Application of Remote Sensing and GIS for Ground Water Potential Zone Investigation in Bulolo-Wau Surrounding Gold Mine, Morobe Province, Papua New Guinea

Tumare, J., Jana, S. K. and Pal, D. K.
Department of Surveying and Land Studies, The Papua New Guinea University of Technology University Lae-411, Morobe Province, Papua New Guinea
E-mail: jtsunsetsurveyors@gmail.com, sujoy2007@gmail.com, dkpal200090@gmail.com

Abstract
Groundwater is one of the most valuable natural resources, which supports human health, economic development and ecological diversity. In the present study, an attempt has been made to evaluate groundwater potential of Bulolo-Wau surrounding, Morobe Province, Papua New Guinea, using Geoinformatics technology. The thematic layers considered in this study are lithology, landform, drainage density, vegetation, hydro-geomorphic/hydrologic soils groups soil, land slope, altitude and Land use/Land cover, which were prepared using the Landsat ETM+, SRTM and conventional data. Analysis of groundwater potential zones shows that the very high groundwater potential zones constitute 3.47% of the study area. The regions were mainly north –west to south east diagonal direction. The hydrologic parameters-based groundwater potential zone map indicates 22.67% of the study area having high potential, 30.14% moderate potential and 29.92% 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.

1. Introduction

Ground water is a precious, renewable resource of crucial importance that warrants prudent management practices. In Papua New Guinea, much of the efforts are directed towards mineral prospecting and exploration, that eventually translates into the bulk of country's GDP banking on non-renewable resources. However, the study and development of groundwater prospecting and utilization as a renewable resource has been neglected so far. Here is the relevance of the present study as the water resources of PNG have not been well studied even though a vast majority of water resources, both surface and groundwater lie unutilized and need to be developed efficiently. This is necessary for sustainable development of the country that warrants adequate emphasis to be given to renewable resource utilization. Over the recent decades PNG has seen an a very fast increase in population growth and in order to feed the ever growing population on a sustainable basis, proper approach in the management of the country's fresh water resources is important. Groundwater resources need to be well developed to help in areas such as large scale farming, irrigation, crop nursery development, rearing of livestock and further purification for human consumption. In addition, the huge livestock potential of the country necessitates reliable water supply. Water shortage happens inevitably both in the lowland and highland areas, so proper planning is of paramount importance so that those areas receive reliable water supply. Such planning and proper monitoring is essential to develop in this country for sustainable water supply and food self-sufficiency (anonymous, 2000). A recent report published in a newspaper on 13-09-2012 from the National Statistics Office (NSO) and National News states that in Papua New Guinea, 82% of the country's Gross Domestic Product (GDP) comes from Mining and Mineral sector and only 12% from subsistence agriculture (anonymous, 2012). A further report from the World Health Organization (WHO) and the United Nations International Children's Emergency Fund-Papua New Guinea (UNICEF-PNG) indicates that in urban areas 88% of the population is exposed to safe drinking water supply while only 32% of the same are people from the rural areas (WHO and UNICEF, 2003). In contrast, this particular study is focused on how to sustain the GDP and make a shift from subsistence agriculture to commercial agriculture by way of preparing groundwater potential mapping. The study uses application of 'Remote Sensing' and GIS, leading to the identification of the geological setting and ground-water potential zone, as investigating ground water in the field by conventional means is cumbersome, costly, time-consuming and requires skilled manpower (Sander et al., 1996). In contrast, space technology, with its advantages of varied spatial, spectral and temporal availability of data covering large and inaccessible areas within a short time, has proven as a very valuable tool for the assessment, monitoring and management of groundwater resources (Jha et al., 2007). However, ground water cannot be detected directly from remote sensors, the presence of groundwater is to be inferred from different surface features derived from satellite imagery. Occurrence of aquifers, its quality and quantity are functions of various environmental entities such as geology, landforms, soils, land use/land cover, surface water bodies along with the quantity and frequency of precipitation received by the catchment etc., which together act as indicators of groundwater existence (Nag and Lahiri, 2011, Chidambaram et al., 2010, Kalantari et al., 2010 and 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., 2000, 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 and Solomon and Quiel, 2006) in different parts of the world. However, to date, there are no studies carried out in general to demarcate the groundwater potentiality in particular for most of Papua New Guinea. In these studies, the commonly used thematic layers are lithology, geomorphology, rainfall, drainage density, soil, vegetation cover, elevation, and the type of inundation areas and topographic slope. Therefore, the present study has been carried out to demarcate the groundwater potential zone in the Bulolo area Morobe province, by considering suitable thematic layers that have direct or indirect control over groundwater occurrence using Geo-informatics technology.

2. Study Area

Bulolo-Wau surrounding Zone, Morobe province of Papua New Guinea., is located between 146° 28′ 18.30″ E and 146° 55′ 49.96″ E longitudes, 6° 59′ 37.19″ S and 7° 26′ 55.10″ S latitudes (Figure 1). The province is bounded on the north by Madang Province, on east by West New Britain Province, on the south by Central Province and on the west by Eastern Highland. The provincial capital, and second largest city of the country is Lae. The province covers 34,500 km², including 719 km² maritime area, with a population of 539,725 (2000 census). It includes the Huon Peninsula, the Markham river, and delta, and coastal territories along the Huon Gulf. Bulolo district shares borders with Oro Province, Gulf and Central Province and district boundaries with Menyamya and Huon District. Menyamya is mountainous and rainy and borders Gulf and Eastern Highland Provinces. Kabwum again is mountainous and is popularly called the 'district of one hundred mountains'. 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 considerably 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.

3. Materials and Methodology

3.1 Generation of Thematic Layer

A multi-parametric dataset comprising satellite data, and conventional maps including topographical sheets were used. Landsat Enhanced Thematic Mapper Plus (ETM+) data collected from the University of Maryland (open source) has been used for the preparation of thematic maps of drainage density and Land-Use/Land-Cover respectively. Topographical maps (1:50000) were collected from a local office of the Pacific Niugini Minerals (PNM) here in Lae. 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 artifacts in the data that would cause problems in later analysis such as pits, spikes and patches of no data (Dowding et al., 2004).

