Geomorphic Characterization of Bulakan, Bulacan and its Implications to the Proposed Land Use Development

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***Abstract*—** Implications to land-use development have been rapidly increasing as the cities in the country have been subjected to continuous urbanization. The municipality of Bulakan, Bulacan is one of those cities that has been continuously being eyed for different development programs. Bulakan is characterized as a floodplain in the north and a coastal plain in the south. Geomorphological characterization is done to delineate a geomorphological map of the area through QGIS v3.4 and ArcMap v10.8 to support and discuss through correlation the possible occurrences of geohazards such as flood and land subsidence in the study area. The results of the correlation showed that the municipality is at high risk in flooding and medium to high to medium risk in land subsidence if urbanization continues. Mitigating procedures such as regular monitoring, installing adequate drainages, and preventing construction of buildings in the high risks area are suggested. The research may be used in preparation for future planning and development of Bulakan, Bulacan as well as in the other areas with similar geology.
Keywords: implications, land-use development, Bulakan, QGIS, ArcMap, flood, land subsidence

I. INTRODUCTION

The Philippines is one of the countries in East Asia that is considered to be one of the fastest urbanizing countries (Baker et al, 2017). With the rapid urbanization happening in the archipelago, numerous infrastructures, as well as land developments, are being built to cope up with the increasing demand for development to provide for the needs of its citizens. In the municipality of Bulakan, Bulacan alone, 26,334 houses are built as of 2020 to house its 99,394 residents, as of the 2020 census, provided by the Comprehensive Land Use Plan and Zoning Ordinance Municipality of Bulacan. Rapid urbanization in an area means that land is converted for urban use and that an area is much more prone to geohazards. To have effective land use planning, geomorphological assessment and characterization should be done to help prevent geohazards.

Based on the existing land use map of Bulakan, Bulacan dated from 2000-2010 *(Figure 1)*, the built-up areas are scattered all around the municipality. Commercial and industrial areas are centered in Brgy. Tibig, Masantol, San Jose, Bagumbayan, and Sta. Ines. While in the proposed land use of Bulakan, Bulacan dated from 2010-2020 *(Figure 2)*, there has been a proposal by the municipality's LGU to divide the municipality into 4 sections: in the north part of Bulakan, industrial expansion, as well as retention of the agricultural area, is to be done; in the east part would be the built-up of commercial buildings as well as investing a hub in consideration with the solid waste management; in the west, fishponds, aquaculture, and

agricultural technology will be expanded; and in the south, purely agricultural for the fishing industry and coastal management will be done.

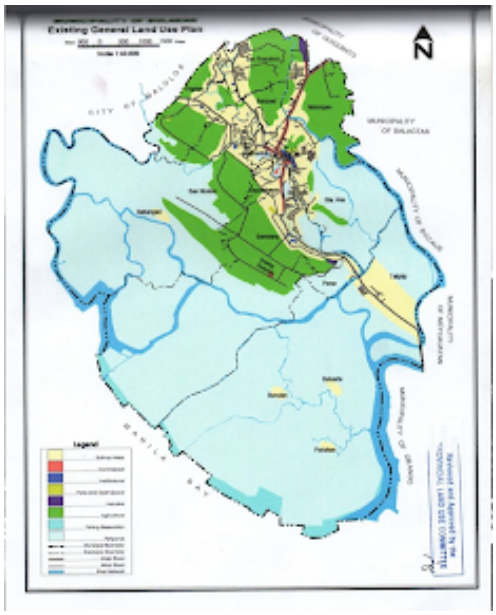

Figure 1. Existing General Land Use Plan of the municipality of Bulakan (Source: Housing and Land Use Regulatory Board)

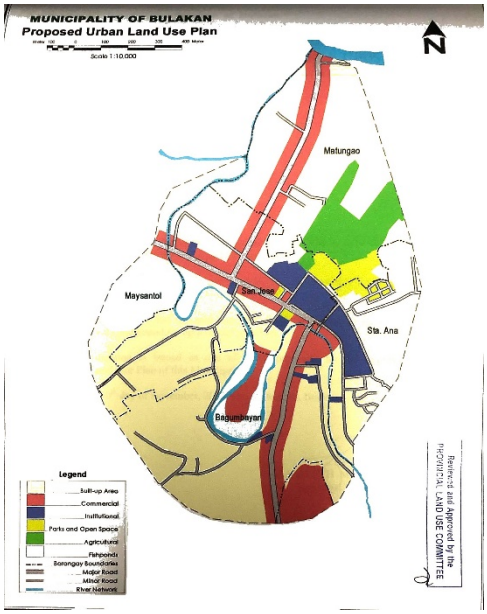

Figure 2. Proposed Urban Land Use Map of the municipality of Bulakan (Source: Housing and Land Use Regulatory Board)

The municipality of Bulakan is located on the western side of the province of Bulacan. The western part of Bulacan is mostly composed of alluvium or river deposits, and pyroclastic deposits, while the eastern part of Bulacan is mainly composed of volcanic remains such as volcanic agglomerates, Lumot volcanics, andesite basalt, and quartz diorite; sedimentary rocks such as crystalline/coralline limestone and Bigte limestone *(Figure 3)*. The whole municipality of Bulakan is located in the Pampanga River Basin which is composed mostly of consolidated

silt or clay, and poorly cemented sand and gravel derived from the Pleistocene Guadalupe Formation.

