Shahid Beheshti University

Sustainable Earth Review

Journal homepage: http://sustainearth.sbu.ac.ir

Toward mapping potential groundwater recharge zones across Viti Levu and Vanua Levu (Fiji islands)

Vilimone Koiroko Raqona[a], Shailesh Kumar Singh[a*], Ude Shankar[a]

[a] National Institute of Water and Atmospheric Research, Christchurch, New Zealand

A B S T R A C T

Water access in Fiji is a critical issue as not everyone can access reticulated water sources which poses heavy dependence on groundwater sources. Along with its various uses, groundwater sources have been left vulnerable to contamination and depletion over the years due to changes in climatic patterns and human influence. Traditional hydrometric groundwater survey is performed monthly to help determine recharge potential areas in Fiji but doesn't cover all the water sources nor considers all the factors contributing to groundwater recharge. GIS, presents a contemporary approach to identify potential recharge areas which has been used in this study. In this study, the Multi Influencing Factor technique was used to determine the weightage of the factors aspect, slope, soil drainage, drainage density, parent materials and rainfall which are believed to have potentially contribute to groundwater recharge. The basic GIS tools of overlaying and reclassification was used to denote the relationships between the factors and groundwater recharge and the potential groundwater recharges areas for Viti Levu and Vanua Levu. Results have shown that higher potential areas are mostly areas with lower altitudes such as plains, wet areas (windward side), water bodies, excessively drained soils and parent materials with high exposure to weathering. Low ground water recharge potential areas are mostly mountainous, poorly drained soils, dense vegetation and poorly permeable bedrocks. These information is compared against existing boreholes and findings are to assist the government to invest more in those areas that have high recharge areas.

A R T I C L E I N F O

Keywords:
Fiji
GIS
Potential groundwater recharge

Article history:
Received: 04 Sep 2020
Accepted: 16 Oct 2020

*corresponding author
E-mail address:
Shailesh.Singh@niwa.co.nz
(S. Kumar Singh)

1. Introduction

Groundwater plays a paramount role in Fiji with its uses ranging from drinking water, agriculture, industrial and ecological diversity but is depleting at an alarming rate. Reticulated water supplies only cover 98% of the urban population and 63% of the rural population respectively. The remnant of the population relies on groundwater sources for survival that now poses cumbersome hefty pressure on utilization making it vulnerably susceptible to depletion. To balance it groundwater recharge is necessary. Groundwater recharge can be defined as the entry into the saturated zone of water made available at the water-table surface, together with the associated flow away from the water table within the saturated zone (Ping et al. Recharge only takes place when the water received from the atmosphere infiltrates into the saturated zone (Yeh et al., 2016). The potential and capacity of water sources to recharge has been an issue over the years in which most organizations and the regime are investing so much efforts in endeavoring to conserve our groundwater.

Due to the physical characteristics of Fiji, the availability of groundwater recharge tends to differ spatially. Most of the islands are volcanic and have poor infiltration of water to the saturated zones. With the increasing influence of climate change, the leeward side of Viti Levu and Vanua Levu are considered drought prone areas compared to the windward side.

These areas have high usage of groundwater sources for farming especially in vegetables. Leeward areas are sheltered by groups of high elevated areas such as the Mt Tomanivi ranges along with steeper slopes that cause great surface run offs to the oceans for the western and northern parts of Fiji. Smaller islands suffer the most as the availability of surface water is less compared to the two main islands and the use of groundwater is extensively exhausted. Few pertinent work has been done in the past in monitoring groundwater recharge but very little has been centralized on ascertaining potential areas for groundwater harvesting. (AQUASTAT, 2005) has calculated the long term annual average groundwater recharge for Fiji engendered from precipitation within the boundaries of the country either by estimating infiltration rate or by computing river base flow but it does not provide a spatial representation or tell us where in Fiji recharge zones are high. To determine groundwater recharge potential areas, electro-magnetic survey and hydrometric survey can be employ which is labor intensive and costly. Over the years, various techniques have been used to delineated potential groundwater recharge areas for better managements of the water resources. Mostly includes hydrological field observations (Thorpe and Scott, 1999) whereby ground water table is calculated and compared with rainfall received, drainage patterns of different soil types, human influence on ground water which is time consuming, expensive, involves extensive machinery usage and least practicable. The problems with these methods are, not providing a full analysis by considering all the factors that may influence the movement of groundwater. Recent techniques involve the use of a more sophisticated approach that encompasses spatial representation of factors using Geographic Information System (GIS) and Remote Sensing (RS). This approach utilized the interactions of various factors which may have bigger relationship with respect to its contributions to groundwater recharge potentials. These techniques basically give different weights to the influencing factor with respect to its contributions to groundwater recharge potentials. These weights than can be incorporated into the GIS platform along with expert knowledge to delineate potential groundwater recharge areas (Krishnamurthy et al., 1996; Sener et al., 2005; Patil and Mohite, 2014; Waikar and Nilawar, 2014; Selvam et al., 2015; Senanayake et al., 2016). A widely used approach calculate the weights are by sketching a relationship chart that shows the interrelationships between factors and this method is called as Multi Influencing Factor (MIF) (Yeh et al., 2009; Magesh et al., 2012; Yeh et al., 2016). Weights are then assigned according to its relative influence on the rest of the factors, the stronger the influence, the greater the weight value is. The objective of this study is to map potential groundwater recharge areas across Viti Levu and Vanua Levu, main Island of Fiji. For this research, the factors that were used to determine potential groundwater recharge areas are aspect, slope, landuse, soil drainage, drainage density, rainfall and parent materials. These data are only limited to Viti Levu and Vanua Levu and is the reason as to why the smaller islands could not be computed. This study is the first ever attempt to map groundwater recharge potential at a national level in Fiji The findings from this study can guide Fijian Government specifically MRD, SPC and WAF to locate area for artificial ground water recharge.