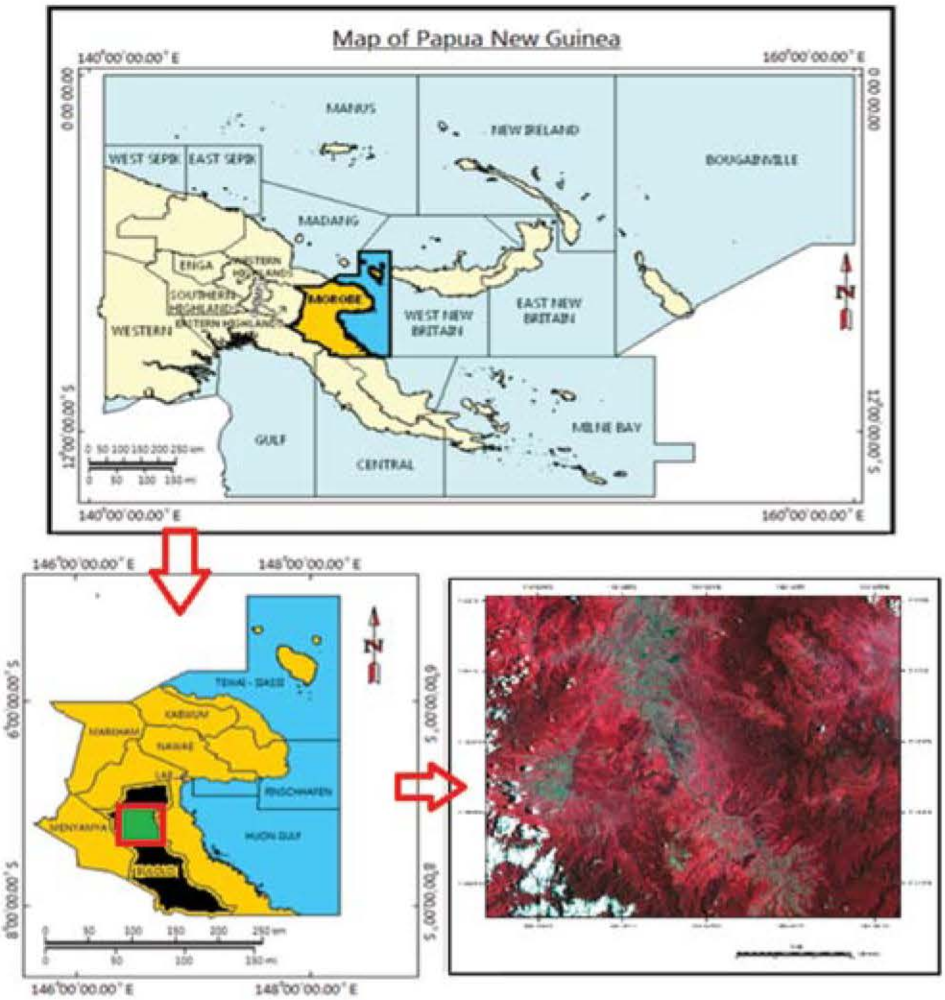


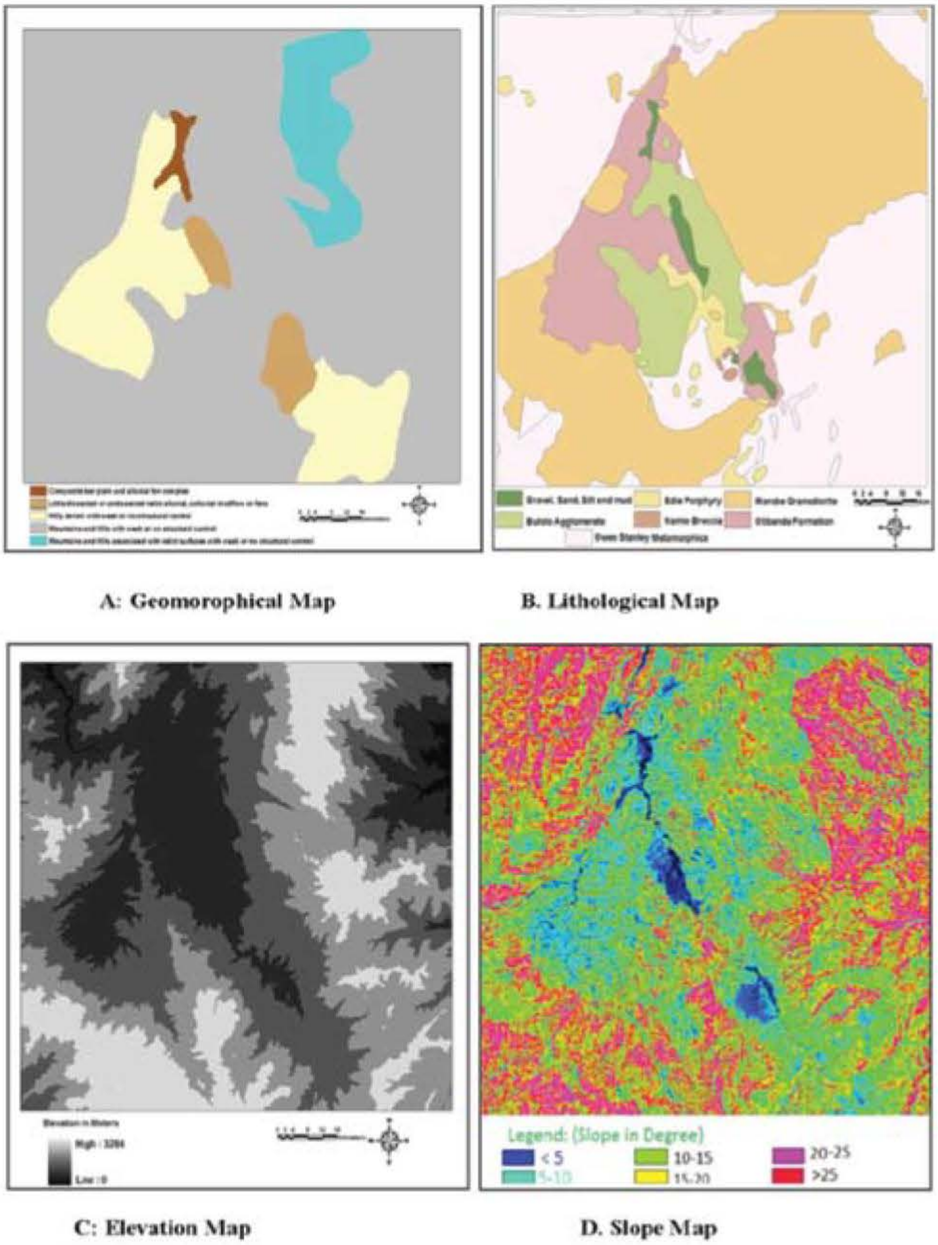
Figure 1: Location of study area

Table 1: Showing different data sets and collateral data used for the preparation of different thematic map layers

Sl. No.	Collateral data	Scale/ Resolution	Year of publication	Source
1	Topographical maps	1:50000	1990	PNM
2	Landsat-7, ETM+	30m	2001	University of Maryland (Open Source)
3	DEM	30m	2013	SRTM
4	Slope Map	1:500000	1975	DEM (30m Resolution)
5	Soil Map	1:50000	2008	PNGRIS
6	Geology	1:50000	2001	PNM
7	Soil Map	1:500000	1975	PNGRIS
8	Rainfall Station	Point data	1972-2006	Weather-forecast.com report