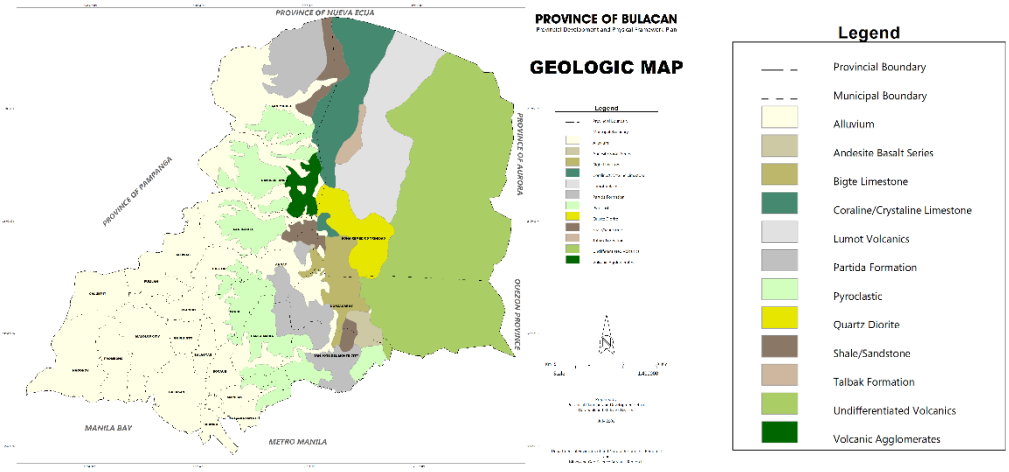

Figure 3. Geologic Map of the province of Bulacan (Source: Physical Development and Physical Framework Plan of the Province of Bulacan)

Lagmay (2011) stated that Bulakan, Bulacan continues to subside 4-5 cm every year, mainly due to haphazard and anthropogenic activities. Based on the geology of Bulakan, alongside oil/groundwater extraction that happens in the area, the compaction rates of the sediments are high, making the municipality susceptible to subsidence. In addition to land subsidence, since the area is a low-lying area and considered a coastal municipality, it is also prone to flooding. To prevent such geohazards, it is important to fully understand and comprehend the information provided by geomorphologic analyses of an area. Data obtained from these analyses can be used for sustainable and efficient land use planning, and proper hazard management.

This study was conducted to identify the different geomorphological features in Bulakan, Bulacan, and its implications on the proposed land use development plan.

The main objectives of this research are: (1) delineate and analyze the different geomorphological features of Bulakan, Bulacan and generate a geomorphological map of the area; and (2) correlate the updated geomorphological map with the existing flood, land subsidence geohazard map of the area, and provide recommendations on the proposed land use development of the area.

Geomorphic knowledge gives an in-depth understanding of how and why geohazards happen in a certain area. This study provides detailed information about the flood and land subsidence in Bulakan, Bulacan. Moreover, the findings of this study can be used in urban planning and can provide recommendations in the proposed land use development.

The study area only covers the municipality of Bulakan, Bulacan with geographical coordinates of 14°47′34″N, 120°52′44″E. This study focuses on determining the geomorphological features present in the municipality and producing a geomorphological map of the area. Map generation will be done by GIS software, and the detailed generated geomorphological map will be based on satellite photos, acquired maps from

the municipality of Bulakan, MGB Region III, and National Mapping and Resource Information Authority (NAMRIA), and field study done by the authors.

The study will only conduct geomorphological analysis only while correlating it with the existing hazard maps. While it was found that Bulakan, Bulacan is also susceptible to liquefaction, however in this research, the correlation for liquefaction is not done; this study will only focus on flooding and land subsidence geohazard. Furthermore, it is recommended to conduct follow-up research on liquefaction susceptibility in the area.

II. METHODOLOGY

Desk Study

A review of the related literature was conducted in the initial part of the study. Numerous books, scientific papers, and scientific journals were used as a reference to complete the study whilst the data obtained were gathered from different sources such as government agencies, and websites containing information related to the study. The references used were mostly related and focused on the geomorphology and the implications of flood and subsidence in the land use of a certain area.

Data Gathering and Preliminary Analysis

The researchers collected data from the National Mapping and Resource Information Authority (NAMRIA), Mines and Geosciences Bureau Region III (MGB), the Provincial Planning and Development Office (PPDO) of Bulacan, the Housing and Land Use Regulatory Board (HLURB) Region III, and the Comprehensive Land Use and Zoning Ordinance Office of the Municipality of Bulakan. Data collected include topographic maps, geologic map, land use map, and administrative map.

The Digital Elevation Model (DEMs) and Landsat images were obtained from the United States Geological Survey (USGS) website; the administrative boundary shapefile of Bulacan from the PHILGIS website; and the satellite images from Google Earth.

The topographic maps obtained from NAMRIA, land-use map from the Municipality of Bulakan, and satellite images from Google Earth were used as a preliminary basis in delineating the geomorphological features of the study area. The green-colored areas in *Figure 4* are floodplains, violet-colored areas are agricultural areas and the blue-colored areas are rivers.