1.1. Study Area

Fiji Islands is situated in the South Pacific between New Zealand and Hawaii. The island is made up of two main islands, Viti Levu and Vanua Levu where most economic activities takes place and 332 small islands where 110 are inhabited. The largest island is Viti Levu which is about 10468 km^2 and approximately 70% of Fijis population live in Viti Levu. Vanua Levu stands the second largest Island which is about 5594 km^2. Fiji is characterized by its unique cone shape mountains believed to be formed through volcanism and its terrain varies throughout the islands. Even though there has no 1323.14 volcano erupted over hundreds of years, several volcanoes are scattered throughout the country and still have thermal activity taking place. The smaller islands are fascinated by its white sandy beaches covered with opulent vegetation and tropical plants that attracts most tourists to come to Fiji. Fijis landforms are somewhat volcanic, raise coral and limestone islands and atolls. Fijis tends to enjoy a tropical climatic condition. At all seasons, the trade winds blow from the east to south-east on the coats of the main islands and may be persistent from June to November. Temperature at a normal day can be as high as 30℃ to 32℃ but often rise by 1 to 2℃ on the leeward side of the islands then those on the windward side or the small islands. Due to the influence of the ocean, the average temperature changes by only 2 to 4℃ during the cool months (July and August) and the warmest months (January and February). Cyclonic months are from November to April where some of the world's worst cases of flooding and cyclones have taken place such as the 2016 category 5 tropical cyclone Winton. Rainfall is highly variable and Fiji receives orographic rainfall which is mostly influenced by the topography and the prevailing south-east trades. The south-east trade winds are carry high levels of moisture and high mountainous areas receives high precipitation resulting in wet climatic zones on the windward side of the islands. The leeward side (dry zones) receives 2000mm or rain in average whereas in the windward side, it receives 3000 mm-6000 mm per annum. Groundwater in Fiji are obtained by drilling or digging wells. There are also few artesian wells that were drilled into an artesian aquifer where pressure is used to push water into the well above form the aquifer. Rain is the main factor considered for recharge while secondary sources are mostly seepage from land surface and water that leaks from lakes and rivers. The utilization of groundwater in Fiji are mainly for domestic or municipal supply either hand dug wells or boreholes. Majority of the boreholes are located along the drought prone areas of Western Fiji. This is due to the demand from the local communities with very few alternative sources of water supplies.

2. Material and Methods

2.1. Data Preparation

Based on readily data availability, in this study data used are aspect, slope, landuse, rainfall, parent materials, soil drainage and drainage density. These data were obtained from Lands Department, Fiji and from the National Institute of Water and Atmospheric Research (NIWA) database. The factors were reclassified into a more realistic classification to show how each factor contributes to the potential ground water recharge as shown on Table 1. The slope and aspect were derived from a 30m x 30m DEM whereas rest of the vectors had to be converted into a raster and were all resampled into a common cell resolution of 100m x 100m. These factors were re-classified differently as to how it was classified originally by the data providers. The soil drainage had previously been classified into 7 classes (Leslie, 1997) and with the merging of two classes, the old classes were narrowed into 5 as described in (Hewitt, 1993). The landuse cover for Fiji is quite different from other case studies used by literatures due to the differences in climate and land characteristics. Most areas are either used for agriculture with wide varieties ranging from crops, vegetables, coconuts, sugar cane , settlement or left with natural vegetation (Ward, 1965). To re-classify this, the classification created by (Thompson et al., 2004) was used but depending on how the different land use types may affect potential groundwater recharge (Scanlon et al., 2005), (Lerner, 1990; Schot and Van der Wal, 1992; Aeschbach-Hertig and Gleeson, 2012). Rainfall is not commonly used by most literatures but was considered important in this study as Fiji is heavily reliant on rainfall as a secondary water source. Mean Annual rainfall of the 29 stations throughout Fiji were collected and interpolated using Inverse Distance Weighted function in ArcGIS (Childs, 2004). The re-classified values were determined using manual breaks to ensure that there is a well distributed value of the dry and wet areas. Parent materials on the other hand was used as an indicator of the lithology that is present below the soil surface. To do this, a thorough understanding of the permeability of rocks was researched and compared to Fiji as described by (Toebes and Palmer, 1969). The drainage density was first calculated using the line density tool in ArcGIS (Magesh et al., 2012) and was reclassified according to base on the classification outlined in (Singh et al., 2016) (Table 1).

Table 1. Reclassified values for each factor.

Factor	Value Interval	Reclassified Value	Contribution
Aspect	North	1	Very Low
	Northeast & Northwest	2	Low
	East, West, Flat terrain	3	Medium
	Southeast, Southwest	4	High
	South	5	Very High
Slope (°)	> 25	1	Very Low
	15 - 25	2	Low
	42278.00	3	Medium
	43378.00	4	High
Soil Drainage	Very Poorly Drained	1	Very Low
	Poorly Drained, Imperfectly Drained	2	Low
	Moderately Drained	3	Medium
	Well Drained	4	High
	Somewhat, Excessively Drained	5	Very High
Rainfall (mm)	1754-2208	1	Very Low
	2209-2318	2	Low
	2319-2637	3	Medium
	2638-3201	4	High
	3202-4882	5	Very High
Drainage Density (km/km²)	< 0.5	1	Very Low
	0.5 - 1	2	Low
	1 - 1.5	3	Medium
	1.5 - 2	4	High
	< 2	5	Very High
Landuse	Settlement	1	Very Low
	Forest	2	Low
	Grassland, shrubland, bush	3	Medium
	Bare Land	4	High
	Surface water body	5	Very High
Parent Materials	Igneous, Basic, Intermediate, Acidic Rocks	1	Very low
	Metamorphic Rocks	2	Low
	Sedimentary Rocks	3	Medium
	Alluvium, Colluvium, Organic materials, Residual	4	High
	Sand, Ash	5	Very High

