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Delineating Drought Risk Areas Using Remote Sensing and Geographic Information Systems– A Case Study of Western Highlands Province, Papua New Guinea

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***Abstract*—In the highlands of Papua New Guinea, rain-fed subsistence farming has been the main source of food and small cash earnings for the majority of the rural population. Consequently, as a result of elongated period of drought, reduction in food and water supply bring forth starvation / malnutrition led sickness and death, especially when authorities fail to intervene because inaccessibility and remoteness of the highly dissected terrain, as a result relief and basic services don't reach the hungry mouth on time. Such conditions were reported recently in many parts of Papua New Guinea especially prevalent in coastal regions and uplands of the highlands region. In this study, GIS and Remote Sensing (RS) technology were employed in highlighting and demarcating potential drought risk zones in Western Highlands Province. Basically, several environmental factors like; soil types, NDVI, rainfall, terrain, population demography and surface temperature were prepared and integrated in GIS environment through multi-criteria evaluation techniques where risk areas were identified. The final output generated from factors integration were then assessed and reclassified to indicate levels of drought risk zones from Low, Medium and High. Hence, several built-up areas where then marked on each risk zones in an attempt to highlight the location, distribution and accessibility in respect to the risk areas identified.**

***Index Terms*—Drought; GIS & Remote Sensing; Multi-Criteria Evaluation.**

I. INTRODUCTION

Drought is generally referred to as the scarcity of water but scientifically, it has 150 debatable definitions [1]. Broadly speaking, drought is caused by hydro-meteorological processes that repress precipitation resulting in scarcity of surface or ground water availability, triggering significantly drier conditions than normal or otherwise reducing moisture availability to an extent that is potentially damaging. Many scholars and organizations [1]-[4], classified drought into four main categories: meteorological, hydrological, agricultural and socioeconomic. A 'meteorological drought' occurs when there is a decline in average precipitation. When prolonged meteorological drought causes scarcity of water, 'hydrological drought' ensues; accompanied by the latter, comes the shrinkage in crop yield giving rise to a condition termed as 'agricultural drought'. A continued drought of severe intensity that destabilizes the economy and socio – political fabric of a region is termed as 'socioeconomic drought' [1].

For the record, the country has been at the receiving end of El Niño and drought conditions for a very long time. The recent drought in Papua New Guinea has been a slice of the current increase in world average temperature [5]. The most recent one has been classified as category 5 (devastating effects, limited water supply, starvation and death) based on the Pacific Island Development Reports. Also, the reported cases published by the two prominent national daily papers of PNG have highlighted affected areas such as Central, Chimbu, Madang, Western Highlands, West New Britain, Morobe, Hela province and parts of Jiwaka Province [6]. There are many indices formulated to monitor drought since the introduction of this integrated system (GIS & RS). Some drought indices use the combination of two parameters like the Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST), such as Vegetation Temperature Condition Index (VTCI), which was modified and conceived by Wang et al [7].

A. *Significance of Study*

The current study aims at using the state of the art space technology to bridge the rift of the lack of high end technological tools' usages in PNG. Also, the focus of the study would be on the preparedness of management to deal with such drought menace with the supply of timely information to the administration in a fast, unbiased, and scientific manner. Western Highlands Province (WHP) is prone to drought related effects, in respect to its geographical location in the region of Papua New Guinea. Furthermore, the use of combined factors as NDVI, LST, rainfall, population density and soil moisture with elevation, helps to distinguish the trend and identifies the factors that contribute much to the onset of drought in different areas. This can reduce the risk of starvation and death, and will enable government to focus on areas that are of high priority instead of channelising funds indiscriminately to areas that are not adversely affected.

B. *Study Area*

WHP is geographically located around 144°26'34.549"E, 5°53'52.6"S (Fig.1). It has a population of 352,935 which contributes to 5% of PNG's population, with an average

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annual growth rate of 3% since 2000. It has a population density of 71.8 persons/km2 with an average household size of 3.0 persons and total land mass of 4483 km2. The mean annual rainfall ranges from 2500 – 3000mm and 3500 – 4000mm in the highest and low lying areas respectively all year around.

