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Spatial Assessment of Groundwater Potential Zones of East New Britain province, Papua New Guinea

Hejumacla Oboko[1], Sujoy Kumar Jana[2], Tingneyuc Sekac[3]*

[1,2,3] Department of Surveying and Land Studies, Papua New Guinea University of Technology, Morobe Province, Papua New Guinea
Email: [1]oboko.hejumacla8@gmail.com, [2]sujoy2007@gmail.com, [3]tingneyucsekac@gmail.com
*Corresponding Author: Sujoy Kumar Jana

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ABSTRACT

Technological advancement nowadays is very helpful with cost effective and time consuming techniques by incorporating GIS and Remote Sensing techniques to delineate groundwater potential map with wide-ranging tools used for the assessment of water resources, its management and conservation. This project is to outline the zonation of groundwater and produces a potential Groundwater map of East New Britain Province. The techniques used are Multi-Influencing Factor (MIF) and Analytical Hierarchy Process (AHP) for the evaluation and assignment of ranks and weights on the different factors such as Lithology, Geomorphology, Soil, Slope, LU/LC, Rainfall, Lineaments & Drainage Density and Vegetation. After assigning each factors with its weightages and ranking individual factors depending on their influence on groundwater potential areas, it is then overlay in the GIS environment using Weighted Sum technique. From the overall results, the groundwater potential areas in the study area are classified into five (5) categories ranging from very good, good, moderate, poor and very poor. With these categories; Very Good (21.90%), Good (37.60%), Moderate (25.81%), Poor (12.39%) and Very Poor (2.30%) which the representation is explicitly decipher that most of the area is potentially suitable for groundwater occurrence. Concurring, Pomio and Gazelle districts have spatially shows moderate to Very Good potential areas of groundwater compared to Rabaul and Kokopo districts having low potential areas of groundwater. After integrating all these 9 thematic layers with their assigned weights, it clearly indicates potential groundwater areas which can decipher potential groundwater sources for drinking water supply, recharge locations and planning for water security.

1. Introduction

In current times it has become apparent in various countries of the world that groundwater is considered as the most vital necessity in the sustenance of life. Groundwater is defined as the underground water trapped in the soil and in pervious rocks with essential advantages compared to surface water. The advantages that groundwater has over surface water is that "it's of greater quality, better protected from probable pollution (infections), less focus to periodic & perennial variations and it is more consistently spread over wider regions" (Zekster & Evereth,2004). From previous study, Shiklomanov (1993) state that Groundwater accounts for 30 % of the earth's freshwater, while surface water properties from lakes and rivers accounts for less than 0.3 %. However, according to Environmental Protection Agency (2009) indicate that out of the total fresh water supply, groundwater contributes about 60 percent, which is about 0.6 percent of the entire world's water. In addition, Waikar et al.(2014) also suggested several essential qualities which are greatly significant and dependable source of water provisions in all climatic conditions including rural and urban areas of developed and developing countries. Furthermore, Rao (2006) and Chowdhury et al. (2009) simplifies Groundwater as important renewable natural resource and plays vital role in drinking, agriculture and meet industrial requirements as a timely source associated with surface water. The demand for this ground water is rapidly escalating due to increase in population growth and urbanization. Additionally, it is also essential in global climate change and sustaining human needs. In some developed and developing countries, groundwater is the only foundation of water stock and supply. Thus, it is very important in irrigation, drinking and industrialization. According to Wellntel.com (2018) it was reported that in the "US alone, 44 million people depend on groundwater as their source of water" (14,761,741). It signifies that the country mostly rely on using this resource in farm areas. In addition, Zekster & Everett (2004) indicated that water supply in some parts of the world particularly Denmark, Saudi Arabia, etc. uses only groundwater that contributes to the total water resource. Here are the statistical figures about Groundwater used in some countries: "Groundwater in Tunisia is 95 percent of the country's entire water resources, in Belgium it is 83 percent, and in the Germany, Netherlands, and Morocco it is 75 percent. Hence, more European countries groundwater use go beyond 70 percent of the entire water drinking" .

In Papua New Guinea, the country is surrounded by vast natural resources however the Government is turning a blind eye on development for prospecting of ground water and utilization of this resources which many of the rural areas are in dire need for fresh water. A further statement from the WHO and UNICEF-PNG indicates that 88 percent of the population in urban areas is exposed to safe drinking water supply which only 32% of the same are people from the rural areas (WHO & UNICEF ,2003). In contrast, Remote Sensing (RS) and GIS skills can be useful in different field of sciences and to deliver prospect for improved opinion and more efficient analysis of several identification and demarcation of groundwater resources (Tumare et al, 2014).

The paper deals with incorporated approach of Remote Sensing and GIS to interpret the groundwater probable zones in East New Britain Province, PNG. The responsible authorities and or water management authorities in PNG are lacking the knowledge and utilization of Remote sensing and GIS skills to acquire ground water. Therefore, water scarcity is on the rise in some parts of East New Britain Province. The impacts of water crisis have on the people are very evident which most of the time it results in poor social, academic, health and other related problems due to water shortage in the Province. Concurring the possibilities now is groundwater. Hence, this researched study is an investigation to delineate groundwater map to the responsible water resource management of East New Britain Province. It will help identify the groundwater potential areas for boreholes.

In the Previous decades, many scholars have used remote sensing (RS) and GIS skills for delineation of groundwater potential map (Jha et al. 2010, Tumare et al, (2014) with positive results. According to Rashid et al. (2011) stated that RS provides temporal, spectral, and multi-sensor data of the earth’s surface. Image Handling skills such as Band Ratioing, Principal Component Analysis (PCA), Filtering and Contrast Stretching have been applied on satellite imagery for clear interpretation. Similarly, GIS is seen as a greatest technique for handling spatial data and making decision in several field of hydrological, geological, and environmental sciences (Rahmati et al. 2014). Both techniques have contributed a lot in deciphering groundwater potential areas in different regions of the world.