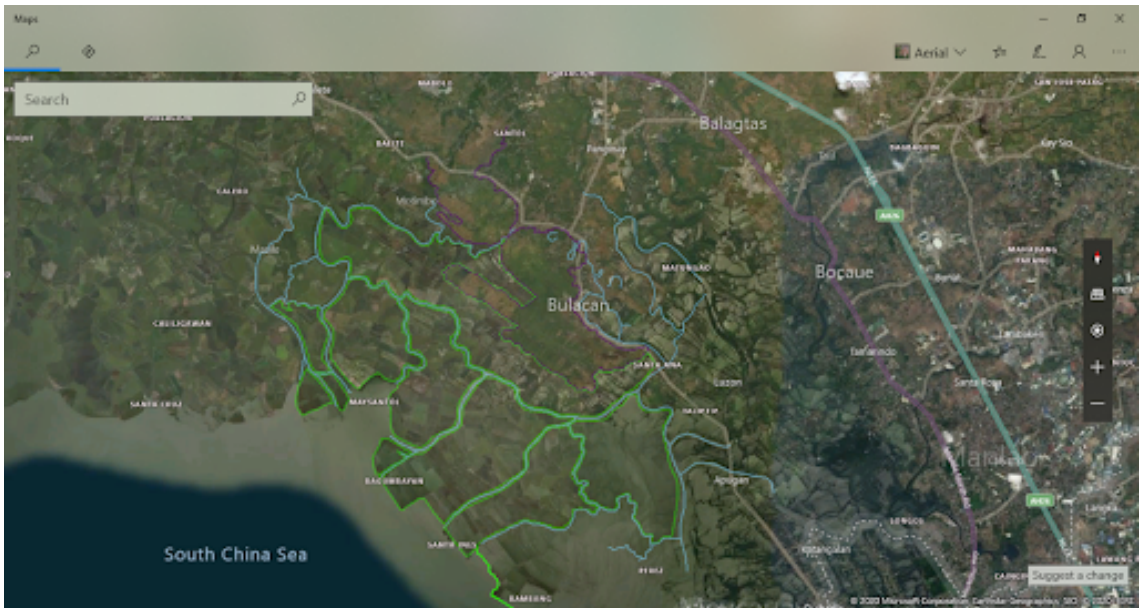

Figure 4. Preliminary analysis of the geomorphological features of the study area using satellite images

Data Processing

Field Surveying

On March 12-13, 2020, the researchers went around Bulakan for field verification. The researchers found geomorphic features that were not observed during the preliminary analysis such as oxbow lakes and tidal flats with forests/vegetation. However, due to the imposed Enhanced Community Quarantine (ECQ) in Luzon, the researchers were not able to continue conducting ground-truthing, so they solely relied on satellite images, street view images, and the collected secondary data for the remaining areas.

Generating a Geomorphological Map

The satellite image and the topographic map of Bulakan were georeferenced in QGIS. The administrative boundary shapefile of Bulacan from PHILGIS was used to clip the boundaries of Bulakan, Bulacan since there were no available shapefiles for the municipality *(Figure 5)*. The layers in QGIS and the SHP Files were reprojected to the WGS 1984 UTM Zone 51N coordinate system.

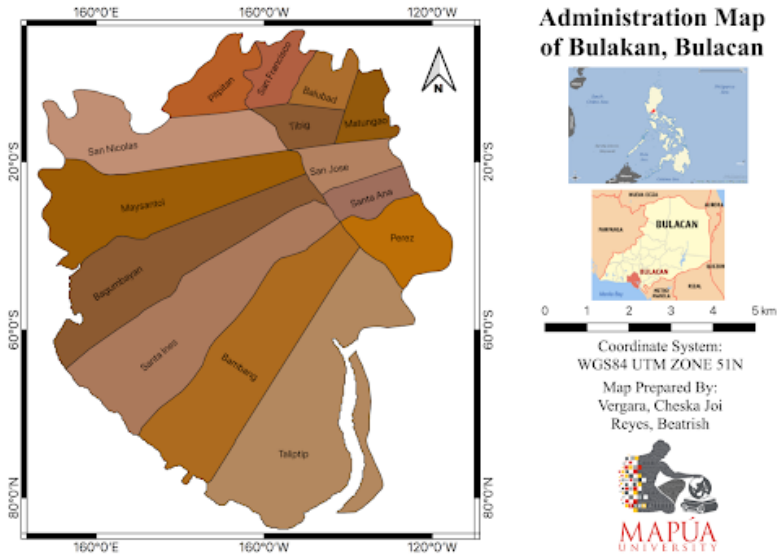

Figure 5. Barangay boundary map of the study area

With the obtained DEM from USGS, hillshading was done to enhance and further see the topography of the area. Moreover, the researchers used the contour function of QGIS to determine the elevation of the area. At first, the researchers tried to contour with a 50-meter interval, but it doesn't show much since the area is mostly flat, so a 10-meter interval was used. Elevation *(Figure 6)* and slope *(Figure 7)* maps of the study area were also generated using 3D analyst tools in ArcGIS to further analyze the terrain of the area.

Since the study area is considered a coastal municipality, the researchers also tried to distinguish the water bodies from the land areas through image classification using Landsat 8 in ArcGIS. The result helped the researchers identify the accurate perimeter or area of the wetlands and the landmasses.