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 coverage was 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 mis-mapping were removed in this process.



A: Geomorophical Map

B. Lithological Map

C: Elevation Map

D. Slope Map

Figure 2: Thematic layer of geomorphology, lithology, elevation and soil map

Table 2: Weightages assigned to 9 thematic layers

Sl. No.	Parameters/Criteria/Themes	Weightage
1	Geomorphology	1.5
2	Lithology	1.5
3	Soil	1.5
4	Drainage density	1.0
4	Elevation (m)	1.0
5	Slope (in °)	1.0
6	Rainfall (mm)	1.0
7	Land use/land cover	0.5
8	Vegetation	0.5

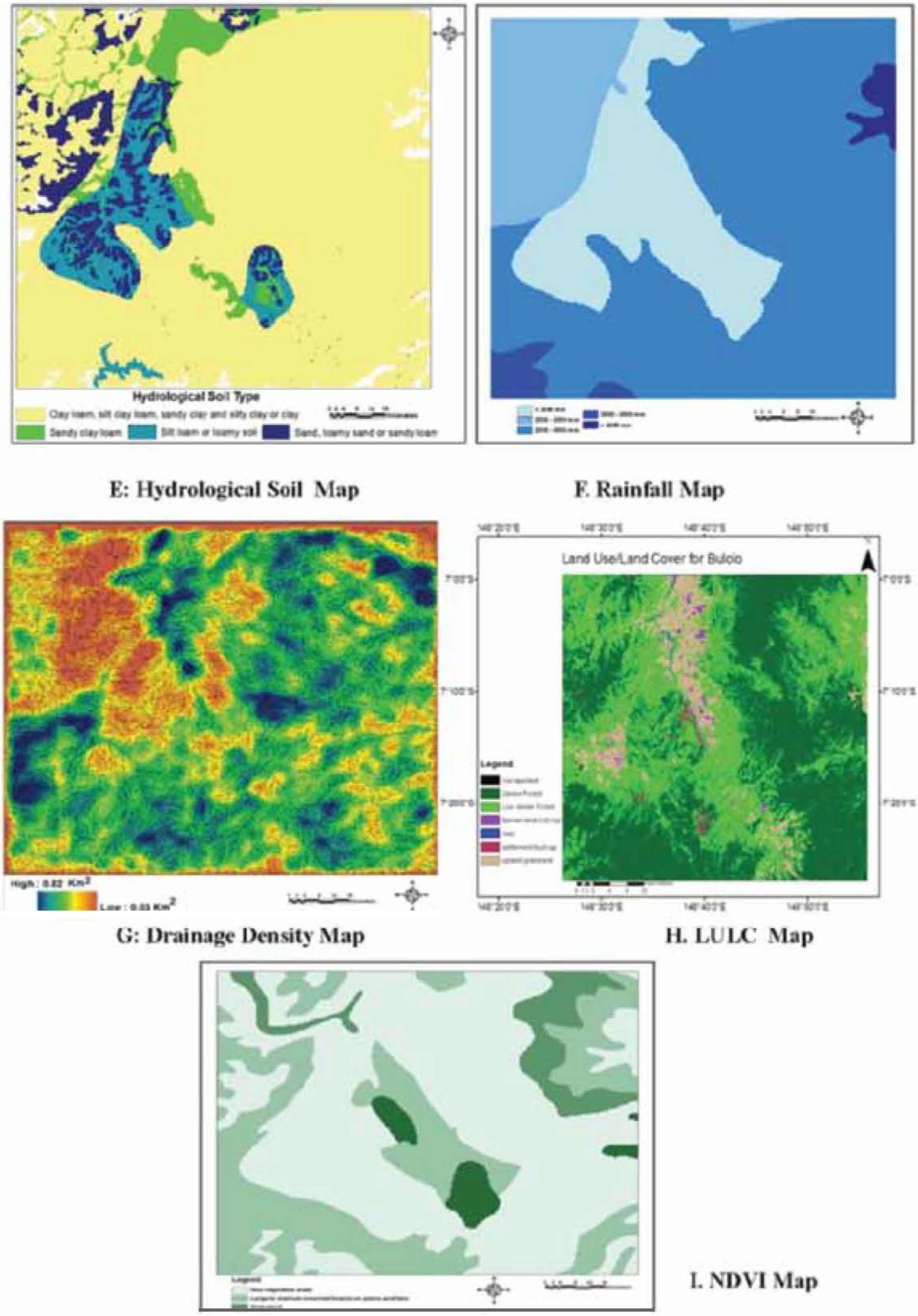


Figure 3: Thematic Layer of Hydrologic-soil, Rainfall, Drainage Density, Land use/Land cover and NDVI Map

