Spatial analysis of soil suitability for plantation development for suitable tree species in Markham Valley, Morobe Province

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Abstract

Soil suitability mapping is a vital component in the functions of Forest Plantation. Annual work programs and operations in plantation establishment, management, harvesting, and roads maintenance require soil map information to guide what type of activity or program is appropriate to apply. This study aims at mapping soil suitability for plantation development of selected forest tree species in the Markham Valley. It plays an especially significant role in determining what type of tree or forest can grow in what type of soil or land area in Markham Valley. GIS and Remote Sensing were used for spatial data analysis, to demonstrate simple techniques deployed in soil suitability mapping. Different land characteristics that contribute to soil suitability of selected tree species were identified for soil suitability potential areas in the Markham Valley. From the analysis the less suitable sites to more suitable sites were demarcated for suitable tree species. Within the study region, 909.35 sq. km. of land was identified as highly suitable for growing appropriate tree species. The map produced is recommended for adoption by the PNGFRI managers and officers in their management plans and operations in the Valley. It may also be especially useful to non-foresters, landowners and private sector players involved in plantation or woodlot development in the Markham Valley and similar areas.

Keywords: *Spatial analysis, AHP, GIS, MCA, Markham Plantation, Tree Species*

1. Introduction

According to Purves (2009) and Benito-Garzon et al. (2013), tree species distribution is caused by biotic influence on demographic process, effect of environment and growing competition. Furthermore, according to Thuiller et al. (2014), the tree species growth rate is determined by tree growth, mortality and balance of establishments resulting in tree species distribution ranges. As was observed by Dobbertin (2005), Rotzer et al. (2005), and Johnstone et al. (2013), regarding tree species, growth is considered the most crucial factor defining good health and growing competitiveness. Such good health tree species growing and in growing competitiveness are determined and/or regulated by site-soil geology, altitude levels, and the climate of the region.

According to PNG Forest Research Authority, the species screening and selection has begun in the Markham Valley around mid - 1960's and trials were established around Nadzab – Erap areas, Leron and Umi areas. Some of the species assessed in these areas were Acacia mangium, Albizia procera, Eucalyptus grandis, Eucalyptus tereticornis, Eucalyptus torelianus, Leucana lecocephalus (giant leucaena) Pinus caribaea, Pinus merkusii, Pinus keysia, and Tectona grandis (Teak). Further species assessed in recent years included Terminalia brassii, Eucalyptus pellita, etc. Additional screenings of new species were established in 1998 at Dabua near Watarais. The species included Anisoptera thurifera, Araucaria cunninhamii, Araucaria hunsteinii, Acacia mangium, Eucalyptus pellita, Instia bijuga, Pinus caribaea, Pometia pinnata and Pterocapus indica. The successful species identified and selected from these trials for the Markham Valley were Albizia procera, Eucalyptus pellita, Pinus caribaea, Leucaena lecocephalus, Anisoptera thurifera, Araucaria cunninhamii, Araucaria hunsteinii, Acacia mangium, Pometia pinnata and Terminalia brassii.

The Valley geographically has a flat land area consisting mainly of grassland with fewer forest areas. Planting of the different successful tree species for plantation development in the area will be beneficial in terms of timber and plywood for the construction of local houses, generate income opportunities, fuel wood, shade, soil stability, watershed protection and forest rehabilitation purposes and to increase the forest cover in the valley in addressing climate change. Given the benefits and possibilities of forest tree species in the area, the development of forest plantation is a potential alternative

As a matter of priority, the PNG Forest Authority (PNGFA) has plans to develop commercial plantations in the valley using the above successful species which had been selected from the trials. This plantation program will start with the expansion of the existing field station at Leron and Umi. The landowning communities will also be encouraged to plant woodlots on their land to support this program and for their own use. The Dabua village community is one of these communities that are interested in planting woodlots in their area because of successful field trials of several commercial timber species that have been assessed on different sites in their area.

In preparation for this plantation program, there are several lead up activities that are planned to be done. One of these activities is the preparation of soil suitability map for the Markham Valley. Hence, geospatial technology was used to define and map the soil suitability of the valley and the potential plantation areas to speed up species site-matching in the valley and expand the plantation areas.

Different land utilization types have different requirements for land quality. If the quality of a land unit matches the land use requirement of defined land utilization type, its suitability is high. Moreover, selection and definition of land utilization types guide the selection of land characteristics to be represented in land resource surveys. These characteristics are then used as evaluation criteria in the suitability analysis (FAO, 1984, 2007). Regarding land suitability studies on forest plantations, Olarieta, et al. (2006) investigated land requirements for growing Pinus radiata in the Basque Country of Northern Spain by comparing site index values with land qualities/characteristics. Their results revealed that soil physical characteristics has a significant impact on the growth rates of trees in loamy texture soils. Furthermore, Dayawansa and Ekanayake (2003) studied suitable areas within the University of Peradeniya, Sri Lanka, for a production forest by using GIS. They found that climate, slope, soil, topography, and vegetation accessibility were key factors in identifying land suitability. Suitability rating is an evaluation problem involving several factors, where the relative importance of the criteria is required (Malczewski, 1996, 2000, 2003 and Lupia, 2012). From such suitability evaluation the results of low to high suitable zones are identified.

The main problem observed within our study region is that soil suitability map for the Markham Valley area is yet to be developed. Many foresters and local people in the area are not clear on what tree species can be grown and what specific site or land area is suitable for planting different tree types. The current preliminary studies can provide some ideas for resolving such problems and can be especially useful to the plantation managers and landowners in the valley. The preliminary soil suitability site selections will assist the plantation managers, non-foresters, landowners, and private sectors involved in plantation or woodlot development in the Markham Valley in plantation management plans and decision making.

This study aims to define soil suitability of the Markham Valley area to see which land areas are suitable for plantation development of suitable tree species using GIS and Remote Sensing technology. The focus of the research is to identify different important land characteristics contributing to soil suitability for the development of these tree species and to identify the soil suitability potential zone for these tree species.

