KARST SUBSIDENCE HAZARD MAPPING AND ASSESSMENT IN THE MUNICIPALITY OF DALAGUETE, PROVINCE OF CEBU

SEPTEMBER 2021

REPORT ON THE KARST SUBSIDENCE HAZARD ASSESSMENT IN THE MUNICIPALITY OF DALAGUETE, PROVINCE OF CEBU

I. INTRODUCTION

The Mines and Geosciences Bureau (MGB) of the Department of Environment and Natural Resources (DENR) has expanded its geohazard mapping and assessment program to include subsidence hazard due to sinkholes collapse in areas of the country that are characterized by karst topography. Sinkholes are one of the most common karst features in the world and are found in a wide variety of geological settings (Festa et al, 2012). They develop in "karst terrains" characterized by subterranean zones of carbonate or evaporite rocks that dissolve forming caves, springs, and sinkholes (Kaufmann, 2007). The presence of sinkholes in an area indicates that additional sinkholes may develop in the future. Man-made structures in the vicinity of sinkholes are at risk for structural damage unless they have been adequately designed.

Sinkhole collapse is now considered one of the most dangerous hazards in the country due to its extreme unpredictability. Collapse incidents could happen in a snap of a second or in a very slow rate of ground subsidence. But regardless of the rate of ground movement, this phenomenon has adverse impacts on the infrastructures and the community within the area affected.

The municipality exemplifies a typical karst landscape, a unique topography that develops in areas underlain by limestone. The beautiful sceneries of Osmena Peak, Kandungaw Peak, Casino Peaks, the cold waters of Obong Spring and the well-formed dripstones of Kulabyaw and the Eagle's Cave, among others are attributed to the underlying rock formation in the area. These sceneries are typical in areas underlain by limestone formed and developed through a complex geologic process erosion and dissolution over a long period of time. However, the presence of these features could also indicate the presence of a potential geologic hazard, sinkhole development and cave collapse.

Sinkhole identification is an important task considering the associated safety and economic risks, but it is not easy to determine since natural and anthropogenic activities can mask the development of these features. Therefore, effective sinkhole identification should integrate a variety of investigative approaches that include geological, geophysical, and geomorphological analysis (Gutiérrez et al, 2008).

Karst Subsidence Hazard Mapping and Assessment was undertaken in all thirty-three (33) barangays of Dalaguete, Cebu. Municipal Disaster Risk Reduction Management Office head, Mr. Junry D. Tenefrancia together with his Assistant DRRM Officer Ms. Merry Ann Q. Sefuentes and MDRRM responders assisted the team in the conduct of the survey and helped the team in the coordination and communication with all concerned barangay officials.

The activity was carried out to delineate areas that are susceptible to ground subsidence as well as map out the location of sinkholes and caverns within the study area.

II. LOCATION AND ACCESSIBILITY

The Municipality of Dalaguete is a 1st class municipality in the Province of Cebu. It is in the southeastern part of Cebu Island and is bounded on the north by the Municipality of Argao, on the west by the Municipality of Badian, on the south by the town of Alcoy, facing Cebu Strait to the east.

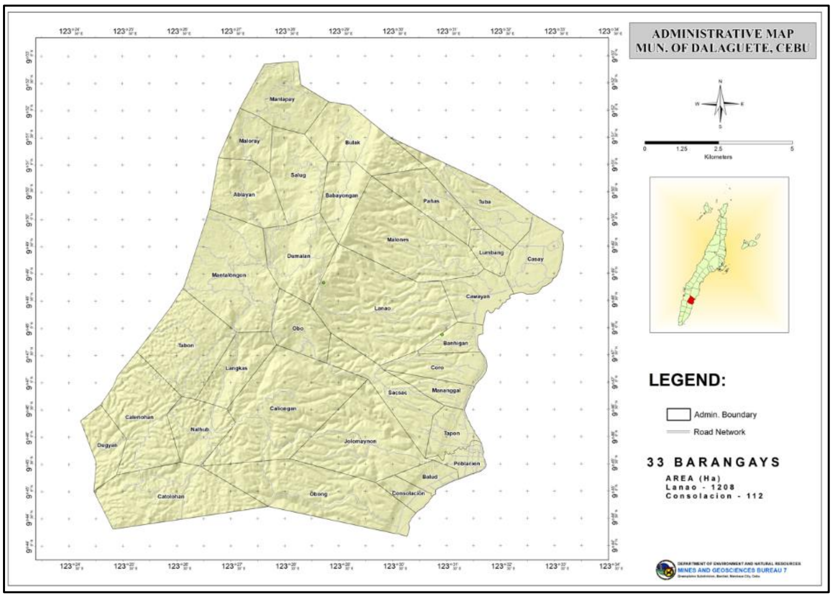


Plate 1. *Location Map of the Study Area*

It is situated approximately 80 aerial kilometers south of the province capital, Cebu City and could be reached by any land transportation through a well-paved National Highway, the Cebu South Coastal Road. Travel time from Cebu City usually takes approximately 3 hours by bus or other four-wheeled vehicles.

III. OBJECTIVES

The objectives of this assessment are the following:

- To conduct sinkhole inventory and ascertain the presence and location of these sinkholes and caves using geomorphological information.
- To determine the subsidence susceptibility of the study areas due to sinkhole and/or cave collapse particularly in the residential areas.
- Provide pertinent information and data regarding the geohazard condition of the area pertaining to Karst Subsidence Hazard.
- To conduct awareness campaign on sinkholes and other karst features, and issuance of threat advisories to LGUs relative to the hazards of subsidence due to sinkholes/caves collapse.

V. METHODOLOGIES

In pursuing the objectives of the assessment, a team from MGB 7 conducted karst subsidence hazard mapping (sinkhole assessment) along with rapid geologic verification of underlying rock formations and terrain appreciation. The proceeding discussions are the specific methodologies employed during the period, September 6 to 24. These includes the gathering of anecdotal accounts, interpretation of satellite data from the Interferometric Synthetic Aperture Radar (IFSAR) 2013 of NAMRIA, and conventional geologic/geomorphologic mapping.

Anecdotal Accounts

The undersigned conducted interviews with keypersons of the LGU, some barangay officials and residents in the area. This is to gather relevant information such as, but not limited to, status of water source, depth of water table, presence and locations of tension cracks, and location of hydrogeological pathways such as subterranean creeks, swallow holes, resurgent creeks, caves, and sinkholes.

Photo 1-2. *Local barangay officials, barangay police/tanods and residents provide information regarding the presence and location of some of the sinkholes and caverns in the area.*

Interpretation of Remote Sensing Data from IFSAR

Remote sensing has been used in karst studies to identify limestone terrain, describe exokarst features, analyze karst depressions, and detect geological structures important to karst development (de Carvalho,O.A., et.al., 2014). In this subsidence hazard assessment, the team used the available IFSAR- Digital Elevation Model (DEM) from NAMRIA, to determine the terrain attributes of sinks and pre-delineate possible locations and distributions of sinkholes based on elevation and sink depth. The Geological Information System (GIS) was utilized to obtain the morphometric attributes of sinkholes using IFSAR-DEM and the IFSAR-ORI data. Initial interpretation of remote sensing data was done prior to, and during the duration of geohazard/geological mapping on the ground. In this assessment, the IFSAR-DEM was utilized to segregate sink-depth range of 0-1 meters, 2-3 meters, 3-5 meters, 5-7 meters, 7-10 meters, 10-12 meters; 15-20 meters and 20-25 meters.

The IFSAR-DEM was utilized to segregate sink-depth range of 1 to 25 meters with aperture size of 50 – 100 meters. The wider range of sink depth and aperture size was considered in this assessment because of three (3) factors, a.) Varied geomorphic units, b.) Presence of three limestone formations of different age and physical characteristics and c.) Presence of lineaments due to tectonic events affecting the study area. These factors were found to have greater influence on rate of dissolution process and subsidence.

