Deciphering prospective ground water zones of Morobe province, Papua New Guinea

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ABSTRACT

The groundwater investigation in Papua New Guinea is a complex task due to the hard rock terrain structure. To overcome this complexity, the integrated approach based on advanced applications of remote sensing and Geographical Information System (GIS) lends itself to evaluate groundwater prospective zone based on multi-criteria decision making approach (e.g. geomorphology, lithology, soil type, elevation, land slope, drainage density, inundation type, land use and vegetation). A probability weightage index overlay method was adopted that allows a linear combination of probability weights of each thematic map with the individual impact value using Bayesian statistics. These capability values are then multiplied with the respective probability weight of each thematic map. Analysis of groundwater potential zones shows that the very high groundwater potential zones constitute 4.29% of the Morobe province. The regions were mainly comprises on some small pocket of north-eastern western region of the province. The hydrologic parameters-based groundwater potential zone map also indicated, 15.71% of the study area was classified as having high potential, 37.16% moderate potential and 42.84% low potential. This study also provides a methodological approach for an evaluation of the water resources in hard rock terrain and enables an opening of the scope for further development and management practices.

Keywords: **Remote Sensing, GIS, Land use/land cover, Soil, Geomorphology and Hydrology**

I. INTRODUCTION

In view of vital demand of water for both agricultural and industrial use, the need to develop groundwater resources to the maximum possible extent has gained importance. Therefore, to delineate the parameters governing groundwater resources and assessment so as to predict groundwater potential is essential for planning and developing this resource. Of the 37Mkm^3 of freshwater estimated to be present on the earth, about 22% exists as groundwater, which constitutes about 97% of all liquid freshwater potentially obtainable for human use (Foster, 1998).

To investigate the ground water directly from the field is very costly, time-consuming and requires skilled manpower (Sander et al., 1996). In contrast, space technology, with its advantages of spatial, spectral and temporal availability of data covering large and inaccessible areas within a short time, has appeared as a very valuable tool for the assessment, monitoring and management of groundwater resources (Jha et al., 2007).

However, ground water cannot detect directly from remote sensors, the presence of groundwater is inferred from different surface features derived from satellite imagery such as geology, landforms, soils, land use/land cover, surface water bodies, etc., which act as indicators of groundwater existence (Nag and Lahiri, 2011; Chidambaram et al., 2010; Kalantari et al., 2010; Jha and Peiffer, 2006). In the past, several researchers have used Geoinformatics techniques for the delineation of groundwater potential zone with successful results (Krishnamurthy et al., 2000; Shahid et al., 2002; Khan and Moharana, 2002; Jaiswal et al., 2003; Rao and Jugran, 2003; Sikdar et al., 2004; Sener et al., 2005; Ravi Shankar and Mohan, 2006; Solomon and Quiel, 2006) in different parts of the world. However, to date, there are no studies have been carried out in general to demarcate the groundwater potentiality in particular. In these studies, the commonly used thematic layers are lithology, geomorphology, rainfall, drainage density, soil, vegetation cover, elevation, land use/land cover, type of inundation area and topographic slope.

Therefore, the present study an attempt has been made to demarcate the groundwater potential zone in the Morobe province by considering suitable thematic layers that have direct or indirect control over groundwater occurrence using Geoinformatics technology.

II. STUDY AREA

This work attempts to develop index model to determine groundwater potential zone in Morobe province of Papua New Guinea. The study area is bounded within 145° 30' to 148° E longitude and 5° to 8° S latitude.

Papua New Guinea's climate is tropical, as one would expect in a country located just south of the Equator. December to March is the wet season, although occasional rain falls year-round. While Port Moresby, the capital, and other towns on the coast are quite hot in the summer months, temperatures are considerable cooler in the Highlands. The climate of PNG is dominated by three factors. These are- (i) the equatorial low pressure and sub tropical high pressure, (ii) the influence of ocean and (iii) the influence of altitude.

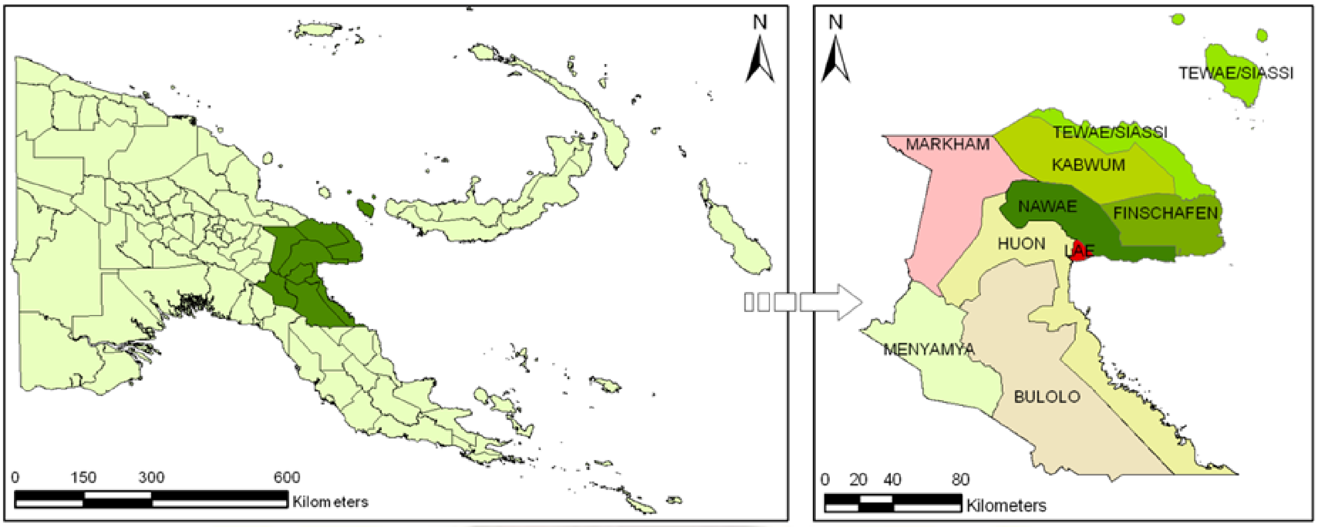

Figure 1. Location map of the study area

III. MATERIALS AND METHODS

Generation of Thematic Layer

In order to differentiate the groundwater potential zone in the study area, a multiparametric dataset comprising satellite data, and conventional maps including topographical sheets were used. Landsat Enhanched Thematic Mapper Plus (ETM+) data collected from the GLCF community has been used for the preparation of thematic maps of drainage density and land use/land cover respectively. Topographical maps (1:250000) were collected from the official web site of University of Texas Libraries, Austin. Further, the thematic layers of geology, geomorphology, soil and inundation were prepared from existing maps obtained from the PNGRIS database. The drainage density map was generated by interpolating spatial distribution of drainage/river across the area in the ARC GIS software. Rainfall was estimated by interpolating between the point data from the rainfall station network. Vegetation health map of the study area was generated from the Landsat ETM+ data using normalized difference vegetation index (NDVI) technique (Samanta et al., 2012). One of the most widely used digital elevation model (DEM) data sources is the elevation information provided by the shuttle radar topography mission (SRTM) (Coltelli et al. 1996), but as with most other DEM sources, the SRTM data requires significant levels of pre-processing to ensure that there were no spurious artefacts in the data that would cause problems in later analysis such as pits, spikes and patches of no data (Dowding et al. 2004). In the case of the SRTM data, these patches of no data were filled, preferably with auxiliary sources of DEM data, like topographical maps.

All the digitized coverages were spatially organized in the GIS environment with the same resolution and coordinate system. The checking of these spatial maps was done with respect to other database layers by the overlaying technique, and refined mutually as part of standardization of the database. The errors due to digitization and mismapping were removed in this process.