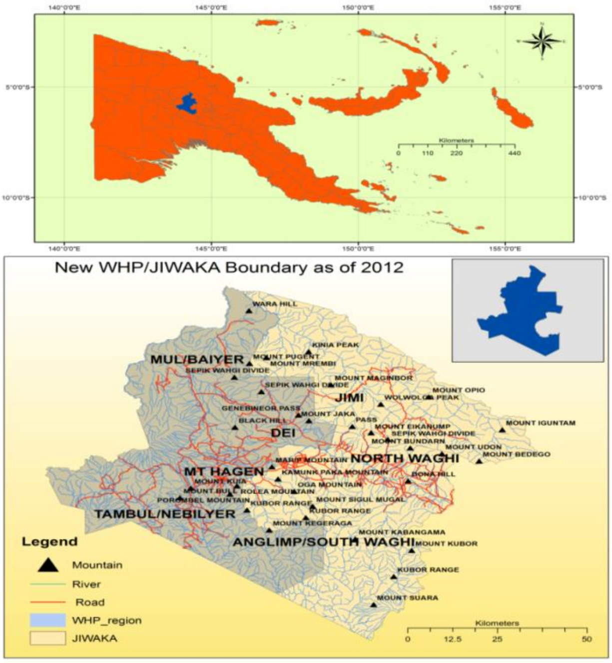


Fig. 1. Map showing the location of the study area

II. MATERIALS AND METHODS

Most of the data used in extracting thematic layers (Table I) of each factors were sourced from the departmental archive of PNG University of Technology.

TABLE I: DATA LAYERS USED FOR ANALYSIS

DATA TYPE	DATA LAYER	DATA SOURCE
LANDSAT 8 OLI, Band 5 (NIR) and Band 4(RED) 30 m resolution, 2014	NDVI	USGS website
LANDSAT 8 TIRS (Band 10 and Band 11) 30 m resolution	Land Surface Temperature	USGS website
Geomorphological	Soil texture, Soil Drainage Soil AWC	PNG Unitech (PNGRIS metadata Geobook)
Meteorological	Rainfall and Temperature	PNG Unitech (PNGRIS)
DEM	Elevation/Terrain	PNG metadata
Demographic	Population density	National Statistics Office (NSO)