The delineated and verified geomorphic features were digitized and generated as a vector file in QGIS to produce the geomorphological map *(Figure 18)*.

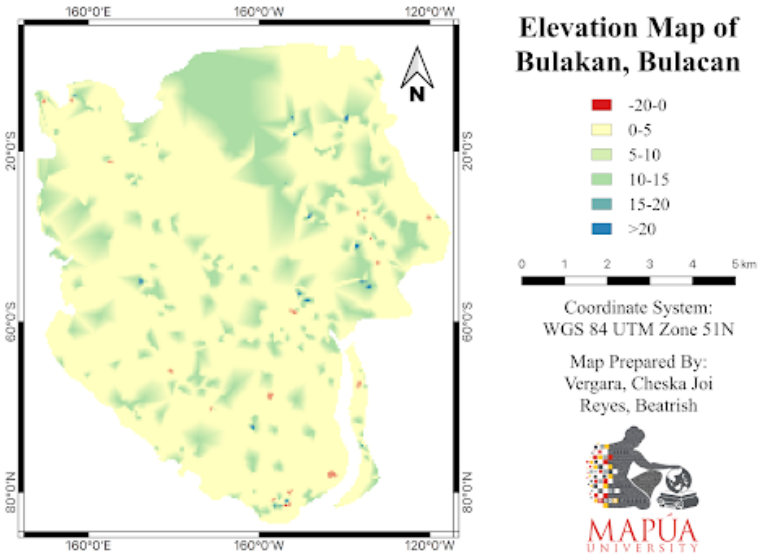

Figure 6. Elevation Map of the study area

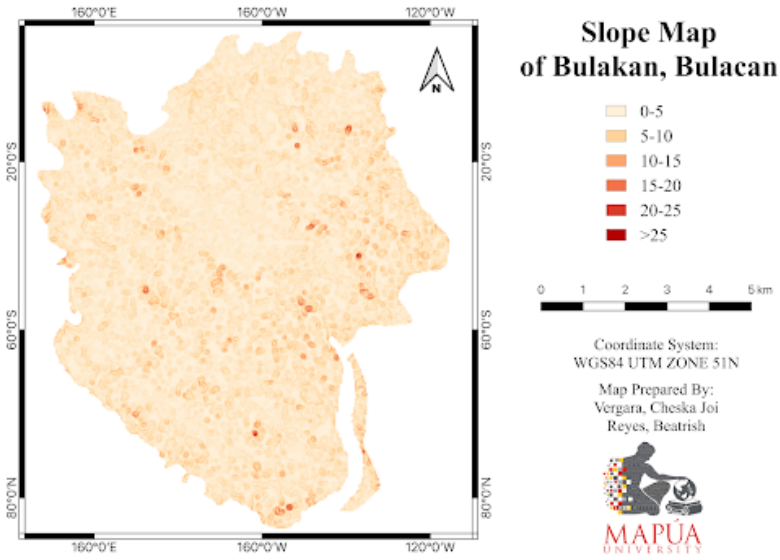

Figure 7. Slope Map of the study area

III. RESULTS AND DISCUSSION

GEOMORPHOLOGICAL UNITS

Most of the geomorphological features observed in Bulakan, Bulacan are coastal and fluvial landforms such as floodplains (vegetated and non-vegetated), tidal flats, oxbow lakes, and point bars.

River Channel

Meycauayan River has two major tributaries upstream: Bulacan River and Bambang River. The Bambang River is situated in the coastal area in the southern part of Bulakan; while the Bulacan River is in the eastern part of Bulakan. Other river channels in the area include the Guiguinto River and Balagtas River that are situated in the northern part of Bulakan; Matimbo River, Taliptip River, and Capiz River on the western part; and Sta. Ines River and Alipit River on the central part.

Meycauayan River is a meandering river, and it flows out to the Manila Bay. The Pulong Gubat Creek is also a river channel feature that is found on the boundary of the municipalities of Bulacan, Balagtas, and Guiguinto.

Figure 8. An actual picture and satellite image via Google Earth of Sta. Ines River traversing the whole municipality of Bulakan, Bulacan with coordinates: 14°46'5.28"N, 120°53'45.03"E

Figure 9. An actual picture and satellite image via Google Earth of Bulacan River traversing the Municipality of Bulakan to the Municipality of Obando with coordinates: 14°45'8.77"N, 120°54'36.38"E

Floodplain (non-vegetated)

Floodplains- both vegetated and non-vegetated- mostly make up the municipality of Bulakan. These are the areas most prone to flooding. Fishponds in the area are established on the non-vegetated floodplains.

Figure 10. An actual picture and satellite image via Google Earth of the fishponds connected to the river with coordinates: 14°46'19.93"N, 120°53'35.06"E

Figure 11. An actual picture and satellite image via Google Earth of the fishponds connected to the river with coordinates: 14°45'27.23"N, 120°54'26.20"E

Floodplain (vegetated)

Other floodplains seen in the area are agricultural areas where different types of crops are planted.