Integration of thematic layer

The thematic layers of lithology, geomorphology, soil, elevation, slope, rainfall, inundation type, land use/land cover, vegetation status and drainage density were used for the delineation of groundwater potential zone in the study area. To differentiate development zones, all these thematic layers were integrated using ARC GIS v9.1 software. The weights of the different themes were assigned on a scale of 1 to 9 based on their influence on the groundwater development. Different features of each theme were assigned weights on a scale of 1 to 7 according to their relative influence on groundwater development. Based on this scale, a qualitative evaluation of different features of a given theme was performed, with: very poor (weight = <1); poor (weight=1-2); moderate (weight = 2–3); good (weight = 3-4.5); very good (weight = 5-6); and excellent (weight = 6-7). Thereafter, a pairwise comparison matrix was constructed using the Saaty's analytical hierarchy process (Saaty, 1980) to calculate normalized weights for individual themes and their features. By integrating different thematic maps such as lithology, geomorphology, soil, rainfall, elevation, slope, inundation area, drainage density, land use and vegetation in Arc view 3.2a software using weightage index overlay analysis, the groundwater potential zone was found out and classified as very good, good, moderate, poor and very poor. GIS modelling technique of index overlay method was then used to produce groundwater potential map. In this modelling method the map classes occurring in each input map are assigned by different scores, in addition to the maps themselves receiving weights. The average score is then defined by using the formula (Borham Carter, 1994)-

$$S = \Sigma\, S_{ij} W_i / \Sigma W_i$$

Where, S is the weight score of an area object (polygon, pixel), W_i is the weight for the i_{th} input map and S_{ij} is the rating score of the j_{th} class of the i_{th} map.

IV. RESULTS AND DISCUSSION

Thematic layer of Morobe province

The details of geomorphology, lithology, soil type, elevation, land slope, drainage density, inundation type, land use and vegetation together with their spatial distribution in the study area are presented below.

Geomorphology

It is well known fact that the geomorphological characteristics of an area affect its response to a considerable extent of groundwater occurrence. Thus, linking of geomorphological parameters with hydrological characteristics of a basin provides a simple way to understand their hydrological behaviour. The geomorphological characteristics were divided into three major groups according to the dominant geomorphic processes by which they were formed, e.g., depositional landforms, erosional landforms and volcanic landforms (Loffler 1974). Most of the area (71.29%) is covered by mountains and hills with weak or no structural control. The detail of the geomorphological characteristics of the study area is shown in table 1 and figure 2. The geomorphological unit such as floodplains, alluvial plain are the good sources of ground water of the study area, whereas, structural plateau, hilly terrain, volcanic landform are poor recharge zones.

Table 1. Geomorphological characteristics of the study area

Geomorphology Type	Area (in km^2)	% covered	Rank
Mangrove swamps	9.4	0.03	4
Beach ridge complexes and beach plains	31.29	0.09	1
Raised coral reefs and associated black reef plains	451.4	1.34	2
Composite alluvial plains	357.38	1.06	7
Meander floodplains: unstable alluvial floodplain	148.68	0.44	6
Back plains	81.4	0.24	2
Back swamps	205.64	0.61	2.5
Undifferentiated swamps	327.2	0.97	2.5
Braided floodplains or bar plains	335.74	1.00	3.5
Composite bar plain and alluvial fan complex	323.55	0.96	4
Little dissected recent alluvial fans	1290.2	3.84	5
Little dissected or undissected relict alluvial, colluvial mudflow or fans	75.84	0.23	3
Dissected relict alluvial, colluvial mudflow and fans	807.7	2.41	4.5
Little dissected volcanic footslopes and volcano-alluvial fans	452.11	1.35	4
Volcano-alluvial plains	54.41	0.16	3
Structural plateau (SP)	1209.68	3.60	1
Finely dissected sloping erosional surface with structural control	1220.69	3.64	2
Hilly terrain with weak or no structural control	789.58	2.35	1
Mountains and hills with weak or no structural control	23936.19	71.29	1
Mountains and hills associated with relict surfaces with weak or no structural control	351.1	1.05	2
Homoclinal ridges and cuestas: inclined asymmetrical structurally controlled ridges	599.17	1.78	1
Strike ridges and hogback ridges: steep, sharp crested structurally controlled ridges	43.51	0.13	1
Polygonal karst: plateaux or broad ridges on limestone covered with numerous rugged hills	12.05	0.04	3
Volcanic cones and domes	449.38	1.34	1
Lake	13.46	0.04	6

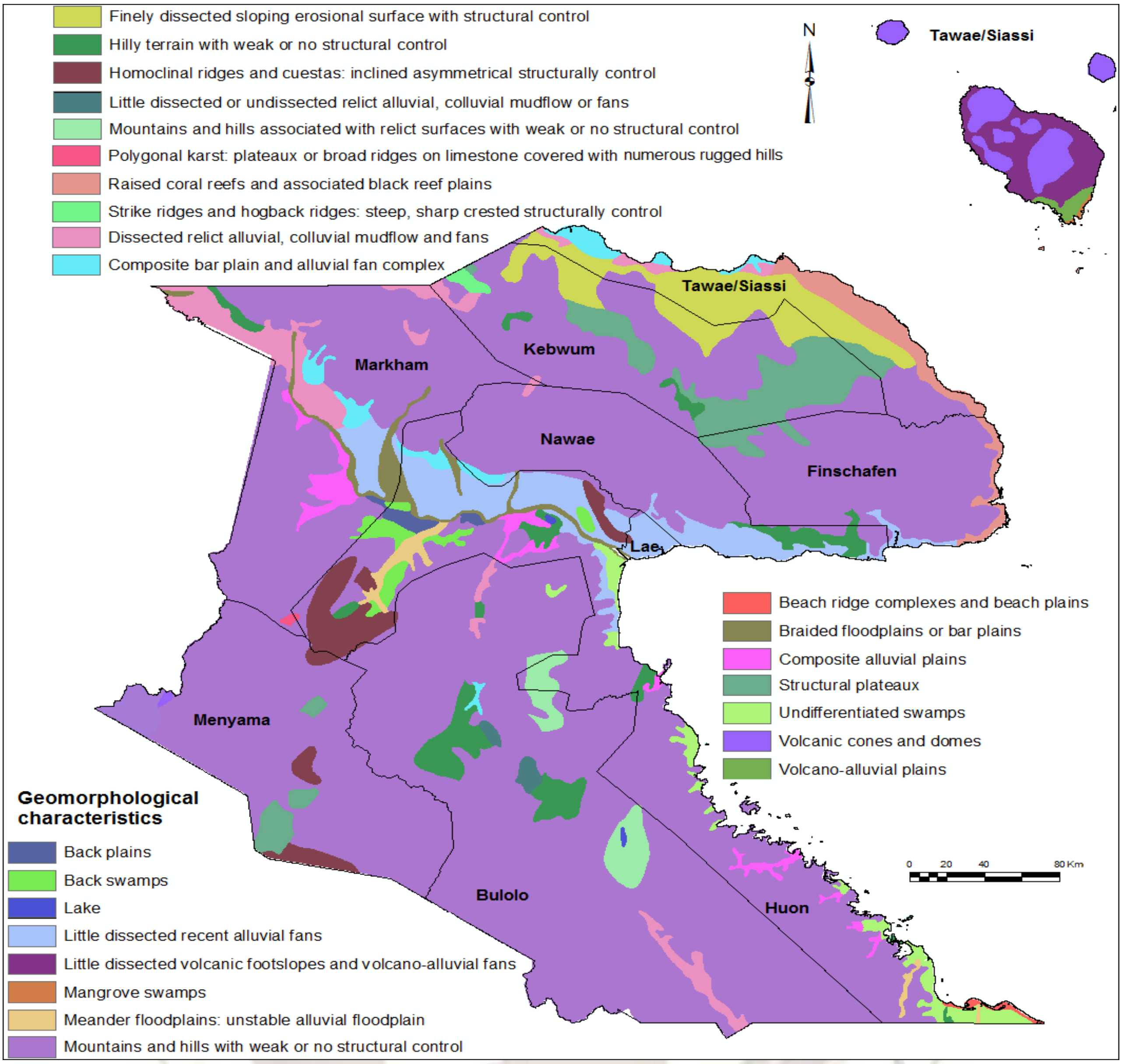

Figure 2. Geomorphological map of the study area

Lithology

In the present study, 19 types of lithological characteristics have been considered to understand the distribution and occurrence of groundwater (table 2). The classification of rock type was adapted from Loffler (1974), and is based on simple criteria, such as origin, composition and grain size of parent material. The three main rock type categories recognised are sedimentary rocks, metamorphic rocks and igneous rocks within the study site. However, 59.47% area covered by the Mixed or undifferentiated sedimentary, limestone, low grade metamorphic and basic to intermediate volcanic rocks. The lithological map of the study area is shown in figure 3.