3.2 Integration of Thematic Layer

The thematic layers of lithology, geomorphology, hydrologic soil group, elevation, slope, rainfall, land use/land cover, vegetation status and drainage density were subjected to overlay analysis 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 5 based on their relative significance on the groundwater development. Based on this scale, a qualitative evaluation of different features of a given theme was performed, eg. very poor (weight =1); poor (weight=2); moderate (weight = 3); good (weight = 4); very good (weight = 5). 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. Since, the water bearing qualities depends upon the porosity of the rocks, the rocks in province like Morobe which underwent multiple deformation phases apart from the inherited porosity, higher weightage must be given to lithology. In crystalline rock terrains the rock types gain more importance in defining the geomorphology. So, higher weightage was given to lithology prior to geomorphology followed by fractures related properties (Table 2). In this method all the vector GIS layers of the 9 themes (Figures 2 and 3) were used and weightages (Wi) were assigned on the basis of their possible influence and control to water resources of a region. Then for each sub variable of the 9 themes, scores were assigned (Sij). Then these scores (Sij) of the sub variables were multiplied with the corresponding weightage (Wi) of the particular theme and thus water potential zones weightages (Wi x Sij) were worked out for each sub variable. For example, Wi for Geomorphology layer was 1.5 and Sij for the Composite bar plain and alluvial fan complex was 4. So the finally accrued water potential weightages (Wi x Sij) for the Composite bar plain and alluvial fan complex was 6 (1.5 x 4). In this method, the total weights of the final integrated map were derived as sum of the weights assigned to the different layers according to their suitability (Table 3).

4. Results and Discussion

4.1 Thematic Layers of Bulolo-Wau Surrounding, Morobe Province

The details of lithology, geomorphology, hydrologic soil group, elevation, slope, rainfall, land use/land cover, vegetation status and drainage density together with their spatial distribution in the study area are presented below.

4.1.1 Geomorphology

It is a 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/ area provides a simple way to understand their hydrological behavior. The geomorphological characteristics were divided into five 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 (76.54%) is covered by composite bar plain and alluvial fan complex of the study area is shown in Table 4 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.

4.1.2 Lithology

In the present study, 6 types of lithological characteristics have been considered to understand the distribution and occurrence of groundwater (Table 4). 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 recognized are sedimentary rocks, metamorphic rocks and igneous rocks within the study site. The greater part of the metamorphic complex which is Owen Stanly Metamorphic is made up of greenschist to low greenschist facies felsic rocks, some clearly derived from felsic volcanic detritus Kagi Metamorphics; (Pieters, 1978) with minor limestone and conglomerate. However, 40.24% area covered by this lithology which has low infiltration rate. Only 10% of area under sedimentary rock which has high infiltration rate are undifferentiated sedimentary, limestone, low grade metamorphic and basic to intermediate volcanic rocks. The lithological map of the study area is shown in Figure 2

4.1.3 Elevation

The topography of this region varied from 0-3264m (Figure 2).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 5 divisions ranging from < 650m to > 2400 m.

Table 3: Assignment of Weightages (Wi) and Scores (Sij) to thematic layers

Parameter	Classes	Weightages (Wi)	Rank/ Scores (Sij)	(Wi x Sij)
Geomorphic-Landform	Composite bar plain and alluvial fan complex	1.5	4	6
	Little dissected or undissected relict alluvial, colluvial mudflow or fans		3	4.5
	Mountains and hills associated with relict surfaces with weak or no structural control		2	3
	Hilly terrain with weak or no structural control		1	1.5
	Mountains and hills with weak or no structural control		1	1.5
Hydrologic- Soil Group	Group A soil: Sand, loamy sand or sandy loam is entire in this group and infiltration rate is greater than 0.3 inch/hr when wet.	1.5	4	6
	Group B soil: Silt loam or loamy soil is entire in this group and infiltration rate is 0.15 to 0.3 inch/hr when wet.		3	4.5
	Group C soil: Sandy clay loam entire in this group and infiltration rate is 0.05 to 0.15 inch/hr.		2	3
	Group D soil: Clay loam, silt clay loam, sandy clay and silty clay or clay is entered in this group and infiltration rate is 0 to 0.05 inch/hr.		1	1.5
Geology (according to rock types available in geologic formation)	Gravel, Sand, Silt and Mud	1.5	5	7
	Bulolo Agglomerate		4	6
	Namie Breccia		4	6
	Eddie Porphyry		3	4.5
	Otibanda Formation		2	3
	Morobe Granodiorite		2	3
	Own Stanley Metamorphic		1	1.5
Rainfall	>4000mm	1.0	5	5
	3000-3500mm		4	4
	2500-3000mm		3	3
	2000-2500mm		2	2
	<2000mm		1	1
Slope	<5	1.0	5	5
	5-10		4	4
	10-15		3	3
	15-20		2	2
	20-25		1	1
	>25		1	1
Elevation	<650 mt height	1.0	5	5
	650-1300		4	4
	1301-1850		3	3
	1851-2400		2	2
	>2400		1	1
Drainage Density	>0.188	1.0	5	5
	0.188–0.346		4	4
	0.346–0.504		3	3
	0.504–0.662		2	2
	>0.662		1	1
Vegetation prepared from NDVI	Large to medium crowned forest on plains and fans	0.5	5	2.5
	Grass land		4	2
	Non forested		2	1
	Built up area		1	0.5
Land use/ Land Cover	Dense Forest	0.5	5	2.5
	Low Dense Forest		4	2
	Upland Grassland		3	1.5
	River & water Bodies		2	1
	Barren Land		1	0.5
	Settlement & Built Up Area		1	0.5

It is found that a total of 682.3046 km^2 (25.13%) area is lying >2400m contour line. The detail of elevation characteristics and their areal extent of the study area are shown in Table 4. The altitude of Bulolo and Wau town is 700 m and 1080 m respectively from Mean Sea Level.