2.2. Multi Influencing Factor (MIF)

MIF approach uses a schematic sketch to define the interactive influences of a factor to another as shown on Figure 1. The influence of a factor and its importance are represented by the arrows. Arrows with major influence have a straight line and are given a value of 1 whereas a minor a value of 0.5 and is represented as dashed dots. The cumulative weightage of both the major and minor are added and then divided by the total weightage of all the factors. The values obtained are used in the final calculation to produce potential ground water recharge areas and should all add up to 1 (Table 2). The potential groundwater recharge areas were then derived by overlaying the sum of all the reclassified raster and when multiplied with the weights obtained by using field calculator in ArcGIS. The results were reclassified from the scale 1-5 using reclass by table as shown on Table 3.

Table 2. Weightage Values produced by the MIF technique

Factor	***w f***	***w f, r***
Aspect	1.5	0.10
Landuse	3.5	0.24
Soil Drainage	2	0.14
Drainage Density	1	0.07
Rainfall	1	0.07
Slope	3	0.21
Parent Materials	2.5	0.17
SUM	**14.5**	**1**

Table 3. Final Reclassified Values to determine potential groundwater recharge areas

Final Values	**Reclassified Value**	**Description**
< 2	1	Very low
2 - 2.5	2	Low
2.5 - 3	3	Medium
3 - 3.5	4	High
> 3.5	5	Very high

3. Results and Discussion

The resultant maps were produced in raster formats, 100mx 100m resolution after reclassifying all the factors shown on Table 1 and using the MIF approach to delineate potential groundwater recharge areas. Since the focus was on Viti Levu and Vanua Levu, the coastline was used as a guide to mask the raster's. Each result was classified 1 to 5, 1 being very low and 5 very high contribution to potential groundwater areas. The final map was also classified 1-5 as shown on Table 3 showing a distribution of potential areas in Viti Levu and Vanua Levu for ground water recharge. The potential groundwater recharge areas were derived using the MIF approach using the factors aspect, slope, landuse, soil drainage, drainage density, rainfall and parent materials. These factors were first converted into a raster with a cell size of 100m x 100m. Each factor was re-classified according to Table 1 with values from 1-5, 1 being low and 5 very high. Using the relationship sketch shown on Figure 1, the weights were determined according to their interrelationships and was multiplied to each factor using the raster calculator where all the factors were overlayed respectively. The final map was re-classified to the values shown on Table 3 to show the distribution of potential groundwater recharge areas for Viti Levu and Vanua Levu (Fig. 1).

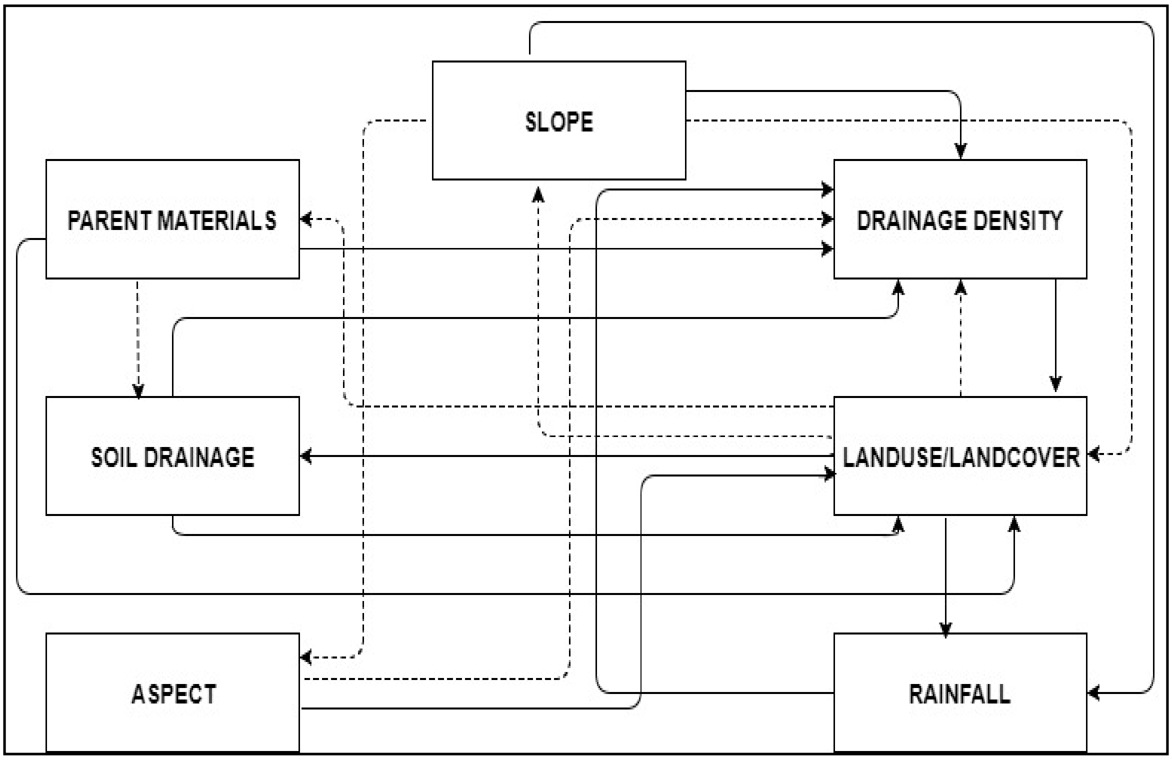

Fig. 1. Interrelationships between the Multi Influencing Factor concerning potential ground water recharge areas