Land evaluation is the process of predicting land performance over time according to specific types of use (Rossiter, 1996) and it has traditionally been based primarily on soil surveys. However, Booth et al. (1989) applied a multiple-criteria evaluation (MCE) adapted from Carver (1991), which describes a technique that identifies and maps locations satisfying six climatic criteria, namely: mean annual rainfall, rainfall regime, dry season length, mean maximum temperature of the hottest month, mean minimum temperature of the coldest month, and mean annual temperature, where Eucalyptus and Pinus can grow. Furthermore, GIS-based multi-criteria analyses have been widely used for forestry applications (Carver, 1991).

Dengiz, et al. (2010) investigated the parametric approach to land suitability evaluation for different forest tree species in the Yesilirmak delta and the central Black Sea region in Turkey. They prepared the final suitability maps and the percentage of suitability for each of the studied tree species. Both techniques have contributed a lot in identifying soil suitability potential areas in different regions of the world. A land suitability analysis was conducted by John Kopatlie, while Cornelio (2014) identified areas in Papua New Guinea that were suitable for the establishment of commercial tree species plantation. Climate and rainfall maps built by PNGRIS (PNG Resource Information System) in 2009 were used as source maps.

2. Study area

The study area (Figure 1) is in the Northwest of Lae City of Morobe Province in Papua New Guinea. The valley covers the land area between Nadzab and the young creek bordering the Eastern Highlands Province to the Northwest and Gusap to the North with Madang Province. The valley lies between the mountain ranges on the Northwest side towards Bulolo in Morobe Province and Yonki in the Eastern Highlands Province and northern side towards Madang Province and Boana-Wain areas of Morobe Province. The study area is situated between coordinates system of six˚0'0" to 7˚0'0" S latitude and 146˚0'0" to 147˚0'0" E longitude. The valley covers a land area of some thousand hectares. The natural inhabitants (villagers) live in the valley, at the foot of the mountains and on the hillsides, and the population is estimated to be over 50,000 people. The vegetation is geographically flat with mostly grassland and scattered trees. The local people depend on the valley for their livelihoods. They farm the land, use the land for hunting and gathering, collecting materials for construction of local houses, fuel wood and materials for clay pots from the foot of the mountain.