Table 4: Weights assignment to different classes of thematic layers

Parameter	Classes	Area in sq./km	% of area	Rank
Geomorphological	Composite bar plain and alluvial fan complex	2077.7541	76.54	4
	Little dissected or undissected relict alluvial, colluvial mudflow or fans	160.000	5.89	3
	Mountains and hills associated with relict surfaces with weak or no structural control	383.01178	14.11	2
	Hilly terrain with weak or no structural control	76.0796	2.80	1
	Mountains and hills with weak or no structural control	17.805004	0.66	1
	Total	**2715.10**	**100**	
Lithological				
	Gravel, Sand, Silt and Mud	67.8775	2.50	5
	Bulolo Agglomerate	187.8849	6.92	4
	Namie Breccia	16.2906	0.60	4
	Eddie Porphyry	81.4531	3.00	3
	Otibanda Formation	349.4334	12.87	2
	Morobe Granodiorite	919.60	33.87	2
	Owen Stanly Metamorphic	1092.5603	40.24	1
	Total	**2715.10**	**100**	
Elevation (height in meter)				
	<650	61.9043	2.28	5
	650-1300	629.0887	23.17	4
	1301-1850	584.2895	21.52	3
	1851-2400	757.5129	27.90	2
	>2400	682.3046	25.13	1
	Total	**2715.10**	**100**	
Slope (in Degree)				
	>5 (Very Gentle)	377.4255	13.90	5
	5-10 (Gentle)	407.2317	15.00	4
	(Low Moderate)	883.2383	32.53	3
	15-20 (High Moderate)	410.7828	15.13	2
	20-25 (Steep)	315.1259	11.61	1
	>25 (Strong Steep)	301.2958	11.10	1
	Total	**2715.10**	**100**	
Hydrologic Soil Group				
	Group A	245.72	9.05	4
	Group B	332.33	12.24	3
	Group C	323.91	11.93	2
	Group D	1813.14	66.78	1
	Total	**2715.10**	**100**	
Rainfall in Millimeter				
	>4000	40.796328	1.53	5
	3000-3500	59.213888	2.15	4
	2500-3000	1654.0276	60.92	3
	2000-2500	402.57277	14.83	2
	<2000	558.48909	20.54	1
	Total	**100**	**100**	
Drainage Density (km/km^2)				
	>0.188	741.5808	27.31	1
	0.188–0.346	340.85763	12.55	2
	0.346–0.504	874.09344	32.19	3
	0.504–0.662	244.85234	9.02	4
	>0.662	534.70589	19.69	5
	Total	**2715.10**	**100**	
Land use/ Land cover				
	Dense Forest	1153.10	42.47	5
	Low Dense Forest	1034.72	38.11	4
	Upland Grassland	318.21	11.72	3
	River & water Bodies	60.55	2.23	2
	Barren Land	96.66	3.56	1

	Settlement & Built Up Area	51.86	1.91	1
	Total	**2715.10**	**100**	
Vegetation				
	Large to medium crowned forest on plains and fans	801.51104	29.52	5
	Grass land	180.66362	6.65	4
	Non forested	1647.6163	60.68	2
	Built up area	85.30884	3.15	1
	Total	**2715.0998**	**100**	

4.1.4 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 2. However, the slope of the study area is ranged from 0º - >20.0º. 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, the area has flat topography, such tracts were also found in northern part of the province. Most of the parts are hilly terrains 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 >20º slope categorized as 'poor' due to higher slope and high runoff / low infiltration rate within the study site. Table 4 shows the slope characteristics and their percent of area covered by each of the category.

4.1.5 Soil

The thematic layer on soil (Figure 3) for the study area reveals 8 main soil classes. Soil texture and hydrologic soil group are very important parameters for estimation of runoff, Infiltration, soil loss, transport capacity and net detachment. The following are the Great Groups under USDA taxonomy found in the study area; Troporthents, Cryorthents, Humitropepts, Eutropepts, Dystropepts, Haplustolls, Argiustolls, and Tropudalfs. It is evident from Figure 2 that the majority of the study area is dominated by Eutropepts. From the following, different hydrological soil groups have been developed to determine different infiltration rate in and around the study areas. All four different hydrological soil groups have been found that mostly affect in the study area. Seven types of soil texture i.e. sandy clay, silty clay loam, silty clay, loam, sandy loam, silty loam and sandy clay loam are found in the study area. The hydrologic soil groups indicate the varied infiltration potential (vertical flow) of the soil after prolonged wetting. The hydrologic soil group model (USDA) has classified all soils into four hydrologic soil groups. These are (i) "Group A" soils, (ii) "Group B"soils, "Group C" soils & "Group D" soils. These 4 Hydrologic soil group classes can be categorized into four classes 'good', 'moderate' 'Poor', 'and ' very poor' according to their influence on the occurrence of groundwater. 66.78% of the area fall under very poor infiltration rate (Table 4).