Figure 12. Vegetated Floodplain in the area observed through Google Street View with coordinates: 14°47'12.40"N, 120°52'28.93"E

Coastal Plain

The southernmost part of Bulakan is a coastal area. Sitio Pariahan in Brgy. Taliptip was once a residential land but is continuously sinking due to land subsidence; houses and other infrastructures in the area are now nearly fully submerged in water.

Figure 13. An actual picture and satellite image via Google Earth of the famous sunken church in Brgy. Taliptip, Bulakan, Bulacan with coordinates: 14°43'49.80"N, 120°53'18.10"E

Tidal Flats with Vegetation

Along the coastal area of Bulakan are tidal flats with vegetation which are mostly mangroves.

Figure 14. An actual picture and satellite image via Google Earth of the mangrove areas prominent in the study area with coordinates: 14°43'28.45"N, 120°52'36.86"E

Oxbow Lake

Oxbow lakes seen in the area are formed from meanders of the Bagong Bayan River.

Figure 15. Actual pictures and satellite images via Google Earth of the oxbow lakes seen in the study area with coordinates: (1) 14°47'13.02"N, 120°53'12.57"E, (2) 14°47'26.07"N, 120°52'37.10"E, (3) 14°47'40.22"N, 120°52'21.51"E

Point Bars

Point Bars were seen in the area through satellite images. These geomorphological units have accumulated on the inside bend of the Bulacan River. Vegetated bars are also observed in the area.

Figure 16. Point bars observed on Google Earth with coordinates: (1) 14°45'12.35"N, 120°53'57.89"E, (2) 14°45'56.31"N, 120°54'52.68"E

Levees

Levees are natural or artificial embankment or dike, usually parallel to the course of the river. Levees help stabilize river flow, preventing flooding and erosion on its adjacent areas.

Figure 17. Levees along Capiz River

FINAL GEOMORPHOLOGICAL MAP OF BULAKAN, BULACAN

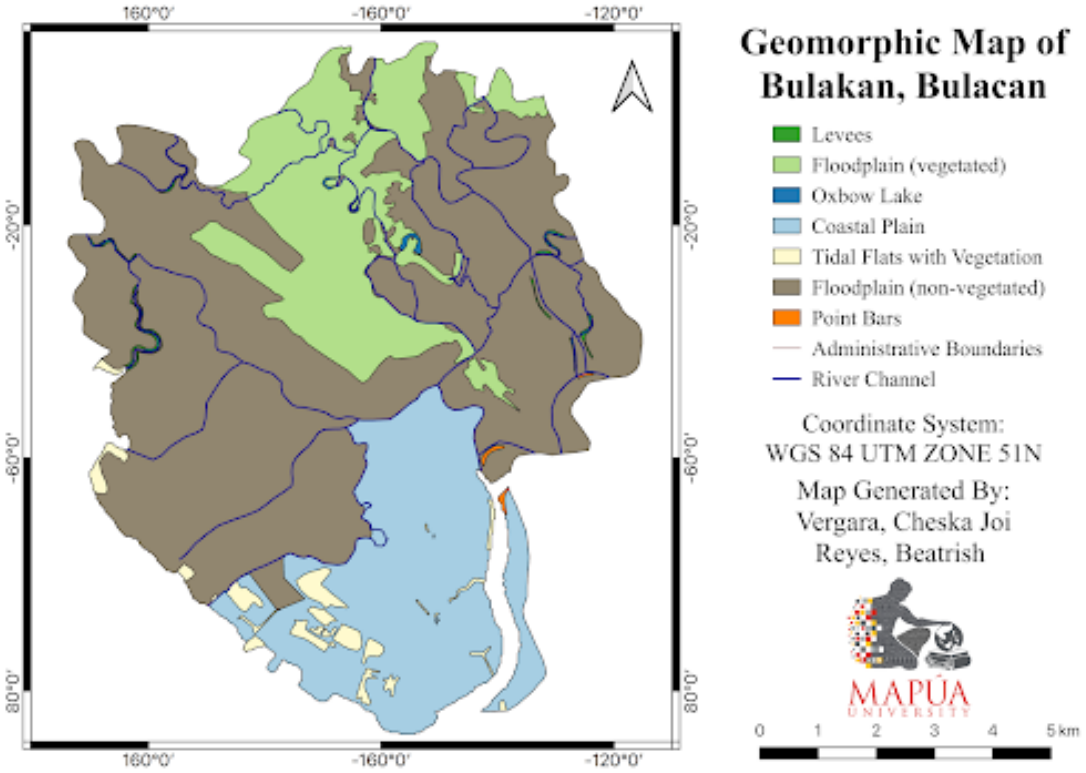

Figure 18. Geomorphological Map of the study area

CORRELATION OF GEOMORPHOLOGICAL UNITS WITH GEOHAZARDS

The main geologic hazards in the area are flood and land subsidence. Based on the elevation map generated, the topography of Bulakan mostly ranges from 0-10 meters above sea level; the slope map also shows that Bulakan is almost flat to gently-sloping with slope class mostly ranging from 0-10 degrees. Alongside flooding in the area is the threat from land subsidence. The continuous flow of water in a continuous subsiding land would most likely create a flood zone.

Flood Hazard

The flood hazard map from the MGB website was delineated in QGIS *(Figure 19)* and was overlaid over the geomorphological units using the intersect tool *(Figure 20)* to further analyze which geomorphological units are the most susceptible to flooding.