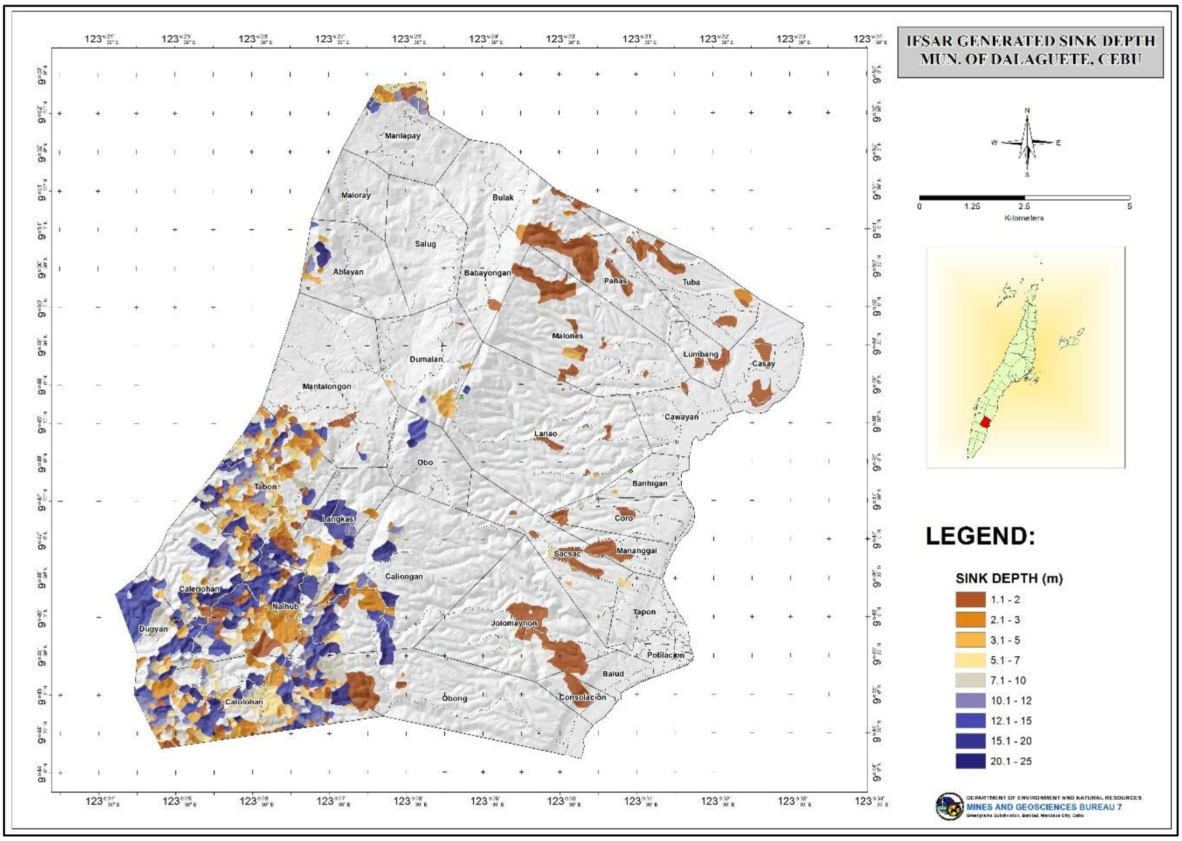


Plate 2. *Sink depth Map generated by processing IfSAR-DEM images using ArcGIS Pro used as one of the primary base maps. Color variation represents depth of depressions and gives initial information on the relative location and distribution of the sinkholes and natural depressions within the study area.*

Geological/Geomorphological Assessment

The conventional geological and geomorphological techniques were applied which entails gathering of field evidence to ground truth information obtained from the most recent remote sensing data available. The assessment includes the study of lithological characteristics and its vertical and lateral distributions, as well as to document the various karst features such as sinkholes, uvalas, karst caverns, swallow holes and underground rivers, including surface water flow directions. Their locations were obtained using the Global Positioning System (Garmin GPSMAP 78s), while the data gathered were plotted on an available base map generated from the Interferometric Synthetic Aperture Radar (IFSAR) 2013 of NAMRIA.

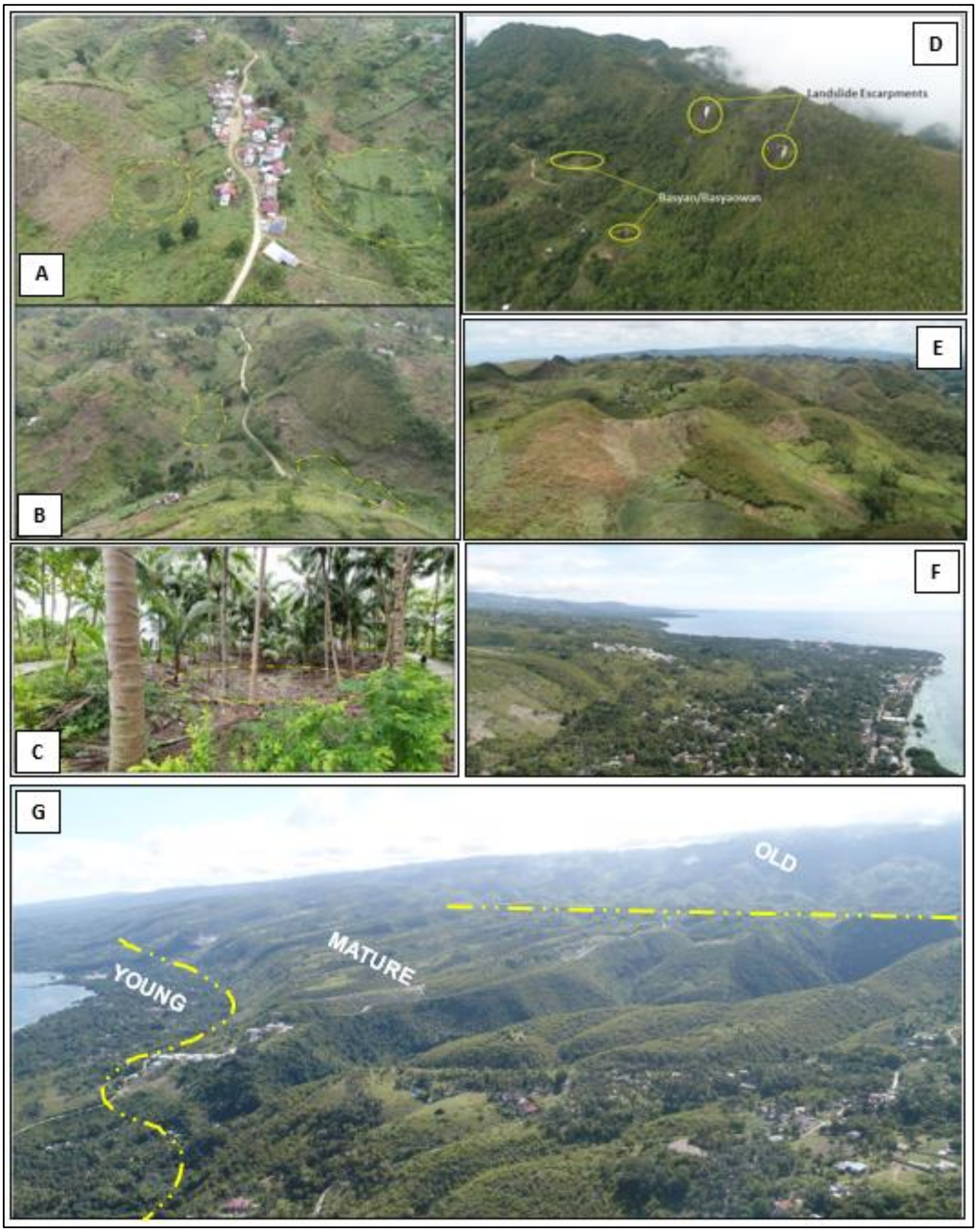


Photo 3-9 *(A-B) Cover Subsidence Sinkhole (yellow outline) along natural waterway (dry river). (C) Cover Subsidence Sinkhole along a wide flat plain. (D) Fault controlled limestone ridge in Barangay Bulak. (E) Isolated hills (cockpit karst). (F) Sharp/abrupt topographic changes indicating periodical uplift (uplifted reef). (G) Unique terrain according to the maturity of limestone rock formations.*