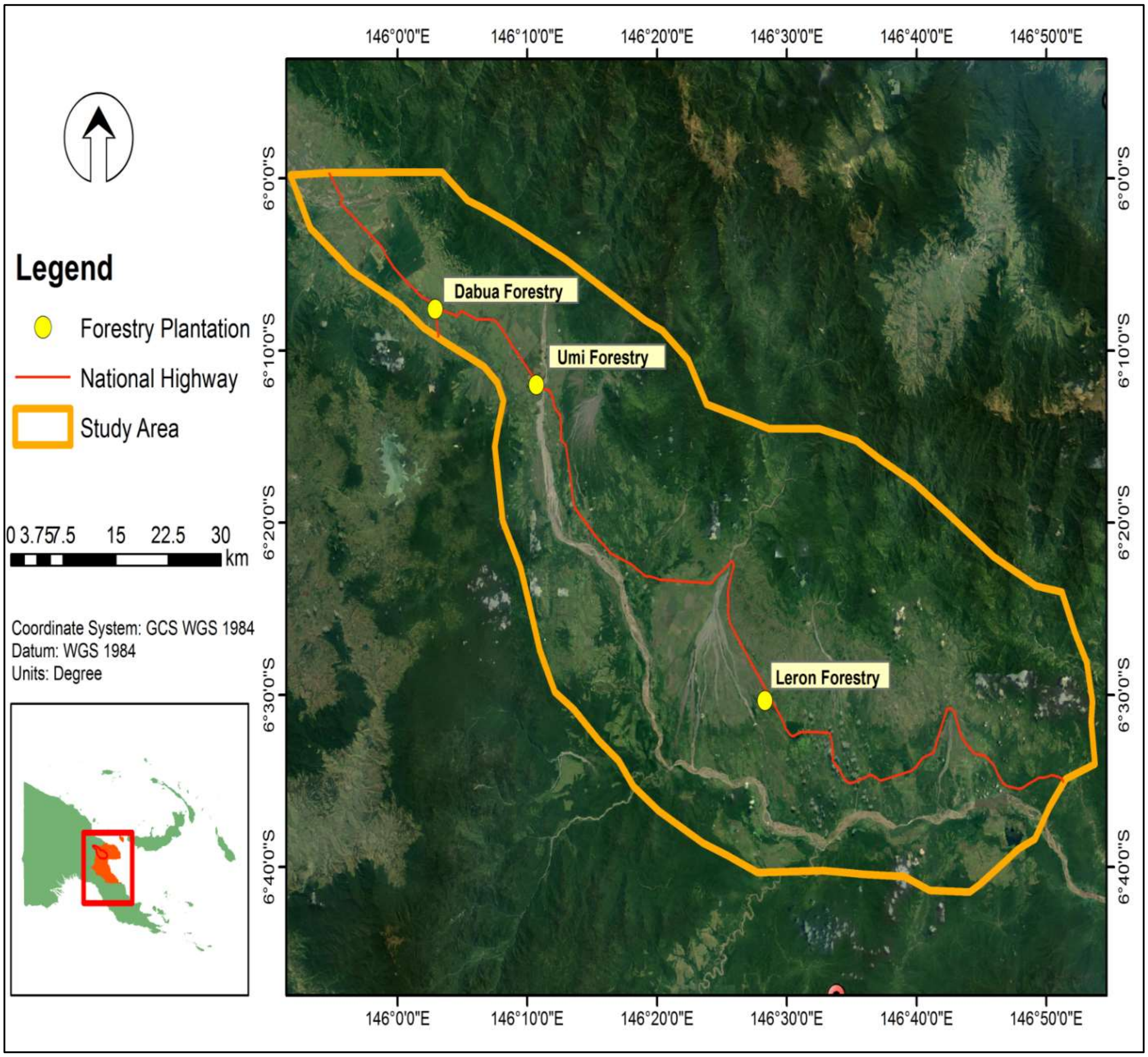

Figure 1: Study area locality

3. Materials and methods

In this section, the data and methods used to achieve the aim and objectives of the research are presented. The overall concept involves the integration of three (3) data sets that result in preparing and weighting of nine (9) thematic layers relating to the study area. The three (3) data sets are soil data, weather data and elevation data (Table 1). The soil and weather data used (Table 1) were downloaded from PNGRIS and the Digital Elevation Model (DEM) was downloaded from USGS Earth Explorer (30m spatial resolution). From the soil data, thematic layers such as soil depth, soil texture, soil drainage, soil erodibility, soil pH and soil nitrogen were extracted and prepared and from the weather data, thematic layers of rainfall and temperature were extracted and prepared. The slope layer was derived from the DEM (Table 1).

Table 1. Data layers, descriptions, and sources

Datasets	Description (Thematic Layers)	Source
1. Soil	Physical Properties ▪ Depth ▪ Texture ▪ Drainage ▪ Erodibility Chemical Properties ▪ PH ▪ Nutrients (Nitrogen)	PNGRIS
2. Weather	▪ Rainfall ▪ Temperature	PNGRIS
3. DEM	Slope	USGS Earth Explorer/Global Mapper

Source: Authors 2021

The datasets (DEM, soil, and weather) collected were pre-processed and analysed in ArcGIS. The soil datasets given were in shape files or vector format. From the soil datasets, soil depth, erodibility, soil drainage and soil texture, soil pH and nitrogen were extracted. Once opened in ArcGIS, the data was clipped to extract only the study area. After clipping, the data was rasterized and then vectorized to standardize the data with the specification of class names. The soil data were again reclassified or rated based on their importance or contributions in identifying site suitability of tree species growth. Reclassifying means, giving values such as one (1) for less important to five (5) for more important to the dataset.

For the weather datasets, the vector files were converted to raster then raster to point. From point data, Inverse Distance Weighted (IDW) Interpolation technique was performed to re-generate the quality raster file. After performing IDW the data were then reclassified into five (5) classes and ratings were assigned based on their levels of importance. For the DEM data, slope layer was created and classified into five (5) classes and the ratings were assigned based on their levels of important. One (1) for less important to five (5) for more important to the dataset.

The weightings and ratings were assigned to each factor and their classes based on expert opinions and several previous studies were reviewed during research. The weightings and ratings assigned were all normalized via the AHP technique. The AHP was developed by Saaty (1980, 1977, 1992), specifically to assess or synthesize judgments or decisions made by the experts to achieve their set goal and to evaluate and check the consistency of judgment made. It is one of the best known and most widely used MCA approaches. It allows users to assess the relative weights of multiple criteria or multiple options against given criteria in an intuitive manner. After normalizing and calculating new weights via the AHP technique for each thematic layer and its classes, the weighted overlay technique was used to identify the soil suitability potential areas in Markham Valley for the suitable tree species.

The thematic layers such as soil (depth, texture, drainage, erodibility, pH, Nitrogen), weather (rainfall and temperature) and DEM (slope) are used in the analysis adopted for this paper. According to Malczewski (2006), the idea of overlay analysis is based on the overlay of geo-referenced cell in a layer with the geo-referenced cell of another thematic layer. The value in each thematic layer was assigned a common scale, thus integrating all the thematic layers to generate the final output layer. The flow chart in Figure 2 illustrates the summary of the methods used in this paper. In summary, the methods used in this paper are Pairwise Comparison technique (AHP) to find the normalized weights and consistency of the weights and then preparing new normalized thematic layers and overlaying and integrating them using weighted overlay tool in ArcGIS to produce the final soil suitability map (Fig. 2).