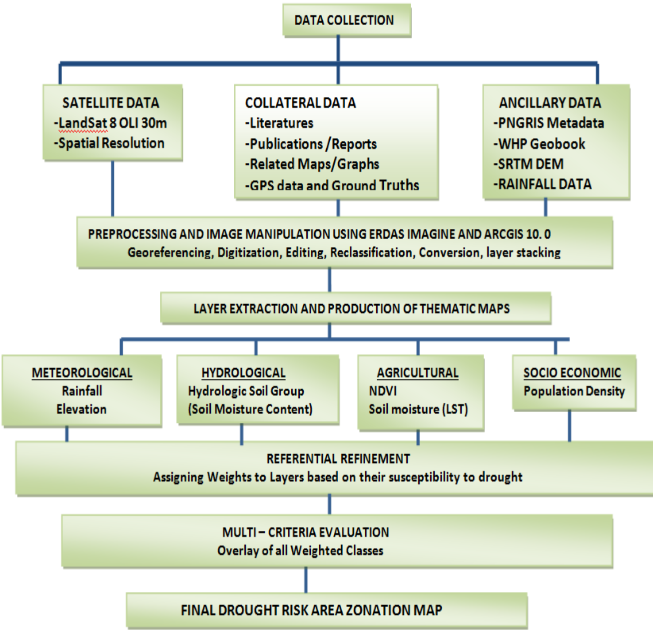


Fig.2. Methodological flow chart

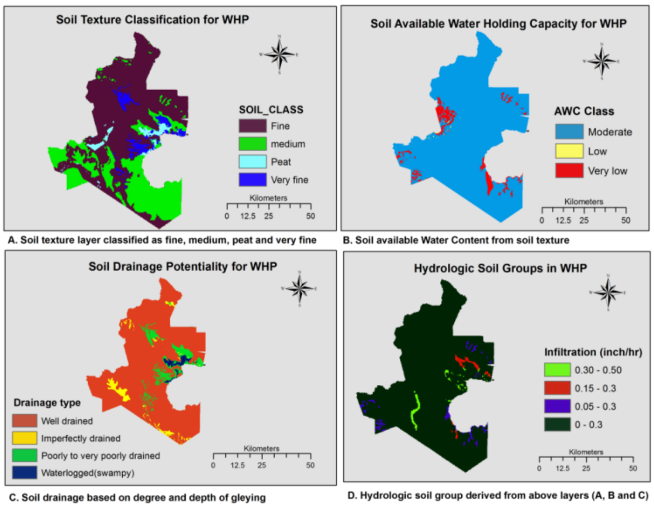
Data Preparation and Analysis

Most of the data used are PNG metadata which are collected from the PNG Unitech (Table I). This includes both satellite data and Geomorphological data. The NDVI and LST of the study area were prepared using Erdas Imagine 8 and ArcGIS 10 using the Landsat 8 Operational Land Imager (OLI), at 30m spatial resolution acquired November, 2014. That is, NDVI was extracted from bands 4 and band 5. Initially, the area of interest was extracted in Erdas and imported to ArcGIS for further manipulation (Fig. 2). The similar strategy was employed in the steps leading to the extraction of Land Surface Temperature, but the band used was thermal infrared (band 10 and band 11) wavelengths. The processing of LST involves mathematical calculations such as conversion of digital numbers (DN) to radiance, then converting radiance to satellite temperature brightness and finally converting the brightness to temperature after accounting for the calibration constants (k1 and k2), which is outlined in the next phase of the study. Both calculations were performed in ArcGIS using raster calculation which is a spatial analysis tool. The outcomes were reclassified using the reclassify tool to desired classes. The Geomorphological layers (soil texture, soil available water capacity, drainage) were obtained from PNGRIS metadata and analyzed and reclassified in ArcGIS. The thematic soil layers were merged and classified to hydrologic soil groups to identify the moisture content based on soil type and their infiltration rate on the assumption of the rainfall exclusively received on bare soil. This assumption does not account for the part of rainfall intercepted and stored on shoots and canopies that get directly evaporated back into the atmosphere. Also, the elevation factor was extracted from the DEM (PNGRIS metadata) and classified to five elevation classes. The primary meteorological factor (mean annual rainfall) was obtained from PNG Unitech and classified to six classes within ArcGIS platform. The process of merging by attributes was applied prior to classification. In the end, the final susceptibility map was overlaid with built up areas to assess the geographical locations with built-up infrastructures on the basis of severity of risks.

III. RESULTS AND DISCUSSIONS

A. Soil Attributes for Drought Analysis

Soil moisture content is one of the primary models aggregated to formulate indices that are used to measure the extent and severity of drought in many countries [8]. The soil moisture can be obtained from land surface model simulations or from satellite estimates. For optimal capture, infiltration, storage and use of soil moisture, three physical capacities of the soil are important; that is, the capacity to allow water to enter, referred to as infiltration, the capacity to allow water to move readily through the profile, referred to as permeability, the capacity to store the acquired moisture in the root zone as available to plant roots easily, referred to as soil water holding capacity (Table II). As such, the necessary attributes in coherence with drought modeling is to classify soil types by their available water holding capacity (AWC) in the soil and texture, drainage, and extrapolating these layers to their hydrologic soil group (HSG). Soils were originally assigned to hydrologic soil groups based on measured rainfall, runoff, and infiltrometer data [9]. The thematic layer of the study area was extracted from the PNG metadata. Initially, the soil texture was identified into various types such as loamy, sandy, clayey, silty etc. These groups of soil were further reclassified and merged to form the broad classes of texture which is fine, very fine, moderate coarse etc. Again, the AWC was derived from the preceding layer and the drainage type based on some inventory (criteria demarcated in the PNGRIS handbook). All layers (Fig. 3) were finally merged into four main groups (HSG) to assess the moisture content capacity based on texture, drainage, their degree of gleying (arising from long moisture saturation – ‘prevalent reduced state’ owing to lack of supply of molecular oxygen), infiltration and water holding capacity.



A. Soil texture layer classified as fine, medium, peat and very fine
B. Soil available Water Content from soil texture
C. Soil drainage based on degree and depth of gleying
D. Hydrologic soil group derived from above layers (A, B and C)

Fig.3. Sequential Thematic layers (A, B, C and D) of Soil Attributes

The Soil attributes/layers above are generated in a tabular orientation to analyze regression and relations between each soil characteristics and their influence to soil moisture content.

TABLE II: TABULAR ANALYSIS OF SOIL TEXTURE, DRAINAGE, AVAILABLE WATER HOLDING CAPACITY (AWC) AND CLASSIFICATION OF HYDROLOGIC SOIL GROUP.

TEXTURE	DESCRIPTION	AWC(CM/M)	DRAINAGE	HSG
Fine	Clay, Silty clay, Sandy Clay	15	Imperfectly drained	C
Medium	Sandy Loam	13	Poorly to very poorly drained	A-B
	Silt	15		
	Loam, Sandy Clay Loam	16		
	Silt Loam Clay Loam, Organic Mud	17		
Peat	Mucks or well decomposed Peat	20	Waterlogged (swampy)	A
	Moderately decomposed Peat	15		
	Peat raw	10		
Very Fine	Heavy Clay, Silty heavy Clay, Sandy Clay, Clay, Silty Clay, Sandy	12	Well drained	D