Table 2. Lithological characteristics of the study area

Lithology types	Area (in km^2)	% covered	Rank
Lake-water	13.46	0.04	5
Coarse grained sedimentary	2497.74	7.44	6
Mixed or undifferentiated sedimentary	3809.05	11.34	4
Mixed sedimentary and limestone	127.4	0.38	5
Limestone	5699.1	16.97	5
Low grade metamorphic	6338.51	18.88	2
Mixed sedimentary and volcanics	1995.66	5.94	3
Basic to intermediate volcanic	4123.34	12.28	1
Intermediate to acid volcanic	264.51	0.79	1

Mixed or undifferentiated volcanic	139.51	0.42	1
Acid to intermediate igneous	1573.34	4.69	1
Basic igneous	1510.93	4.50	1
Ultrabasic	955.03	2.84	1
Mixed or undifferentiated igneous	28.63	0.09	1
Pleistocene sediments	816.65	2.43	3
Alluvial deposits	3136.68	9.34	7
Marine sand	31.29	0.09	7
Estuarine deposits	9.4	0.03	6
Pyroclastics	506.52	1.51	2

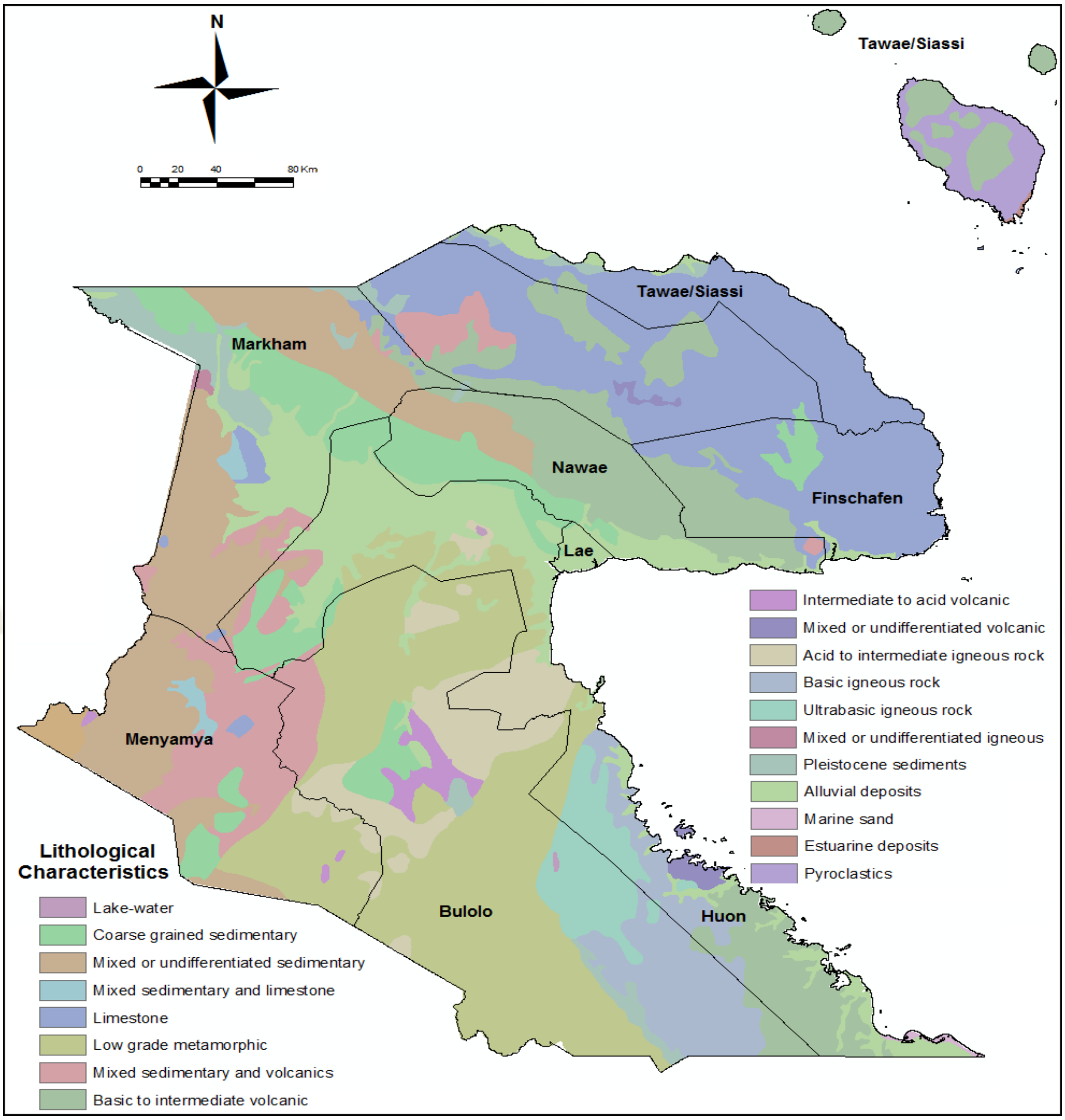

Figure 3. Lithological map of the study area

Elevation

The topography of this region varied from 0-4094m (figure 4).The highest elevation zone was found in northern and southern part of the province while, lowest elevation observed in the north-central and coastal part of the study area. The entire region is divided into as many as 7 divisions ranging from < 250 to > 1500 m. It is found that a total of 11882.25 km^2 (35.39%) area is lying >1500m contour line. The detail of elevation characteristics and their areal extent of the study area are shown in table 3.

Table 3. Elevation characteristics and their areal extent of the study area

Elevation Range (m)	Area (in km^2)	% covered	Rank
<250	5303.743	15.80	7
251-500	3475.537	10.35	6
501 - 750	3375.87	10.05	5
751 – 1000	3354.656	9.99	4
1001 – 1250	3117.998	9.29	3
1251 – 1500	3066.701	9.13	2
>1500	11882.25	35.39	1

