has 154,160.14 hectares covering Legazpi City, Ligao City, Tabaco City, Daraga, Camalig, Guinobatan, Malilipot, Bacacay, and Sto. Domingo. With the ArcGIS spatial statistics tools mentioned above, the patterns were analyzed using Table 1, in which the overall z-score is 90.60 confidence level, having a p-value of 0.000000 or near zero which revealed that there is a less than 1% likelihood that this clustered pattern could be the result of random chance. This makes clear that the risk reality (in terms of hotspot and coldspot information) bell curve as shown in Figure 2 convey risk reality variants hinted at the absolute value of the largest z-score and the probabilities are small. (Abante, 2020) We are getting a statistically significant hotspot or a statistically significant coldspot, respectively (Abante, 2020).Figure 16 and Figure 17 present the 7,100

Ha are risk hotspots with a 95% level of confidence, and about 3,100 Ha are risk hotspots with a 90% level of confidence(Abante, 2020).

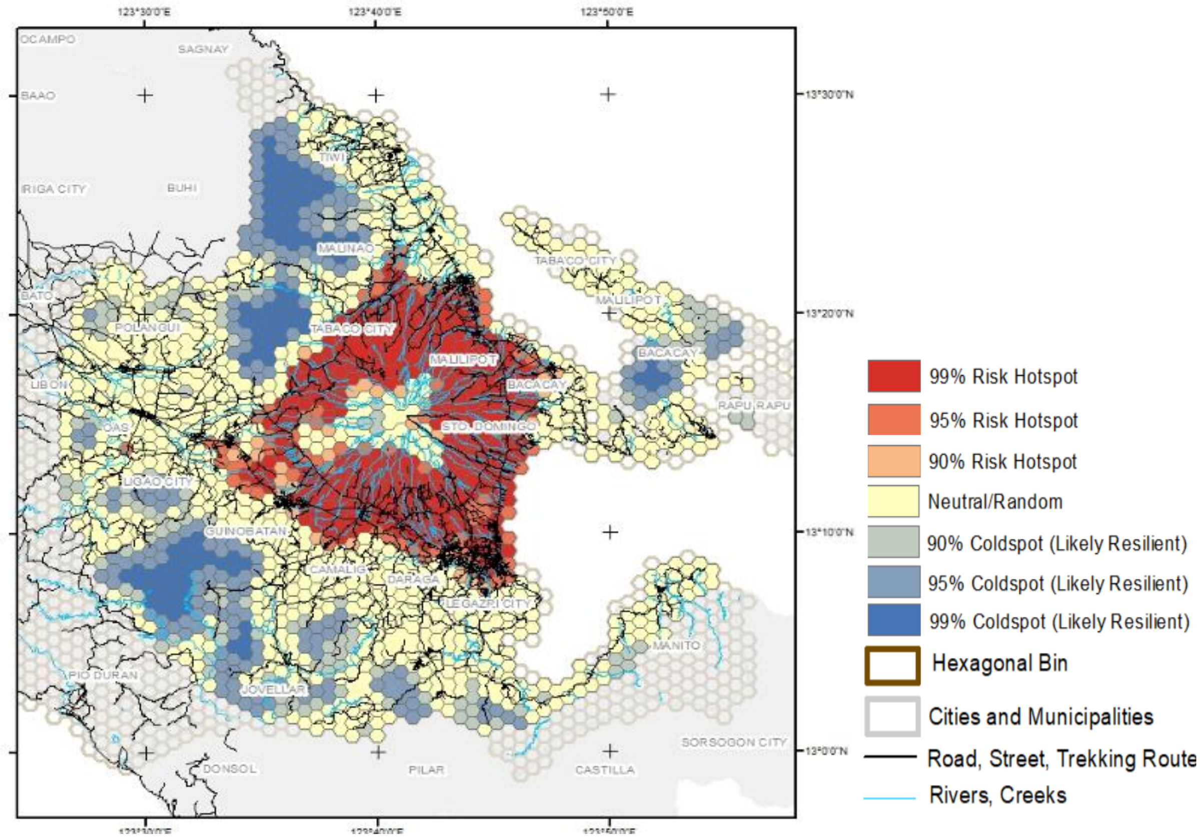

Figure 16. Risk Reality Bin Map presents the risk reality hexagonal bins which reveals the 29,400 hectares of land in Albay are risk hotspots with a 99% level of confidence.

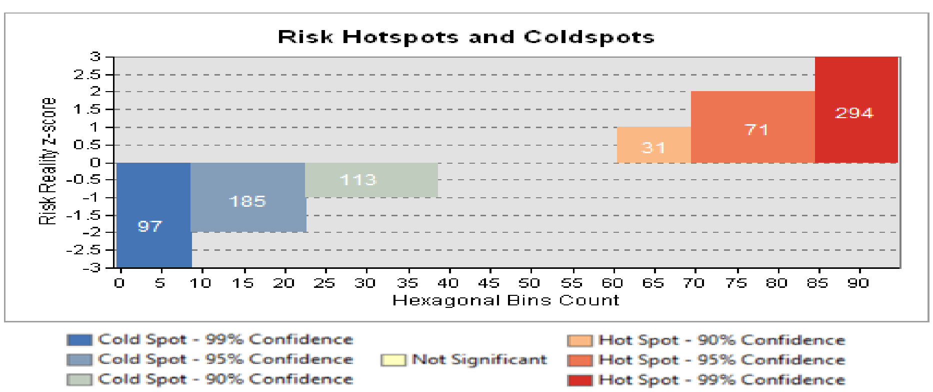

Figure 17. Risk Hotspot and Coldspot Graph presents the Risk Hotspots and Coldspots Hexagonal Bin Count for Albay Province

CONCLUSION AND RECOMMENDATIONS

The risk z-scores are regarded as the risk reality is the function (multiple hazards, landscape vulnerability, passive exposure, preparedness, competency, and coping capacity). The z-scores equal to one-unit risk constitute stability (state of balance) and any value greater than one-unit represents a risk hotspot contained in hexagonal bins mimicking the geographical aspects of the risk realness. This underlines the z-score for coldspot less than one-unit of risk hints at a resilience state. Although the author acknowledges the limitations of the spatial data modeling only accurate for 1:50000 scale input maps suitable for macro planning and rapid risk assessment, this study infers that the more detailed information and smaller hexagonal bins can lead to greater variations of risk and its elements. Moreover, the same hexagonal binning technique may be adopted for micro development planning or comprehensive risk assessment, or health risk and trend assessment and monitoring. The researcher concluded that disaster risk reduction entails interdisciplinary thinking to apply hexagonal to determine where the natural and man-made hazards, landscape vulnerable, and passive and active exposure hotspots or coldspots exist.

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