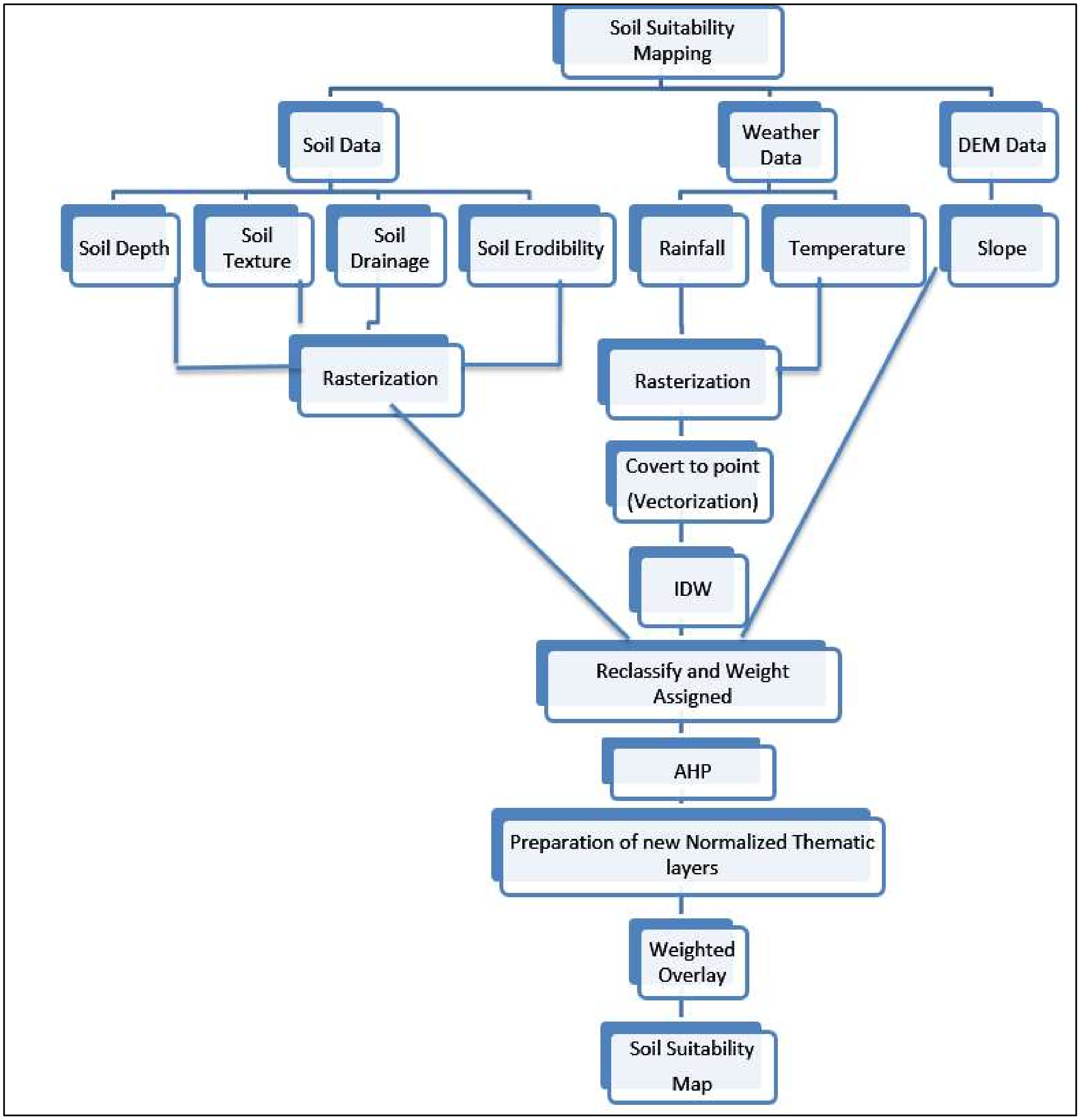

Figure 2: Methodology flow chart

4. Results and discussion

Nine (9) different environmental factors such as soil depth, soil texture, soil drainage, soil erodibility, soil pH, nitrogen, rainfall, temperature, and slope were extracted and overlaid using weighted overlay tool in ArcGIS to demarcate or identify low to high soil suitability potential areas for suitable tree species in Markham Valley. Tree growth and geographic distribution are greatly affected by the environment. If any environmental factor is less than ideal, it limits tree growth and/or distribution. For example, only trees adapted to limited amounts of water can grow in dry areas. Environmental factors that affect tree growth include temperature, water, slope, and nutrition. It is important to understand how these factors affect and contribute to the growth and development of these tree species (Teka and Welday, 2017; Dolos, et al, 2015). With a basic understanding of these factors, GIS can be used to integrate and manipulate thematic layers to determine the level of soil suitability for planting tree species. The thematic layers used are explained in detail below.

4.1 Thematic layers used for integration

Soil texture plays a key role in tree growth as in limiting which type of trees can be grown on which type of soil. For example, some tree species perform best in sandy soil because it is loose and allows the trees to expand. On the other hand, some trees may experience stunted growth in a sandy soil because the soil lacks water- and nutrient-holding ability. According to Loi (2008), soil textures of coarse sand and heavy clay create difficult conditions for land development not only for forestry production but also for agricultural production. Figure 3a illustrates the soil texture distribution of the study site. The soil texture layer was assumed as the most influential input for assessing soil suitability for tree species development within the study region (Table 2) for class level distribution, ratings and weightings assigned.

Rainfall contributes to water availability in the soil and is the strongest driving factor in tree growth. It was considered as the second most influential factor in the delineation of soil suitability for tree species growth. Plants or trees take up food in solution form; therefore, it requires rain to dissolve the strong content of nutrients into solution form so that the roots of the trees can suck it in for their growth and development. Figure 3b illustrates rainfall distribution at the study site (Table 2) for class level distribution, ratings and weightings assigned.

Temperature influences most tree processes, including transpiration, photosynthesis, respiration, germination, and flowering. As temperature increases (up to a point), photosynthesis, transpiration, and respiration increase. Temperature also affects the change from vegetative (leafy) to reproductive (flowering) growth (Mari, 2008). Depending on the situation and the specific tree, the effect of temperature can either speed up or slow down this transition. Wet areas require enough temperature to dry the soil so that trees can grow otherwise trees become underdeveloped due to excess amount of water table. Figure 3c illustrates the temperature distribution at the study site (Table 2) for class level distribution, ratings and weightings assigned.

Adequate soil drainage is critical for good tree growth. Poor soil drainage will result in water-logged, saturated soils, which adversely affect tree growth. Saturated soils reduce oxygen availability to roots and decrease the tree's ability to take up water through its roots. Figure 3d illustrates the soil drainage distribution of the study site (Table 2) for class level distribution, ratings and weightings assigned.

Soil depth can influence the types of trees that can grow in them (Van Loi, 2008). Deeper soils can provide more water and nutrients to trees than more shallow soils. Furthermore, most trees rely on soil for mechanical support, and this is especially true for tall woody trees and shrubs. According to Bryan and Shearman (2008), most annual crops have a rooting depth of about 50cm, while for tree crops the rooting system can reach beyond 150cm. However, most tree crops produce good yields in soils with an effective soil depth of about 100cm, and this value has been used as an upper limit. Figure 3e illustrates the soil depth distribution at the study site (Table 2) for class level distribution, ratings and weightings assigned.

Nitrogen in soil plays a significant role in tree growth; however, analysis suggests that an increase in nitrogen deposition has increased tree growth by 12%, but it is evident that other nutrients will become crucial with the present nitrogen deposition (Hari, 1998). Figure 3f illustrates the soil nitrogen distribution at the study site (Table 2) for class level distribution, ratings and weightings assigned.