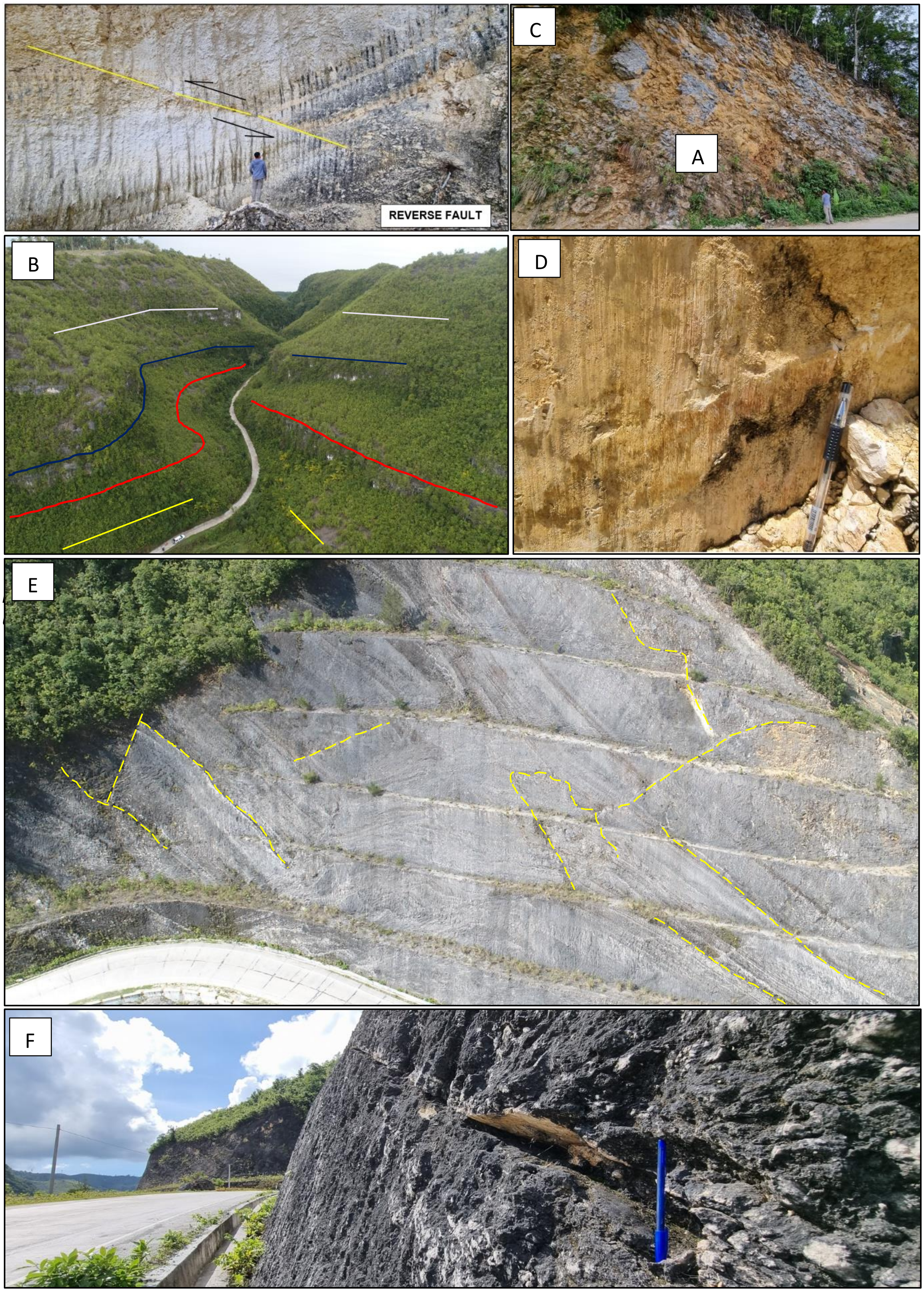


Photo 10-15 *(A) Reverse fault along abandoned quarry in Lanao. (B) Periodic exposure of underground river/drainage (multi-level cave system) in Barangay Obong. (C) Highly fractured, well bedded limestone exposed along road in Barangay Ablayan. (D) Fault striations noted on an outcrop exposed in Barangay Dumalan. (E) Notable sings of an impending slope failure indicated by presence of numerous cracks along a road exposed in Sitio Paling-paling. (F) Closer view of one of the cracks noted in Sitio Paling-Paling.*

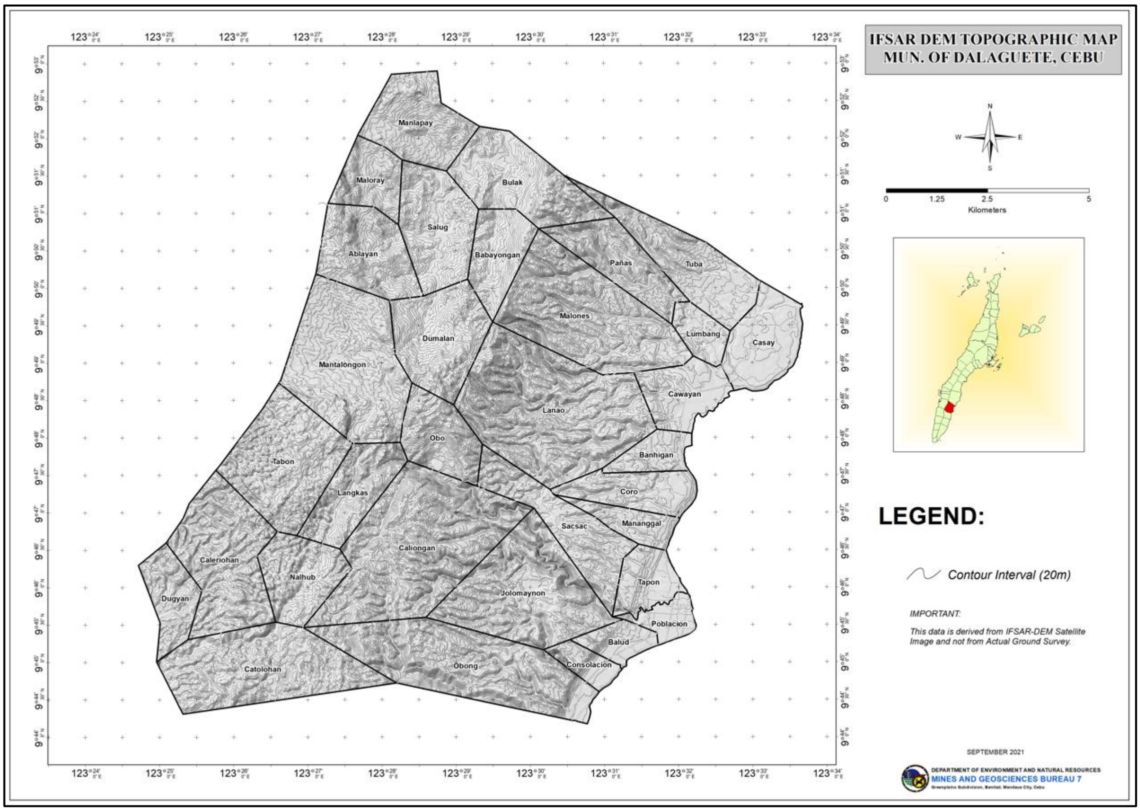


Plate 3. *IFSAR DEM Generated Topographic Map of Dalaguete, Cebu showing the relative topography and elevation of the study area.*

Information, Education and Communication (IEC) Campaign and Issuance of Threat Advisories

The IEC for karst subsidence sinkhole hazards awareness was conducted to the LME's, MPDO, MDRRMO and all concerned barangay LGUs covered by the assessment. It is deemed necessary that policymakers should be fully aware of these geohazards for their guidance in locating settlement/relocation sites, and in planning for rehabilitation of damaged critical infrastructures.

VI. DEFINITION OF TERMS

For better understanding of the proceeding discussion, the following are the definition of some geomorphic/geologic terms used in this report:

Caves	A hollow or natural passage under or into the earth, especially one with an opening to the surface
IFSAR-DEM	Interferrometric Synthetic Aperture Radar – Digital Elevation Model
Escarpment	It is a long, steep slope, especially one at the edge of a plateau or separating areas of land at different heights.

Karst	It is a comprehensive term applied to limestone and dolomite areas that possesses a topography peculiar to and dependent upon underground water solution and diversion of surface waters to underground route. The common features are sinkhole, uvalas, caves and subterranean rivers.
Karst spring or resurgence	A spring emerging from karstified limestone
Karst Valley	An elongate solution valley or a valley produced by collapse of cavern roof
Karst Window	Depression revealing a part of a subterranean river flowing across its floor, or an unroofed part of a cave
Land Subsidence	The lowering of the land surface. Subsidence can occur rapidly due to a sinkhole collapse or during a major earthquake.
Limestone	It is a sedimentary rock which is primarily composed of grains made up of calcite and/or aragonite and minor amount of magnesium carbonate. It is usually made up of skeletal remains of calcareous organisms.
Sinkhole	Ground surface depressions that resulted when the subterranean voids weaken support of the overlying surface. Common when the underlying rocks are limestone, dolomites, or salt beds.
Subterranean river/creek	A river or creek that runs wholly or partly beneath the ground surfaces.
Swallow hole	A place where water disappears in a limestone region
Tension cracks	Extension fractures due to tensile stress.

