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USING GEOSPATIAL ANALYTICS TO FIND PROSPECTIVE LOCATIONS FOR WATER HARVESTING IN NORTHERN GHANA

UNDERGRADUATE THESIS

B.Sc. Computer Science

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UNDERGRADUATE THESIS

Undergraduate Thesis submitted to the Department of Computer Science, Ashesi University College in partial fulfilment of the requirements for the award of Bachelor of Science degree in Computer Science.

Naa Lamle Boye

2020

DECLARATION

I hereby declare that this Undergraduate Thesis is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature:

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Candidate's Name:

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Date:

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I hereby declare that preparation and presentation of this Undergraduate Thesis were supervised in accordance with the guidelines on supervision of Thesis laid down by Ashesi University.

Supervisor's Signature:

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Supervisor's Name:

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Date:

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Abstract

Access to potable water is a difficulty for about a quarter of the world's population. The people living in the northern regions of Ghana, which have arid to semi-arid vegetation cover, form a significantly large percentage of that number in Ghana. Rainwater harvesting has been found to be an appropriate measure to mitigate the effects of water shortages, but its practice has also been fraught with various challenges. Advancing technology has encouraged much research into the best ways to optimise water catchment and distribution in Ghana, but little documented evidence exists on the application of Geographic Information Systems and Remote Sensing. This study investigates the potential of geospatial analytics in selecting suitable locations to channel resources for optimised rainwater harvesting. Adopting a Multi-Criteria Overlay Analysis model, suitability maps were created to be used as a visualisation tool for the classification of places as suitable or not.

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Chapter 1: Introduction

1.1 Importance of Water

Water is one of the most important substances on earth. Humans drink water and use it for cleaning, cooking and irrigation of plants. Water is indispensable to life, and should be available to all. However, the United Nations Educational, Scientific, and Cultural Organization (UNESCO) reports that 2.1 billion people lack access to safe water in their homes, and this creates challenges such as poor health, unemployment, conflicts and displacement leading to migration [20]. UNESCO also finds that people living in poverty, slum dwellers, and people living in isolated areas are less likely to receive water, sanitation and hygiene services. If they do get access, it is usually expensive [20].

Climate change aggravates this situation. Global warming is drying up water bodies and negatively affecting rainfall patterns, rainfall levels and rainwater quality. The World Health Organization (WHO) estimates that by the year 2025, half of the world will be living in water-stressed areas [16] - where the demand for water exceeds supply, or the quality of available water is low. The United Nations' sixth Sustainable Development Goal (SDG) deals with ensuring availability and sustainable management of water and sanitation for all. As at 2015, 844 million people in the world lacked basic drinking water service, 263 million people spent more than 30 minutes to gain access to potable water and 159 million people obtained their drinking water from surface water sources, out of which a little over half were from sub-Saharan Africa [21]. To achieve SDG 6, societies need to explore cheaper methods of obtaining, providing and storing potable water which can reach every individual and last towards the future.

1.2 Problems Ghana Faces Regarding Water Supply

Ghana suffers from shortages in drinking water. Eleven percent of Ghana's population drinks unclean water from surface water sources [8]. Fifty percent of people in the Northern Region are using unimproved sources of drinking water, higher than the average for the African continent, where overall, forty percent of the population uses these unimproved sources [5]. Recent efforts to augment the water supply in Ghana has been primarily focused on borehole installation [15], where water is sourced from underground. Now, attention is being shifted towards harvesting rainwater as an alternative potable water source.

Rainwater harvesting (RWH) is carried out to store rainwater for re-purposing. The process is carried out in a variety of scales, from households using buckets to collect water streaming down from the roof, to entire cities laying expensive pipework and complex storage facilities to store runoff water [10]. While rainwater harvesting is carried out across the country, it is not widespread. Storage of rainwater is often found to be a financial burden because of the costs involved in building and maintaining tanks [5]. Water quality is not satisfactory [4, 17], and the filters needed to improve this are expensive as well [2, 5]. Other issues include unsuitable materials used for storage, unreliable and uneven rainfall patterns, living in rented homes which restricts how much storage a person can have, and land disputes resulting in confusion over where storage facilities can be situated [2].