4.1.6 Rainfall

Rainfall is the principal source for replenishment of moisture in the soil water system and also for recharging of ground water. Moisture movement in the unsaturated zone is controlled by suction pressure, moisture content and hydraulic conductivity relationships. The amount of moisture that will eventually reach the water table is defined as natural ground water recharge. The amount of this recharge depends upon the rate and duration of rainfall, the subsequent conditions at the upper boundary, the antecedent soil moisture conditions, the water table depth and the soil type. Rainfall is the most important source of ground water recharge in the country. 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 quantity 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 annual rainfall ranging from 2000 mm to more than 4000 mm ranked to be one of the wettest regions in the country. A few lowland areas are drier with annual rainfall of less than 1000 mm. In contrast large areas of upland regions have average annual rainfall in excess of 4000 mm. The Bulolo-Wau study area has been divided into five rainfall zones (Figure 3). Out of the total area, 2000 - 3000 mm rainfall zone occupies bulk of the area i.e. 1654.0276 km^2 (60.92% of the state). On the other hand, highest rainfall zone is found on north-eastern part of the state and a small pocket is also delineated at south-western part of the study area; whereas, lowest rainfall zone is found in the central part of the study area.

4.1.7 Drainage density

Drainage pattern of any terrain reflects the characteristics of surface as well as subsurface formations. In order to prepare the drainage map of study region, streams were digitized in orderly manner according to Stahler method. Drainage density (expressed in terms of km/sq.km) indicates the total length of all streams and rivers in a drainage basin divided by the total area of the drainage basin. More the drainage density, higher would be the runoff. Thus, the drainage density characterizes the runoff in the area or in other words, the quantum of rainwater that could have infiltrated. Hence lesser the drainage density, higher is the probability of recharge to potential groundwater zone. The drainage density in the area has been calculated after digitization of the entire drainage pattern. The quality of a drainage network depends on lithology, which provides an important indication of the percolation rate. Drainage density measurements have been made in the study area, and range from 0.03 km/sq.km to 0.82 km/sq.km (Figure 3). The drainage density map for the study area is shown in Figure 3. Based on the drainage density of the study area, it is grouped into five classes using geometric intervals: (i) 0–0.188; (ii) 0.188–0.346; (iii) 0.346–0.504; (iv) 0.504–0.662; and (v) >0.662 km/km^2. 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 4).

4.1.8 Land use/ land cover

For the identification and interpretation of the land use pattern of area through image interpretation of remote sensing data, eleven land cover classes were delineated. It includes Dense Forest, Low Dense Forest, Upland Grassland, River & water-body, Barren land and urban-built up region (Figure 3). Out of the total area, 80.58% fall under forests. 11.72% area is covered by Upland Grassland in this region. Moreover, water-body, Barren land, and urban-built up region covered only 7.70% of the study area (Table 4).

4.1.9 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. 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 3). However, the vegetation characteristic of Bulolo-Wau surrounding has been categorized into four categories is shown in Table 4.1 Out of the total area 60.68% fall under non forested vegetation class. 29.52% area is covered by Large to medium crowned forest on plains and fans (Table 4).

4.2 Integration of Remote Sensing and GIS Modeling for Groundwater Potential Zone Mapping

Weighted overlay analysis was carried out leading to their hydrogeomorphological segmentation that evinces 'varied potential aquifers' in the study area. They are classified into five categories as 'very good', 'good', 'moderate', 'poor' and 'very poor'. 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. The details are shown is Table 5.

4.3 Validation

The validation of the model developed was checked against the borehole data which reflects the actual groundwater potential. A comparison of this study between the water level depth data and groundwater potential zones prepared by the model was made to check the validity of the proposed model. The Groundwater borehole data was collected from the Pacific Niugini Minerals (Table 6).

Table 5: Integration groundwater category for groundwater prospects with weight value

SL No	Groundwater Prospect	Weight Value	Area (Sq/Km)	% of Area
1	Very Good	>34.26	94.25	3.47
2	Good	29.80-34.25	615.39	22.67
3	Moderate	26.18-29.79	818.27	30.14
4	Poor	21.72-26.17	812.23	29.92
5	Very Poor	<21.71	374.96	13.80

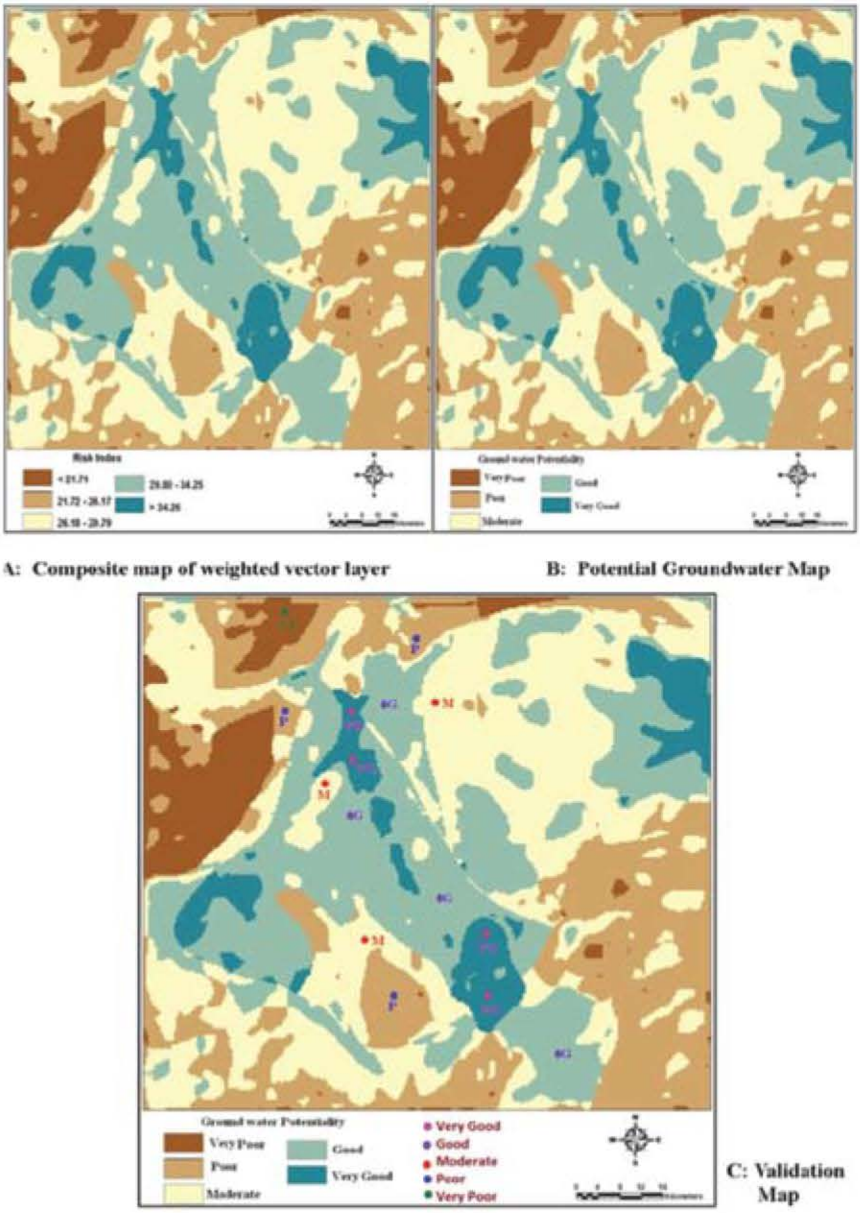
Table 6: Ground water potential categories of the study area (data collected from PNM)