The current study aims at identifying prospective groundwater for availability utilizing GIS and Remote Sensing techniques. The objectives of this project focuses on; (1) collecting the secondary data and to evaluate the RS data for retrieving information that is associated to groundwater existence, (2) to identify the potency of groundwater occurrence of different parameter using MIF technique, (3) to identify the groundwater potential zone by assigning weightage for each theme based on AHP technique, and contribute a systematic groundwater delineation study, and finally (4), to have appropriate administration for bearable use of groundwater.

3. Materials and Methods

3.1 Introduction

The general research idea involved incorporation of nine (9) thematic factors of conventional and RS data. And its fundamental constraints for the methodology are the research site, materials and methods required to do the implementation of this project. The overall capture of methodology carried out is illustrated in figure 2.

3.2 Study Area

The study zone (Figure.1) is focused on delineating groundwater potential map of East New Britain Province, PNG. The locality is at Zone 56 South of the equator and is situated between coordinates system of 4˚0’0” to 6˚0’0” S latitude and 150˚0’0” to 153˚0’0” E longitude.

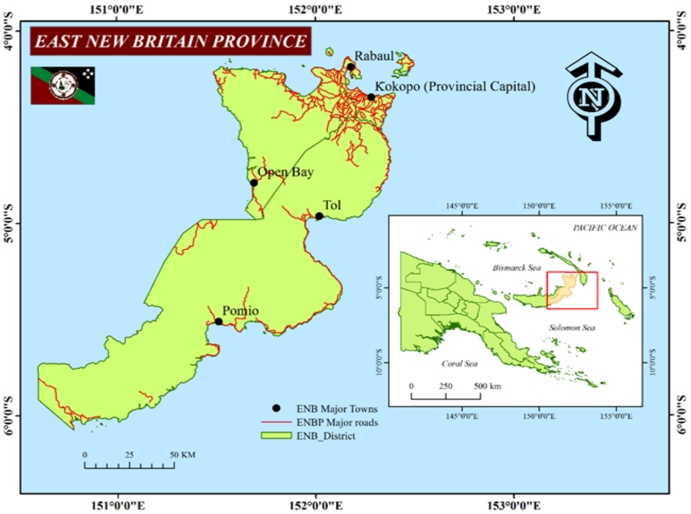


Figure 1: Locality map of East New Britain Province

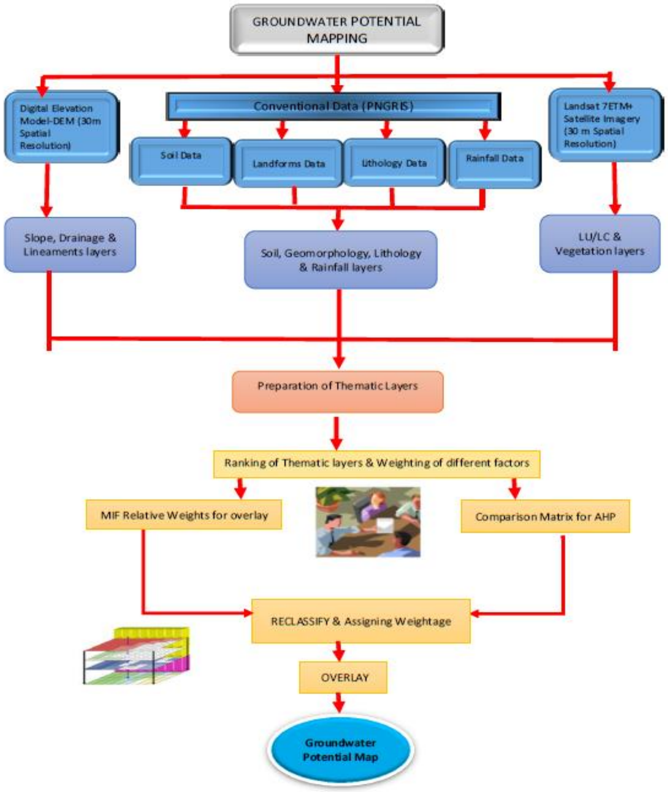


Figure 2: Methodological Flow Chart

The Landsat 7 ETM+ path row for the province boundaries are 9363, 9364, 9463 and 9464. East New Britain Province is the fourth capital city of Papua New Guinea and it is located at the north-eastern part of New Britain and Duke of York Islands. The new capital is Kokopo due to volcanic eruption (Mt Tavurvur & Vulcan) in 1994 have destroyed the old capital of Rabaul. The Province comprised of four (4) districts: Kokopo, Pomio, Rabaul and Gazelle district covering a total landmass area of 15,816 square kilometres (6,107sq mil). According 2011 Census, the total population recorded is 328,369. Currently, the province relies mostly on tourism and cash crops for provincial economy however in some ways, water crisis is also a contributing factor towards the development growth of the province.

3.3. Data Capture & Acquisition

The datasets were collected from Department of Surveying and Land Studies, PNG University of Technology, PNG. The data collection comprised of Conventional data, Digital Elevation Model (DEM) data and Satellite images. From these datasets the conventional data contains thematic layers derived from reproject PNGRIS and Geobook metadata to prepare Lithology, Geomorphology, Rainfall and soil layers. The Normalized Difference Vegetation Index (NDVI) was generated from the Landsat ETM+ (30m) imagery using Arc GIS software. The slope, Drainage and Lineaments density layers were derived from the 30m Digital Elevation Model (DEM) respectively. In addition, Drainage Density and Lineaments Density raster were derived with line density tool in ArcGIS 10.2. The Land Use and Land Cover (LULC) data was arranged from Landsat ETM+ (30m) imagery and classified using Maximum Likelihood technique.