VII. CLIMATE AND VEGETATION

There are four (4) climate types in the Philippines according to the Modified Corona system of classification. This system of climate classification was devised by Fr. J. Corona (1920), these are:

Type I Two pronounced seasons, dry from November to April and wet during the rest of the year.

Type II	No dry season with a very pronounced maximum rainfall from November to January.

Type III	Season is not very pronounced, relatively dry from November to April and wet in the rest of the year.

Type IV	More or less evenly distributed rainfall throughout the year.

Coronas classification is mainly based on rainfall characteristics using the average monthly distribution of rainfall over the archipelago. A dry month is one with less than 50 mm of rainfall but also considers dry a month having more than 100 mm of rainfall that comes after three or more very dry months.

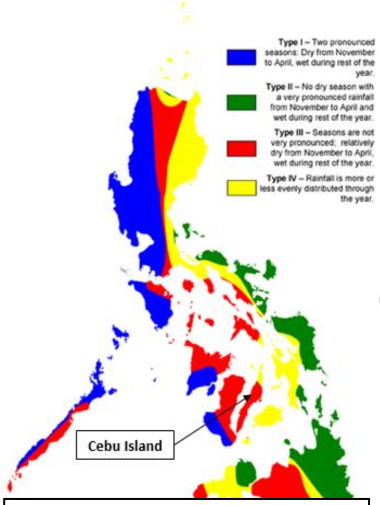


Plate 4. *Climate Map of the Philippines. (Fr. J. Corona, (1920)*

The climate of the whole island of Cebu is classified under two types: the Type III and the Type IV. The Type III covers the southern part while the Type IV covers the northern part **(Plate 4)**. This suggests that the southern municipalities/cities have no very pronounced season while the northern municipalities/cities have more or less evenly distributed rainfall throughout the year. The average annual rainfall in the island is 1636.7 millimeters.

The Municipality of Dalaguete is considered as the Vegetable Basket of Cebu Province for yielding massive crops and vegetable products. Vegetables are common along rolling hills while coconuts and secondary growth trees are commonly found on steep ridges/slopes.

VIII. GEOLOGY AND GEOMORPHOLOGY

GEOLOGY

Local Geology

In addition to the karst subsidence hazard assessment, the team also conducted rapid geological assessment in the municipality. Geologic Map modified from previous workers, BMG, 1985 among others is attached on this report.

Based on available geologic maps of MGB, the area is underlain by at least eight stratigraphic units, from oldest to youngest, namely: Cretaceous Pandan Formation; Oligocene Calagasan Formation; Late Oligocene to Early Miocene Butong Limestone Formation, Early to Middle Miocene Linut-od Formation, Early Pliocene Barili Limestone Formation and Pliocene to Pleistocene Carcar Limestone Formation. Descriptions in each stratigraphic units will be presented in this report. However, discussions will be focused on the three limestone rock formations namely Butong Limestone, Barili Limestone and Carcar Limestone Formations as sinkholes, caverns and other karst features only develop in these soluble rock units.

Cretaceous Pandan Formation

The Pandan Formation was originally described as a wide assortment of metamorphosed limestone, shale, and conglomerate, with occasional coal stringers named by Corby and others (1951) after the type locality at Pandan River, Barrio Pandan, Naga, near the Naga-Uling Road. The beds are greenish gray, highly contorted and steeply dipping. Aside from the limestone and clastic sequences, thick layers of thin bedded chert and pillow basalt intercalations were also mapped as part of the Pandan (Santos-Yñigo, 1951).

In the study area, this unit is observed cropping out along the upper reaches of Argao River in Barangay Salug. It is comprised of interbedded siltstone, sandstone and paraconglomerate chiefly composed of volcanic fragments with well-preserved quartz and hornblende.

Well bedded clastic sequence exposed along the upper reaches of Argao River in Barangay Salug, Dalaguete.

Oligocene Calagasan Formation

The Calagasan Formation was named by Barnes and others (1958) for the exposures of a thick succession of conglomerate, sandstone, mudstone and carbonaceous shale with interbedded limestone and coal at Barrio Calagasan, Argao. The basal beds consist dominantly of conglomerate with interbeds of coarse- to medium-grained sandstone. These grade into finer clastic rocks upsection. The conglomerate is dark greenish gray to yellowish brown with cobbly to pebbly subangular to subrounded clasts of andesite, quartz, indurated shales and chert with occasional jasper and dense limestone. The middle to upper components of the formation are predominantly sandstone and mudstone with sporadic lenses of limestone, coal beds and coal stringers. Coral- and orbitoid-rich limestone lenses are often set in sandy or shaly matrix. The sandstone is greenish gray, poorly sorted and carbonaceous while the shale is brown to dark greenish gray, thinly bedded, and carbonaceous.

This formation is observed in the northcentral part of Dalaguete occupying most of the areas of Barangays Dumalan, Ablayan, Maloray, Manlapay and western part of Barangays Babayongan and Bulak. In some areas, coal deposits were being successfully mined-out from this formation in the past.

Highly weathered, highly oxidized carbonaceous clastic sequence exposed along barangay road in Barangay Babayongan, Dalaguete.

Early Miocene Butong Limestone Formation

The Butong Limestone (Barnes and others, 1956) refers to the massive to thin bedded, white to light brown and yellowish gray, medium-grained crystalline, sandy, or shaly limestone outcropping in a narrow strip from Calagasan, Argao to Ablayan, Dalaguete. Abundant fossils, mostly small orbitoids, corals and algae may be found in the limestone. In places, interbeds of calcareous sandstone and shale are present.

Massive to well bedded crystalline limestone exposed along road near the boundary between Barangay Dumalan and Ablayan. This formation forms a narrow prominent ridge extending along the boundaries of Mantalongon and Dumalan towards west of Ablayan and Maloray. The massive limestone occupying the Kandungaw Peak belongs to this formation.

Early to Middle Miocene Linut-od Formation

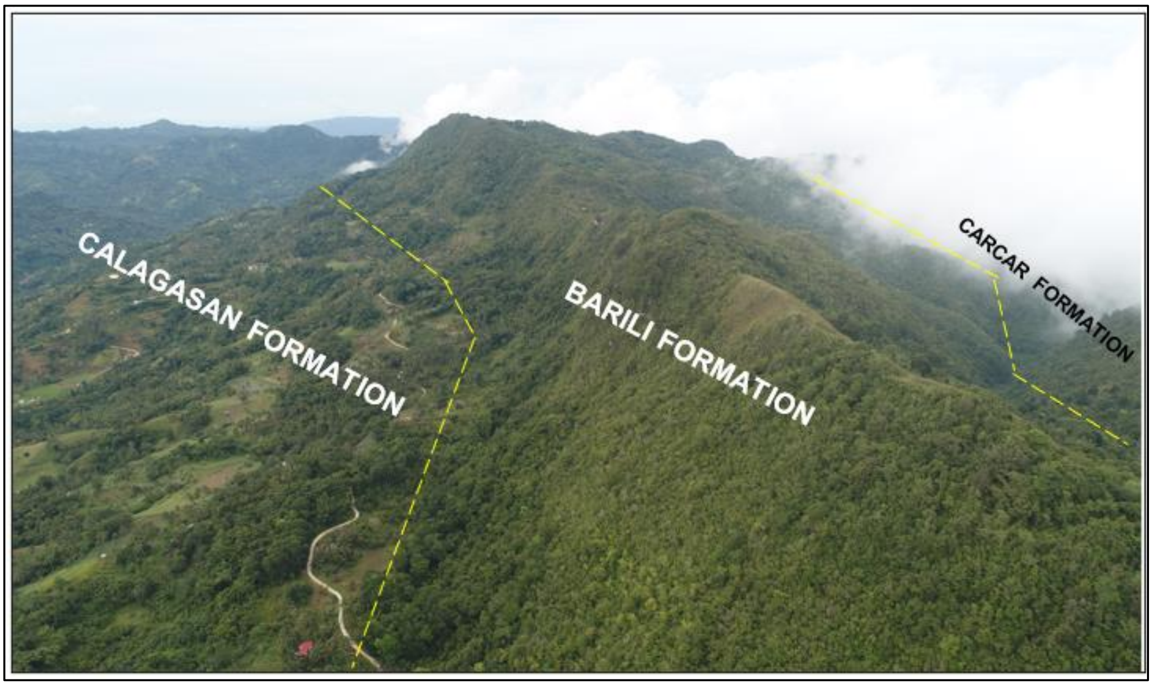
The Linut-od is another coal-bearing formation occupying most of the areas in Barangay Mantalongon. It was named by Barnes and others (1958) for the shale, sandstone and conglomerate with occasional coal beds exposed at Barrio Linut-od, Argao. It is almost lithologically similar to the Calagasan except that in this formation the shales and mudstones are more dominant. The coal beds of the formation are mostly located in the lower sections of the unit.