Soil pH can affect tree growth in several ways. In some mineral soils, aluminium can be dissolved at pH levels below 5.0 becoming toxic to tree growth. Soil pH may also affect the availability of nutrients. Nutrients are most available to plants in the optimum 5.5 to 7.0 range (Loi, 2008). In highly acidic soils, aluminium and manganese can become more available and more toxic to trees while calcium, phosphorus, and magnesium are less available to the trees. In highly alkaline soils, phosphorus and most micronutrients become less available. Figure 3g illustrates the soil pH distribution at the study site (Table 2) for class level distribution, ratings and weightings assigned.

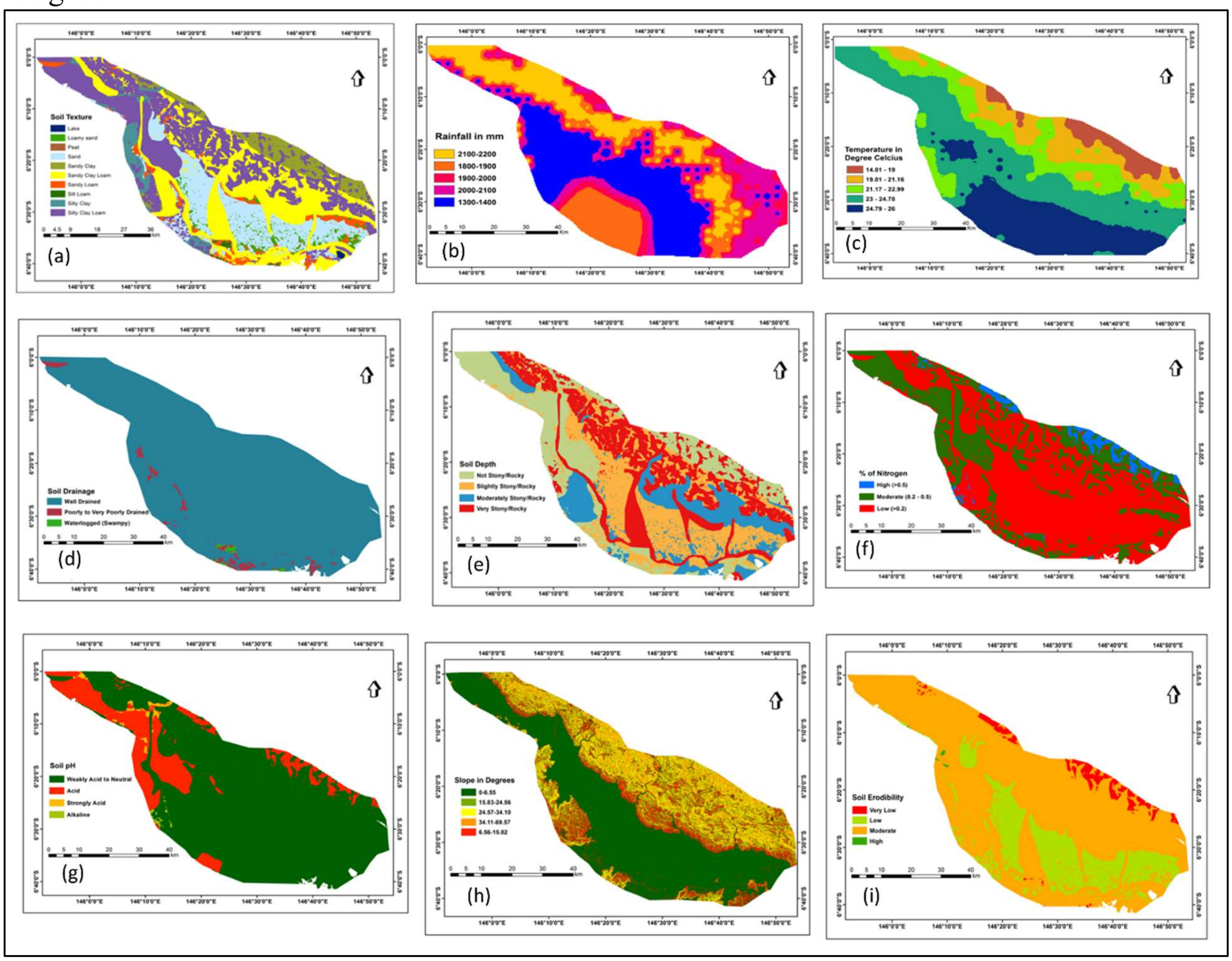

Figure 3: Thematic layers integrated for demarcation of soil suitability for suitable tree species.

Slope aspect is known to affect the variety and density of plant groups. Luminous or lightened slopes maintain less moisture because solar radiation is stronger, and evaporation is higher. Therefore, plants on luminous slopes are more likely to be drought and radiation resistant (Xue, 2018). Trees on a slope greater than 45 degrees (>45°) are considered for conservation purposes. Slope less than 45 degrees (<45°) are for forestry plantations and for commercial purposes. Figure 3h illustrates the slope distribution at the study site (Table 2) for class level distribution, ratings and weightings assigned.

Soil erodibility does not contribute to tree growth; however, a tree with strong root system acts as an anchor holding the soil together preventing soil loss (erosion). Therefore, it is important to plant trees to avoid soil erosion. Figure 3i illustrates the soil depth distribution at the study site. This factor was considered as the lowest influential contribution in selecting suitability soil sites for tree species growth in the study region (Table 2) for class level distribution, ratings and weightings assigned.