1.3 Proposed Solution

It has been determined that a lot of rainwater is wasted during harvesting in Ghana because the storage tanks being used are inappropriately sized. The water runs off, and this could have been saved towards dry spells. The recommendation is to use larger underground tanks or tanks on raised platforms [2]. These underground tanks are best sited in areas which have "[l]atrite soils with low rooting depths" [5], indicating that the geology and soil conditions of an area are important in the considerations for situating water storage tanks. Besides these, the amount of rainfall, the ability of the community to afford building and maintaining storage tanks and environmental conditions which may affect the quality of water need to be thought through.

Geospatial analytics, the manipulation of geographic information systems data, has been explored as a tool for optimising the selection of the best places to harvest rainwater. It has been experimented with in various countries and found to be a satisfactory technology in performing this task. Experiments on this have been carried out with varying success in districts in India and Iraq, and it is expected that the decision-making models used would work similarly for Ghana. This assumption is based on the similarity of the socio-economic and environmental climates of these countries. All three countries are developing countries [7] and in semi-arid regions (places which receive low rainfall but are not as dry as deserts) [3]. This study will investigate the feasibility of using geospatial analytics on satellite imagery to identify candidate locations for setting up rainwater harvesting tanks in rural areas in Ghana. Feasibility is assessed by the availability of data and tools to build a GIS-based decision-making model, and whether the results can be used to segregate regions in terms of their suitability for rainwater harvesting.

1.4 Results of This Study

In this experiment, the most optimum locations for rainwater harvesting were near a river. This result suggests that resources towards rainwater harvesting should be situated near large water bodies. However, there are several criteria which influence the choice of an optimal location, and many of these were not included in this study. Also, little data is available to validate these findings, but it was determined that geospatial analysis offers promising potential as a means to optimally select locations for rainwater harvesting in the country.

Chapter 2: Related Work

2.1 Benefits of Rainwater Harvesting

Rainwater is advantageous in many ways. Khoury-Nolde writes that it is a free source of water and potable if well-treated [10]. Harvesting rainwater is helpful to the environment by reducing soil erosion, and may lessen the severity of floods by reducing pressure on sewers [10]. The harvested water can be used for irrigation, cleaning, toilet flushing and drinking (if treated), which can amount to as much as fifty percent savings in household water consumption [10]. Rainwater harvesting has been found to be a viable source for sustainable water supply in rural areas in Ghana [15], thus should be considered as a way to economise water resources.

2.2 Factors to Consider for Rainwater Harvesting

Khoury-Nolde [10] finds that the factors to be considered in selecting appropriate rainwater harvesting technologies can be put in two categories. For domestic use, the factors for consideration are:

1. the type and size of catchment area (where the rainwater will be collected)
2. local rainfall and weather patterns
3. family size
4. length of the drought period (when there is low to no water supply)
5. alternative water sources and
6. the cost of the rainwater harvesting system.

If rainwater is being harvested purely for irrigation purposes, what should be taken into account are:

1. rainfall amounts, intensities and evapo-transpiration rates (the rate of earth surface and water body evaporation and plant transpiration into the atmosphere)

2. soil infiltration rate (the ability of soil to absorb water), water holding capacity, soil depth and fertility

3. crop characteristics such as water requirements and length of growing period

4. hydrogeology (the branch of geology concerned with water occurring underground or on the surface of the earth) of the site and

5. population density, labour, costs of materials, regulations governing water resources use.

2.3 Criteria and Methods for Selecting Optimum Sites for Rainwater Harvesting

For their research in India, Gupta et al. identified catchment as the most important factor in rainwater harvesting [9]. The authors recognise the huge costs associated with building rainwater harvesting tanks, and so create a model which identifies prospective locations to situate them. Using Geospatial Analytics on Remote Sensing (RS)[1] and Graphical Imaging System (GIS)[2] data, they implement an Analytic Hierarchy Process (AHP) which transforms the spatial data into decisions. This is a GIS-based Multi Criteria Decision Making (MCDM) model. They also make use of convex hull and sliding window algorithms to geocode the data. They note that rainfall and elevation are the most important factors, with an optimum site having average to high rainfall and elevation which does not allow for water runoff. However, they take into account the nearness of the prospective site to factories or mines (pollutants), socio-economic status of the location, landcover (normalized difference vegetation index - NDVI) and soil (normalized difference water index - NDWI). They successfully identify areas which can be used for water harvesting using a scoring system.