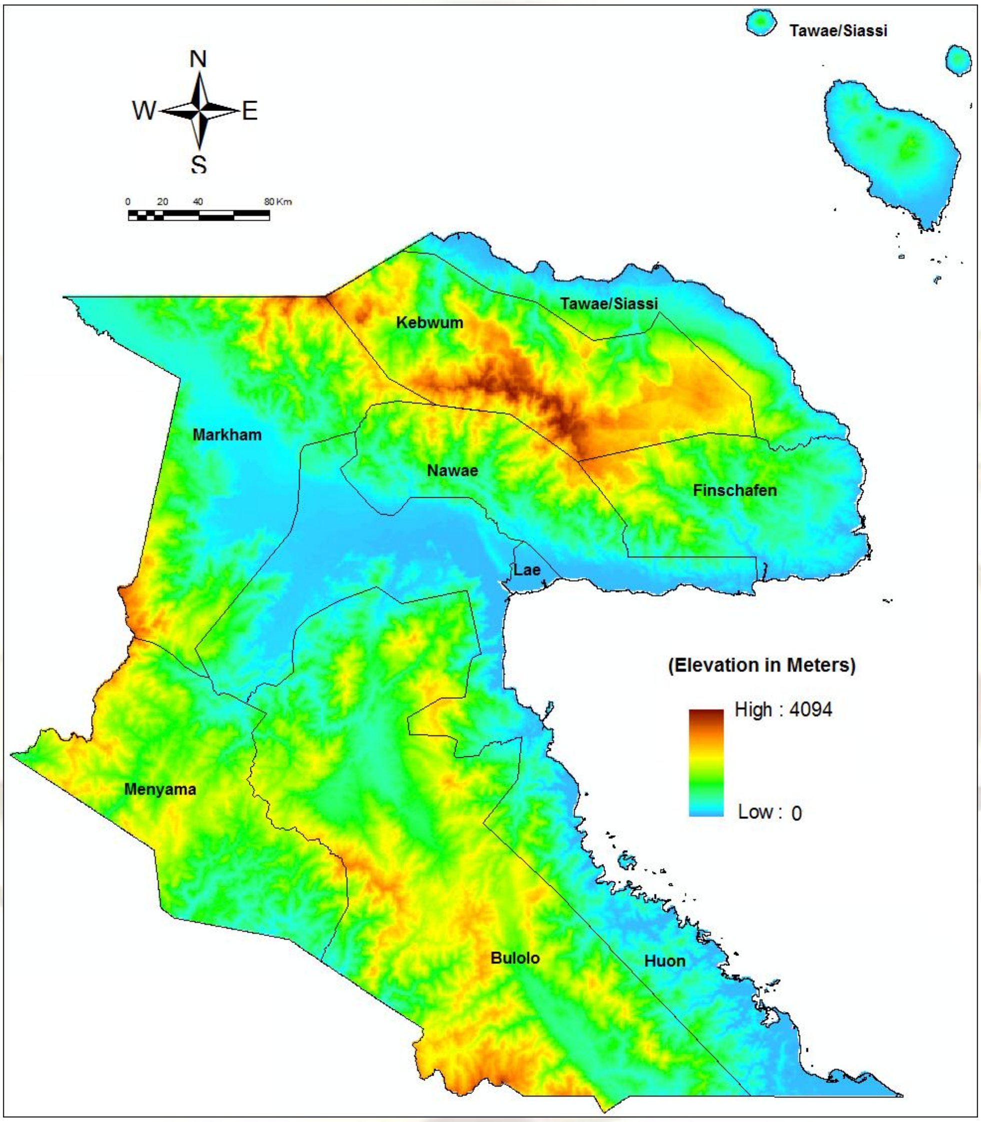

Figure 4. Digital relief map of the study area based on SRTM data and toposheet

Slope

Slope of a surface refers to change in height across a region of surface. Slope is an important factor since it affects land stability. Slope map was prepared from SRTM data as shown in figure 5. However, the slope of the study area is ranged from 0º-89.72º. Steep slope was found mainly in north-west part of the province, some tracts were also persisted in south east and central region. In the north-central area has flat topography, some tracts were also found in northern part of the province. Most of the part is as hilly terrain having moderate to steep slope. A high sloping region causes more runoff and less infiltration and thus has poor groundwater prospects compared to the low slope region. Conversely, the area with <10º is considered as 'good' for groundwater storage due to slightly undulating topography with some run-off. The area with a slope of 10º-20º causes relatively high run-off and low infiltration, and hence is categorized as 'moderate' and >30º slope categorized as 'poor' due to higher slope and run-off within the study site. Table 4 shows the slope characteristics and their percent of area covered by each of the category.

Table 4. Slope characteristics and their percent of area covered by each of the category

Slope	Description	Area (in km^2)	% covered	Rank
< 5	Very gentle	4921.556	14.66	7
5-10	Gentle	3793.461	11.30	6
10-15	Low moderate	5190.639	15.46	5
15-20	High moderate	5766.006	17.17	4
20-25	Steep	5318.776	15.84	3
25-30	Strongly steep	4068.262	12.12	2
>30	Very steep	4518.055	13.46	1

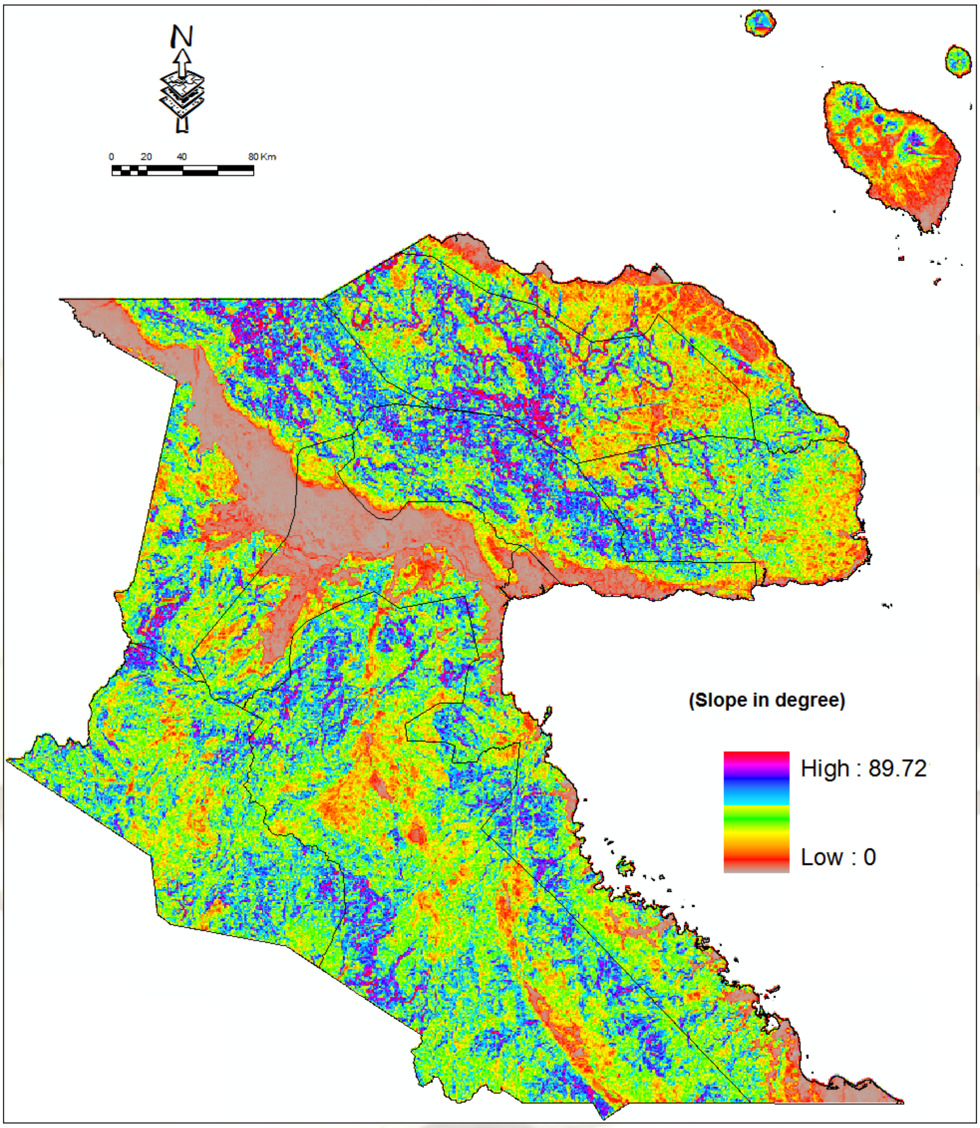

Figure 5. Slope map of the study area based on SRTM data and toposheet

Soil

The thematic layer on soil (Figure 6) for the study area reveals twenty main soil classes: lake, hydraquents, fluvaquents, ustipsamments, tropofluvents, ustifluvents, tropothents, cryorthents, ustorthents, eutrandepts, dystrandepts, humitropepts, ustropepts, eutropepts, dystropepts, rendolls, haplustolls, hapludolls, haplustalfs, and tropudalfs. It is evident from Figure 6 that the majority of the study area is dominated by humitropepts (9172.73 km^2) and troporthents (7039.83 km^2) soils, with other soil types covering relatively small areas (Table 5). These twenty soil classes can be categorized into seven classes ‘excellence’, ‘very good’, ‘good’, ‘moderate’ ‘moderate to low’, ‘poor’, and ‘very poor’ according to their influence on groundwater occurrence.