3.1. Slope

The gradient of the slope is one of the factor that influences the infiltration of rainfall (Sener et al., 2005). The slope determines whether the precipitation received will seep into the soil or will it erode as surface run off. In gentle slope, the surface run off is slow that allows more time for rainfall to penetrate into the soil whereas areas with steeper slope, there is high chance of run offs since there is less time for water to percolate which results in poor infiltration (Patil and Mohite, 2014). Hence, groundwater recharge and slope have a negative relationship. Figure 2 shows the contribution of slope in groundwater recharge throughout Viti Levu and Vanua Levu. High potential areas are those that are on gently or flatly slope areas such as at the base of mountains, hills, near water catchment areas and urban areas. These areas are in the plains of Naisoso, Noco, Nakelo in Viti Levu and Macuata, Nadogo in Vanua Levu. Greater contributions are also found in the river deltas of Ba, Sigatoka, Navua, Rewa and Macuata. The low potential areas are mostly centralised in the centre of the Viti Levu and the windward side of Vanua Levu. These areas are characterised by rugged relief, high mountainous areas such as the Evan ranges, Mt Nasorolevu in Vanua Levu, Mt Voma that runs from the north to the south of Viti Levu and the highest mountain in Fiji Mt Tomanivi (extinct volcano- 1324 meters). These areas have high rainfall therefore due to the topography there is massive surface run-off (Fig. 2).

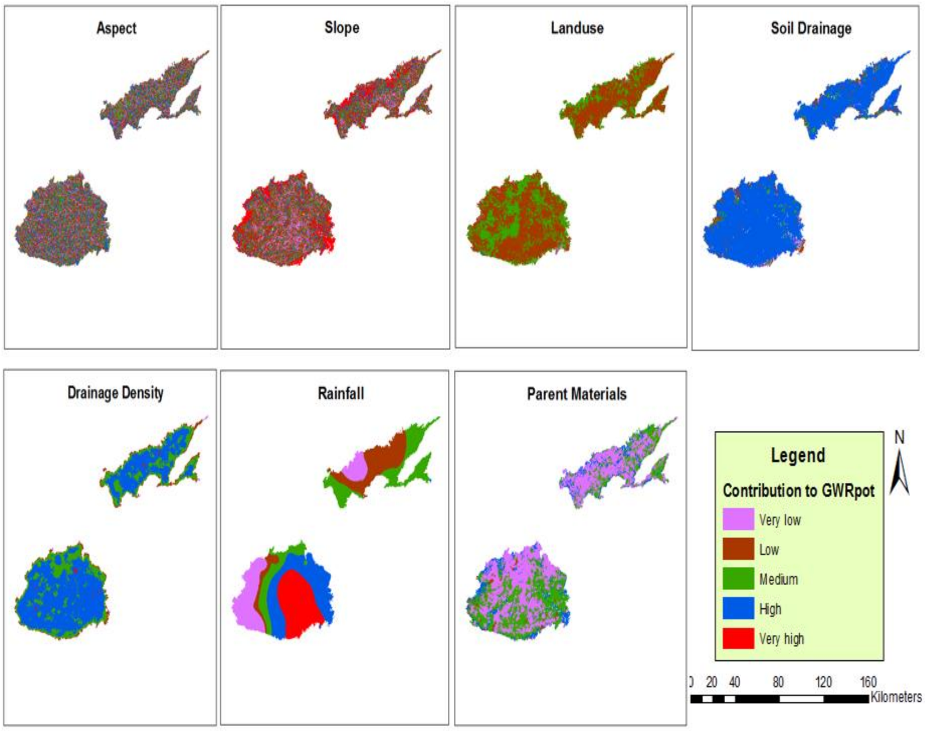

Fig. 2. Reclassified values for all the factors contributing to groundwater recharge potential areas

3.2. Aspect

The aspect is useful in this study as it shows the direction the slope is facing. Aspect strongly influences the local climatic pattern in an area and significantly the direction of solar radiation which is correlated with evapotranspiration. Insolation strikes a south facing slope at a direct angle therefore energy and heating is concentrated on a smaller portion of the slope. This results in higher contributions to groundwater recharge as there is less evapotranspiration taking place and more water percolating into the ground. This is the same for easterly and westerly slope facing aspect. On the other hand, insolation that strikes a north facing slope in a less direct angle allows the amount of energy and heating to be spread across the slope therefore very less contribution to groundwater recharge. Most literatures have not used aspect in their research except for (Singh et al., 2017).

3.3. Soil Drainage

The soil drainage is considered in this study as it shows the infiltration rate of the different soil types on the earth surface. Groundwater recharge depends on the amount of precipitation that infiltrates into the soil rather than been collected on the top horizon. As indicated by (Leslie, 2012), the soil type, soil depth, chroma, parent material from which the soil was made of, permeability and soil texture were considered in determining the drainage pattern of a particular area. Considering these factors, areas were then classified into their drainage classification shown on Table 1. Soil drainage and groundwater recharge are positively correlated. To qualify for potential recharge areas, the soil must be well drained. Viti Levu and Vanua Levu mostly have well drained soils such as the Nuku, Vunibau, and Yasawa soils that are high in quartz and sand. Very high areas are those soils that contains situ quartz porphyry and quartzite rocks such as Lutu soils. Few areas along the coasts and the urban areas have very low contribution to ground water recharge as they contain river alluvium of basic and intermediate rocks for example Nausori soils.

3.4. Drainage Density

Drainage density is a vital contributor for hydrogeological identification as the pattern, texture and density are controlled by the underlying lithology (Sener et al., 2005). Drainage density is inversely related to permeability, the less permeable a rocks is, less infiltration will occur and more rainfall is subjected to surface runoff (Magesh et al.