Similarly, Faez Buraihi and Abdul Shariff [6] use RS and GIS techniques to select rainwater harvesting sites in Iraq. They use a multi criteria decision analysis (MCDA) method, and consider the runoff depth (which was calculated using a curve number (CN)), slope, drainage, and land cover or land usage of candidate sites. Three classifications were used - high suitability zone, moderate suitability zone and low suitability zone. They found

[1] RS refers to the process of capturing earth information by satellites

[2] GIS are computer-based systems for capturing, managing and analysing spatial and geographic data

that an integration of RS, GIS and MCDA provided a low-cost, eco-friendly solution to the problem of finding suitable RWH locations. The researchers propose the use of thematic layers using ArcGIS and ENVI software.

Other factors which have been considered are proximity to irrigation and drinking water supply zones, soil porosity and permeability [19, 18]. One study on finding suitable locations for RWH used RS together with a GIS-based Decision Support System (DSS) [12], another used DSS, RS and field surveys [13], while another used GIS, Multi Criteria Evaluation (MCE) and the AHP [14]. Adham et al. argue that any successful rainwater harvesting system should be well-designed and well-situated, while admitting that this task is a challenging one [1].

There are different approaches to solving this problem. This study will make use of the Analytic Hierarchy Process with Multi Criteria Decision Making (implemented as Multi Criteria Overlay Analysis) as proposed by [9] and [14].

Chapter 3: Methodology

3.1 Tools and Data

QGIS software was the main tool used in this study. Data used were a Landsat-8 scene dataset and Digital Elevation Model (DEM) files, which were obtained from the United States Geological Survey (USGS) Global Visualization Viewer (GloVis). The northern belt of Ghana was the focus of this research. The areas used for this study span the Northern, Savanna and Oti Regions of Ghana. Table 3.1 shows the latitude and longitude coordinates of the region under consideration using the WGS84 datum.

Table 3.1: Coordinates of area under study

Point	Latitude	Longitude
Upper Left Corner	9°43’17.72”N	1°33’53.96”W
Upper Right Corner	9°21’41.54”N	0°07’45.34”E
Lower Left Corner	7°59’10.82”N	1°56’07.98”W
Lower Right Corner	7°37’24.82”N	0°14’57.55”W

3.1.1 Tools

QGIS, a geographic information systems software, was used for map visualisation, calculation of NDVI and NDWI, pansharpening of images, merging and clipping the digital elevation model, generating histograms of data and performing suitability analysis. QGIS is capable of performing multi-criteria weighted-overlay analysis, which mirrors traditional multi criteria decision making models.

3.1.2 Data

All analyses were done with raster data. A raster is a matrix of pixels in a grid where each cell contains information on features of the area under consideration. Raster data are continuous and typically used as basemaps for other layers and surface maps. Types of raster data include aerial photographs and satellite images. For this study, Landsat-8 satellite images were used as raster data.

Landsat-8 is a satellite launched by NASA (National Aeronautics and Space Administration) and the USGS. Images from the Lansdsat-8 satellite were downloaded from the USGS GloVis website. The dataset is composed of scenes which contain eleven bands of different electromagnetic frequencies. Each frequency is captured by unique sensors which detect different colours. Bands 2, 3 and 4, which are the red, blue and green sensors of the satellite, when combined produce a true colour RGB composite image *(figure 3.1)*. The cubic convolution algorithm was used in creating this RGB image. The RGB image has a 30m resolution. The image was then pansharpened using Band 8 (panchromatic band) which has a 15m resolution *(figure 3.3)*. Pansharpening creates a higher resolution image.