Clastic sequence with carbonaceous layer (dark brown) observed cropping out in Barangay Mantalongon along Dalaguete-Basac-Badian Road.

Early Pliocene Barili Limestone Formation

Corby and others (1951) originally named the rock unit after the town of Barili in southern Cebu. The designated type locality is along the Carcar-Barili road between Sibonga anticline in central Cebu and the town of Barili. Exposures have been observed near the center of the island and persist south to Ginatilan. The lower limestone member of the Barili is predominantly cream to buff, hard, coralline, locally porous or sandy and richly fossiliferous.

In this study, most of the sinkholes and caverns were observed in this limestone formation. It follows a narrow north-south trend extending from Barangay Catolohan to Tabon. While it terminates as it approaches the Linut-od Formation in Barangay Mantalongon, it persistently extends from Barangay Obo to Barangay Bulak forming a narrow sliver between Carcar Formation and Calagasan Formation.



Barili Limestone formation observed to conspicuously towers as a long, narrow ridge in Barangay Bulak.

Pleistocene Carcar Limestone Formation

Carcar Formation is a transgressive limestone of Pliocene to Pleistocene age confined in the lower flanks of the island ridge and covers almost all the coastal areas of the Cebu Island. This formation is composed of porous, coralline, poorly bedded to massive and fossiliferous limestone. It is usually hard and generally cavernous in nature.

In the study area, this formation is dominantly massive, coralline, and in some places, rubbly to conglomeratic. Limestone exposures along roadcuts show poorly bedded, cream to buff, clastic materials with minute fossil fragments.

Uplifted coral reef fringing along the eastern part of the municipality is the Carcar Limestone Formation. (Inset) Cavernous coralline limestone exposed along a rocky coast in Barangay Coro.

Quaternary Alluvium

Unconsolidated deposits of clay, silt, sand to boulder sized fragments of clastic and limestone rocks derived from older formations. These are common along river channels and coastal plains, sometimes as valley fills and as mantles resting immediately below ridges and hills.

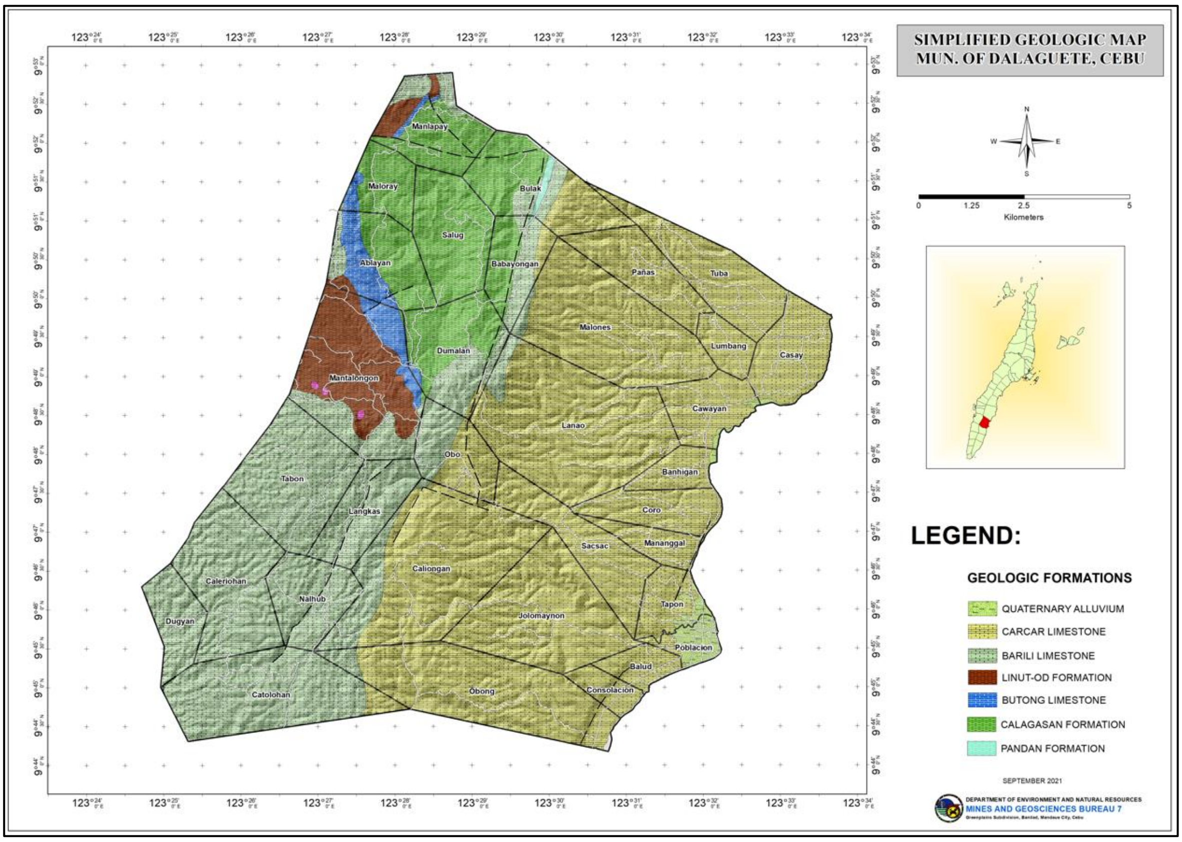


Plate 5. Simplified Geologic Map of Municipality of Dalaguete, Cebu. Modified from BMG, 1995 among others.

GEOMORPHOLOGY

The Municipality of Dalaguete and its topography shows great evidence of having been modified in shape by denudation and dissolution processes. Caves, springs subsurface river and isolated peaks and stone towers are some of the natural features that make the municipality attractive to local and foreign tourists. The general topography is hilly to undulating and in many places the ridges abut the sea forming steep cliffs of limestone. Unique isolated hills typical in mature karst land can are common in the area particularly in areas underlain by Barili Limestone and Butong Limestone Formation. Numerous creeks/rivers traverse the municipality; however, these are usually dry except during heavy downfall or during typhoons as numerous depressions/sinkholes have developed along natural waterway believed to be connected to a subsurface conduit/underground river. Dalaguete River is the major river system draining the municipality. It is a perennial river fed by numerous springs draining in a southeast direction. The peaks in Barangay Tabon and Ablayan marks the highest points in the Municipality reaching an altitude of 1020 meters above sea level. The South Cebu Fault System is an active fault system in the area that runs a north-northeast-south-southwest trend cutting traversing on the central part of the town.

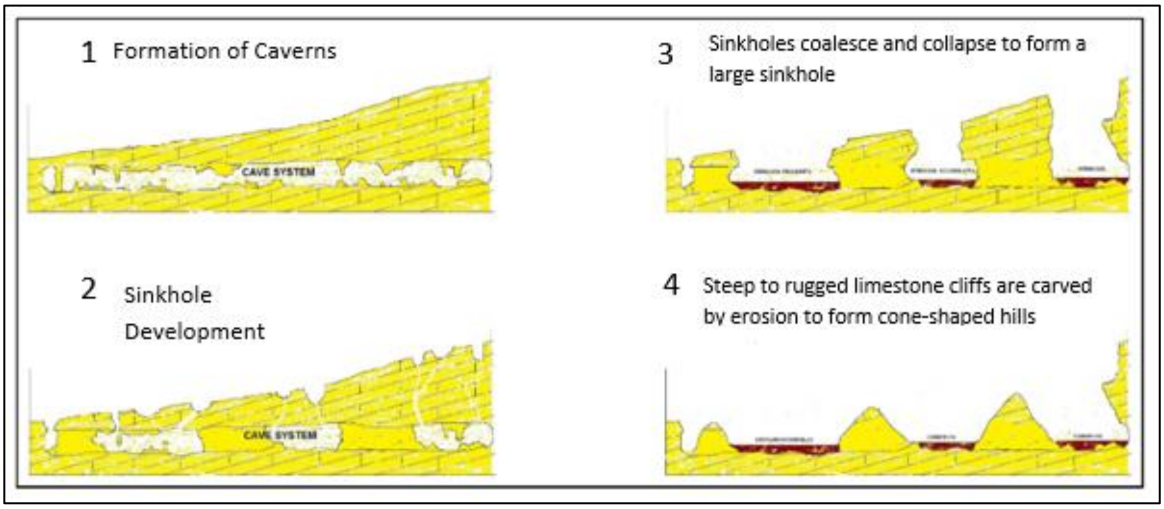


Plate 6. Diagram showing the series of events that led to the formation of wide sinkholes/uvala (commonly utilized as croplands) and conical hills in the Municipality of Dalaguete