Table 2. Weightage assignment of various thematic maps for soil suitability zones for suitable tree species

Factor	**Class Type**	**Rating**	**Weights**		**Area (km^2)**	**Area (%)**
			Normalized	**Final Weights**		
Soil Texture	Sand	1	0.218	21.8	732.99	18.96
	Silty Clay Loam	4			1310.80	33.91
	Sandy Loam	5			168.92	4.37
	Silty Clay	4			140.10	3.62
	Sandy Clay	4			290.10	7.51
	Sandy Clay Loam	4			1117.02	28.90
	Silty Loam	5			12.16	0.31
	Peat	1			3.61	0.09
	Lake	1			5.70	0.15
	Loamy Sand	5			83.86	2.17
Rainfall	2100-2200	1	0.160	16	735.39	19.06
	1800-1900	2			770.49	19.97
	1900-2000	3			458.54	11.89
	2000-2100	4			705.40	18.28
	1300-1400	5			1188.21	30.80
Temperature	14.01-19	1	0.154	15.4	228.10	6.028
	19.01-21.16	2			536.41	14.18
	21.17-22.99	3			726.49	19.20
	23-24.78	4			1373.92	36.31
	24.79-26	5			919.12	24.29
Drainage	Well Drained	5	0.109	10.9	3763.69	97.45
	Poorly to Very Poorly Drained	3			82.49	2.14

	Waterlogged (Swampy)	1			15.88	0.41
Depth	Not Stony/Rocky	5	0.076	7.6	944.85	24.48
	Slightly Stony/Rocky	3			1085.38	28.13
	Moderately Stony/Rocky	3			694.82	18.01
	Very Stony/Rocky	1			1133.93	29.38
Nitrogen	High (>0.50	5	0.053	5.3	146.13	3.79
	Moderate (0.2-0.5)	3			1201.08	31.12
	Low (<0.2)	1			2512.35	65.09
pH	Weakly Acid to Neutral	5	0.037	3.7	3138.97	81.32
	Acid	1			676.83	17.54
	Strongly Acid	1			34.62	0.90
	Alkaline	4			9.40	0.24
Slope	0-6.55	1	0.026	2.6	1918.98	49.17
	6.56-15.82	2			589.86	15.11
	15.83-24.56	3			626.13	16.04
	24.57-34.1	4			503.25	12.90
	34.11-69.57	5			264.31	6.77
Erodibility	Very Low	5	0.019	1.9	135.36	3.51
	Low	4			815.73	21.13
	Moderate	3			2905.71	75.26
	High	1			4.24	0.11

4.2 Integration of the thematic layers to identify soil suitability zones for suitable tree species

The soil suitability zones for the study area were generated by overlaying various thematic layers such as soil (depth, drainage, erodibility, texture, pH, and Nitrogen), weather (rainfall and temperature) and DEM (slope) in ArcGIS using the Weighted Overlay Analysis tool.

The demarcation of the soil suitability potential zones for the tree species is analyzed using the pairwise comparison technique to find the normalized weights. The normalized weights derived for each class are presented in Table 2. The consistency ratio of each matrix for the classes was checked to be okay. Thus, it was accepted that the weights assigned and also the random distributions of weights assigned are consistent enough. After normalizing all the factors with their classes, the thematic layers were overlaid using the weighted overlay analysis tool in ArcGIS 10. The result obtained is shown in Figure 4. The class distribution according to overall output weights is tabulated in Table 3, including area coverage in sq.km and the percentage of each class range.