B. Preparation of NDVI in drought analysis

Various forms of vegetation indices based on remote sensing data have been used to monitor vegetation that indirectly monitor drought, with the most widely adopted being the Normalized Difference Vegetation Index, NDVI. Kriegler, et al. [10] were the first to propose NDVI and it is calculated by ratioing the difference of the red band from the near-infrared (NIR). Because of close relationship between vegetation and available soil moisture, NDVI was widely used to evaluate drought condition by directly comparing it to precipitation or drought indices. It is indicated that NDVI not only assess the behavior of vegetation over time, it can monitor the rainfall and drought situation. The data used in compiling the NDVIs are closely related to the radiation absorbed and reflected by vegetation in the photosynthetic processes. That is, healthy vegetations highly reflect infrared, highly absorb blue and red while reflecting appreciable quantity of green light in the visible spectrum, thus signifying healthy vegetation. Stressed (drought affected) vegetation or less vegetated areas will show a reduced blue-red absorption as a result of stagnated photosynthesis. The NDVI (Fig. 6 A) of Western Highlands Province was generated from LANDSAT 8 using band 5 (NIR) and band 4 (R) in ArcGIS 10.0 with raster calculator using the following ratio; NDVI= (Band 5 – Band 4) / (Band 5 + Band 4).

C. Extraction of Land Surface Temperature for drought Analysis

The land surface temperature of target classes can be assessed by their spectral reflectance (signatures) through analyzing especially the infrared spectrum of the thermal domain. LST is in direct correlation to the moisture content of earth features. LST is often used with NDVI to identify stressed crops on a temporal basis to map out the proliferation of drought affected crops. Carlson et al [11] showed that the sensitivity of surface temperature to soil moisture variations differs for the leaf and surface soil around the plants, and tends to be much greater between areas of bare soil rather than across the leaves. This basic idea is the basis for determining the scatter space to monitor the soil moisture content. For this reason, soil moisture alone is a poor indicator of drought as the reflectance may depend on the soil texture, organic matter, angle of incidence or surface cover and surface reflectance. LST was calculated from LANDSAT 8 TIRS (using Band 10 and 11) in ArcGIS 10.0 with raster calculator using the following sets of formula;

1. Conversion of DN to Top of Atmosphere (TOA) Radiance (Spectral Radiance L λ);

Lλ = MLQCal + AL
Where Lλ = TOA spectral radiance (in Watt m-2 sr-1 µm-1)
ML = Band specific multiplicative rescaling faction from metadata
AL = Band specific additive rescaling faction from metadata
Qcal = Quantised and calibrated standard product pixel value (DN)

2. Conversion from spectral radiance to brightness temperature received by satellite using thermal constants provided in the satellite metadata file;

ln (K1 /Lλ + 1)

$$T = \left(\frac{K2}{In\left(\frac{K1}{L\lambda}+1\right)}\right) - 272.15$$

where T= Satellite brightness temperature (in Kelvin)
L_λ = TOA spectral radiance (in Watt m^{-2} sr^{-1} μm^{-1})
K_1 = Band specific thermal conversion constant from the metadata
K_2 = Band specific thermal conversion constant from the metadata

3. Finally, the land surface temperature is calculated;

T/1 + **W** * (T/ρ)*ln(e)
where **W** is the wavelength of emitted radiance (11.5µm) and ρ = h * c /s
where
ρ = Constant
h= planks constant ($6.626*10^{-34}$Js)
s = Boltzmann Constant ($1.38*10^{-23}$ J/K)
c = speed of light (2.99 *108 m/s)
e = the land surface emissivity which is calculated by (e = 0.004Pv + 0.986)
where **Pv** is the Vegetation proportion [**Pv**=(NDVI-NDVI_{min}) / (NDVI_{max} – NDVI_{min})

Finally, the LST was calculated showing thermal distribution of ground features including soil, water and built up areas and also the portion of radiance reflected from vegetation (Fig. 6 B).

D. Elevation demarcation and its significance in Drought Analysis

Within landform, 'altitude above mean sea level' has a direct bearing on the near-surface temperature with the change in concentration of green-house gases (GHG). That is, temperature is lowest in the higher altitude in the highlands of PNG as always, and gradually increases towards the low lying areas with concomitant increase in the concentration of GHG, making the escape of heat difficult from low lying areas (Fig. 4). Depending on their severity, the depleting rainfall and higher frost rate often lead to water shortages, crop losses and famine. These factors increase the vulnerability of the inhabitants to diseases, and the moisture stress in the vegetations make them more susceptible to bush fire. The main variations in temperature patterns that occurs within and between regions result from physiographic factors arising from differences in altitude, latitude, density of vegetations and the relative position within the PNG landmass especially the extent of maritime influences. Western Highlands constitutes some of the highest altitudes in PNG such as Mt Giluwe in the Giluwe rural district and Mount Hagen (Hagen District) which are both more than 4000 meters above msl, and also the Kubor range (Nebilyer rural) which is more than 3000 meters above msl. A substantial landmass in Western Highlands above 2200m is the main causes of frost and drought [12]. The terrain height of WHP was extracted and deduced from the WHP DEM data and reclassified to five continuous intervals. The result was again reclassified to five major altitude classes ranging from 272 meters to 4378 meters (Table III). It may be surmised from the preceding discussions that the severity of the frosts at high altitudes increases, but in the absence of temperature records, this is impossible to confirm (Fig. 6).