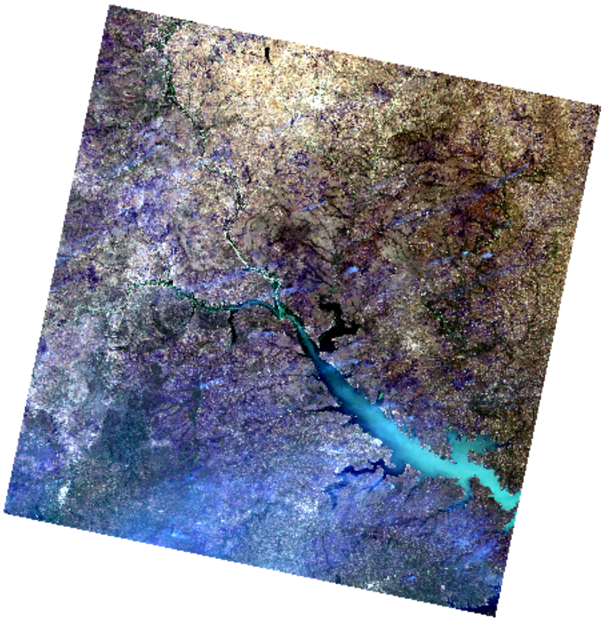


Figure 3.1: RGB composite image - composed from Landsat 8 bands 2, 3 and 4

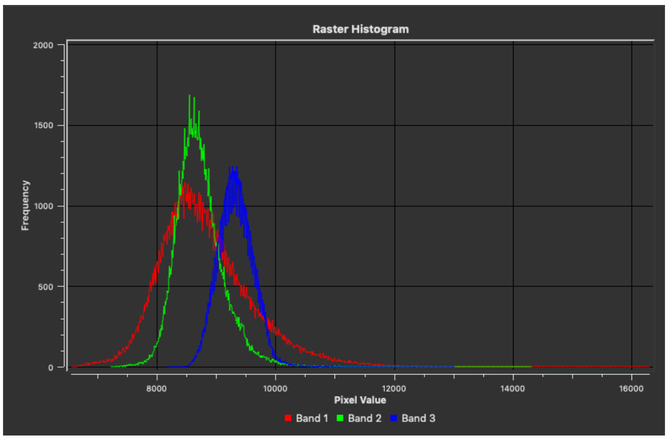


Figure 3.2: Histogram of RGB composite image

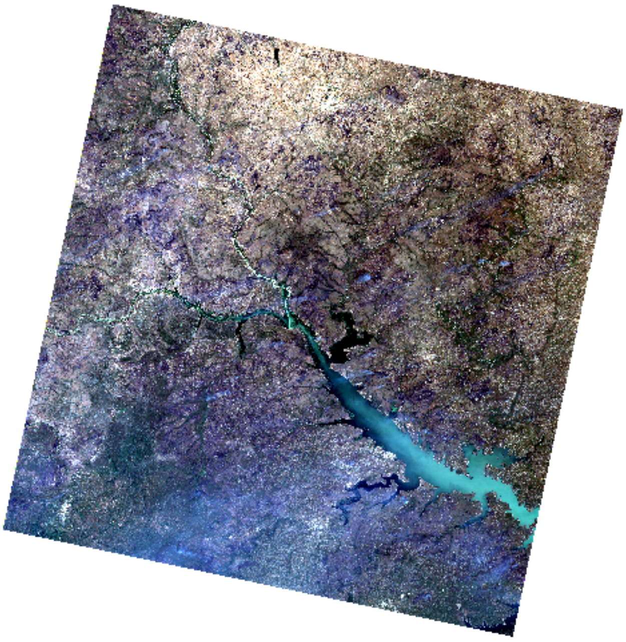


Figure 3.3: Pansharpened image

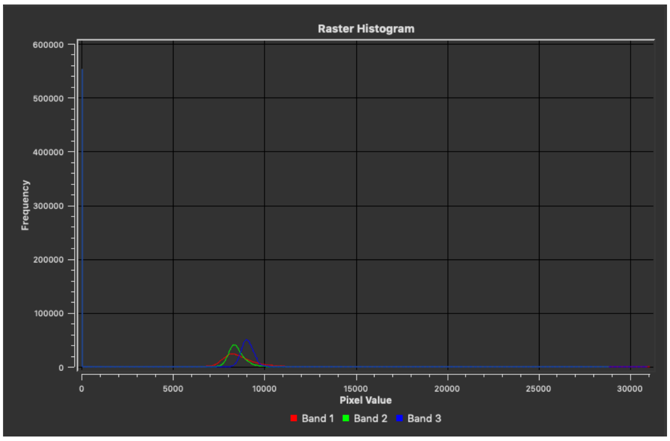


Figure 3.4: Histogram of pansharpened image

The DEM data was of type SRTM (Shuttle Radar Topography Mission) Void-Filled. This was also downloaded from the USGS GloVis Website for the same coordinate boundary. SRTM DEM satellite imagery was selected over other DEM data types because it has been enhanced to fill areas of missing data to provide more complete digital elevation data. One DEM raster did not cover the entire region under study, so nine separate ones were downloaded, then merged and clipped to the right boundary with QGIS.