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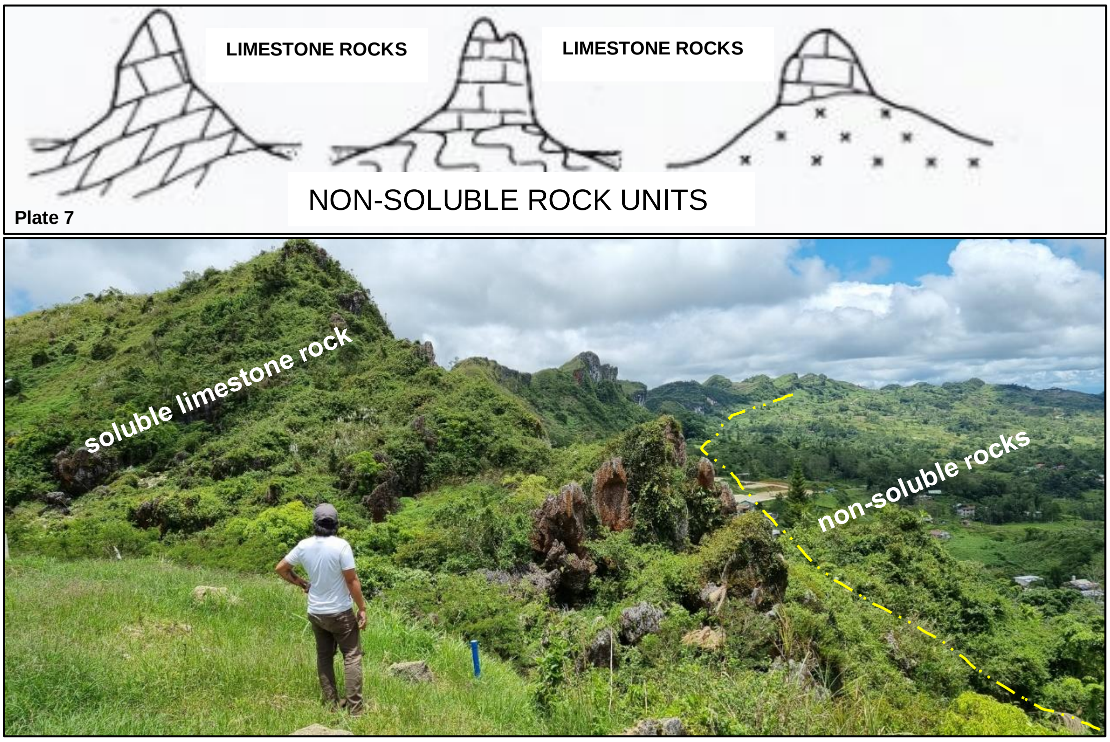
Isolated cone-shaped hills in Dalaguete.



Rock disparities displaying different terrains. Soluble rock formation (Barili Limestone Formation) forming karst towers and limestone cliffs overlying a non-soluble rock (clastic sequence of Linut-od Formation) in Barangay Mantalongon. Relative boundary/contact between the two rock formations is indicated by yellow dashed line.

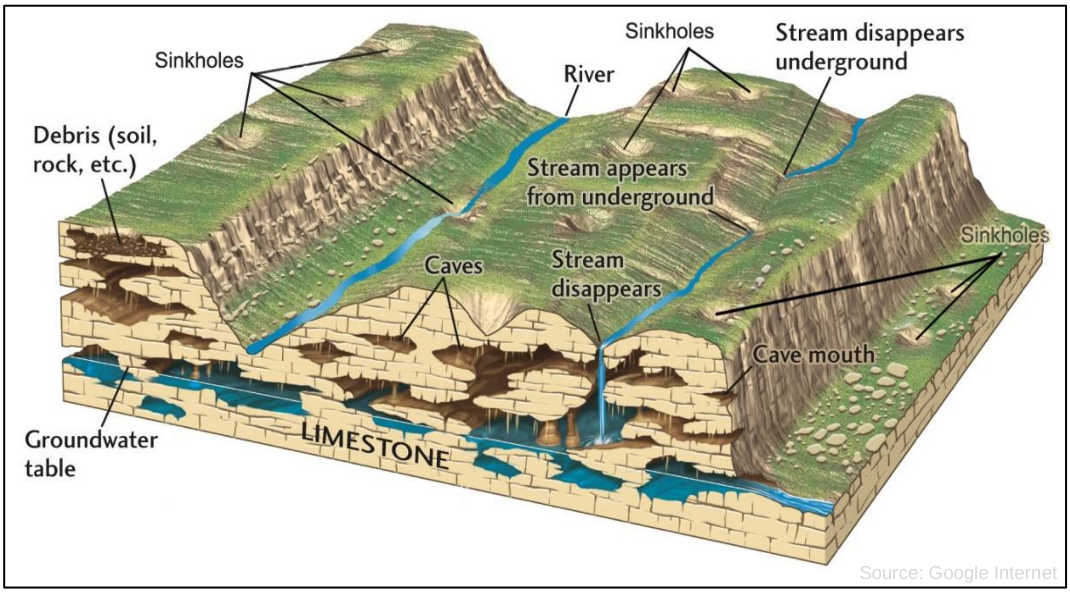
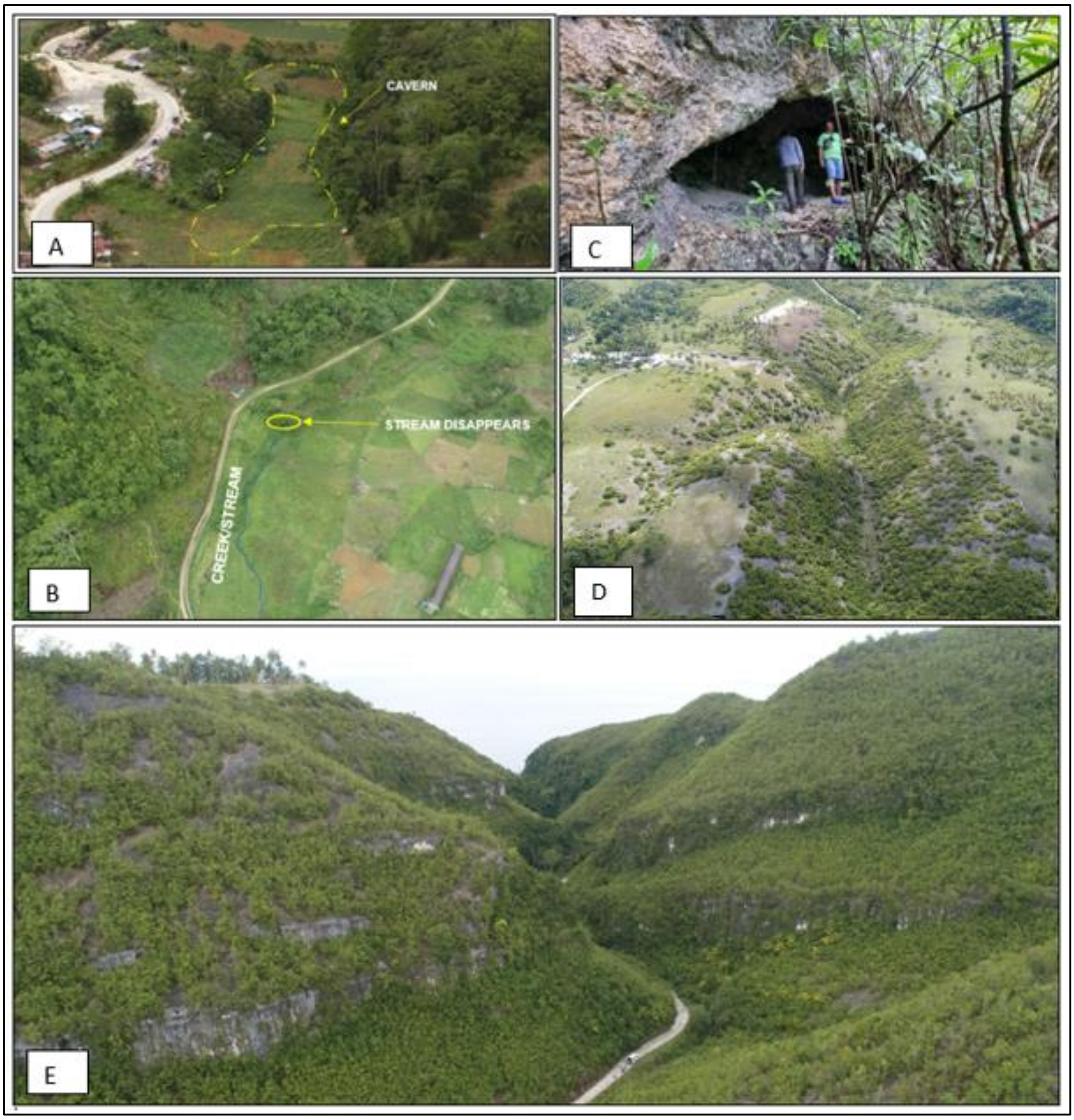


Plate 8. 3D Cross-section showing karst features typical in areas underlain by limestone.