2012). It is calculated using the formula below (Eq. 1):

$$DD = \frac{\sum LWS}{AWS} \quad (1)$$

Where DD= drainage density, LWS= total length of streams in watershed and AWS=area of watershed (Murthy, 2000). The formula above measures the average length of stream channels of the whole catchment and can indicate whether an area is suitable for groundwater recharge in linking it with surface run off and permeability (Krishnamurthy et al., 1996). Higher densities are preferred as they contribute more to groundwater recharge. Few areas throughout Viti Levu and Vanua Levu have very high contributions but majority are classified as high contributions as shown on Table 2 (drainage density). As we move towards the coastal areas, contributions decrease from medium to low and very low contributions are found in Udu point and on the shores.

3.5. Land Use

The land use classes affects the occurrences of groundwater as it controls many hydrological processes in the water cycle such as infiltration, evapotranspiration and surface runoff (Waikar and Nilawar, 2014). These surface covers act as a shield on the surface that will reduce discharge and increase infiltration. Viti Levu and Vanua Levu tend to have more areas classified as low contributions as these areas are mostly dense forest areas that results in high evapotranspiration. These areas also include most of the towns and cities. Medium contributions reflect areas with sparse vegetation and high altitudes mostly around mountainous areas. Very low groundwater recharge areas are mostly where settlements and barren lands are found as they have weak water holding capacity. On the other hand, water bodies and cultivated areas have very high contributions as there is presence of water on the surface such as Sigatoka river, Rewa Delta, Dreketi Delta, Ba River and Monasavu lake.

3.6. Parent Materials

The parent materials were used as an indicator of the possible lithology that is present below the soil horizon. The different soil types in Fiji were formed from parent materials which are from weather bedrocks. Since Fiji is relatively small and very less tectonic movement occurs other than natural disasters, there are very high possibilities that parent materials could indicate the underlying bedrocks. The weightage for parent materials are reliant on mineral assemblage, alteration, fractures and weathering conditions. More weightage is given to those rocks that have high weathering conditions that results in high infiltration (permeable rocks) and is runoff resistant. Most areas in Fiji are classified as very low contribution to groundwater recharge since Fiji is highly volcanic and most areas have igneous, basic rocks, intermediate, metamorphic and acidic rocks which are poorly permeable. These rocks are prone to less weathering and therefore have poor infiltration. Sedimentary bedrocks have medium contribution to groundwater recharge as they consist of a mixture of weathered volcanic and metamorphic rocks with cracks and joins and this allows water to penetrate through. High areas of groundwater recharge are found in plateaus with low altitude and presence of water surface bodies such as Sigatoka Delta, Rewa Delta, Naisoso and Ba. These areas mostly alluvium, colluvium, organic materials, residuals, sand or ash which has excellent infiltration.

3.7. Rainfall

Rainfall is considered to be the dominant source of groundwater recharge across all climatic regions (Selvam et al., 2015). The amount of precipitation received throughout Viti Levu and Vanua Levu are uneven. The islands are divided into the leeward that includes Ba, Lautoka, Nadi, Sigatoka, Tavua, Rakiraki, Labasa, Macuata, Bua and Navakasiga and the windward which covers the rest of the areas. The leeward side as shown on Table 2 (rainfall) are classified mostly as very low and low since they receive 2000ml annual rainfall and these areas are dry receiving 7 hours of sunshine in a day. On the other hand, very high and high areas are mostly in the windward side of Viti Levu. These areas receive 3000 mm - 6000 mm of rainfall and more during the cyclonic wet period. Vanua are mostly low and medium.

3.8. Groundwater recharge potential zones across Viti Levu and Vanua Levu

The factors above were classified from 1-5 depending on how well they contribute to groundwater recharge. Using the raster calculator all the layers were overlayed with the weights calculated using the MIF factor approach and results are shown in Table 3. These were then reclassified according to Table 3 to show favorable areas in Viti Levu and Vanua Levu that are considered to have potential groundwater recharge. The distribution of potential groundwater recharge very well signifies the contributions of the factors and varies across space. Viti Levu is considered to have more potential areas than Vanua Levu. Very high areas are mostly in the windward side of Viti Levu around the river deltas or surrounding areas and likewise for Vanua Levu. Lomaivuna area has the greatest potential of groundwater recharge. High areas are mostly in areas of low altitude such as the plains of Ba, Lautoka, Nadi, Sigatoka Valley and Rewa. Moreover, very low potential areas are found in high mountainous areas with high altitude. These areas include the Evan ranges, Koroba and Navatu. There is also dense vegetation present in these areas. Overall, Viti Levu and Vanua Levu are said are said to have low to medium ground water recharge potential. There has been similar work done by (AQUASTAT, 2005; Kumar, 2010; Loco, 2011; Dixon-Jain et al., 2014) which are centered on groundwater pollution, conservation but little has been researched on the location of groundwater or the potential recharge areas across Fiji. The economy is heavily reliant on groundwater sources to supplement reticulated water provided by the government and in conjunction with recent effects of climate change along with human influences, groundwater sources are at risks of degradation. The Hydrogeology unit under the MRD is responsible for the monitoring and protection of Fijis groundwater sources from abuse and contamination. Hydrometric survey for groundwater is performed monthly where the water table are monitored in terms of aquifer recharge through rainfall, evaporation rate, nature of ecology and vegetation types. This is limited only to those that are prone to depletion or heavily contaminated from underlying poor-quality water due to over pumping thus is not a good technique to identify groundwater recharge. GIS techniques has been used all over the world as it has been considered reliable analysis method which can aid decision making. With the limited resources, scientific research and finances to cater for traditional groundwater investigation, GIS techniques proves a better approach to delineate groundwater recharge areas in Fiji which is cost effective, less time consuming, high accuracy and results can be interpreted visually through maps. The factors used in this research namely aspect, slope, soil drainage, drainage density, parent materials, rainfall and landuse play a significant role in identifying potential groundwater recharge areas. Using the MIF factor, landuse had the highest weightage of 0.24 which is similar to (Yeh et al., 2009; Yeh et al., 2016) followed by slope which was 0.21. The weightage for parent materials was 0.17 which is also used by (Sener et al., 2005) and 0.14 for soil drainage (Senanayake et al., 2016). The aspect is hardly used by most literatures except in (Singh et al., 2017) and drainage density had the same value with rainfall. The difference within the weights calculation was due to the factors used by most authors such as soil types, lineaments which is not used in this study and the absence of rainfall and aspect. Furthermore, the final map shown on Figure 3 is highly linked with the maps on Figure 2 and these results also corresponds to relevant studies carried out previously. High potential areas are mostly plains with flatly slopes areas with good infiltration and less surface runoffs (Patil and Mohite 2014). Highly cultivated areas reduces the rate of evapotranspiration and water bodies contribute more water to the aquifers (Magesh et al., 2012) (Fig. 3).