3.2 Data Processing and Classification

To determine whether a location is suitable for RWH, it was scored using a Multi Criteria Decision Making model. The primary factors under consideration are the soil type and rainfall levels of the catchment area, because this study prioritises the possibility of building underground storage tanks. NDWI is heavily weighted because it is an index of the soils and hydrology of an area. Optimum locations are selected based on their score, with the highest scores representing the most suitable locations.

However, an Analytic Hierarchy Process (AHP) is still needed to determine weights and priority for each criterion. For the AHP which produces the output, steps are:

1. Structure problem in a hierarchy, as seen in figure 3.5.

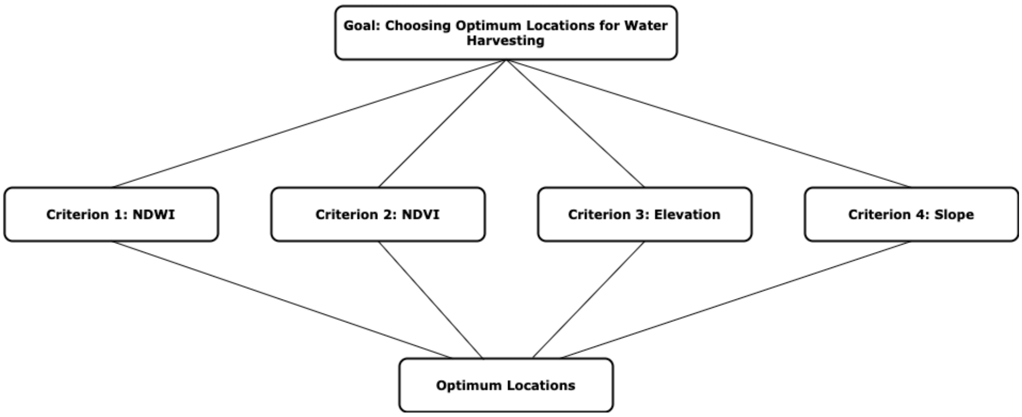


Figure 3.5: Analytical process flow

2. Gather data
3. Normalize data
4. Perform a pairwise comparison of the criteria and determine priorities
5. Select optimum locations based on scores
6. Validate results

The criteria for the Multi Criteria Overlay Analysis are:

1. NDWI

2. NDVI

3. Elevation

4. Slope

3.3 Evaluation of Criteria

NDWI, the normalized difference water index, is a ratio derived from Near-Infrared (NIR) and Short Wave Infrared (SWIR) bands. In Landsat-8, these are bands 5 and 6 respectively. High NDWI values indicate a high vegetation (or leaf) water content, and lower values indicate low vegetation water content. Values range from -1 to 1, with 1 being highest water content and -1 indicating no water content. The index is suitable for indicating vegetation water content which gives an idea about the moisture conditions of an area. NDWI is calculated as seen in equation 1.

$$NDWI_t = \frac{NIR_t - SWIR_t}{NIR_t + SWIR_t} \tag{1}$$

Figure 3.6 shows the generated NDWI image of the region under consideration. Visual analysis indicates that the majority of NDWI values for this area are approximately between -0.5 and 0.5. The histogram in Figure 7 shows that the values range from -0.3 to 0.2, with the modal NDWI value being -0.2. The assumption which can be made from this is that the region does not have very high vegetative moisture.

Figure 3.9 shows the generated NDVI image. This is the Normalized Difference Vegetation Index, which is used to sense the presence of vegetation by computing an index using the difference between Near Infrared (NIR) (which is reflected by vegetation), and Red Band or Red Light Reflectance (Red) (which is absorbed by vegetation). These correspond to bands 5 and 4 respectively in the Landsat-8 data. Also ranging from -1 to 1, where values close to -1 indicate lack of vegetation and higher likelihood of water, and values close to 1 indicate high presence of vegetation. An NDVI close to 0 could indicate nearly no vegetation, so it is a good indicator of urbanization. NDVI is also used to identify areas susceptible to or already experiencing drought. NDVI is calculated as seen in equation 2.