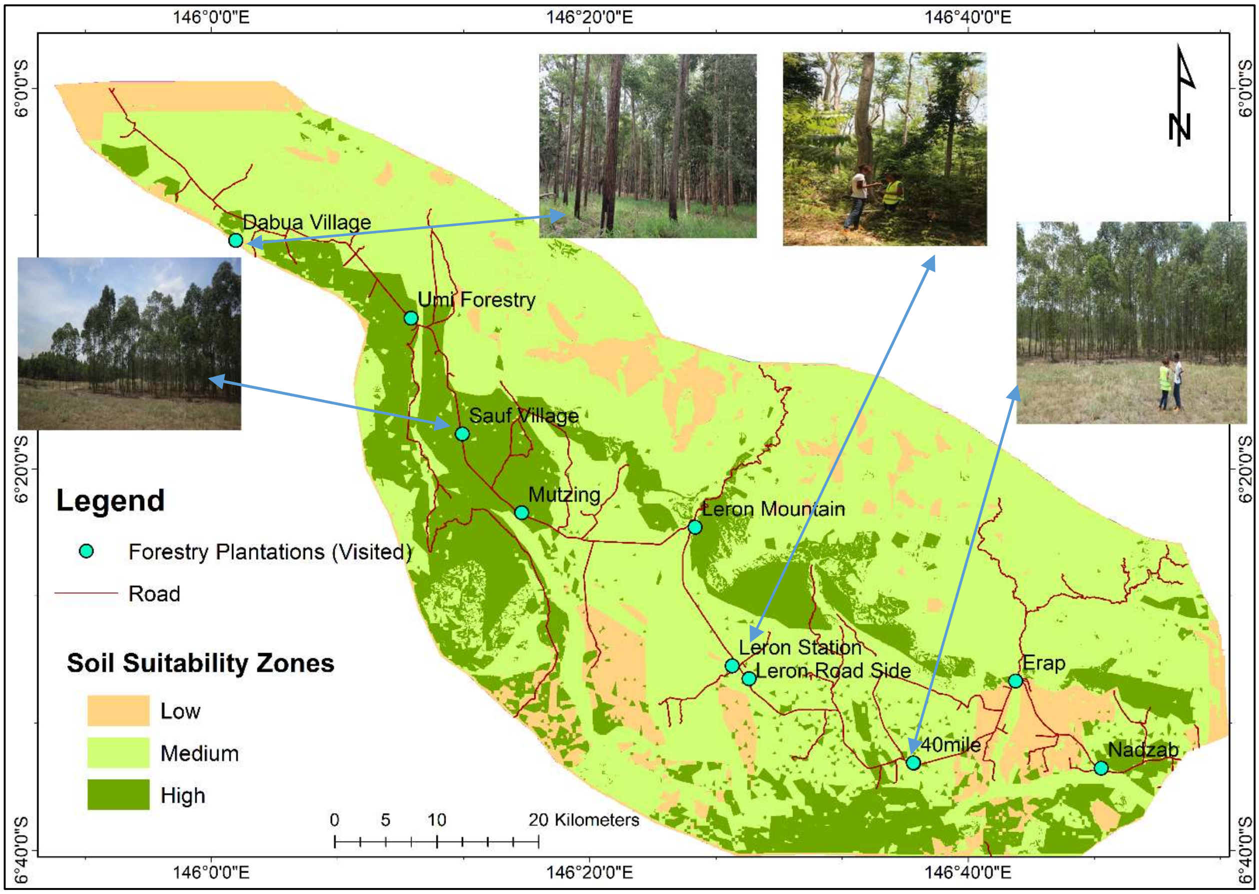

Figure 4: Soil suitability zones for suitable tree species growth

Table 3 Soil suitability assessment as per soil suitability map.

Soil Suitability Overall Weights	Soil Suitability Class range	Area in Sq.km	Area in %
83.36 - 244.88	Low	497.95	12.68
244.88 - 325.64	Medium	2521.12	64.18
325.64 - 430.40	High	909.35	23.15

4.4. Field Verification of forestry plantations in the Markham Valley

The field verification of different tree species was conducted to identify the forestry plantations, the tree species grown in each plantation and soil type suitable for the growth of the tree species. A handheld GPS was used to collect field data (Figure 4 and Table 4) to understand the data types collected to make judgments and summarization in line with the soil suitability map produced.

Table 4. Field verification of forestry plantations, tree species and soil types (See Figure 4 for corresponding locations and site suitability).

Forestry Plantation	**Forest Plantation photos taken during field visit**	**Tree Species**	**Soil type**
Nadzab		Pinus Carribea	Loam, Clay Loam
Erap		Tectona Grandis (Teak)	Clay Loam
40 Mile		Eucalyptas Pelita, Eucalyptus Degupta, Acacia Crassicapa	Wet Land (Semi), Loam to Clay Loam, Sandy Loam with presence of stones, silty loam
Leron Roadside (near Noah Village)		Terminalia Brassia, Eucalyptus Pellita, Eucalyptus Camaldunensis	Clay loam (semi-wet area)

Leron Forestry Station		Eucalyptus Pellita, Tosna Sureni (Red Cedar), Araucaria Cunninghamii (Hoop), Pinus Caribaea, Leucaena lecocaphalus (Giant Leucaena)	Loam Soil with presence of coarse sand and gravels/stones, silty loam
Leron Mountain (Before the bridge from Lae)		Pinus Caribaea	Clay loam and presence of stones
Mutzing		Eucalyptus Pellita, Acacia Crassicarpa, Tectona grandis, Cassuarina Papuana	Clay Loam, Silty Loam with presence of gravels
Sauf Village		Eucalyptus Pellita, Eucalyptus Camalduensis	Silty Loam, Clay Loam
Umi Forestry station		Eucalyptus Pellita, Pinus Caribaea, Araucaria Cunninghamii (hoop), Araucaria Hunsteinii (Klinki), Cassuarina papuana, Eucalyptus, teriticornis	Loam, Clay Loam

Dabua Village		Eucalyptus Pellita, Araucaria Cunninghamii (hoop), Araucaria hunsteinii (Klinki), Anisoptera thurifera (Mersawa), Intsia Bijuga, Accacia Mangium, Pometia pinnata, Pinus Caribaea, Pterocarpus indicus (rosewood) and Accacia Auriculiformis	Silty Loam, Loam, Clay Loam

5. Conclusion

The identification of soil suitability potential areas can be distinguished among the categories, which depict the areas that are potentially suitable for the development and growth of these tree species. The final output map (Fig. 4) is classified into three classes indicating the amount of land areas, which are low, moderate, and highly suitable for the tree species. From the Table 3, the land areas that are classified as low suitability constitute about 12.68% and are on the most mountainous area of the valley. Land areas that are classed as moderate suitability is 64.18 %, which are the hilly areas including flat lands; while the highly suitable (23.15%) land areas are all the areas in the valley where the soil type is mostly clay to loamy soils and where most of the current forestry plantations are situated. Most of the forestry plantations as indicated on the map during field verification are along the main road due to road access for harvesting and for commercial purposes. The problem encountered during the implementation phase is the lack of some data and most of the data are outdated. To produce up to date and quality output, there should be more and updated data on hand. However, regardless of lack of data, the final output was obtained using the other available data. The current research provides some background understanding or a steppingstone to more detailed research that can be bridged soon.

In conclusion, the soil suitability potential zones of the tree species of the study area is controlled by soil depth, soil texture, soil drainage, soil erodibility, soil pH and soil nitrogen as well as rainfall, temperature, and slope layers. Remote Sensing and GIS technology are especially useful for the preparation of soil suitability maps for forestry plantation development plans. Thus, soil suitability map produced can be used in planning for plantation development in the Markham Valley by PNG Forest Research Institute (PNGFRI). On the other hand, current results may be used as a background knowledge to help conduct more detailed investigations and analyses soon by utilizing updated data layers. The current results may also assist other stakeholders in both the public and private sectors, as well as landowners involved in woodlot development and the forestry business in Markham Valley area and similar jurisdictions in the country.