TABLE III: ALTITUDE AND TEMPERATURE OF WHP IN ACCORDANCE WITH PNGRIS DATABASE.

Altitude (Meters)	Minimum Temperature (Degree Celsius)	Maximum Temperature (Degree Celsius)
272-947	19 – 16	32 – 27
947-1473	16 – 12	27 – 23
1473-2374	12 – 9	23 – 19
2374-2971	9 – 7	19- 16
More than 2971	<7	<16

In Papua New Guinea, there is a strong correlation between elevation and temperature of areas above 500m (Table III). Annual maximum temperature decreases at a rate of 0.6270 C and annual minimum temperature decreases at a rate of 0.535 C0 per 100m rise respectively. Temperature varies from 260 C (790 F) to 280 C (820 F) throughout the year.

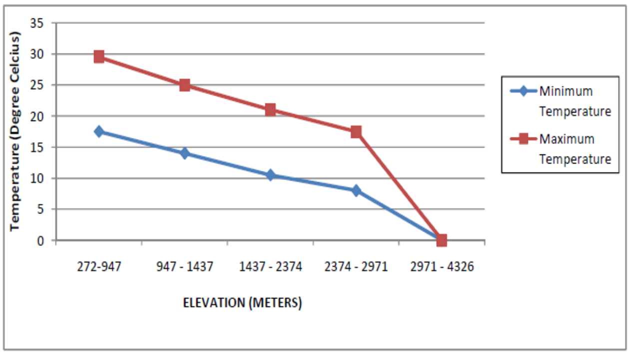


Fig. 4. The graph below exemplifies the variation and geophysical relationship of temperature and Elevation.

E. Precipitation (rainfall) analysis in drought assessment

Rainfall is an essential hydrological factor that the inhabitants mostly depend upon, for growing food and for other domestic chores. Thus, the reduced precipitation (rainfall) can create complex environmental, social and agricultural collapse. The mean annual rainfall of Western Highlands was derived from the PNG metadata (Fig. 5). The layer was further merged and reclassified to extract a minimum number of classes. The range of rainfall was averaged from the minimum and maximum at a particular point. The average value is the average yearly rainfall that is deduced for all points in the region (Fig. 6 D).

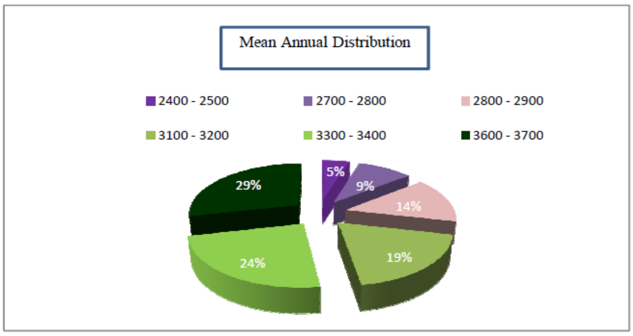


Fig. 5. Percentage distribution from the total mean annual rainfall

F. *Population Density in Drought Analysis*

Population density (Table IV) is categorized as a socio-economic factor that is considered after the onset of drought. The higher the population in an area, the higher the risk involved in terms of access to food and water. That is, the severity of drought can be assessed based on population and distribution of relief and health services to highly populated areas. The population of Western Highlands Province was extracted from the 2011 National Census data to give a concurrent weight that is parallel to the other factors analyzed. The geographical location of village points was superimposed on the density layer as shown in Fig. 6 C.

TABLE IV: POPULATION DISTRIBUTION OF STUDY AREA

Name	Area (Sq_Km)	Total population	Total Male	Total Female	Density
Dei Rural	766.9	49767	25338	24429	64.9
Baiyer Rural	919.4	20319	10293	10026	22.1
Lumusa Rural	166.9	5976	3180	2796	35.8
Mul rural	298.3	30391	15379	15012	101.9
Tambul	795.4	31617	15703	15914	39.7
Nebilyer rural	1004.7	29206	14800	14406	29.1
Mt hagen urban	9.8	27877	14974	12903	2844.6
Mt hagen rural	293	59074	29759	29315	194.8