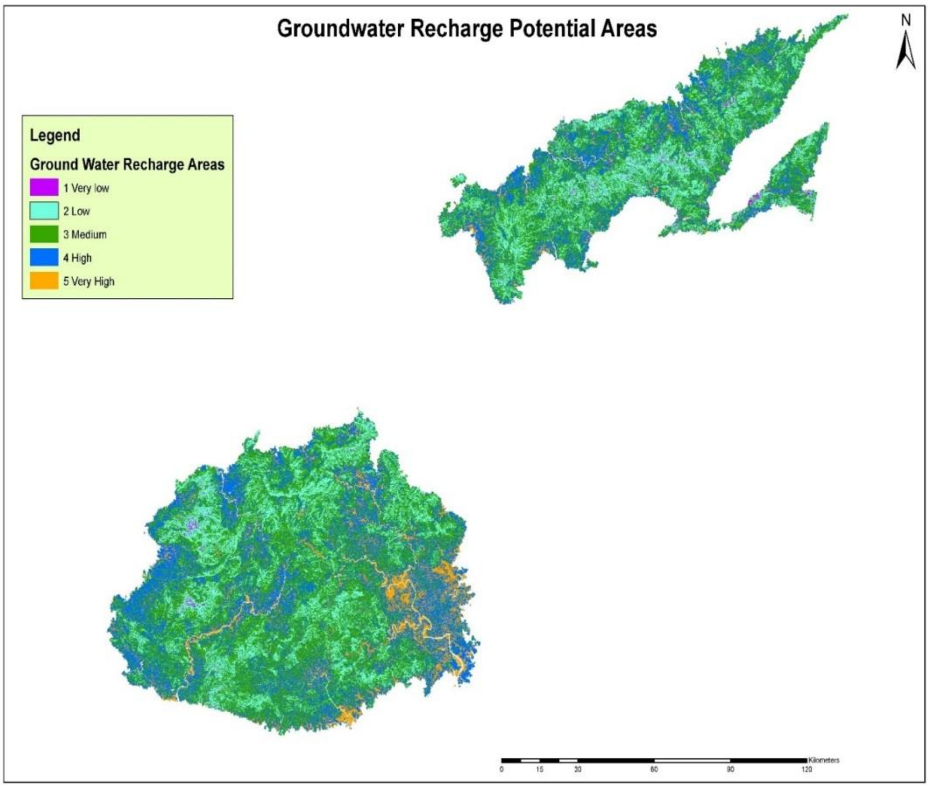

Fig. 3. Potential Groundwater Recharge Zones across Viti Levu and Vanua Levu using MIF approach

High rainfall is preferred as groundwater rely solely on precipitation for recharge (Selvam et al., 2015) as well as bed rocks consisting of alluvium, colluvium, sand and volcanic ash (Ganapuram et al., 2009). Low potential areas are areas that are dry, very little rainfall or drought prone areas, poorly drained soils that leads to poor infiltration, mountain areas with steep slopes leading to more surface rainfall, less permeable parent materials such as igneous and acidic rocks with no secondary pores to allow infiltration to occur, high human influenced areas such as settlements and urban areas and also dense vegetation where evapotranspiration is at great (Ganapuram et al., 2009; Yeh et al., 2009; Magesh et al., 2012; Patil and Mohite, 2014; Selvam et al., 2015). Moreover, the results obtained above were compared to current locations of boreholes managed by the MRD, Fiji. The boreholes are unevenly distributed across Viti Levu and Vanua Levu. Very high number are found mostly on the leeward side of both the islands and this is interesting as these areas are prone to drought. Most of the people that live in these areas are farmers and have little or no access at all to water supply other than rainwater itself. Recently, these boreholes were dug under the Nadi groundwater project to help assist the residents with sugar cane, crops and vegetable farming as well as their livelihood. Few boreholes are used by the villages and schools. The Nadi groundwater project boreholes sit perfectly on the area depicted by this study as very high potential recharge areas as shown on Figure 4. This is because of the Meigunyah aquifer which is underlying the Nadi basin and is mostly used for irrigation purposes. This is the same for the boreholes established under the Labasa rural groundwater project in Vanua Levu as they sit perfectly on very high and high recharge areas. Lomaivuna was described as having the highest areas with very high recharge zones and there are 10 boreholes drilled under the Rewa basin project the provides water to most families, farmers, villages and school in Viria and Naitasiri. Overall, the locations of the boreholes perfectly correspond to the areas deemed by this study are high or very high groundwater recharge areas. The Minerals Department should continue to monitor the water level of all the groundwater sources as these are great potential areas for groundwater recharge in the future. There are also potential areas discovered through these findings but do not have any boreholes present now such as Navua Delta, Ba Delta and the interior of

Sigatoka valley. This also resembles why landuse had very high weights as compared to other factors because most of the very high and high recharge zones are mainly water bodies such as river basins and lakes. For future research, water table statistics could be compared to rainfall and then analyzed with current usage to predict the amount of groundwater that can be available in the future for decision making. Hence, the government should continue to invest and protect all these water sources as they lie perfectly on areas potentially with high recharge capabilities for future use (Fig. 4).