3.4 Weighted Sum Technique coupled with MIF and AHP.

The weighted Sum technique was used to delineate groundwater potential areas in East New Britain Province. The thematic factors such as Lithology, Geomorphology, LULC, Slope, Drainage and Lineament density, Rainfall, soil and Vegetation were used in this analysis. According to Malczewski 2006, Sekac et. al 2016 & 2019 and Varo et. al 2019 idea of overlay analysis is established on the intersection of geo-referenced cell or pixcel in a thematic factor with the geo-referenced cell or pixel of additional thematic factor. The value in individually thematic factor were given a mutual scale, thus incorporating all thematic factors to create an output layer.

3.4.1 Multi-Influencing Factors (MIF)

Table 1 shows score for individually influencing factor designed based on the greater and less effect values. The design of multi-influencing dynamics for each thematic layers are displayed as points. Lithology: 1(5) major=5 points, Geomorphology: 1(4) major + 0.5(2) minor=5point, Soil: 1(3) major +0.5(4) minor=5points, Rainfall: 1(3) major +0.5(3) minor=4.5points, Drainage: 1(2) major + 0.5(5) minor=4.5 points, Slope: 1(3) major + 0.5(3) minor=4.5 points, Lineament: 1(3) major +0.5(3) minor=4.5points, LU/LC: 1(2) major + 0.5(4) minor=4 points, and Vegetation: 1(3) major + 0.5(2) minor=4points.

Each thematic factors will be reclassified and allocated appropriate weightage agreeing to their potency towards the occurrence of groundwater. The weights will be based on their major and minor effects on individual factors by assigning 1 and 0.5 respectively. The relative weights are assigned to each thematic map to generate increasing weightage of mutually minor and major effects, which are then reflected to calculate comparative rates (Table 1). Throughout weighted overlay examination, the grade given for separate parameter of individually thematic layer and weights were given agreeing to the MIF of that certain feature on the hydro-geological environment of the study zone (Shaban et al. 2006).

Table 1 Impelling factors, their major-minor effects and corresponding scores in the MIF method. Adapted: *Source:* Magesh et al. (2012) and Das et al. (2017)

Factors	Major Effect Factor	Minor Effect Factor	Weight for Major Effect (M_j)	Weight for Minor Effect (M_i)	Proposed relative weight (M_j+M_i)	Proposed Score(S) for each factor
Lithology(LIT)	LULC, SL,SO,LD, DD		1+1+1+1+1		5	12
Geomorphology (GM)	LIT,DD, LULC,SL	SO,LD	1+1+1+1	0.5+0.5	5	12
Soil(SO)	DD,LIT, LULC	SL, LD, GM,V	1+1+1	0.5+0.5+0.5+0.5	5	12
Rainfall(RF)	SO, DD, LULC	LD,GM, SL	1+1+1	0.5+0.5+0.5	4.5	11
Drainage Density(DD)	LD,LULC	RF,SL,LIT,SO,GM	1+1	0.5+0.5+0.5+0.5+0.5	4.5	11
Slope(SL)	DD, RF, SO	GM,LIT, LULC	1+1+1	0.5+0.5+0.5	4.5	11
Lineaments Density(LD)	DD,LULC,SL	RF,GM, LIT	1+1+1	0.5+0.5+0.5	4.5	11
LandUseLandCover(LULC)	RF,DD	LIT,SL, LD,V	1+1	0.5+0.5+0.5+0.5	4	10
Vegetation (V)	LULC,RF,SO	GM, LIT	1+1+1	0.5+0.5	4	10
Total ∑					**41**	**100**

This formula (eq. (1)) was adopted to compute scores for each influencing thematic factors (Das et al.2017).

$$\boldsymbol{S}= \frac{(\boldsymbol{M_j}+ \boldsymbol{M_i})}{\sum(\boldsymbol{M_j}+\boldsymbol{M_i})}\ \mathbf{*100} \tag{1}$$

Where, S is the planned score of the influencing layer. M_j represents foremost inter-relationship among two factors and M_i represents the minor inter-relationship among two thematic factors.

3.4.2 *Pair-wise comparison (AHP)*

In demand to assess the weight of individually thematic factor or parameters, a pair-wise comparisons matrix of the criteria for the AHP procedure was determined (Table 3), and the consistency ratio (CR) was measured while examining the comparisons. For the comparisons to be consistent, and satisfactory, the CR must be less than 0.1(10%) grounded on the major and minor effects. Lithology, Geomorphology and Soil are ranked as 1, 2, 3 and Rainfall, Drainage Density, Slope and Lineaments Density were ranked 4, 5, 6 and 7 successively, followed by Land Use/Land Cover and Vegetation with 8 and 9 respectively (Table 1).

The matrix of standard pair-wise comparison was constructed by normalizing pairwise comparison matrix (Table 2). The Consistency Index is calculated by this following equation introduced by Saaty (1980):

$$CR = \frac{CI}{RI} \tag{2}$$

$$CI = \frac{\lambda max-n}{n-1} \tag{3}$$

Where, CR is Consistency Ratio, CI is Consistency Index, λ max is the standard eigenvalue of matrix, n is the number of factors.

Random Index (RI) values are calculated by the numeral of constituents in Saaty’s (1980) paper. RI values are straight taken from the table delivered by Saaty (1980) which hinge on on the number of constituents (Table 2.) Hence, from these two (2) techniques the maps generated will be based on the calculations provided in table 4 of normalized weights column.

Table 2. Random Index (RI)

No. factor	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
R I	**0.00**	**0.00**	**0.52**	**0.90**	**1.12**	**1.24**	**1.32**	**1.41**	**1.46**	**1.49**	**1.51**	**1.48**	**1.56**	**1.57**	**1.59**

Source :(Saaty, 1970)

Table 3. Pairwise appraisal matrix for the AHP method.