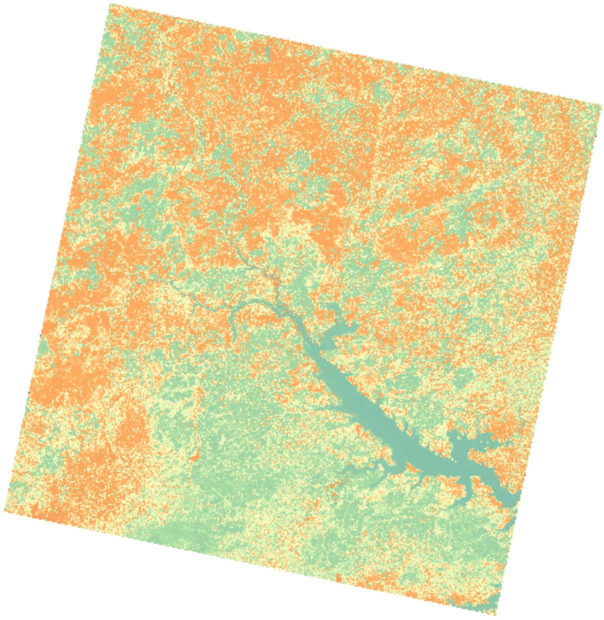


Figure 3.6: NDWI

Figure 3.7: NDWI image legend

$$NDVI = \frac{NIR - Red}{NIR + Red} \tag{2}$$

For water harvesting, elevation should be as low as possible so that water can run off from more mountainous areas down to the valleys. The mean elevation in the region under study was 149.6 meters, with the majority of values between 100 and 200 meters. The highest point in the region was 531 meters. Figures 3.12 and 3.14 show the elevation of the area.

Water harvesting is not recommended for areas with a gradient five percent or more.