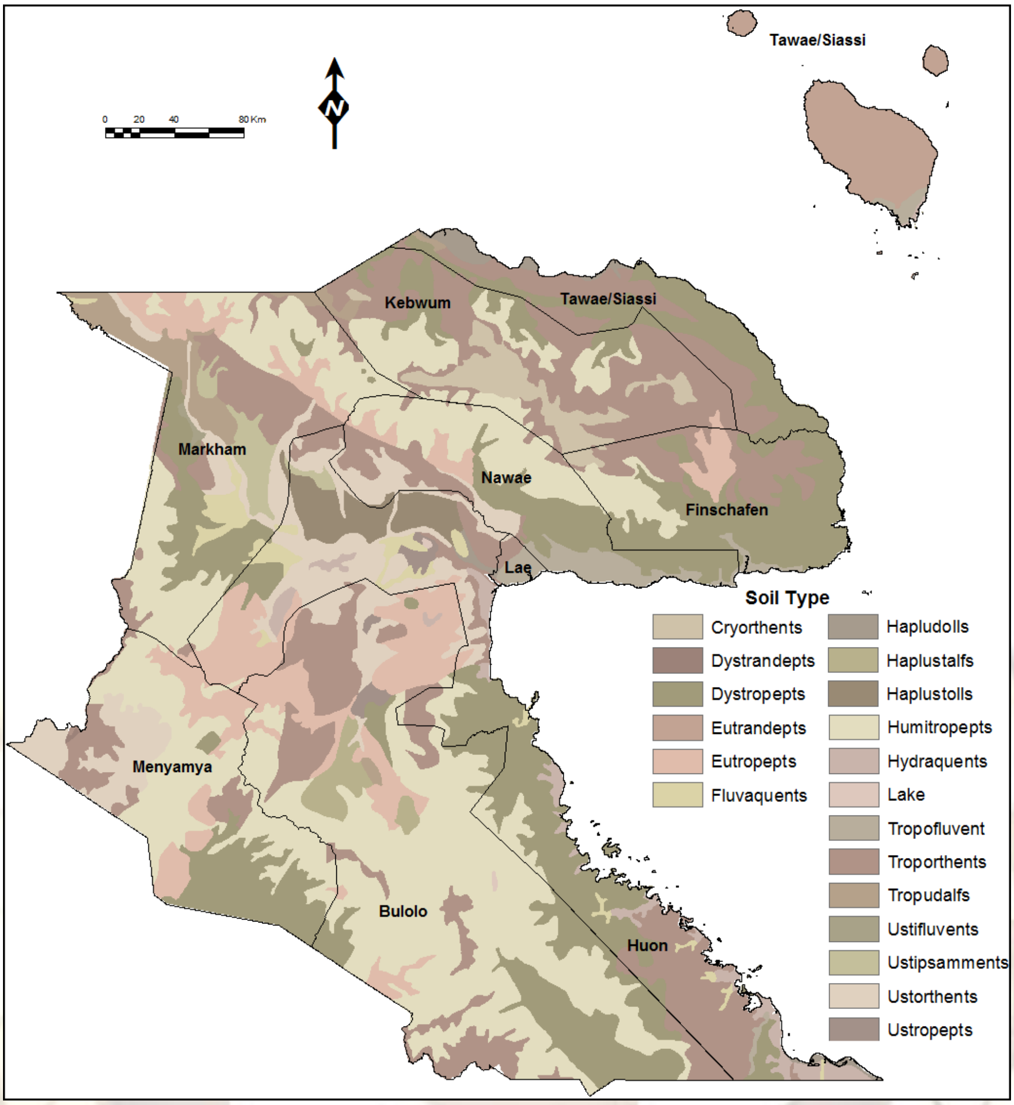

Figure 6. Soil characteristics of the study area based on PNGRIS data base

Table 5. Different soil type found in the Morobe Province

Soil Type	Description	Area	% covered	Rank
Lake	Water body	13.46	0.04	5
Hydraquents	Permanently saturated, undifferentiated soils which are soft underfoot and mainly fine textured	458.43	1.37	6
Fluvaquents	Poorly drained, undifferentiated soils with high (>0.2%) or variable organic C contents to > 125cm	436.19	1.30	4
Ustipsamments	Well to imperfectly drained undifferentiated sandy soils subject to seasonal moisture stress	309.03	0.92	3
Tropofluvents	Mainly well drained undifferentiated soils with high (>0.2%) or fluctuating org C to > 125 cm	479.69	1.43	5
Ustifluvents	Mainly well drained undifferentiated soils subject to seasonal moisture stress and var org C with depth	23.27	0.07	3
Troporthents	Undifferentiated, mostly shallow soils typically found in wet climates on moderate to steep slopes	7039.83	20.97	3
Cryorthents	Undifferentiated mostly shallow soils found in cold climates on moderate to steep slopes	628.72	1.87	1
Ustorthents	Undifferentiated , mostly shallow soils which are subject to seasonal moisture stress	2188.58	6.52	5
Eutrandepts	Slightly weathered ash soils with high (>50%) subsoils BS values and thick black topsoils	893.15	2.66	3
Dystrandepts	Moderately weathered ash soils with low (<50%) subsoil BS values	7.21	0.02	2

	and thick black topsoils			
Humitropepts	Moderately weathered soils having high org carbon contents (>12 kg/m2) and low subsoil BS values	9172.73	27.32	6
Ustropepts	Slightly to moderately weathered soils with weathered, mostly shallow (<1m) soils subject to seasonal moisture stress	124.98	0.37	4
Eutropepts	Slightly to moderately weathered soils with an altered B horizon and high (>50%) subsoils base saturation values	2763.96	8.23	7
Dystropepts	Moderately weathered soils with altered B horizons and low (<50%) subsoils base saturation values	5292.3	15.76	6
Rendolls	Shallow, dark, weakly acid to neutral soils formed on calcareous parent materials	2168.79	6.46	1
Haplustolls	Weakly acid to alkaline soils with thick, dark topsoils and subject to seasonal moisture stress	535.1	1.59	2
Hapludolls	Weakly acid to alkaline soils with thick dark topsoils and high (>50%) base saturation levels	192.1	0.57	3
Haplustalfs	Moderately weathered soils subject to seasonal moisture stress and having finer textured subsoils	295.8	0.88	2
Tropudalfs	Well to imperfectly drained, moderately weathered soils with finer textured subsoils	553.43	1.65	7

Rainfall

The water table of an area is mainly controlled by variations in groundwater recharge, discharge and rainfall (Todd, 1980). Rainfall is the most vital input in the hydrological cycle and fluctuations in quality and distribution strongly influence surface and sub-surface water sources. Part of the rain water, which falls on the ground, is infiltrated into the soil. This infiltrated water is utilized partly in filling the soil moisture deficiency and part of it is percolated down reaching the water table. This water reaching the water table is known as the recharge from rainfall to the aquifer. The high average rainfall ranging from 2000mm to 6000mm ranked to be one of the wettest regions in the world. A few lowland areas are drier with annual rainfall of less than 1000mm. In contrast large areas of upland regions have average annual rainfall in excess of 4000mm. The Morobe province has been divided into six rainfall zones (Figure 7). Out of the total area, 2000 - 3000 mm rainfall zone covered 23493.11 km^2 (69.97% of the state). On the other hand, highest rainfall zone was found on north-eastern part of the state and a small pocket was also delineated south-western part of the study area; whereas, lowest rainfall zone was persevered in the central part of the study area.