Factor	LIT	GM	SO	RF	DD	SL	LD	LULC	V
Lithology**(LIT)**	1	5/5	5/5	5/4.5	5/4.5	5/4.5	5/4.5	5/4	5/4
Geomorphology **(GM)**	5/5	1	5/5	5/4.5	5/4.5	5/4.5	5/4.5	5/4	5/4
Soil(SO)	5/5	5/5	1	5/4.5	5/4.5	5/4.5	5/4.5	5/4	5/4
Rainfall**(RF)**	4.5/5	4.5/5	4.5/5	1	4.5/4.5	4.5/4.5	4.5/4.5	4.5/4	4.5/4
Drainage Density**(DD)**	4.5/5	4.5/5	4.5/5	4.5/4.5	1	4.5/4.5	4.5/4.5	4.5/4	4.5/4
Slope**(SL)**	4.5/5	4.5/5	4.5/5	4.5/4.5	4.5/4.5	1	4.5/4.5	4.5/4	4.5/4
Lineament Density **(LD)**	4.5/5	4.5/5	4.5/5	4.5/4.5	4.5/4.5	4.5/4.5	1	4.5/4	4.5/4
LULC	4/5	4/5	4/5	4/4.5	4/4.5	4/4.5	4/4.5	1	4/4
Vegetation **(V)**	4/5	4/5	4/5	4/4.5	4/4.5	4/4.5	4/4.5	4/4	1
TOTAL	**8.20**	**8.20**	**8.20**	**9.11**	**9.11**	**9.11**	**9.11**	**10.25**	**10.25**

Table 4. Standard Pairwise comparison matrix for the AHP process.

Factor	LIT	GM	SO	RF	DD	SL	LD	LULC	V	Normalized Weights
Lithology(LIT)	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12195122
Geomorphology (GM)	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12195122
Soil(SO)	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12195122
Rainfall(RF)	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.109756098
Drainage Density(DD)	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.109756098
Slope(SL)	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.109756098
Lineament Density (LD)	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.109756098
LULC	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.097560976
Vegetation (V)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.097560976
Total	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	

Consistency Ratio=0

4. Results and Discussions

Nine (9) parameter which is Influencing factors such as Lithology, Geomorphology, Soil, Rainfall, Drainage Density, Slope, Lineaments Density, LULC and Vegetation Index were studied to delineate different groundwater potential areas of East New Britain Province. Below are detailed of individual factors plays part in influencing the Groundwater regime with their spatial scattering in the study area.

4.1 Lithology

Lithology (Figure 3a) offers evidence on underlying rock strata where permeability of rocks determines its infiltration ability. In other words, Porosity and permeability are governed by the lithology of an aquifer material (Ayazi et al. 2010; Chowdhury et al. 2010). The Groundwater holding capacity of rocks depends on compactness of the rocks .In turn the rocks compactness depends mainly on the presence of pore spaces within the rocks (porosity) and permeability. It’s one of the foremost factor which it plays an important role in the circulation and existence of groundwater. Lithology arrangement of type of rock was revised from Loffler (1974), and is founded on modest criteria, such as the origin, structure and grain size of parent material. The 3 main type of rock classes recognized are metamorphic rocks, sedimentary rocks, and igneous rocks. However, 66.97% of the study zone is shielded with Limestone and Basic to intermediate volcanic rocks (Table 5). Figure 3a shows that the area is mostly covered with sedimentary rocks and igneous rocks.

4.2 Geomorphology

Geomorphology (Figure 3b) mirrors different landforms and structural features, various of which favor the incidence of groundwater. It constitutes the greatest vital features in assessing the groundwater potential and prospect (Kumar et al. 2008). The Landforms determines the run-off, flooding, groundwater restore and rainfall to some degree which the topography within a zone also controls the existence of groundwater. The different landform (Loffler, 1974) types were separated into 3 foremost groups according to the leading geomorphic procedures by which they were made: Erosional landforms, Depositional landforms, and Volcanic landforms. About 73.78% of the two types of landforms are covered with Mountains and hills with fragile or no essential controller and Polygonal karst: plateaux or broad ridges on limestone shielded with numerous rugged hills (Table 5). Figure 3b shows the geomorphological characteristics of the study area.

4.3 Soil Texture (Hydrologic Soil Group)

Soil (Figure 3c) is the most important factor to control the groundwater potential as soil texture influences the infiltration process (Mehra and Singh 2018; Mehra et al. 2016; Sekac et. al 2017; Jana et.al 2018). Its physical properties are directly interrelated based on the infiltration rate & permeability, and run-off Potential. The hydrologic soil group model (USDA) has classified all soils into four groups and these are: ‘Group A’, ‘Group B’,’Group C’ and ‘Group D’ (Table 5). Within the study region (refer Figure 3c), twelve (12) types of soil texture were derived and were grouped into the hydrologic soil group thus, 98.41% are soil texture under group A and D with very good influence of Groundwater occurrence and Poor regions respectively. Weights were given individually to each soil unit afterward taking into justification the kind of soil and its water holding capacity.

4.4 Rainfall

Rainfall (Figure 3d) is the most important input in the hydrological phase and variations in quality and distribution strongly influence sub-surface and surface water foundations. According to Todd (1980) stated that water table of a zone is mainly controlled by differences in Groundwater recharge, discharge and rainfall. Rainwater which drops on the ground is penetrated into the soil. The penetrated water is consumed partly in satisfying the soil moisture shortage and also part of it is seep into down reaching the water table. Adiat et al. (2012) verified that the rainfall has a significant result on percolation and Groundwater Potential Mapping precision. The different annual rainfall is generated and shown in table 5. Figure 3d depicts that the high mean annual rainfall (McAlpine et al. 1975) of the study area ranges between 2500mm to 4000mm.