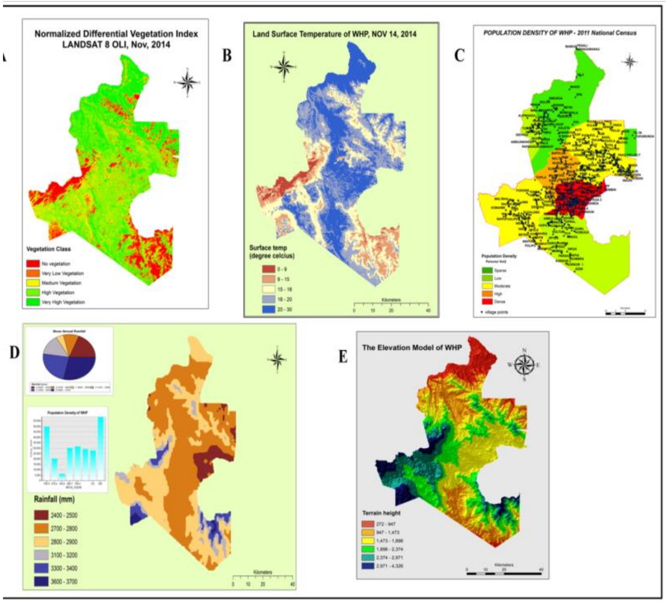


Fig. 6. Environmental factors integrated for Drought risk

G. *Assigning Ranks and Weights of each factor and corresponding classes*

Each layer was ranked according to their susceptibility to drought. The more significant factor was marked with the highest value and their corresponding classes were then given a weight according to criteria or conditions that stimulates drought.

TABLE V: WEIGHTED ANALYSIS OF THEMATIC LAYERS.

Factor	Classes	Rank	Weight	Remarks
Rainfall (mm)	2300 – 2500	6	6	A decline in rainfall stimulates dry condition which results in inadequate supply of water for plant growth. Thus, the highest weight (6) was assigned to that group out of the highest number of class that were overlaid and analyzed.
	2500 – 2800		5	
	2800 – 3100		4	
	3100 – 3300		3	
	3300 – 3600		2	
	3600 – 3900		1	
HSG	0.3 – 0.5	5	1	There are four main hydrologic soil groups (A, B, C and D). Group D has the lowest infiltration rate (0 – 0.05inch/hr) which means less water absorbed in root zone. As such, this soil group is more prone to drought and given a weight of 6.
	0.15 – 0.3		3	
	0.05 – 0.3		5	
	0 – 0.05		6	
LST (Co)	0 – 9	4	1	High radiation from land surface features means less water content, stress in vegetation and minimum vegetation cover to absorb infrared radiation as detected from TIRS.
	9 – 15		2	
	15 – 18		4	
	18 – 20		5	
	20 – 30		6	
NDVI	No vegetation	3	6	A reduction in vegetation over time or less vegetated areas (bare soil, rocks) is an indication of the onset of drought effects. Hence, The first class (no vegetation) was assigned the highest weight.
	Low vegetation		4	
	Moderate vegetation		3	
	High Vegetation		1	
Elevation (mts)	272-947	6	1	Most areas at higher altitudes are more prone to drought. The higher the elevation, there is an number of frost days in parts of the Highlands above 2,200 meters (UNEP)
	947-1473		2	
	1473-2374		3	
	2374-2971		5	

	More than 2971		6	
Pop. Density (Sq/km)	Sparse	1	1	The densely populated class is given the higher rank (6). That is, the higher the population, the higher is the demand for water with concomitant risk in terms of food and water shortage.
	Low		2	
	Moderate		4	
	High		5	
	Dense		6	

H. Analysis in ArcGIS using MCE – The Weighted Overlay Method

Weighted overlay is a study that analyzes factors based on multiple criteria. The purpose of this technique is to identify suitable conditions or susceptibility in a certain area (Table V). The application of this technique also gives decision makers the necessary information (risk and constraints) about a particular area of interest. As such, the final drought susceptibility mapping was performed in ArcGIS using the spatial analysis tools. All parameters were assigned a weight based on how influential they are in triggering drought conditions. As above, the rainfall was given a weight of 6 out of six classes. Furthermore, the class of rainfall (lowest) in the range of 2300 – 2500mm was also given the highest weight (6) by assuming that lower the rainfall, higher the drought risk potentiality. Using spatial analysis tools in ArcGIS 10.2, all classes assigned in each factor were ranked according to certain criteria and characteristics. Each factor was given a scaling in percentage on the basis of referential refinement. That is, each layer was assigned percentage according to their contribution in drought. For instance, rainfall was assigned 30% weight because it is a primary factor that determines drought conditions.

I. Extraction of Final drought risk zones

After overlaying all layers in ArcGIS, the final susceptibility map (Fig. 7) was obtained with corresponding drought hazard index outlining the degree of risk as shown in Table VI and Fig. 8 below. Firstly, the drought hazard index was calculated, followed by assessing and reclassing the index where drought risk classes (low, medium and high) were demarcated.