Table 6. Average annual rainfall characteristics of the study area

Rainfall	Area	% Covered	Rank
1000 - 1500 mm	1034.41	3.08	3
1500 - 2000 mm	3314.36	9.87	4
2000 - 2500 mm	14125.5	42.07	5
2500 - 3000 mm	9367.61	27.90	6
3000 - 3500 mm	1894.11	5.64	6
4000 - 5000 mm	3840.74	11.44	7

Drainage density

The quality of a drainage network depends on lithology, which provides an important index of the percolation rate. Drainage density measurements have been made in the study area, and range from 0.02 km to 1.18 km (Figure 8). The drainage density map for the study area is shown in Figure 8. Based on the drainage density of the study area, it is grouped into five classes using geometric intervals: (i) 0–0.18km; (ii) 0.18–0.49 km; (iii) 0.49–0.75 km; (iv) 0.75–1.11; and (v) >1.11km. Accordingly, these classes have been assigned 'very good' to 'very poor' categories, respectively. Most of the study area (70%) has a drainage density of 0.49 – 0.75 km^2 (Table 7).

Table 7. Drainage density categories in the study area

Drainage density (km^2)	Area (in km^2)	% covered	Rank
<0.18	6720.413	17.96	3
0.18 - 0.49	5129.503	13.71	4
0.49 - 0.75	13577.19	36.29	5
0.75 - 1.11	7531.289	20.13	6
>1.11	618.3638	1.65	7

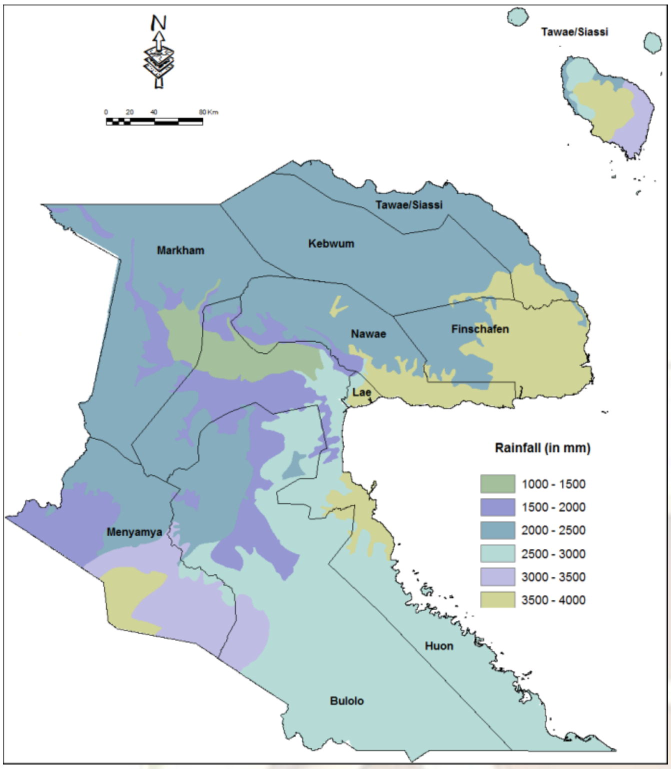

Figure 7. Rainfall distribution map of the study area

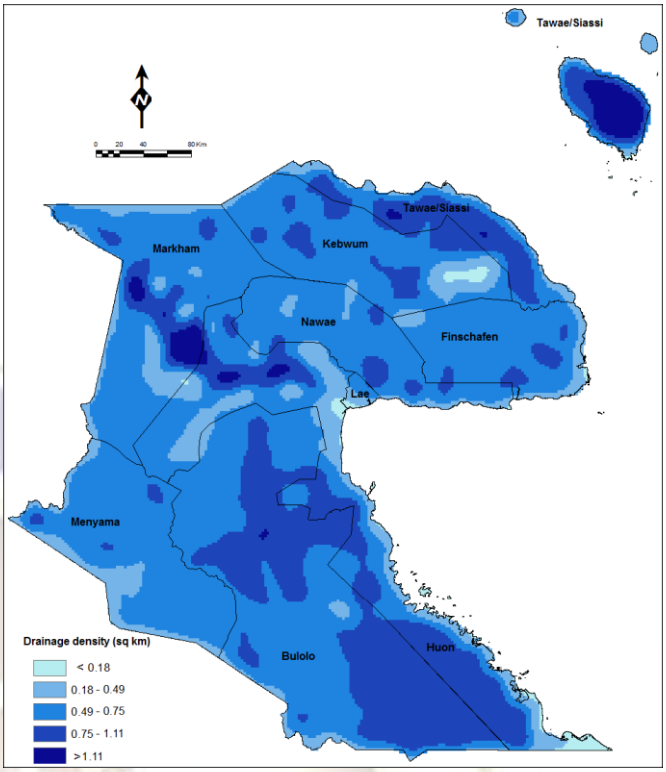

Figure 8. Drainage density map of the study area

Land use/ land cover

For the identification and interpretation of the land use pattern of area image interpretation through remote sensing data, eleven land cover classes delineated includes waterbody, evergreen needle leaf forest, deciduous needle leaf forest, mixed forest, woodland, woodland grassland, closed shurbland, open shurbland, grass land, crop land and urban-built up region (Figure 9). Out of the total area 51.17% is falling under evergreen needle leaf forest. 23.46% area is covered by mixed forest in this region. Moreover, waterbody, woodland grass land, crop land and urban-built up region covered only 0.73% of the study area (Table 8).

Table 8. Land use/land cover class statistics according to classification

Land use/land cover class	Area	% cover	Rank
Waterbody	9.53	0.03	7
Evergreen needle leaf forest	17181.93	51.17	5
Deciduous needle leaf forest	1628.025	4.85	5
Mixed forest	7878.14	23.46	6
Woodland	3456.127	10.29	6
Woodland grassland	86.85004	0.26	4
Closed shurbland	778.4546	2.32	3
Open shurbland	1955.211	5.82	2
Grass land	452.5988	1.35	2
Crop land	135.7796	0.40	6
Urban and built	13.45564	0.04	0

Vegetation

Classification of groundwater interactions with the surface (i.e., recharge vs. discharge areas) using classification of indicator vegetation is straightforward in concept but can be tricky in practice. Vegetation may respond slowly to ground water flow changes and are constantly in a state of transition. The relationship between the presence of phreatophytes and shallow water tables is particularly obvious in desert environments (Nichols 1994). Vegetation canopy cover data set was generated from satellite images using a hybrid maximum-Normalized Differential Vegetation Index (NDVI) and minimum-red compositing technique (Figure 10). However, the vegetation characteristic of Morobe province has been categorized into five categories is shown in Table 9.