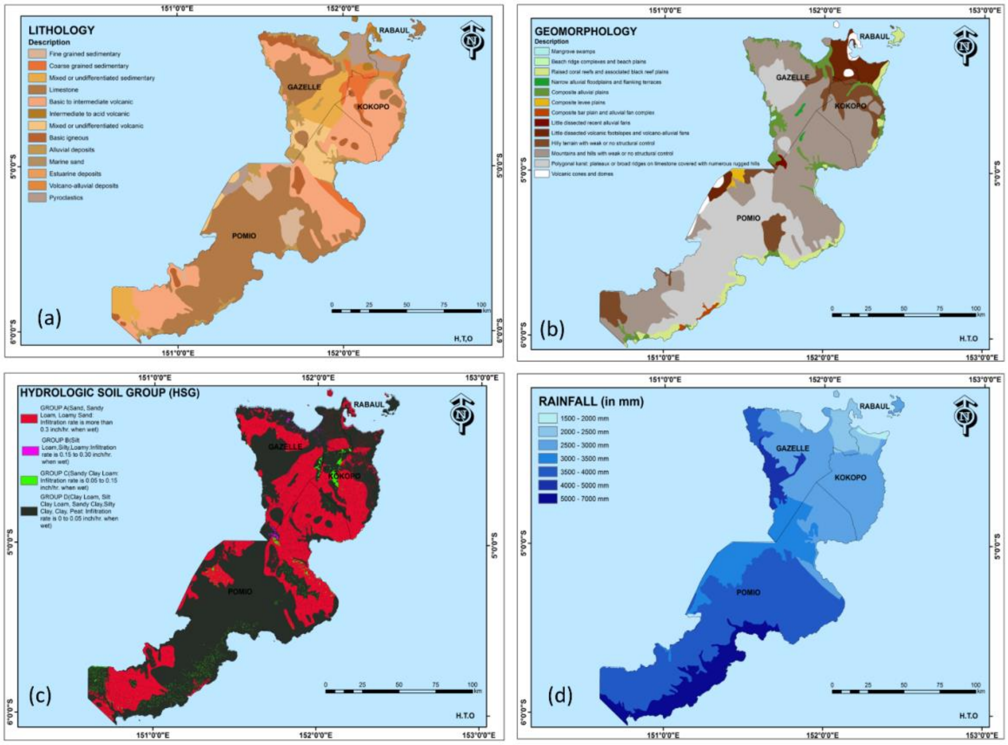


Figure 3: Thematic Layers; a. Lithological classes, b. Geomorphological Classes, c. Soil Classes, d. Rainfall (mm)

4.5 Drainage & Drainage Density

Drainage Density (Figure 4a) outline mirrors surface features as well as subsurface formations. It is defined (in terms of km/km^2) to indicate closeness of spacing of stream channels as well as the nature of surface material (Prasad et al., 2008; Sekac et. al 2017, Varo et. al 2020). The type of drainage pattern found in this study area is the dendritic drainage pattern. Drainage Density measures the overall dimension of the river subdivision of all orders per unit area using this formula (eq. (4)). The Drainage Density is inversely proportional to permeability which the stream flow design is frequently controlled by its lithology of the area. The higher drainage density of the area, the more run-off it will have with less infiltration and vice versa. The Drainage Density (Table 5.) is calculated using the line density tool under Spatial Analyst in Arc GIS 10.4 Software. According to the Drainage Density (Figure 4a) of the study area, it was categorized into five (5) classes using Natural Breaks(i)0-0.16km; (ii)0.16-0.26km;(iii) 0.26-0.33km; (iv)0.33-0.41km; and (v)>0.41km with categories assigned from Very Good to Very Poor. The appropriateness of groundwater potential zonation is indirectly linked to drainage density because of its relative with surface run-off and penetrability.

The drainage density is calculated using this equation (4) (Horton, 1939).

$$\mathbf{DD} = \frac{\sum \boldsymbol{D}\mathbf{i}}{\boldsymbol{A}} \qquad \mathbf{(4)}$$

Where:
DD=Drainage Density
Di=Total length of streams
A= Area of Grid (km^2)

4.6 Slope

Slope (Figure 4b) is a vital factor to identify potential areas for groundwater. In other lyrics, these thematic factors can be deliberated as the substitute of surface runoff rate and perpendicular percolation (i.e., infiltration is in reverse related to the slope) and thus disturbing recharge progressions (Adiat et al. 2012). Moderate slope lessens the velocity of surface runoff, therefore increasing the time for infiltration into the ground. Steep slope does not allow water to penetrate into the ground, the water run fast avoiding the chances of penetration. Therefore, spatial analysis of slope is important for the forecast of groundwater accessibility (Figure 4b). The slope map was generated from ASTER DEM data using the Spatial Analyst Tool in Arc GIS 10.4 .It was divided into five (5) groups: 0°-7.19°: Very Gentle; 7.19°-14.37°: Gentle; 14.37°-22.81°: Low Moderate; 22.81°-33.12°: High Moderate; and more than 33.12°: Steep (Table 5).

4.7 Lineaments & Lineaments Density

Linear or curvilinear arrangements on the earth surface, which portrays the frailer zone of bed rocks is called lineaments which controls water movement between the surface and sub-surface through different geological structures such as faults, fractures, joints and dykes. In this study, Lineament map was generated from ASTER DEM 30m resolution. The Lineaments density (Figure 4c) is then derived using line density tool under Spatial Analyst in Arc GIS 10.4 software. It is calculated using this formula (eq. (5)):

$$\mathbf{LD} = \frac{\sum \boldsymbol{L}\mathbf{i}}{\boldsymbol{A}} \qquad \mathbf{(5)}$$

Where:
LD=Lineaments Density
Li=Total length of Lineaments
A= Grid Area in sq./km

Potency of groundwater can be detected/identified on the map based on the closeness distribution of the different geological structures. That is closer/near the lineaments, the more infiltration of groundwater compared to lineaments that are far apart. As shown in Figure 4c, the area that has the high lineament density can be a suitable location for groundwater occurrence (Magesh et al, 2012). The Lineament Density (Table 5) is classified into 5 groups: i)0-0.45(Very Low); ii)0.45-0.73 (Low) ;iii)0.73-1.00(Moderate) ;1.00-1.30(High) and 1.01-1.78(Very High).