Upon observation, the geomorphological units that are highly susceptible to flooding are the coastal areas, tidal flats, and non-vegetated floodplains which include Brgy. Bagumbayan, Brgy. Bambang and Brgy. Taliptip, Brgy. San Nicolas, Brgy. Perez, Brgy. Sta. Ana and Brgy. Matungao. The geomorphological units that are moderate to low susceptible to flooding are mostly the vegetated floodplains in the area which also has higher elevation; these include Brgy. Pitpitan, Brgy. San Francisco, Brgy. Tibig, Brgy. Balubad, Brgy. Maysantol, Brgy. San Jose, Brgy. Bagumbayan and Brgy. Sta Ines.

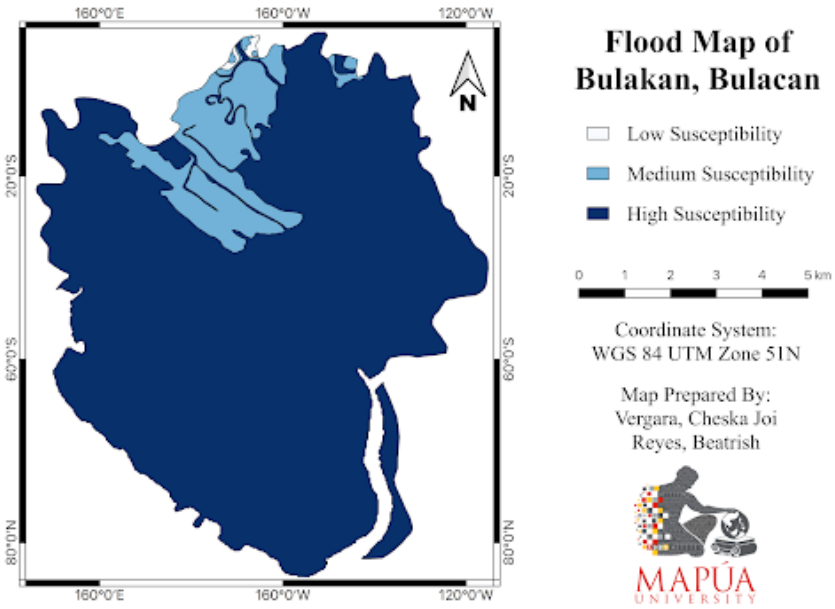

Figure 19. Flood map of the study area (source: MGB website)

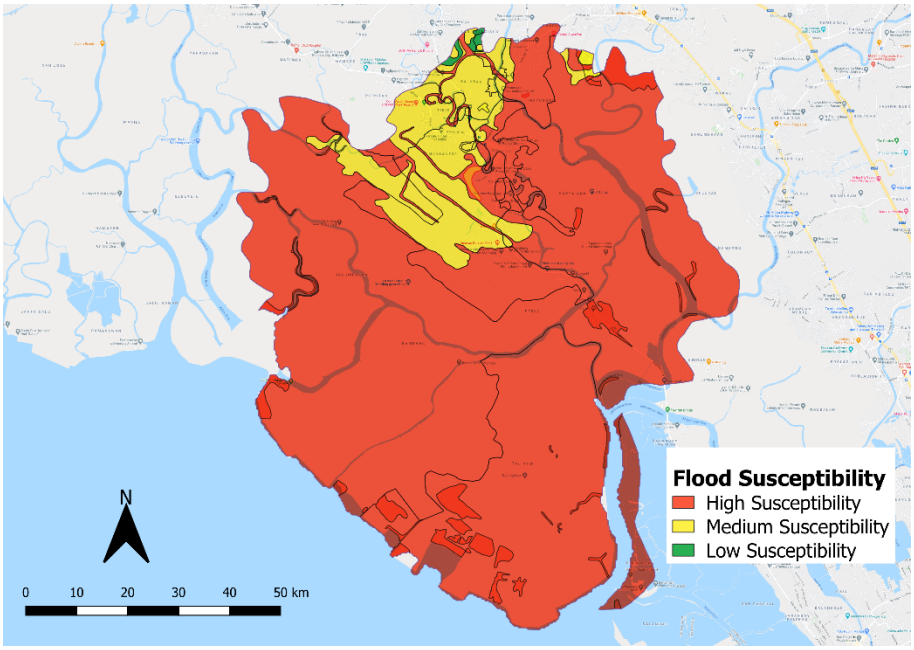

Figure 20. Flood Hazard Map, Geomorphological Map and Road Map overlay

Land Subsidence

The study of Siringan and Rodolfo (2003) showed the subsidence rates in Pampanga Delta from well data and re-surveyed old benchmarks by DPWH, and the history of the repeated highway rising in response to enhanced flooding and tidal incursion. Another study by Rodolfo & Siringan (2006) mentioned that the Pampanga Delta is subsiding a cumulative >100 cm or a rate of 3-9 cm/yr. The municipality of Bulakan, which is a part of the Pampanga Delta, is under the same circumstances. The historical imagery of satellite images in *Figure 21* shows that Bulakan has subsided rapidly in the span of 15 years.