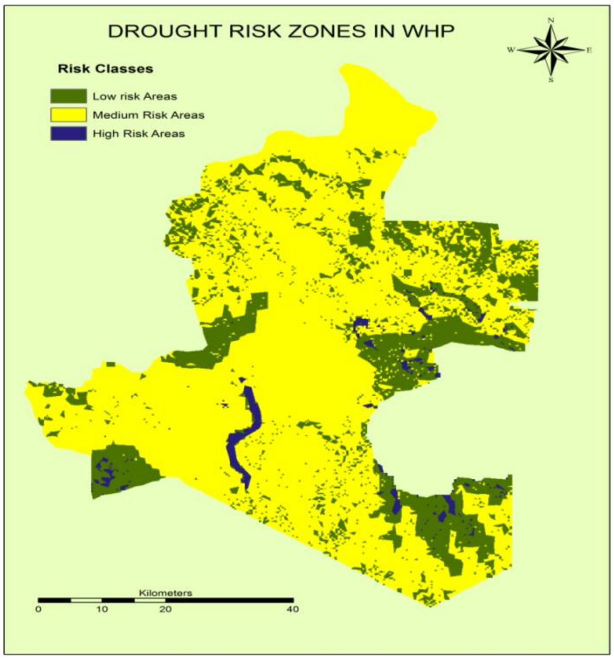


Fig. 7. Final susceptibility map of drought potential zones in WHP.

J. Calculating area of risk zones

From the final risk zonation, the total area risk for each class was calculated through conversion and merging of similar attributes. Hence, the total area in square kilometers was deduced by using geometric calculator and the area in percentage was calculated manually from the total land area.

TABLE VI: FINAL ZONATION AND AREA CALCULATION OF DROUGHT SUSCEPTIBILITY ZONES IN WHP

Drought Hazard Index (DHI)	Drought risk Classes	Area (Sq _Km)	Area in % (Percentage)
2	Low risk Zones	988	23.3
3	Medium Risk Zones	3167	74.7
5	High risk Zones	81	2

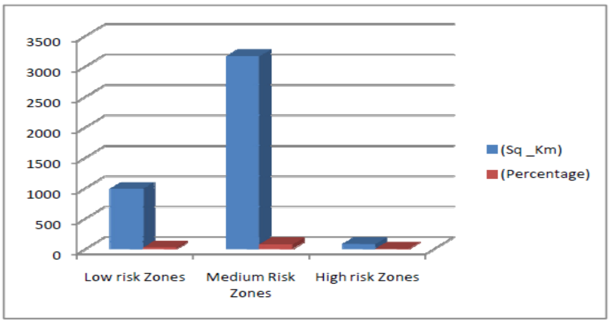


Fig. 8. Percentage and overall area of risk levels (classes).

K. Assessment of Built-up infrastructures on Drought risk zones

The effects of drought often vary from one location to another and depends on the status and accessibility to government services. A village experiencing the effects of a severe drought can have access to relief supplies in an adequate amount, and can also be medically treated for drought related diseases given the availability of health services. Thus, the risk can be contained regardless of the severity and duration of drought. Likewise, a village experiencing less or moderate effect can be classified as a high risk area if such expanse is highly populated with little access to health services and no road links for evacuation on time. From the final risk classification, a further analysis on infrastructures over the risk areas was analysed. Infrastructures include village points, bridge and roads and education and health services. This is an attempt to visualize the collateral implications that warrant analysis of basic services and accessibility by major roads.

L. Road links to village points

Road network is a very important aspect of development, especially in the rural areas. The rural populace is often left neglected during times of drought and other natural events. Careful distribution and construction of road is vital in enabling the accessibility to government services by the rural people in times of drought. The access to village points by road was analyzed to identify risk-prone areas shown in

Fig.9 is the current road network and village locations in the province.