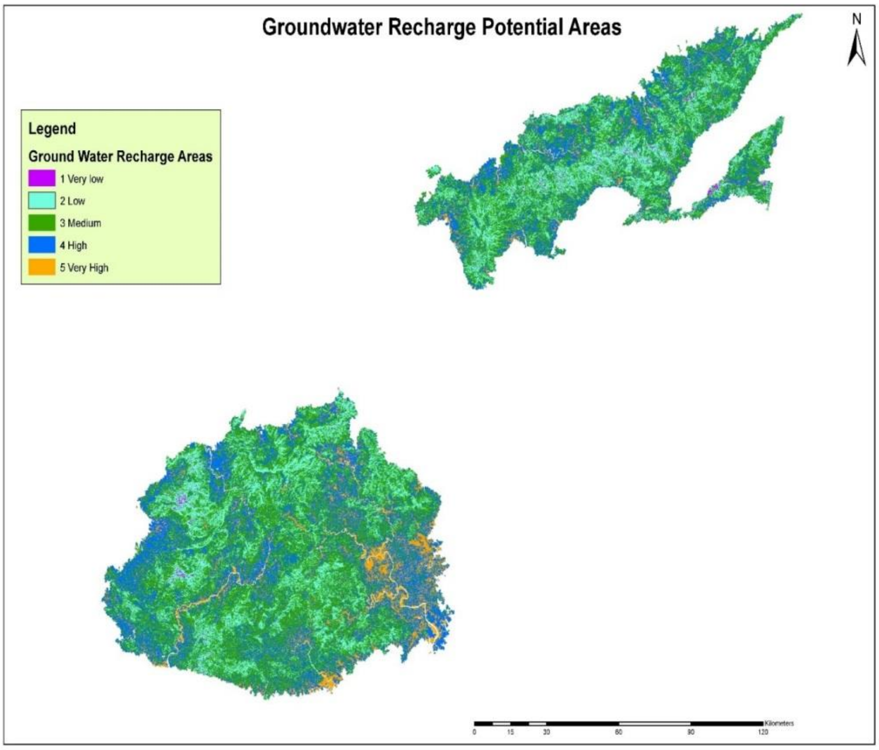

Fig. 4. Potential Groundwater Recharge Zones across Viti Levu and Vanua Levu using MIF approach overlayed with existing boreholes and rivers

4.Conclusion

GIS has been proven a least cost and least time-consuming technique that could be used to delineate potential groundwater recharge areas in Fiji. As compared to the previous hydrometric survey the government uses to calculate groundwater recharge and to drill new boreholes, GIS could have been used that allows users to determine potential areas using all the factors that contributes to groundwater recharge and can be visually represented. In this study, the factors were carefully analyzed ranging from the sources of groundwater (rainfall) and the factors that affects transportation of rainwater into the aquifers (aspect, slope, soil drainage, drainage density, parent materials and landuse). These factors were first re-classified as very low (1), low (2), medium (3), high (4) and very high (5) depending on a clear understanding, expertise and previous research on how the different components of the factors contributes to groundwater recharge. The MIF approach was used as it helps signify the relationship between the factors in an illustration and the weights are determined based on that. Using the overlay technique, all the factors were superimposed and the final map were reclassified into five main classes as the factor maps. Results have shown that high potential recharge areas are mostly plains on lower altitudes of the islands with excellent soil drainage, high water content, high rainfall, high cultivate/agriculture areas and soils rich in alluvium, colluvium, sand and volcanic ash deposits. Throughout Viti Levi and Vanua Levu most areas fall under low to medium areas. The final map was then compared to existing groundwater sources and clearly shows the boreholes are in areas where this research considers high to very high potential recharge areas. Another important finding was that these areas are highly water bodies that explains why landuse had a very high weighting compared to the rest of the factors. It was also recommended that various underground water information could be obtained and compared with water usage and the amount of precipitation received in an area to predict usability of these ground water sources in the future. This study is focused to the main islands only and did not include the 110 inhabited small islands. Groundwater is the main source or water for small islands as they face water shortages all time and due to the unavailability of data, they were not considered. This however could be researched in the future. Lastly, this research can be used by the Fijian government to make decisions in terms of conserving ground water sources and to create more boreholes to help those people that don't have access to water.

Acknowledgment

I would like to convey my sincere appreciation to the Ministry of Lands and Mineral Resources- Geospatial Division (Fiji) and Fiji Meteorological Services for providing the relevant data necessary for this study. Also, the Pacific Corporation Foundation, Auckland New Zealand for providing technical and research support and not forgetting.

References

Aeschbach-Hertig, W. & Gleeson, T., 2012. Regional strategies for the accelerating global problem of groundwater depletion. *Nature Geoscience*, 5(12), 853-861.

Ankita, D.P. & Kazuo, N., 2014. Modeling hydrological response to land use change in watersheds of viti levu island, FIJI. *Journal of Environmental Research and Development*, 8(3), 492 p.

AQUASTAT, F., 2005. AQUASTAT database.

Childs, C., 2004. Interpolating surfaces in ArcGIS spatial analyst. ArcUser, July-September, 3235, 569 p.

Dixon-Jain, P., Flannery, E., Sundaram, B., Walker, K., Fontaine, K., Stewart, G., Norman, R., Wallace, L. & Riddell, A., 2014. Pacific Island groundwater and future climates: first-pass regional vulnerability assessment. Geoscience Australia.