With this, it can be seen that the geomorphological units most affected by land subsidence are the coastal areas and non-vegetated floodplains along Manila Bay. Brgy,

Taliptip, which falls under the coastal area, suffers the most land subsidence in the area. Non-vegetated floodplains are also affected by land subsidence since fishponds are one of the main extractors of groundwater.

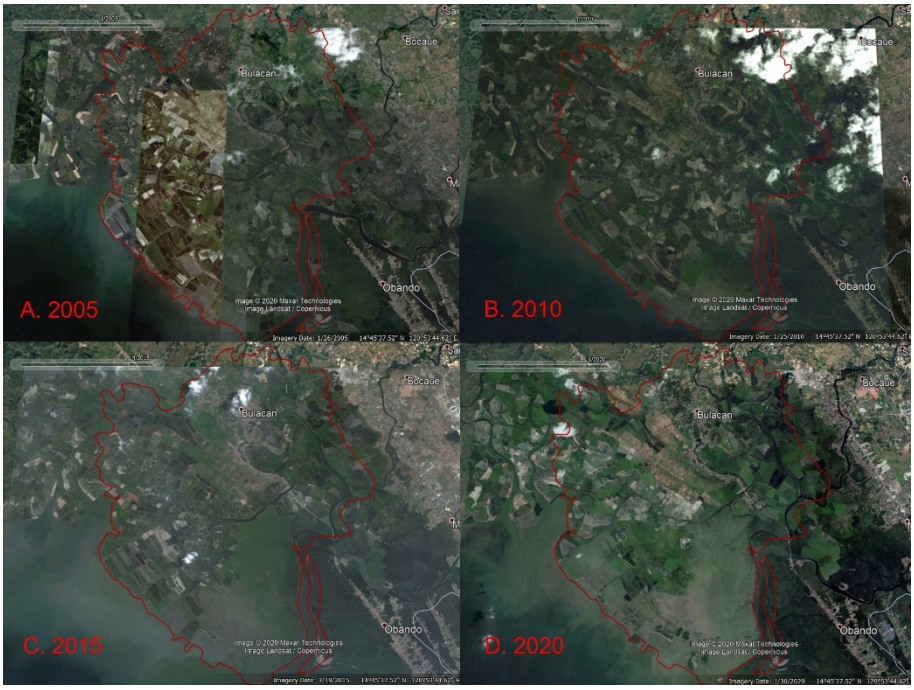

Figure 21. Time-series of satellite images of the study area showing proof of land subsidence

CORRELATION OF GEOMORPHOLOGICAL UNITS WITH LAND USE

The land-use map of the area was obtained from the office of the Municipality of Bulakan, and a more in-depth supervised land classification was generated through ArcGIS using Landsat 8 images *(Figure 22)*. Based on the raster file, most built-up areas are situated on vegetated floodplains, as well as the bare lands**,** agricultural lands, commercial, institutional and open spaces. Water bodies, fishponds, and fishing reservation areas, and some of the built-up areas are found on non-vegetated floodplains. Under coastal areas are mainly fishponds and fishing reservations with little areas of forests, agricultural lands, built-up areas, and water bodies.

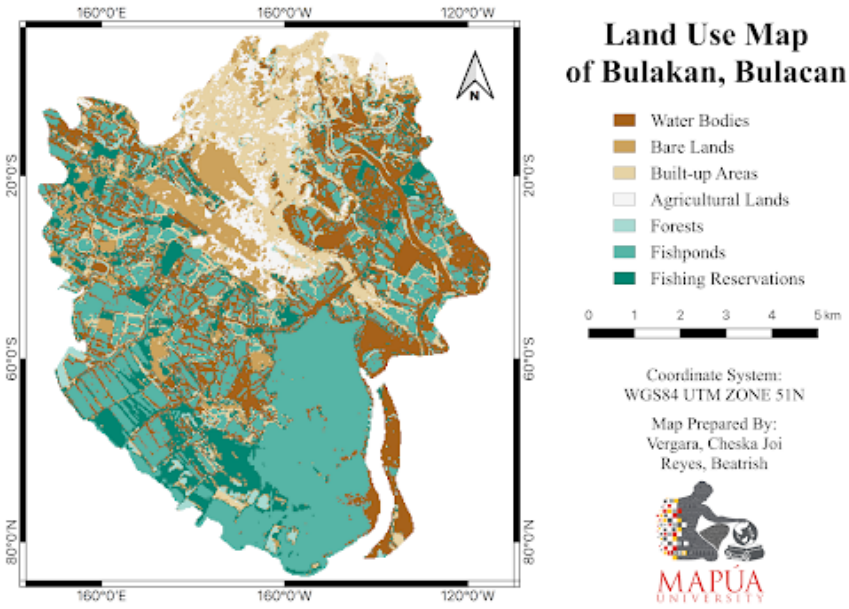

Figure 22. Land Use Map of the study area

Urbanization of the floodplain area will increase the amount and rate of surface runoff because there is hardly any surface area to absorb rainfall. Moreover, the rate of water flowing through channels and sewers will be fast.