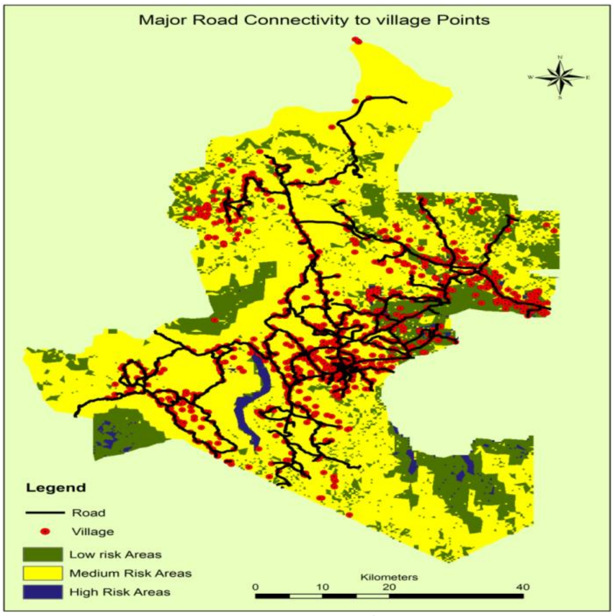


Fig. 9. Road links to geographical location of village points over risk areas

M. *Analyzing infrastructures over risk areas*

Establishments of infrastructures and services such as bridge, School and health centers are key aspects of development for the people. These features are important in delineating risk areas during the onset of natural disasters like drought. Thus, the distribution of schools, health services and bridges were superimposed over the risk areas to assess the level of vulnerability with respect to their location and distribution over risk areas see Fig.10 and Table VII.

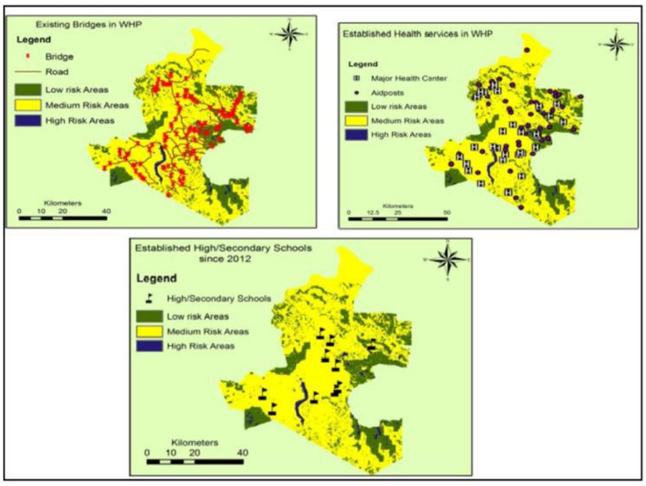


Fig. 10. Assessment of Infrastructure and built up areas over risk zones.

N. *Assessment of Basic Infrastructure on risk areas*

TABLE VII: COUNT OF BUILT-UP INFRASTRUCTURES ON RISK ZONES

WHP Infrastructure	Levels of risk areas		
	L	M	H
Health Services (count)	27	32	7
Bridges (count)	21	70	7
Schools (Count)	88	11	10
TOTALS	136	113	24

O. *Percentage (%) evaluation of Built-up infrastructure on risk zones*

The results were further analyzed to isolate the distribution of each utility on risk areas. This analysis identifies the percentage of vulnerability on respective risk areas. Hence, from the Table VIII about 81% of all schools in Western Highlands Province are located on low risk areas, 9% medium and 10% on high risk zones. The 10% on high risk areas must be monitored and assisted during drought conditions. Also, 11% of the overall health services are found on the high risk zones. This is a major concern and requires authorities to build more hospitals in these settings. Furthermore, the establishment of bridges in high risk areas comprises 9% of the total. This can also have an impact on villages intending to access government services apart from crossing rivers and using bush tracks.

TABLE VIII: PERCENTAGE BUILT UP INFRASTRUCTURE OVER LEVELS OF RISK ZONES

Risk Classes (Levels)	Built up Infrastructure in WHP (%)		
	Schools	Health Services	Bridge
Low risk	81	41	21
Medium risk	9	48	70
High risk	10	11	9

IV. CONCLUSION AND RECOMMENDATION

The Multi criteria approach has been proven to be an integrated concept that can be used to analyze natural hazards or proving hypothesis based on some criteria. The overlaying concept incorporates all parameters that may in one way or the other, contribute to a problem. Thus, the LST, NDVI, elevation data, rainfall and soil moisture content (HSG) are useful parameters in delineating drought risk zones. Equally important is the population density of a particular area. That is, most findings reveal that the severity of drought in certain locations of Western Highlands Province. Thus, those reports have highlighted additional areas that are to be monitored during the onset of drought. Also, the identification of infrastructures on risk areas is important in prioritizing drought risk areas. From the results, it can be seen that there are fewer public utilities (11% health services and 9% bridges) located in high risk areas acting as the positive feedback mechanism in worsening the malady of drought. Hence, such studies can help government, decision makers and concerned organizations to plan and prepare mitigation strategies through awareness and appropriation of development funding.

The major limitations were the time and unavailability of temporal remote sensing data and meteorological data. However, the approach used in this study can be used with the available data to monitor drought effects and severity and highlight areas that are prone to drought associated effects. However, this report is a pilot project which guides researchers and decision makers to achieve a better understanding on the topic for further research and clarification purposes.

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