References

1. Booth, J., Stein, J., Nix, H., Hutchinson, M. G. (1989), Mapping regions climatically suitable for particular species: an example using Africa. Forest Ecology and Management 28:19-31. http://dx.doi.org/10.1016/0378-1127(89) 90071-6.
2. Bryan, J. E., and Shearman, P.L. (2008), Papua New Guinea Resource Information System Handbook 3rd Ed. University of Papua New Guinea. Port Moresby

3. Carver, S. J. (1991), Integrating multi-criteria evaluation with geographical information systems. International Journal of Geographical Information Systems 5: 321–39
4. Dengiz, O., Gol, C., Sarioğlu, F. E., and Ediş, S. (2010), Parametric approach to land evaluation for forest plantation: A methodological study using GIS model. African Journal of Agricultural Research Vol. 5 (12), pp. 1482-1496,
5. Dobbertin, M. (2005), Tree growth as indicator of tree vitality and of tree reaction to environmental stress: a review. Eur J For Res 124:319–333. doi:10.1007/s10342-005-0085-3
6. Dolos, K., Bauer, A., and Albrecht, S. (2015), Site suitability for tree species: Is there a positive relation between a tree species' occurrence and its growth. Springer-Verlag Berlin Heidelberg, Eu J Forest Res.
7. FAO. (1984), Land Evaluation for Forestry. Retrieved April 2021, from Food and Agriculture Organization Website: http://www.fao.org.
8. FAO. (2007), land evaluation towards a revised framework, Land, and water discussion paper 6. Rome, Italy: Food and Agriculture Organization of the United Nations
9. FAO., (1984), Land Evaluation for Forestry. Retrieved April 2021, from Food And Agriculture Organization Website: http://www.fao.org
10. Garzo´n, B. M., Benito, R.P., Zavala, M. A. (2013), Interspecific differences in tree growth and mortality responses to environmental drivers determine potential species distributional limits in Iberian forests: including tree growth and mortality into species distribution. Glob Ecol Biogeogr 22:1141–1151. doi:10.1111/ geb.12075
11. Johnstone, D., Moore, G., Tausz, M., Nicolas, M. (2013), The measurement of plant vitality in landscape trees. Arboric J 35:18–27. doi:10. 1080/03071375.2013.783746
12. Kopatlie, J., Cornelio, D. L. (2013), GIS Analysis of Land Suitability for Commercial Tree Species in Papua New Guinea Forestry Department, Papua New Guinea University of Technology, Private Mail Bag Lae, Morobe Province, Papua New Guinea
13. Loi, V. N. (2008), Use of GIS modelling in assessment of forestry land's potential in Thua Thien Hue province of central Vietnam. Dissertation Remote Sensing and GIS, M. Sc
14. Lupia, F. (2012), Crop/land suitability analysis by Arcgis tools. Technical Report.
15. Malczewski, J. (1996), A GIS-based approach to multiple criteria group decision-making. International Journal of Geographical Information Science, 10: 955 - 971.
16. Malczewski, J. (2000), Review article on the use of weighted linear combination method in GIS: common and best practice approaches. Transactions in GIS, 4:5-22.
17. Malczewski, J. (2003), GIS-based land-use suitability analysis: a critical Overview, Progress in Planning 62: 3 – 65
18. Malczewski, J. (2006), GIS-based multi-criteria decision analysis: a survey of the literature. International Journal of Geographical Information Science 20: 703 -726.
19. Nissinen, A., and Hari, P. (1998), Effects of nitrogen deposition on tree growth and soil nutrients in boreal Scot's pine stands, Environmental Pollution, Volume 102, Issue 1, Supplement 1, Pages 61-68, https://doi.org/10.1016/S0269-7491(98)80016-X.Elsevier
20. Olarieta, J. R., Besga, G., RodrI ´guez-Ochoa, R., Aizpurua, A., & Uson, A. (2006), Land evaluation for forestry: a study of the land requirements for growing Pinus radiata D. Don in the Basque Country, northern Spain. Soil Use and Management, 22(3): 238-244. Doi:10.1111/j.1475-2743.2006. 00038.x
21. Purves, D. W. (2009), The demography of range boundaries versus range cores in eastern US tree species. Proc R Soc B Biol Sci 276:1477–1484. doi:10.1098/rspb.2008.1241

22. Ro¨tzer, T., Grote, R., Pretzsch, H. (2005), Effects of environmental changes on the vitality of forest stands. Eur J For Res 124:349–362. doi:10.1007/s10342-005-0086-2
23. Rossiter, D. G. (1996), A theoretical framework for land evaluation, Geoderma, Volume 72, Issues 3–4, Pages 165-190, ISSN 0016-7061. https://doi.org/10.1016/0016-7061(96)00031-6.
24. Saaty, T. L. (1977), The analytic hierarchy process: planning, priority setting, and resource allocation. McGraw-Hill, New York, Ed. 1. 17.
25. Saaty, T. L. (1980), The analytic hierarchy process: planning, priority setting, and resource allocation, McGraw-Hill, New York, Ed. 2. 18.
26. Saaty, T. L. (1992), Decision making for leaders, RWS Publications, Pittsburgh 19
27. Teka, K., and Welday, Y. (2017), Evaluation of Land Suitability for Selected Tree Species in the Mesozoic Highlands of Ethiopia Kassa. Department of Land Resources Management and Environmental Protection, College of Dryland Agriculture and Natural Resources. Momona Ethiopian Journal of Science (MEJS), V9(2):215-231.
28. Thuiller, W., Mu¨nkemu¨ller, T., Schiffers, K.H, et al. (2014), Does probability of occurrence relate to population dynamics? Ecography n/a–n/a. doi: 10.1111/ecog.00836
29. VanDerZanden, A. M. (2008), Environmental Factors Affecting Plant Growth. Master Gardener statewide coordinator (Former). *https://extension.oregonstate.edu/gardening/techniques/environmental-factors-affecting-plant-growt*
30. Xue, R., Yang, Q., Miao, F., Wang. X., and Shen, Y. (2018), Slope aspect influences plant biomass, soil properties and microbial composition in alpine meadow on the Qinghai-Tibetan plateau. Journal of soil science and plant nutrition *version On-line* ISSN 0718-9516. J. Soil Sci. Plant Nutr. V-18(1) no.1 Temuco mar. http://dx.doi.org/10.4067/S0718-95162018005000101

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