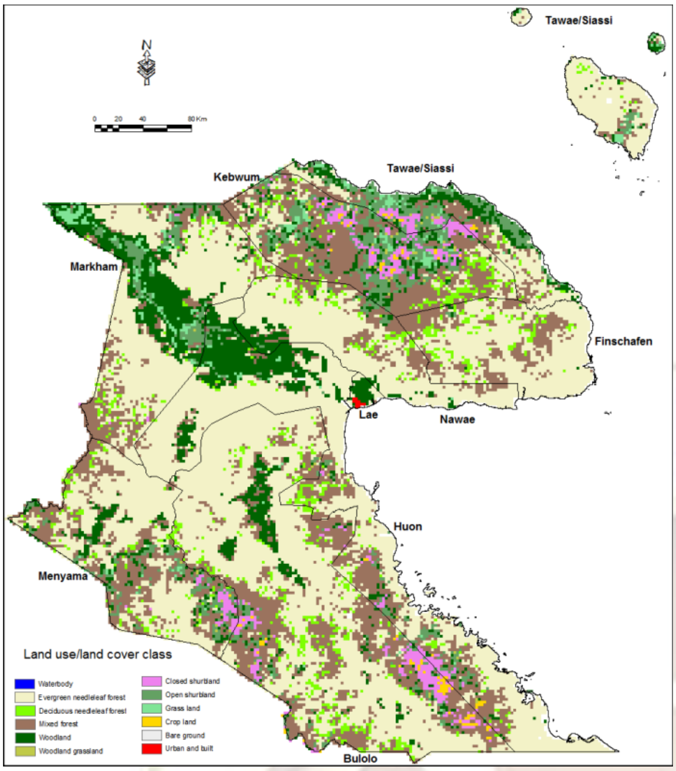

Figure 9. Land use/land cover of the study area

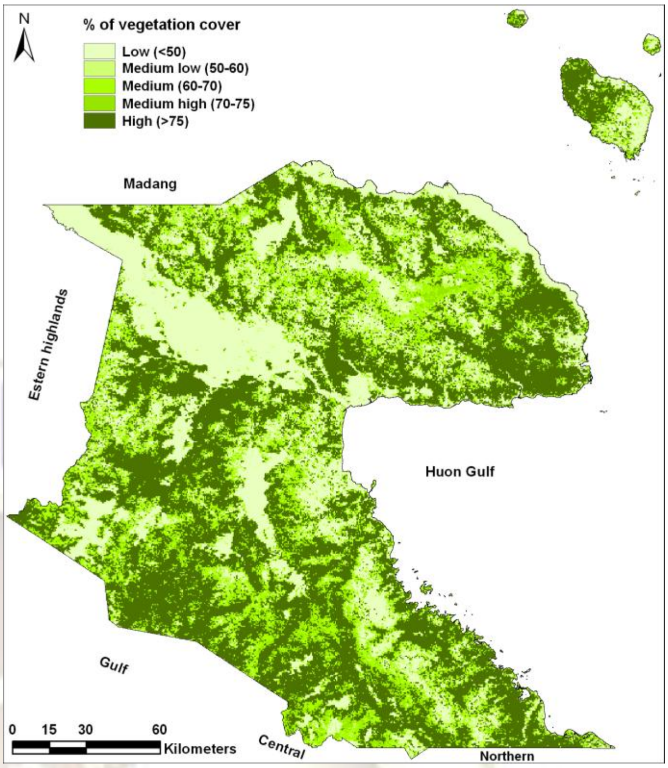

Figure 10. Vegetation cover map of the study area

Table 9. Vegetation covers class statistics according to hybrid maximum- NDVI

Percent of vegetation cover according to NDVI	% of area covered	Rank
Less than 50	25.4	1
50 to 60	12.5	2
60 to 70	14.3	3
70 to 75	17.1	4
More than 75	30.7	5

Type of inundated or flooded areas

Evaluation of the impacts of high rainfall and consequents floods on ground water and surface water resources would pave a way for managing the additional available water for development. Increased inundation of an area, there is likely to be a localised increase in groundwater levels. Simultaneously heavy rainfall resulted in strong infiltration in the surrounding areas which cause additional groundwater rising. Generally permanently inundated areas may help to the infiltration process through a sequential increase in vadose zone water content ultimately, a rise in groundwater table as a final indication of the recharge process. The whole study area has been categorized into eight divisions, such as: flood free area, waterlogged, periodic brief flooding, and seasonal inundation, near permanent, permanent inundation, tidal flooding, and tidal flooding with freshwater inundation (Figure 11). However, within the Morobe province, 91.84% areas are free from the flood/inundation, whereas permanent inundation area enclosed only 1.50% (Table 10).

Table 10. Type of inundation characterise in the study area

Inundation type	Description	Area (km^2)	% covered	Rank
No flooding	-	30838.3	91.84	2
Waterlogged	Areas with only very little or no standing water at the surface but with a soil profile that is saturated either permanently or for time periods in excess of six months.	284.27	0.85	3
Periodic brief flooding	Areas which are generally flooded for 3 to 4 days or less as a result of brief river flooding overflow or short term flooding and ponding due to intensive rainfall events.	742.73	2.21	3
Seasonal inundation	Areas that are seasonally inundated to a moderate (> 0.25 m) or greater depth and which do not dry out.	1116.07	3.32	5
Near	Areas that are seasonally inundated in the wet season and subject to long	11.32	0.03	6

permanent	term inundation during the dry season but can occasionally dry out.			
Permanent	Areas that are permanently inundated usually to a considerable depth.	502.05	1.50	7
Tidal flooding	Areas subject to tidal flooding. Normally associated with mangroves.	9.4	0.03	4
Tidal flooding with freshwater	Areas subject to both tidal flooding and inundation as a result of river flooding with restricted estuarine conditions.	72.6	0.22	5

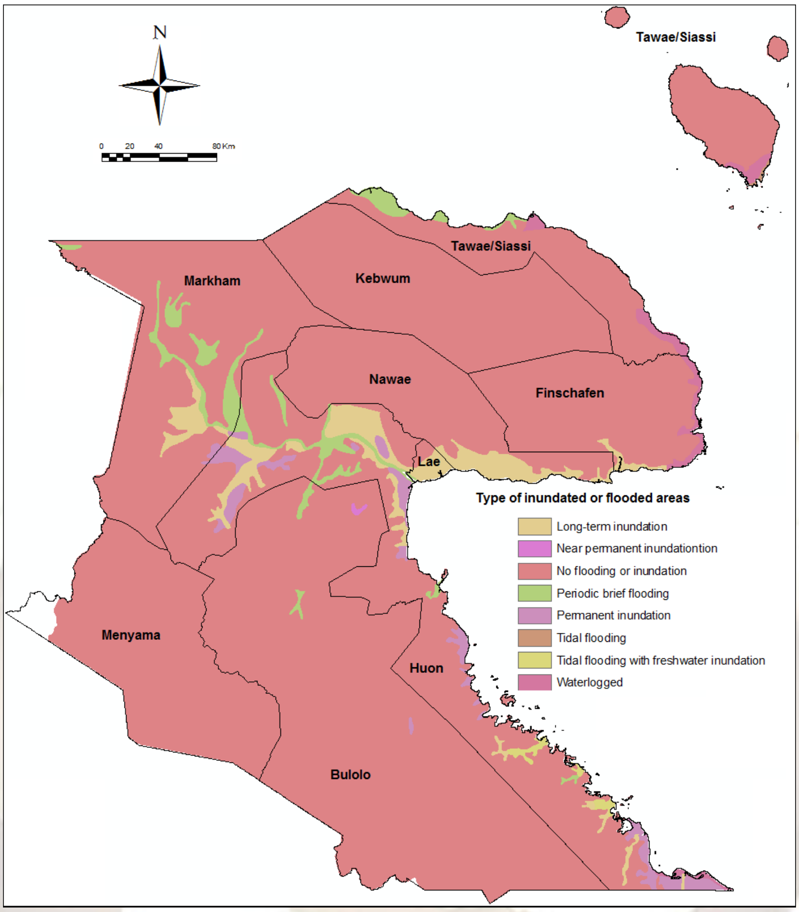

Figure 11. Inundation map of the study area

Weight assignment for hydrological modelling

Suitable weights were assigned to the ten themes and their individual features after understanding their hydrogeological importance in causing groundwater occurrence in the study area. Weighted overlay analysis is a simple and straightforward method for a combined analysis of multi-class maps. The efficacy of this method lies in that human judgment can be incorporated in the analysis. Weighted index overlay method takes into consideration the relative importance of the parameters and the classes belonging to each parameter. There is no standard scale for a simple weighted overlay method. For this purpose, criteria for the analysis should be defined and each parameter should be assigned importance (Saraf and Choudhury, 1998; Nag, 2005). Determination of weightage of each class is the most crucial in integrated analysis, as the output is largely dependent on the assignment of appropriate weightage. The weights assigned to different classes of all the thematic layers are given in Table 11. To cite an example, the maximum weight assigned for the greater potentiality of groundwater and vice-versa.