4.8 Land Use Land Cover (LULC)

Land use indicate the people with respect to its suitability for specific use, whereas land cover is the portrayal of physical substantial that covers the earth's surface irrespective of its suitability for specific use. LULC (Figure 4d) is a form of classification where Remote Sensing technique plays an important handy tool for providing reliable basic information for depicting the type of LULC through mapping. It also has impact towards the potency of groundwater occurrence. Within the study area (Figure 4d)), the major LU classes i.e. Dense Vegetation (30.31%), Low Dense Vegetation (62.75%), Built-Up Area (0.78%), Barren Land (4.92%) and Water Bodies (1.23%). The weights in table 5 were assigned according to influence of groundwater occurrence. The water bodies have high impact on the influence of groundwater potential than the built-up areas which play as impervious walls and constrain water infiltration to the underground. In other case, it is presumed that the vegetation cover has an active role in the enrichment of recharge amount (Shaban et al. 2006).

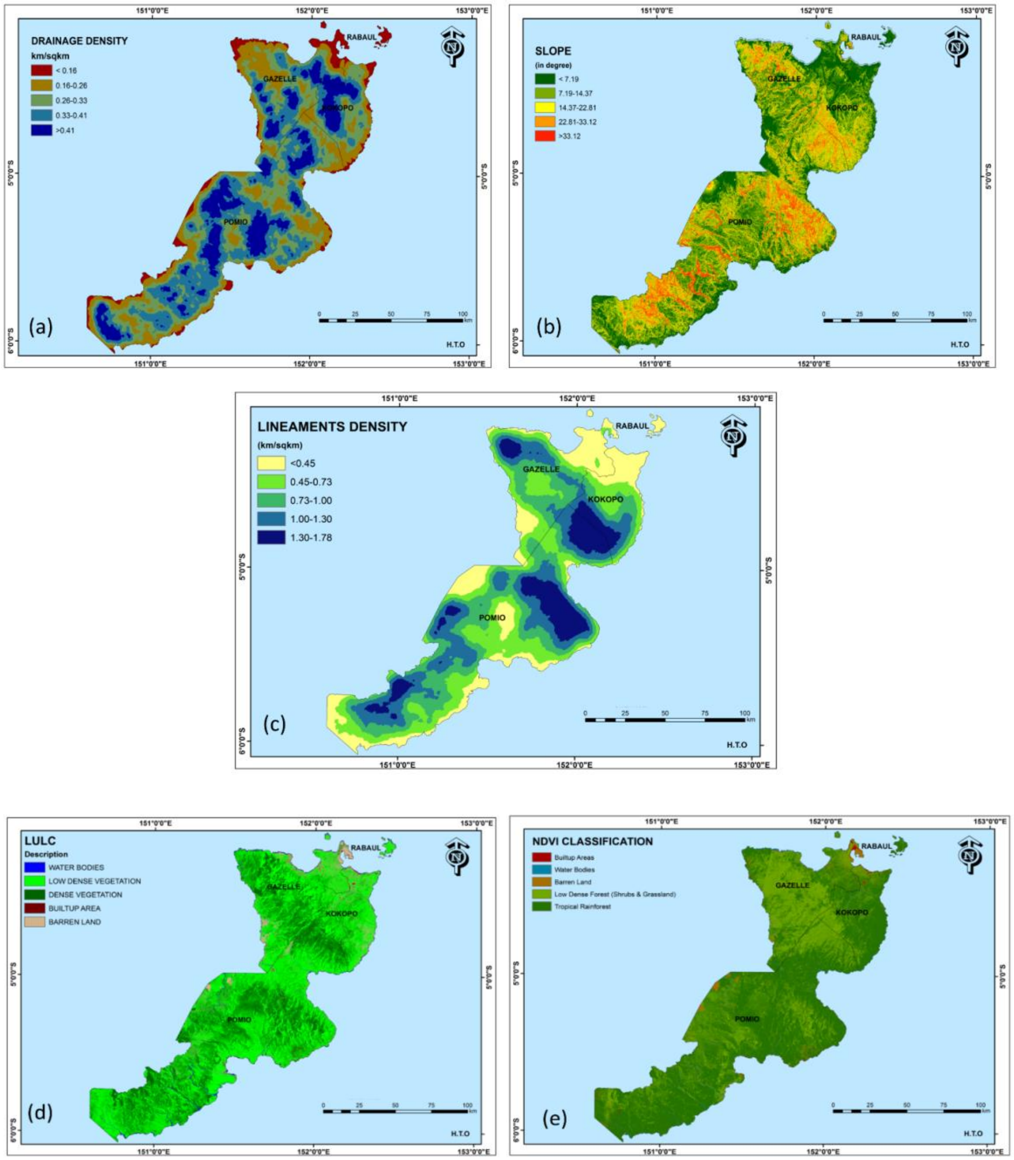


Figure 4: Thematic layers; a. Drainage Density derived from Drainage Networks, b. Slope, c. Lineaments density derived from Lineaments, d. LULC, e. NDVI

4.9 Normalized Difference Vegetation Index (NDVI)

Vegetation is another factor that also has impact towards the influence of groundwater potential. It comes in different variety of natural land covers based on their characteristics. Classification of groundwater interactions with the surface (i.e., recharge vs. discharge areas) using classification of instrument vegetation is candid in concept but can be complicated in practice (Tumare et al, 2014). Its respond towards the flow of groundwater may slowly changes due to its constant state of transition. The canopy cover was created from Landsat 7 etm+ satellite images (using hybrid Maximum-Normalized Difference Vegetation Index (NDVI) and minimum-red compositing technique

(Figure4e)). Hence, NDVI is categories into five (5) classes:1) Built-up Areas;2) Water Bodies;3) Barren Land;4) Low Dense (Shrubs & Grassland) and 5) Tropical Rainforest according to its NDVI signatures (Table 5). In addition, Built-up areas has least influence compared to Tropical rainforest due to its run-off and infiltration properties. Out of the total area, 63.27% is covered with Tropical Rainforest and Low Dense Forest of 33.46%

Table 5. Weightage assignment of various thematic maps for ground water prospect zones