SL No	Data _Type	Hole_ID	Total_Depth (m)	Longitude (Easting)	Latitude (South)	RL_WGS84 (m)	Water_Table Depth (m)	Ground water Category
1	Pit	BP01	4.00	146⁰36' 51.83"	7⁰ 04' 57.40"	701.20	3.5	Very Good
2	Pit	BP02	6.00	146⁰39' 50.09"	7⁰ 05' 08.43"	696.50	5.1	Good
3	Pit	BP05	7.00	146⁰38'14.53"	7⁰ 12' 09.28"	699.50	5.2	Good
4	Pit	BP06	8.00	146⁰37' 15.72"	7⁰ 07' 55.67"	713.50	3.9	Very Good
5	Pit	BP08	8.00	146⁰34' 52.37"	7⁰ 09' 01.83"	710.50	8.3	Moderate
6	Pit	BP14	8.00	146⁰42'11.60"	7⁰ 17' 47.43"	695.90	6.4	Good
7	Pit	BP17	5.00	146⁰ 44' 01.87	7⁰ 21'40.83"	707.30	3.4	Very Good
8	Pit	BP19	12.00	146⁰ 42' 06.09"	7⁰ 05' 12.10"	721.00	7.8	Moderate
9	Pit	BP20	13.00	146⁰ 33' 48.05"	7⁰ 05' 28.64"	716.00	10	Poor
10	Pit	BP21	9.00	146⁰39' 24.36"	7⁰ 19' 10.13"	705.00	7.2	Moderate
11	Pit	BP22	16.00	146⁰36' 35.29"	6⁰ 54' 57.84"	707.10	9.6	Poor
12	Pit	BP32	10.00	146⁰39' 48.26"	7⁰ 21' 05.91"	688.00	10	Poor
13	Pit	BP33	6.00	146⁰47' 29.54"	7⁰ 24' 50.12"	679.20	5.8	Good
14	Pit	BP38	7.00	146⁰ 42' 57.55"	7⁰ 18' 44.41"	700.5	3.7	Very Good
15	Pit	BP42	19	146⁰ 33' 29.67"	7⁰ 00' 14.38"	725.25	15.2	Very Poor

The co-ordinates were collected using GPS in all the selected borehole site and incorporated in groundwater potential zone map as depicted in Figure 4 (c). The five zone wise bore holes were identified for the groundwater level depth in each zone. Normally below ground level (bgl) < 4 meter is considered to be 'very good', 4-6 m is 'good', 6-8 m is 'moderate', 8-10 m is 'poor' and >10 m in 'very poor'). All zones were validated with available borehole water level depth data. The results showed that both sets of data complemented each other.

5. Conclusion

Analysis of groundwater potential zones shows that the very high groundwater potential zones constitute 3.47% of the study area where main river Bulolo-Wau flows South east to north west diagonally and finally bending again towards north east regions along a narrow strip valley. High groundwater potential zones are seen at the north-eastern and south-western part of the study site and constitute 22.67% of the study area. Moreover, these regions were seen along the periphery of the very high groundwater potential zone, except at the corner of north-western and south -east part of the study area. A moderate groundwater potential zone occupies about 30.14% of the total area. The moderate groundwater potential zone encompasses in the pocket of low land dissected areas. Meanwhile the north-west and small part of south east corner and some central small pockets fall under poor and very poor groundwater potential zones, constituting about 43.72% of the study area. Percentage of each groundwater potential zones is shown in Table 5 and figure 4 (b). 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 high runoff zones resulting in 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 provide ideal recipe for groundwater potential. On the other hand, slope more than 20° and higher elevation thereby indicates more runoff and less infiltration within the study area. However, because of the thick vegetation cover throughout the study area, lineament and fractures could not be captured successfully from the remote sensing data in the present study through any degree of scientific visualization, which could have enhanced the quality of aquifer characterization. However, within the study site a very small percentage of area is covered with very high ground water potential zone. Therefore, judicious utilization of groundwater resources coupled with proper water management is essential for ensuring groundwater sustainability. Selection of an adequate number of relevant 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 to look for 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.



A: Composite map of weighted vector layer

B: Potential Groundwater Map

C: Validation Map

Figure 4: Groundwater potential map

References

Anonymous, 2000, Department of Agriculture and Livestock, P O Box 2033, Port Moresby, Papua New Guinea

Anonymous, 2012, National Statistical Office, Kumul Avenue (past Telikom Rumana building next to NBC Transmitters, Waigani), Port Moresby, Papua New Guinea

Chdambaram, S., John, P. A., Parsanna, M.V. and Kermegam, U., 2010, A Study on the Impact of Land Use Pattern in the Ground Water Quality in and Around Madurai Region, South India using GIS Technique. *Journal of Earth Science*, 4(1): 27-31.