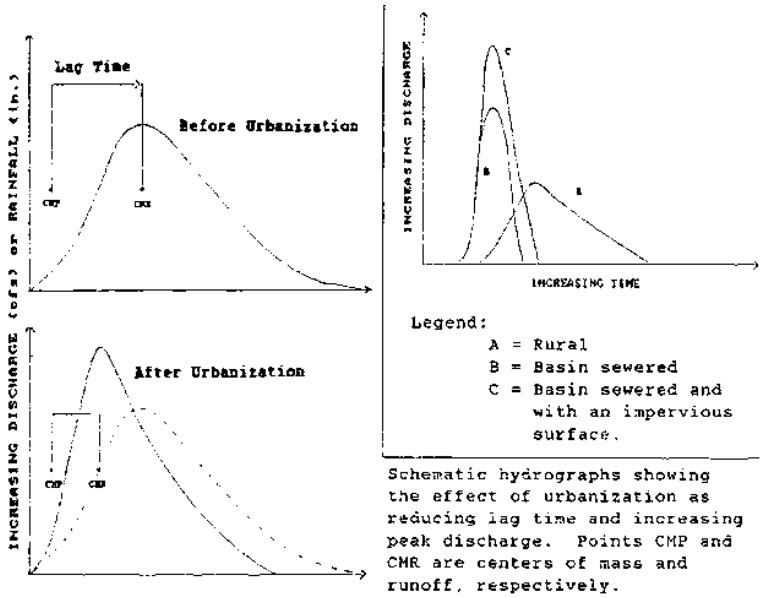

Figure 23. A diagram showing the correlation between runoff and discharge

F*igure 23* shows that as the runoff time is decreased, the discharge rate increases. Artificial fills in the floodplain can reduce the flood channel capacity in the area and it will definitely increase the flood height.

Coastal areas in terms of its elevation are at sea level or close to sea level thus making them susceptible to flooding caused by a series of geohazards such as typhoons. Building infrastructures in the area will increase flood impacts since the runoff will increase like when building infrastructures on floodplains. Moreover, urbanization of coastal areas will destabilize

shallow banks, increase erosion, will increase demand for fresh water, sewage treatment, and also will bring more damage to coastal ecosystems such as mangrove areas.

Subsidence will occur along with flooding when infrastructures are built on coastal and floodplain areas. In a study by Erban et. al. (2014), natural subsidence of deltaic deposits will occur thus it will be compensated by deposition of new sediments. However, with natural subsidence occurring, building infrastructures in the area will promote a faster rate for subsidence since the demand for surface water and extraction of groundwater will increase. Moreover, there will be no redeposition of deltaic deposits since the way has been paved by building infrastructures near and in the area.

IV. CONCLUSIONS AND RECOMMENDATIONS

In this study, the authors utilized the data obtained from government sectors, websites, satellite images, and fieldwork observations to generate the geomorphological map of Bulakan, Bulacan and use it as a basis in identifying its implications in the proposed land use development of the municipality.

The geological map of Bulakan showed that the municipality is mostly composed of alluvium, which is loose or unconsolidated soil and rocks deposited by rivers. This means that anthropogenic events such as oil/groundwater extraction in the area resulted in compaction of the land, i.e. land subsidence. Continuous land subsidence in the area has aggravated flooding. This study showed that the municipality experienced both geohazards as some of its barangays are now nearly fully submerged in water.

The generated geomorphological map of the area showed that the municipality of Bulakan is a lowland, which mainly consists of floodplain and coastal plain areas. Vegetated floodplains are situated on the upper part of Bulakan, while coastal plain areas and most of the non-vegetated floodplains are located on the lower part. Tidal flats with vegetation were widely seen in coastal plains. The river channel in the area has a meandering pattern that flows across the floodplains. Oxbow lakes, point bars, and riparian zones were also seen in some parts of the river channel.

Based on the flood hazard map of the area, almost the entirety of Bulakan is prone to flooding; infrastructures that were built along or on coastal plain areas are the most susceptible to flooding. Since the study area is closer to the sea, it is more vulnerable to incursion of seawater especially when it sinks or subsides. Other parts of Bulakan that are highly susceptible to flooding are mostly non-vegetated floodplains or fishponds.

Identification of geomorphic features is necessary for understanding and analyzing the geohazards in the area, especially its flood susceptibility. Such information can provide significant information on land-use development and disaster risk management.

To mitigate the said hazards and diminish possible implications caused by the impending land use development, the following actions are recommended:

1. Regulate or minimize the use of wells to avoid or slow down subsidence.

2. Implement structural measures such as the provision of appropriate and adequate drainages, building embankments and dykes, and construction of flood control gates to address flooding.
3. Avoid, if possible, the construction of massive infrastructures that can result in further compaction of sediments and land subsidence, especially on areas that are most susceptible to flooding, i.e. Brgy. Taliptip Brgy. Bambang, and Brgy. Bagumbayan.
4. Monitor regularly the stability of the infrastructures built on floodplains and coastal plain areas for possible problems on subsidence.
5. Ensure that the National Building Code and other related laws are followed in the issuance of building permits.

For future research, the authors recommend the conduct of an extensive study of subsidence and liquefaction in the municipality of Bulakan, Bulacan to produce a subsidence map and liquefaction map. A more detailed geomorphic characterization of the area is also suggested especially in the areas where the authors were not able to conduct fieldwork due to the Covid-19 pandemic.

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Comprehensive Land Use of Bulakan Bulacan (2000)

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