Description	Area (KM^2)	% Area Covered	Rank	Weight	Groundwater Prospects
Lithology Types					
Fine grained sedimentary	553.63	3.60	4	12	Good
Coarse grained sedimentary	484.98	3.15	5		Very Good
Mixed or undifferentiated sedimentary	993.32	6.46	3		Moderate
Limestone	5974.34	38.86	5		Very Good
Basic to intermediate volcanic	4299.69	27.97	1		Very Poor
Intermediate to acid volcanic	118.94	0.77	1		Very Poor
Mixed or undifferentiated volcanic	762.81	4.96	1		Very Poor
Basic igneous	501.54	3.26	1		Very Poor
Alluvial deposits	921.52	5.99	5		Very Good
Marine sand	14.99	0.10	5		Very Good
Estuarine deposits	8.66	0.06	5		Very Good
Volcano-alluvial deposits	182.57	1.19	1		Very Poor
Pyroclastic	557.92	3.64	2		Poor
Geomorphology Types					
Mangrove swamps	8.66	0.06	4	12	Good
Beach ridge complexes and beach plains	14.99	0.10	1		Very Poor
Raised coral reefs and associated black reef plains	719.14	4.68	2		Poor
Narrow alluvial floodplains and flanking terraces	31.58	0.21	4		Good
Composite alluvial plains	718.20	4.67	5		Very Good
Composite levee plains	81.48	0.53	4		Good
Composite bar plain and alluvial fan complex	54.54	0.35	2		Poor

Little dissected recent alluvial fans	35.73	0.23	4		Good
Little dissected volcanic foot slopes and volcano-alluvial fans	736.53	4.79	3		Moderate
Hilly terrain with weak or no structural control	1417.85	9.22	1		Very Poor
Mountains and hills with weak or no structural control	6526.22	42.45	1		Very Poor
Polygonal karst: plateaux or broad ridges on limestone covered with numerous rugged hills	4816.39	31.33	3		Moderate
Volcanic cones and domes	213.60	1.39	1		Very Poor
Hydrologic Soil Group					
Group A Sand, Sandy Loam, Loamy Sand, Peat: Infiltration rate is more than 0.3 inch/hr. when wet	5475.45	35.80	5	12	Very Good
Group B Silt Loam,Silty,Loamy:Infiltration rate is 0.15 to 0.30 inch/hr. when wet	33.21	0.22	4		Good
Group C Sandy Clay Loam: Infiltration rate is 0.05 to 0.15 inch/hr. when wet	208.44	1.36	3		Moderate
Group D Clay Loam, Silt Clay Loam, Sandy Clay, Silty Clay, Clay,: Infiltration rate is 0 to 0.05 inch/hr. when wet	9575.71	62.61	2		Poor
Rainfall(in mm)					
1500 - 2000 mm	67.56	0.44	3	11	Moderate
2000 - 2500 mm	806.75	5.25	3		Moderate
2500 - 3000 mm	4604.42	29.95	4		Good
3000 - 3500 mm	1862.71	12.12	4		Good
3500 - 4000 mm	6088.81	39.60	4		Good
4000 - 5000 mm	437.96	2.85	5		Very Good
5000 - 7000 mm	1506.72	9.80	5		Very Good

Drainage Density (km/km^2)					
<0.16	865.66	5.65	1	11	Very Poor
0.16-0.26	3121.41	20.39	2		Poor
0.26-0.33	4403.73	28.77	3		Moderate
0.33-0.41	4368.09	28.53	4		Good
>0.41	2550.19	16.66	5		Very Good
Slope (°)					
<7.19 (Very Gentle)	4599.94	30.25	**5**	11	Very Good
7.19-14.37 (Gentle)	4738.60	31.16	**4**		Good
14.37-22.81(Low Moderate)	3259.46	21.44	**3**		Moderate
22.81-33.12(High Moderate)	1895.89	12.47	**2**		Poor
> 33.12(Steep)	711.44	4.68	**1**		Very Poor
Lineament Density (km/km^2)					
< 0.45	2803.70	18.31	1	11	Very Poor
0.45 – 0.73	3661.34	23.92	2		Poor
0.73– 1.00	3910.38	25.54	3		Moderate
1.00 – 1.30	3080.61	20.12	4		Good
1.30-1.78	1853.14	12.10	5		Very Good
LULC					
Dense Vegetation	4639.44	30.31	**5**	10	Very Good
Low Dense Vegetation	9605.28	62.75	**4**		Good
Built-Up Area	119.27	0.78	**1**		Very Poor
Barren land	752.86	4.92	**2**		Poor
Water bodies	188.34	1.23	**3**		Moderate
Vegetation					
Water bodies	185.61	1.21	2	10	Poor
Tropical Rainforest	9686.33	63.27	5		Very Good
Barren Land	207.37	1.35	3		Moderate
Built-up areas	107.46	0.70	1		Very Poor
Low Dense Forest(Shrubs & Grassland)	5121.98	33.46	4		Good

4.10 Integration of groundwater potential modelling and Zonation.

With the integration of various thematic layers, we prepare a suitable groundwater potential zones; layers viz., Lithology, Geomorphology, Hydrologic Soil Group, Rainfall, Drainage Density, Slope, Lineaments Density, LULC and Vegetation (NDVI) using Remote Sensing and GIS Environment. The demarcation of the potential zones for groundwater is analysed in MIF and then evaluated through Analytical Hierarchy Process (AHP) to create the normalized weights for the overlay technique using weighted sum (Eq.6). Determination of the weightage is very critical when integrating parameters as the final output is essentially dependent on the weights assigned to individual parameters.

Table 6 Weight distribution to each parameter.