Coltelli, M., Fornaro, G., Franceschetti, G., Lanari, R., Migliaccio, M., Moreira, J. R., Papathanassiou, K. P., Puglisi, G., Riccio, D. and Schwäbisch, M., 1996, SIR C/X SAR Multifrequency Multipass Interferometry: A new Tool for Geological Interpretation. *Journal of Geophysical Research 101: doi: 10.1029/96JE01301. issn: 0148-0227.*

Dowding, S., Kuuskivi, T. and LI, X., 2004, Void fill of SRTM Elevation Data –Principles, Processes and Performance, In: Images to Decisions: Remote Sensing Foundations for GIS Applications, ASPRS, Fall Conference, September 12-16, Kansas City, MO, USA

Jaiswal, R. K., Mukherjee, S., Krishnamurthy, J. and Saxena, R., 2003, Role of Remote Sensing and GIS Techniques for Generation of Groundwater Prospect Zones Towards Rural Development: An Approach. *International Journal of Remote Sensing*, 24, 993–1008

Jha, M. K. and Peiffer, S., 2006, Applications of Remote Sensing and GIS Technologies in Groundwater Hydrology: Past, Present and Future (Bayreuth, Germany: BayCEER).

Jha, M. K., Chowdhury, A., Chowdary, V. M. and Peiffer, S., 2007, Groundwater Management and Development by Integrated Remote Sensing and Geographic Information Systems: Prospects and Constraints. *Water Resources Management*, 21, 427–467.

Kalantari, N., Khoobyari, A., Charchi, A. and Keshavarzi, M. R., 2010, Deciphering Groundwater Potential Zones in Sand Stone Terrain Based on GIS Applications (Case Study: Masjed -e-Soleiman, Iran). *The 1st International Applied Geological Congress*, Department of Geology, Islamic Azad University -Mashad Branch, Iran, 26-28 April 2010

Khan, M. A. and Maharana, P. C., 2002, Use of Remote Sensing and GIS in the Delineation and Characterization of Groundwater Prospect Zones. Photonirvachak, *Journal of Indian Society of Remote Sensing,* 30, 131–141.

Krishnamurth y, J., Mani, A.N., Jayaram, V. And Manivel, M., 2000, Groundwater Resources Development in Hard Rock Terrain: An Approach using Remote Sensing and GIS Techniques. *International Journal of Applied Earth Observation and Geoinformatics,* 2, 204 – 215.

Loffler, E., 1974, Geomorphological Map of Papua New Guinea, scale 1:1000000, CSIRO Land Research Series, No 33.

Nag S. K. and Lahir, A., 2011, Morphometric Analysis of Dwarakeswar Watershed, Bankura District, West Bengal, India, using Spatial Information Technology. *International Journal of Water Resources and Environmental Engineering*. Vol. 3(10), 212-219.

Pieters, P. E., 1978, Port Moresby-Kalo-Aroa - 1:250,000 Geological Series. Explanatory Notes to Accompany Port Moresby-Kalo-Aroa: 250,000 Geological Map: Geological Survey of Papua New Guinea, Explanatory Notes SC/55-6, 7, 11

Rao, S. Y. and Jugran, D. K., 2003, Delineation of Groundwater Potential Zones and Zones of Groundwater, for Domestic Purposes using Remote Sensing and GIS. *Hydrological Sciences Jour*. 48(5), 821-833.

Ravi Shankar, M. N. and Mohan, G., 2006, Assessment of the Groundwater Potential and Quality in Bhatsa and Kalu River Basins of Thane District, Western Deccan Volcanic Province of India. *Environmental Geology*, 49, 990 –998.

Samanta, S., Pal, B., Pal, D. K. and Antonio, W., 2012, Market Access and Agriculture Suitability Analysis using GIS Technique - A Case Study on Morobe Province, Papua New Guinea, *International Journal of Marketing and Technology (IJMT),* 2 (1), 53 - 67.

Saaty, T. L., 1980, Analytic Hierarchy Process: Planning, Priority Setting, Resource Calculation, *McGraw-Hill International Book company,* New York and London, 1980, 1-287.

Sander, P., Chesley, M. M. and Minor, T. B., 1996, Groundwater Assessment using Remote Sensing and GIS in a Rural Groundwater Project in Ghana: Lessons learned. *Hydrogeology Journal*, 4, 40–49.

Sener, E., Davraz, A. and Ozcelik, M., 2005, An Integration of GIS and Remote Sensing in Groundwater Investigations: A Case Study in Burdur, Turkey. *Hydrogeology Journal*, 13, 826–834.

Shahid, S., Nath, S. K. and Roy, J., 2000, Groundwater Potential Modeling in a Soft Rock Area using a GIS. *Intern. Jour. of Remote Sensing*, V.21:9, 1919- 1924.

Sikdar, P. K., Chakraborty, S., Adhya, E. and Paul, P. K., 2004, Land Use/Land Cover changes and Groundwater Potential Zoning in and Around Raniganj Coal Mining Area, Bardhaman District, West Bengal: A GIS and remote sensing approach. *Journal of Spatial Hydrology,* 4, 1– 24.

Solomon, S. and Quiel, F., 2006, Groundwater Study using Remote Sensing and Geographic Information System (GIS) in the central highlands of Eritrea. Hydrogeology Journal, 14, 729 –741.

Todd, D. K., 1980, Groundwater Hydrology, 2nd edn. John Wiley New York, 1-535.

WHO and UNICEF 2003, Joint Monitoring Programme for water supply and sanitation database for Oceania. http:// www.wssinfo.org/en/watquery.html