(A) Sinkhole along a natural waterway (streamsink) in Barangay Langkas. (B) Disappearing Stream in Barangay Nalhug. (C) Cavern along ridge slope in Barangay Banhigan. (D) Dry creeks and river IN Barangay Coro. (E) Marginal cliff indicating periodic collapse of subsurface drainage/underground river.

IX. KARST SUBSIDENCE HAZARDS AND SUSCEPTIBILITY IN THE MUNICIPALITY OF DALAGUETE, PROVINCE OF CEBU

Subsidence is the lowering of the land surface due to sinkhole and cave collapse or during a major earthquake. Sinkholes are common and natural feature of a karst landscape, but the hazards it will cause to lives and properties has yet to be known and understood by concerned LGUs and communities. Karst subsidence is often associated with collapse of cover-subsidence type sinkholes. These are sinkholes that develop gradually and may remain undetected for over a long period of time. The covering sediments or overburden is usually permeable or sandy soil materials. Commonly, subsidence in sinkholes will start as hardly noticeable ground settlement or depression less than a meter deep.

However, slow surface subsidence may be a precursor to imminent failure on a larger scale. Subsidence may be very slow or very fast wherein damages can be low to catastrophic.

Large areas in the municipality are susceptible to subsidence because of three (3) factors, namely: I.) presence of soluble carbonate rocks in the three sedimentary rock formations that underlies the municipality *(Butong Limestone Formation, Barili Limestone Formation, Carcar Limestone Formation),* 2.) Presence of large tension cracks, faults/lineaments, and 3.) Climatic conditions that favor caves and sinkholes formations.

Past tectonic events and the presence of active South Cebu Fault within the study area may have contributed to the present condition on the ground subsidence hazard in Dalaguete. Cracks and fissures served as conduits that hasten the subsurface erosion and dissolution activity on the limestone bedrock which resulted to the presence of numerous caverns, which eventually led to ground subsidence or sinkhole collapse.

Majority of the sinkholes observed and assessed by the undersigned are the cover-subsidence type and cover-collapse sinkholes. These sinkholes become almost a permanent feature of the natural landscape in most barangays. However, they always have the potential of renewed activity, especially that some of the cave systems have been affected by the 2012 Negros Earthquake and the 2013 Bohol earthquake. Sinkholes can develop almost anywhere in areas underlain by soluble limestone rocks and subsidence could happen without any warning.

The western part of the municipality with the exception of Linut-od Formation in Barangay Formation rest on an old limestone rock, the Barili Limestone and Butong Limestone Formations that had undergone intense weathering, erosion, and dissolution. The sinkholes in these areas are relatively larger, wider with smoothed surfaces compared to those that are present on Carcar Limestone Formation. This may suggest that the area had experience ground subsidence in the past either abrupt or gradual as indicated by the presence of the conical hills which are remnants of an old subsidence and sinkhole collapse events. The flat plains utilized as rice fields and croplands were once a rugged terrain with numerous small sinkholes. Through time, these smaller sinkholes merged and coalesced to form a larger sinkhole forming wide plains where soil and other earth debris accumulates during run-off. The walls of the sinkholes were carved by erosion forming perfectly coned-shape hills. Fortunately, this thick accumulation of soil and the flat terrain favors crop plantation which allow locals to find their living. However, water supply in these areas is relatively low to none, due to presence of subterranean drainage resulting to dried-up streams and rivers. Local farmers greatly rely on rainwater and few spring water source. Recent discovery of underground river systems (uncovered) greatly helped in supplying potable water and waters for irrigation.

The sinkholes noted in Barili and Butong Limestone Formations are utilized as crop lands rather than settlement sites. In this case, the threat for ground subsidence to the populace is lesser. Nonetheless, vigilant monitoring is still advice in case of an impending ground collapse indicated by the presence of tension cracks, bulging ground and subsiding land. Moreover, roads traversing in these areas should be monitored as heavy loads aggravates subsidence or ground collapse.

Sinkholes may also develop in areas underlain by Linut-od and Calagasan Formation but with a minimal occurrence due to the presence of non-carbonate rock component. Formation of sinkhole may be gradual and cave development may be confined on the carbonate rock. Nonetheless, the undersigned recommends that residents and barangay officials should immediately report any indications or signs of ground movement or ground subsidence. In case of sinkhole collapse, report immediately to the Municipal Disasters Risk Reduction Management Office of Dalaguete for appropriate action. Please refer to the attached Geologic Map for the rock formation distribution.

The Carcar Limestone is a young coral reefal limestone that have been subjected to periodic uplift indicated by marginal coast (marine terraces) and marginal cliffs noted along narrow karst valley. This young coralline Limestone is a raised coral reef that is highly porous and cavernous. Numerous caverns and sinkholes were also noted in these areas. Some of these are noted near residential areas and traversed road networks. Some caverns were also noted to be present directly below structures and buildings. Moreover, typical in these areas are dry rivers and creeks, uniformly oriented rivers and ridges and deep ravines and gorges.

Ground validated, inferred and sinkholes based on satellite images were presented on the Sinkhole Distribution Map attached in this report together with the Karst Hazard Susceptibility Map of Dalaguete. Summary of findings in the form of threat advisories are also provided on a separate document. Finally, table showing the locations of sinkholes and caves and other relevant data will also be attached in this report.

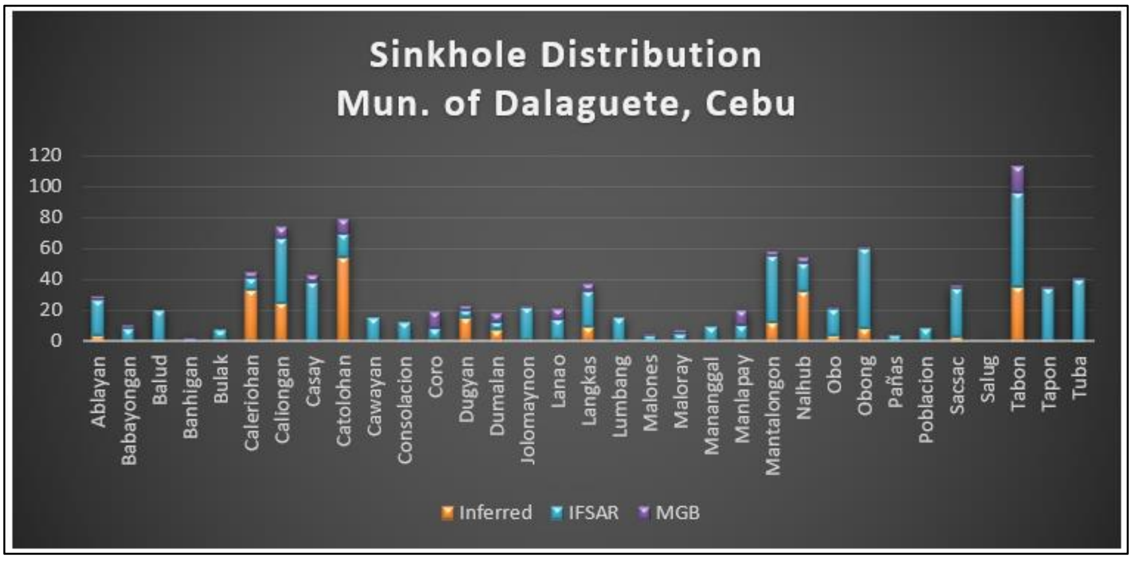


Plate 9. *Graphical presentation of Ground validated, Inferred and Sinkholes Based on Satellite Images and Maps delineated in each barangay.*