-Falkland, A. & Custodio, E., 1991. Hydrology and water resources of small islands: a practical guide: a contribution to the International Hydrological Programme. *Studies and reports in hydrology*, 49, i-xiii.

Ganapuram, S., Kumar, G.V., Krishna, I.M., Kahya, E. & Demirel, M.C., 2009. Mapping of groundwater potential zones in the Musi basin using remote sensing data and GIS. *Advances in Engineering Software*, 40(7), 506-518.

Hewitt, A.E., 1993. *Methods and rationale of the New Zealand soil classification*. Landcare Research science series No. 2. Lincoln, New Zealand.

Krishnamurthy, J., Venkatesa Kumar, N., Jayaraman, V. & Manivel, M., 1996. An approach to demarcate ground water potential zones through remote sensing and a geographical information system. *International Journal of Remote Sensing*, 17(10), 1867-1884.

Kumar, V., 2010. Water management in Fiji. *International Journal of Water Resources Development*, 26(1), 81-96.

Lerner, D.N., 1990. Groundwater recharge in urban areas. Atmospheric Environment Part B: *Urban Atmosphere AEBAE 5*, 24 B, 1, 29-33.

Leslie, D., 2012. A reference manual for utilising and managing the soil resources of Fiji. Secr. Pac. Community Nabua Fiji.

Leslie, D.M., 1997. An introduction to the soils of Fiji. An introduction to the soils of Fiji.

Loco, R.A., 2011. Hydrogeology of the Middle Sigatoka Valley, Southwest Viti Levu, Fiji.

Magesh, N.S., Chandrasekar, N. & Soundranayagam, J.P., 2012. Delineation of groundwater potential zones in Theni district, Tamil Nadu, using remote sensing, *GIS and MIF techniques. Geoscience frontiers*, 3(2), 189-196.

Murthy, K.S.R., 2000. Ground water potential in a semi-arid region of Andhra Pradesh-a geographical information system approach. *International Journal of Remote Sensing*, 21(9), 1867-1884.

Patil, S.G. & Mohite, N.M., 2014. Identification of groundwater recharge potential zones for a watershed using remote sensing and GIS. *International Journal of Geomatics and Geosciences*, 4(3), 485-498.

Ping, J., Nichol, C. & Wei, X., 2014. Quantification of groundwater recharge using the chloride mass balance method in a semi-arid mountain terrain, South Interior British Columbia, *Canada. Journal* of *Chemical* and *Pharmaceutical Research*, 6(1), 383-388.

Portmann, F.T., Döll, P., Eisner, S. & Flörke, M., 2013. Impact of climate change on renewable groundwater resources: assessing the benefits of avoided greenhouse gas emissions using selected CMIP5 climate projections. *Environmental Research Letters*, 8(2), 024023.

Scanlon, B.R., Reedy, R.C., Stonestrom, D.A., Prudic, D.E. & Dennehy, K.F., 2005. Impact of land use and land cover change on groundwater recharge and quality in the southwestern US. *Global Change Biology*, 11(10), 1577-1593.

Schot, P.P. & Van der Wal, J., 1992. Human impact on regional groundwater composition through intervention in natural flow patterns and changes in land use. *Journal of Hydrology*, 134(1-4), 297-313.

Selvam, S., Magesh, N.S., Chidambaram, S., Rajamanickam, M. & Sashikkumar, M.C., 2015. A GIS based identification of groundwater recharge potential zones using RS and IF technique: a case study in Ottapidaram taluk, Tuticorin district, Tamil Nadu. *Environmental earth sciences*, 73(7), 3785-3799.

Senanayake, I.P., Dissanayake, D.M.D.O.K., Mayadunna, B.B. & Weerasekera, W.L., 2016. An approach to delineate groundwater recharge potential sites in Ambalantota, Sri Lanka using GIS techniques. *Geoscience Frontiers*, 7(1), 115-124..

Sener, E., Davraz, A. & Ozcelik, M., 2005. An integration of GIS and remote sensing in groundwater investigations: a case study in Burdur, Turkey. *Hydrogeology Journal*, 13(5-6), 826-834.

Singh, S.K., Zeddies, M., Shankar, U. & Griffiths, G.A., 2016. Potential groundwater recharge zones within New Zealand. *Geoscience Frontiers*, 10(3), 1065-1072.

Singh, S.K., Zeddies, M., Shankar, U. & Griffiths, G.A., 2017. Potential groundwater recharge zones within New Zealand. *Geoscience Frontiers*, 10(3), 1065-1072.

Thompson, S., Gruner, I. & Gapare, N., 2004. New Zealand land cover database, version 2–illustrated guide to target classes. Ministry for the Environment, Wellington, 126.

Thorpe, H.R. & Scott, D.M., 1999. An evaluation of four soil moisture models for estimating natural ground water recharge. *Journal of Hydrology* (New Zealand), 179-209.

Toebes, C. & Palmer, B.R., 1969. Hydrological regions of New Zealand. Water and Soil Division, Ministry of Worrks for the National Water and Soil Coservation Organisation.

Waikar, M.L. & Nilawar, A.P., 2014. Identification of groundwater potential zone using remote sensing and GIS technique. *International Journal of Innovative Research in Science, Engineering and Technology*, 3(5), 12163-12174.

Ward, R.G., 1965. Land use and population in Fiji. Land use and population in Fiji., (9).

Yeh, H.F., Cheng, Y.S., Lin, H.I. & Lee, C.H., 2016. Mapping groundwater recharge potential zone using a GIS approach in Hualian River, Taiwan. *Sustainable Environment Research*, 26(1), 33-43.

Yeh, H.F., Lee, C.H., Hsu, K.C. & Chang, P.H., 2009. GIS for the assessment of the groundwater recharge potential zone. *Environmental geology*, 58(1), 185-195.