S/N	Factors	Normalized Weights(N_W)
1	Lithology (LIT)	0.12195122
2	Geomorphology (GM)	0.12195122
3	Soil (SO)	0.12195122
4	Rainfall (RF)	0.109756098
5	Drainage Density (DD)	0.109756098
6	Slope (SL)	0.109756098
7	Lineament Density (LD)	0.109756098
8	LULC	0.097560976
9	Vegetation (V)	0.097560976

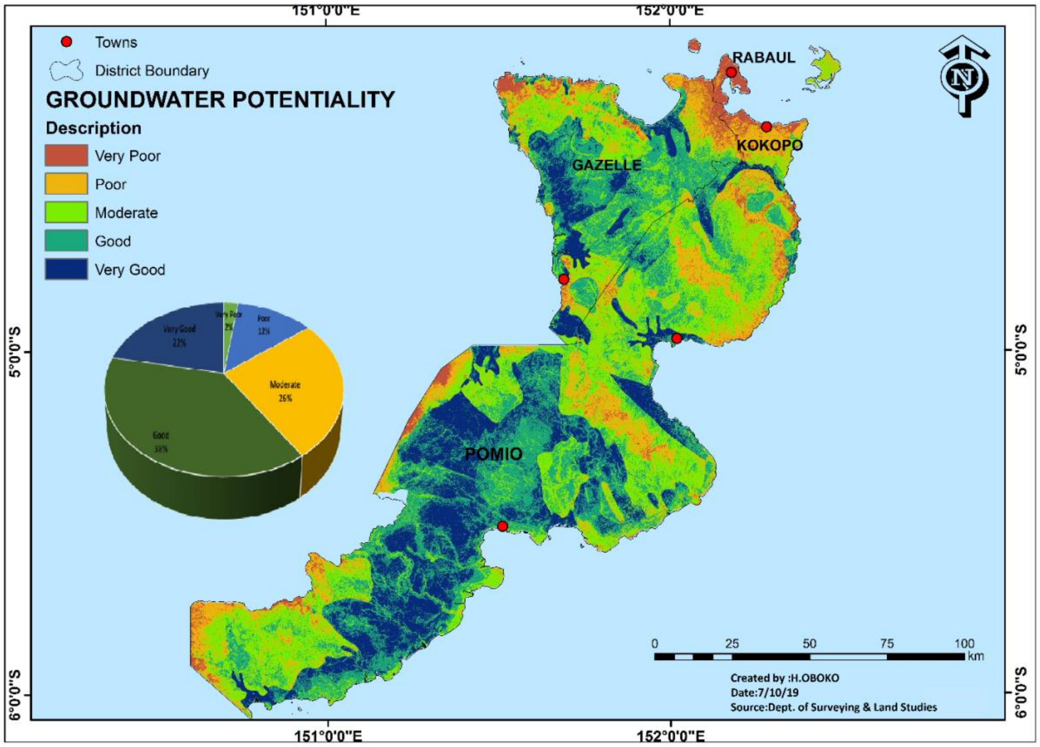
Fig.5 GWPZ Model

$$\mathbf{GWPZ}=\boldsymbol{LIT_{Nw}+GEOM_{Nw}+HSG_{Nw}+RF_{Nw}+DD_{Nw}+SLP_{Nw}+LD_{Nw}+LULC_{Nw}+V_{N}} \quad \mathbf{(6)}$$

Where:

LIT=Lithology	LD=Lineament Density
GEOM=Geomorphology	LULC=Land Use Land Cover
HSG=Hydrologic Soil Group	Vegetation=Vegetation
RF=Rainfall	
DD=Drainage Density	
SLP=Slope	

The normalised weights assigned to nine (9) thematic layers are shown in table 6. The final output map of Ground Water Potential model was qualitatively displayed in the categories, such as: Very Poor (1); Poor (2); Moderate (3); Good (4) and Very Good (5). Figure 5, displays a Groundwater Potential Zone (GWPZ) Model created in Model Builder, Arc GIS. After integrating all these nine (9) thematic layers with their assigned weightages and ranks, the outcome is spatially explicit representation of potential groundwater areas as shown in (Figure 6).



Created by :H.OBOKO
Date:7/10/19
Source:Dept. of Surveying & Land Studies

Figure. 6 Groundwater potential Zone

The identification of groundwater prospective zones (Figure 6) can be distinguished among the categories which depicts the areas that are potentially suitable for groundwater. The proposed map indicates the promising zones for groundwater storage are almost located in areas where limestone rocks in fractures is concentrated with a very low soil infiltration rate. In addition, it also shows the suitable surface and sub-surface conditions such as occurrence of lineaments and permeable formations. However, almost every part of the region is classified under Moderate (25.81%), Good (37.60%) and Very Good (21.90%) as shown in table 7 where most of the areas that come under this category are located in Pomio and Gazelle district compared to Rabaul and Kokopo district which have low groundwater potential. Therefore, in figure 6 it clearly delineates the potential areas that are suitable for groundwater extraction.

Table 7. Groundwater Potential categories

SI N<u>O</u>	Description	Area (KM^2)	% of Covered Area
1	**Very Poor**	348.69	2.30
2	**Poor**	1878.44	12.39
3	**Moderate**	3911.49	25.81
4	**Good**	5699.19	37.60
5	**Very Good**	3319.02	21.90

The problem encountered during the Implementation phase are the unavailability of the satellite images, the GIS applications and the data required for the validation of the project. All satellite images have been outsourced and used to put together the final output of the nine (9) parameter. Also despite numerous dialogue and plea to Water PNG and PNG Water Drillers of East New Britain Province to release the data for the boreholes and wells inventory but they still could not disclose the information in order to validate the final output. The purpose of the validation data is to identify the location of how many wells or boreholes in that area in order to make predictions. Current research can be used as a preliminary approach or can be used as a background information to conduct more in-depth research towards near future.

5. Conclusion

The final groundwater prospective map of the study area is controlled by Geology, Geomorphology, Soil and Lineaments as discovered from GIS analyses. Utilization of geomatics technology is very helpful to prepare the groundwater prospective map by which it can be nicely manage and planning in the study area. In addition, it identifies potential groundwater sources for drinking water supply, recharge locations and planning for water security. Thus the final output map will significantly guide the responsible authority in identifying, planning and managing of this resource. Furthermore, the final out put result can be used as a stepping stone to conduct more detailed research relating to ground water potential towards near future.

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