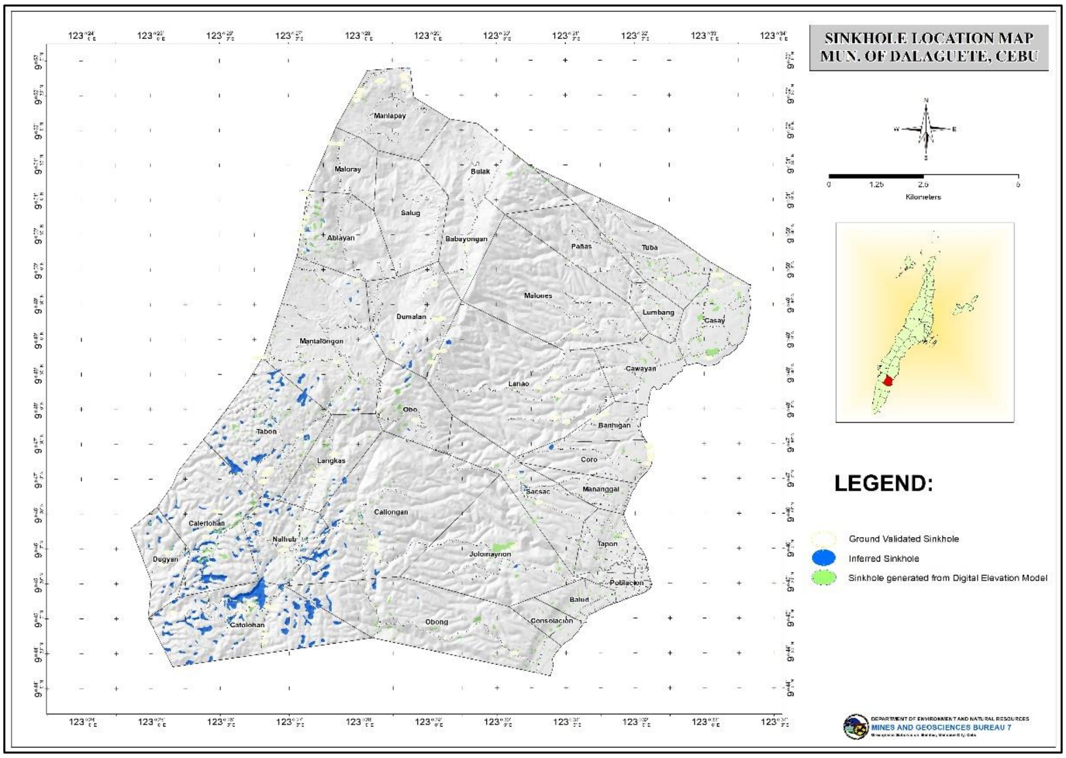


Plate 10. *Sinkhole location and Distribution Map showing sinkholes delineated through actual ground validation, inference (geologic interpretations) and based on available NAMRIA Topographic Maps and IFSAR DEM Satellite Images.*

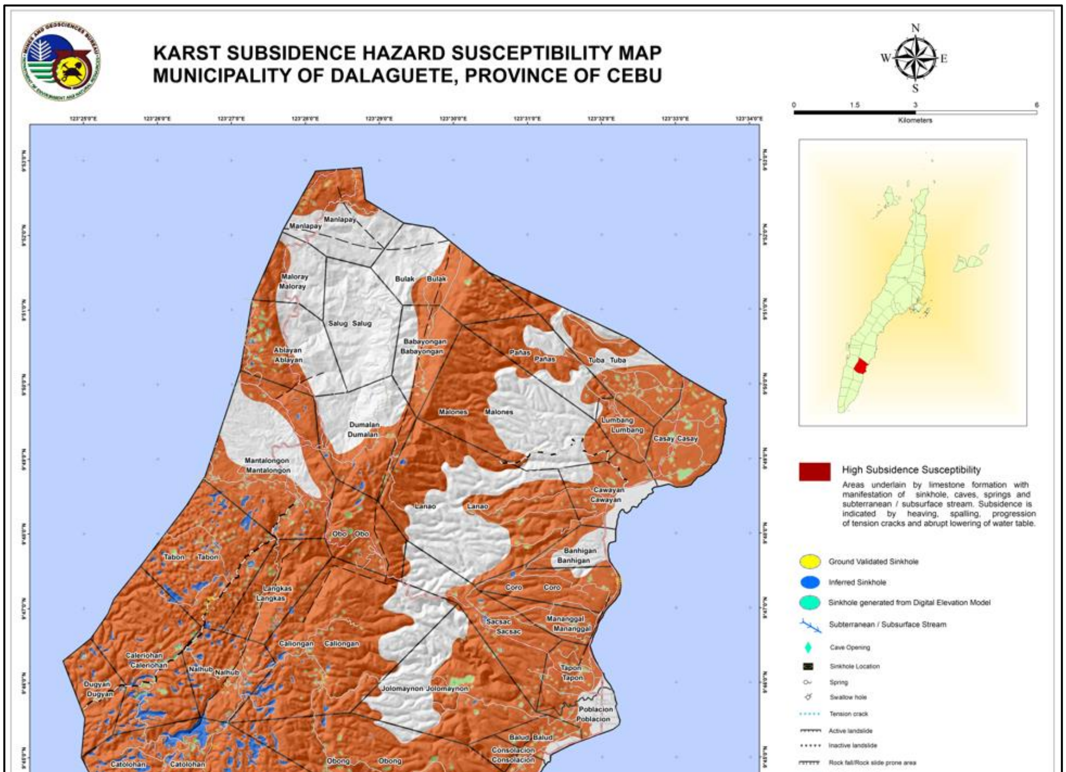


Plate 11. *Karst Subsidence Susceptibility Map of Municipality of Dalaguete, Province of Cebu.*

X. RECOMMENDATIONS

Based on the result of the assessment, the following are the recommendations:

1) Vigilant monitoring of signs of sinkhole/cave collapse, and subsidence in the areas identified on the subsidence susceptibility map (Plate 9 and 10) by concerned barangay officials. Monitor presence of tension cracks that are widening and/or progressing, and circular ground depressions that are subsiding, especially every after heavy rainfall and flood events. Report the same immediately to municipal authorities/MDRRO.
.
2) Extra vigilance by residents during heavy, continuous rains brought by typhoon or monsoon rains, especially if areas with identified sinkholes are flooded. Divert run-off away from sinkholes. (Sinkhole Location Map).

3) In case of sinkhole and/or cave collapse, cordon off the area. Report situation to municipal authorities/MDRRMO. Do not cover sinkholes unless recommended by authority , especially if subterranean river or creek is noted beneath. This will result to ponding of subterranean river/creek and induce subsidence in the immediate vicinity.

4) Monitor displaced surfaces along national, provincial and barangay roads. Report situation to municipal authorities/MDRRMO. Limit the load capacity of vehicles passing on this type of road. Signages should be put up indicating the threat of subsidence. If possible, find alternative route to lessen the load brought by vehicles and heavy traffic.

5) Dwelling units should be made of light materials, two-storey concrete structure is not advisable in areas near sinkholes and cave system with spalling roof. Avoid infrastructure development on top of cover-subsidence sinkhole as these are usually covered with thick accumulation of soil and clay constituents and are susceptible to ground deformation and lateral displacement. Residents should be made aware of the hazards and signs of ground subsidence. Collapse incidents could happen in snap of a second or in a very slow rate. Collapse could be caused by lowering of water table, heavy rainfall, or earthquake.

6) For school sites with identified sinkholes and cave, it is suggested that further infrastructure development should be avoided to reduce the load of the unstable ground and slope, to ensure safety of school children, and to save on cost for mitigation measures. School authorities should look for alternative sites for expansion outside the present school campus.

7) Caves such should not be used as evacuation area during typhoons as their cave roofs are susceptible to collapses since the trees standing above the cave cover may trigger collapse when swayed intensely by typhoon winds.

8) Avoid disposing garbage and wastewaters to sinkholes and caves to prevent contamination of groundwater. Septic tanks should be well protected, and proper solid and wastewater management should be strictly implemented.

9) For rehabilitation and development of damaged structures and buildings, the concerned agency/office and LGUs should consult experts on rock and soil mechanics, foundation engineer, structural geologists, and engineering geologists. The subsurface condition and geological limitations should be considered in the design and cost of engineering interventions. For the meantime, it is recommended that warning signages should be installed to remind motorists of the presence of geologic hazards, decrease traffic load, and these roads/bridges should be closed during inclement weather condition.

10) Activate Barangay Disaster Risk Reduction and Management Council and establish an effective evacuation protocol. Evacuation and relocation sites as well as evacuation routes should be properly identified. Evacuation and relocation sites should be geologically assessed and suitable for the purpose.

11) Awareness campaign on subsidence hazards due to sinkhole collapse should be conducted to barangay officials and residents in Dalaguete.

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