The final weights of each polygon in the final integrated layer were derived by summing up the weights of polygons from individual layers and the highest derived sum of the weights in the final integrated layer was divided into five equal classes, i.e. 'very good', 'good', 'moderate', 'poor' and 'very poor', in order to delineate groundwater potential zones. The delineation of groundwater potential zones was done by grouping the polygons in the final integrated layer having weights of any of the five classes.

Table 11. Weight distribution table to each parameters

Sl. No.	Parameters/Criteria	Weightage
1	Geomorphology	15
2	Lithology	10
3	Soil	15
4	Elevation (m)	10
5	Slope (°)	10
6	Rainfall (mm)	10
7	Land use/land cover	5
8	Vegetation	5
9	Drainage density	15
10	Inundation type	5

V. CONCLUSION

Analysis of groundwater potential zones shows that the very high groundwater potential zones constitute 4.29% of the Morobe province. The regions were mainly comprises on some small pocket of north-eastern western region of the province. Some small pockets were also found on the south-eastern part of the region. High groundwater potential zones are seen at the north-eastern and south-western part of the study site and constitute 15.71% of the province. Moreover, these regions were covered the peripheral of very high groundwater potential zone, except the north-western part of the province. A moderate groundwater potential zone occupies the biggest area as about 37.16% of the total province. The moderate groundwater potential zone were encompasses in the southern and western part of the province. Meanwhile the northern part and some central pockets fall under poor and very poor groundwater potential zones, constituting about 42.84% of the province. Percentage of each groundwater potential zones is shown in table 12 and figure 12.

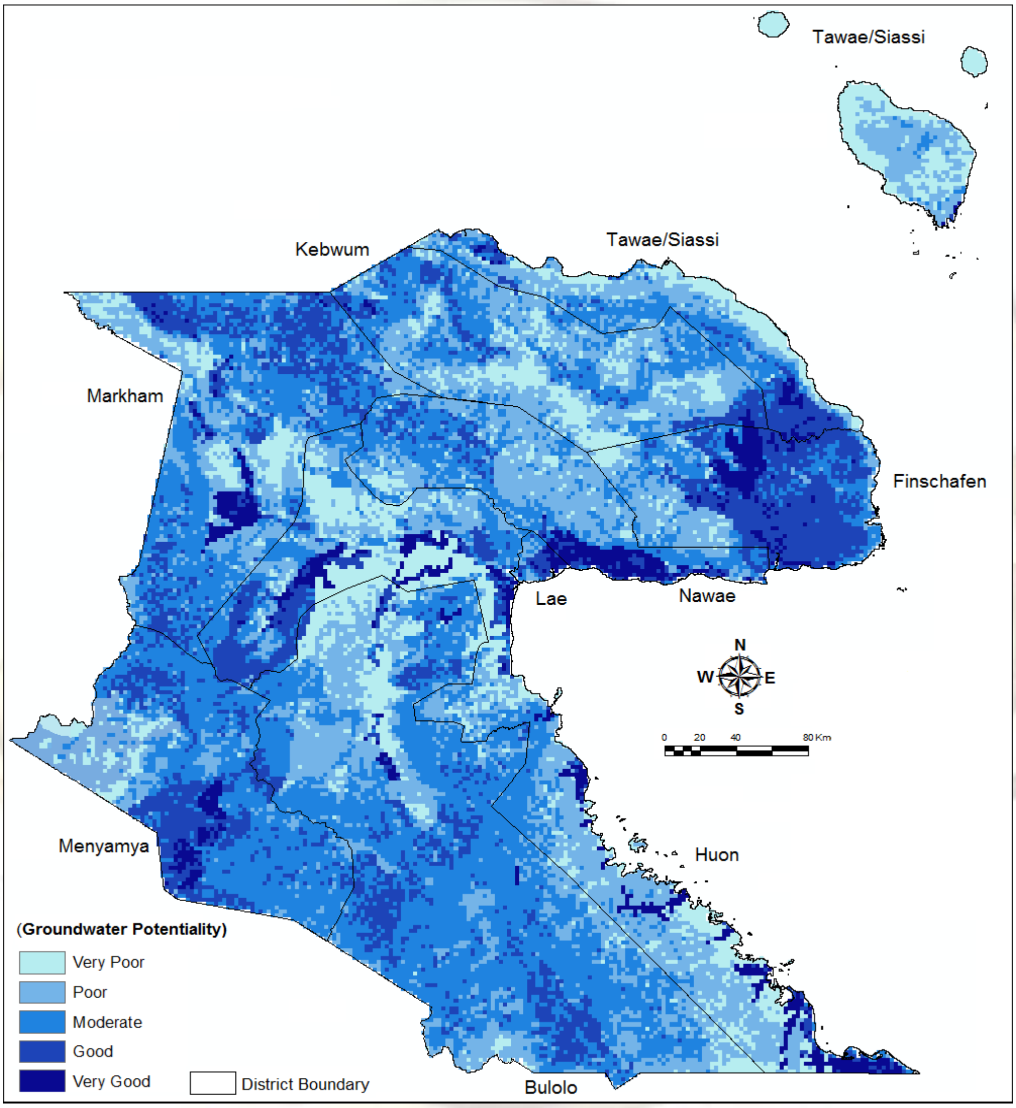

Figure 12. Groundwater potential zone map of the study area

The groundwater prospect map is a systematic effort and the map depicts geomrphological aspects, which are essential as basis for planning and execution of groundwater exploration. The high potential zone because of suitable surface and subsurface conditions like presence of alluvial plains and fan, floodplain and lakes create favourable environment for higher water yield as well as favourable discharge. Low potential zones include rocky area and volcanic structures, which act as runoff zones as well as low water yield. In the study area, the lithological formation consisting of coarse grained sedimentary and marine deposits, high rainfall and fine texture of drainage pattern provides suitable for groundwater potential. On the other hand, slope more than 30° and higher elevation thereby indicating more runoff and less infiltration within the study area. The presence of weathered and fine texture soil, inundation areas, waterbody, cropland and high dense vegetated areas in the study site; thereby indicates the possibility of acting as major conduits for subsurface movement and for the storage of groundwater.

Table 12. Ground water potential categories of the study area

Lower and upper weight Value	GW potentiality	Area (in km^2)	Perimeter (meter)	Thickness
25.00-37.98	Very poor	4400.68	6,610,000	4,077
37.99-41.51	Poor	9934.94	14,166,000	4,988.5
41.52-45.04	Moderate	12434.63	14,718,400	5,254.10
45.05-49.14	Good	5256.23	8,031,800	5,550.299
49.15-61.00	Very good	1434.66	2,208,400	3,419.099

However, within the study site a very less percent of area is covered with high ground water potential zone. Therefore, judicious utilization of groundwater resources coupled with proper water management is essential for ensuring groundwater sustainability. Considering of an adequate number of thematic layers and proper assignment of weights are keys to the success of Geoinformatic techniques in identifying groundwater prospects. The final map prepared in the form of a prospect map would provide firsthand information to local authorities and planners about the areas suitable for searching ground water followed by its suitable exploration. Based on the results of the study, concerned decision makers can formulate an efficient groundwater utilization plan for the study area so as to ensure long term sustainability of this vital resource.

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