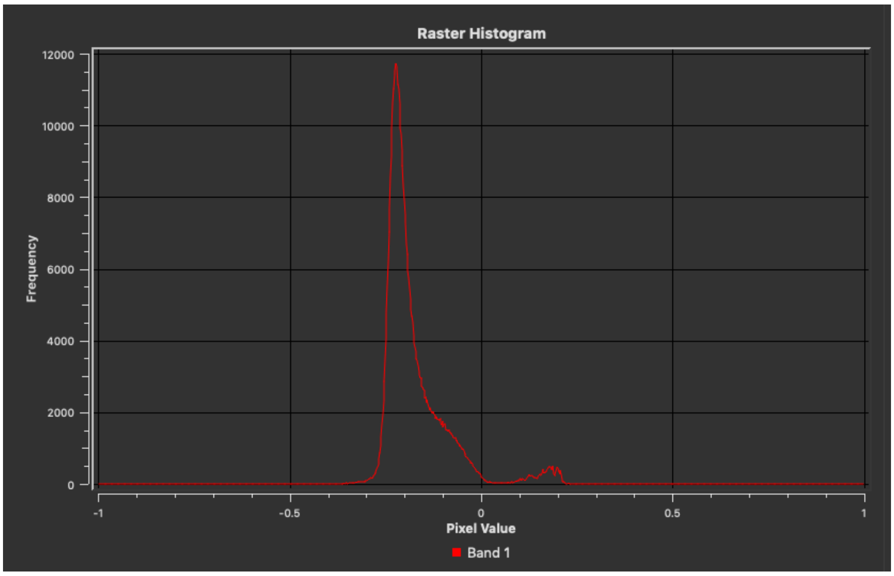


Figure 3.8: Histogram of NDWI values

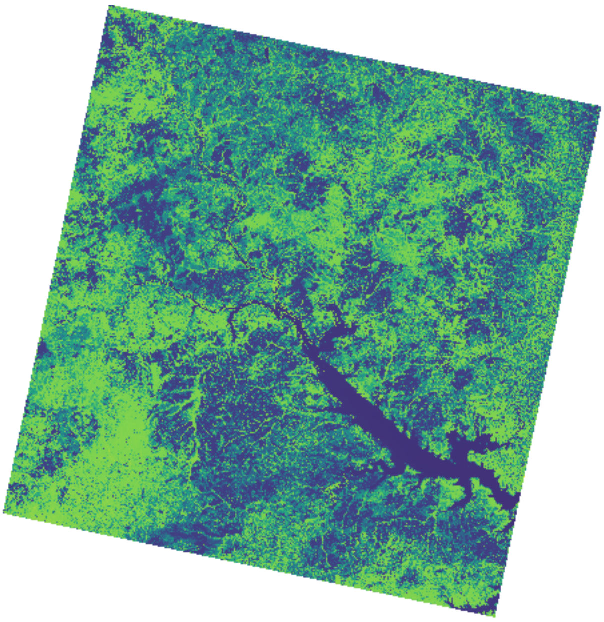
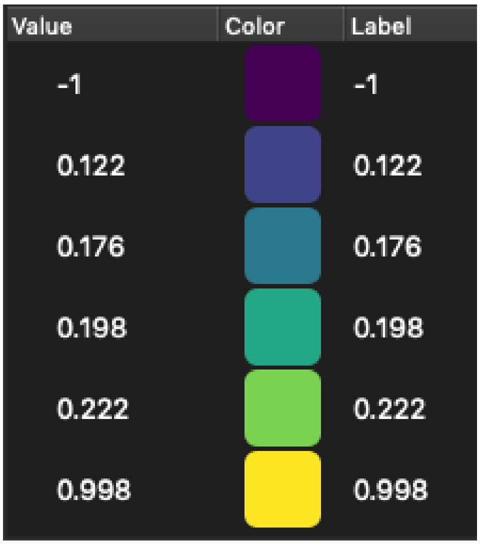


Figure 3.9: NDVI

It is an important criterion in selecting a location because it influences water runoff, speed of water flow and the amount of material needed to construct water catchment facilities such as dams. For this study, all areas with slope less than five percent were considered as optimal *(figure 3.15)*.



Value	Color	Label
-1		-1
0.122		0.122
0.176		0.176
0.198		0.198
0.222		0.222
0.998		0.998

Figure 3.10: NDVI image legend

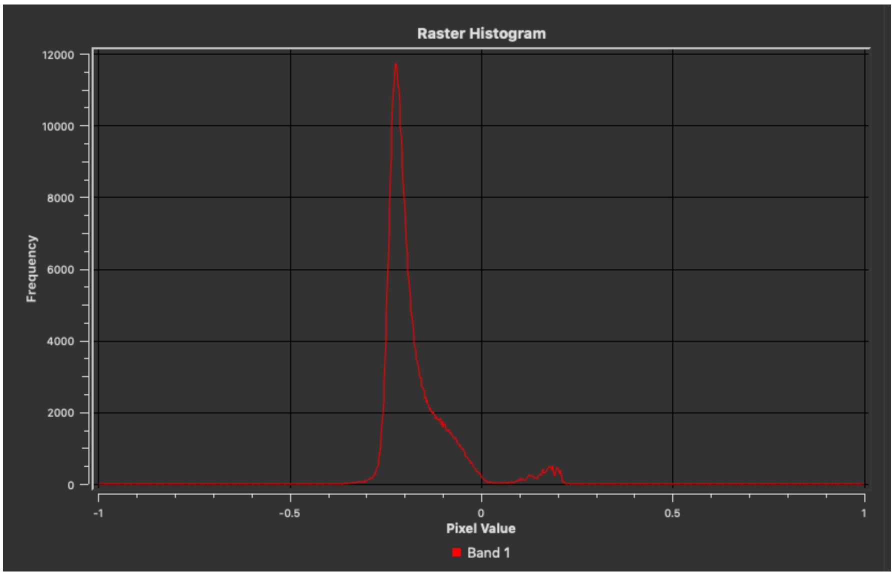


Figure 3.11: Histogram of NDVI values

3.4 Pairwise Comparison of Criteria

Elevation and slope have been found to be of highest importance in determining placement of water tanks. Elevation and slope were valued at an equal importance, but both were of higher importance than NDWI and NDVI. NDWI was ranked as being of slightly higher importance than NDVI. Based on literature review, the priority of criteria was determined as seen in tables 3.2, 3.3 and 3.4.

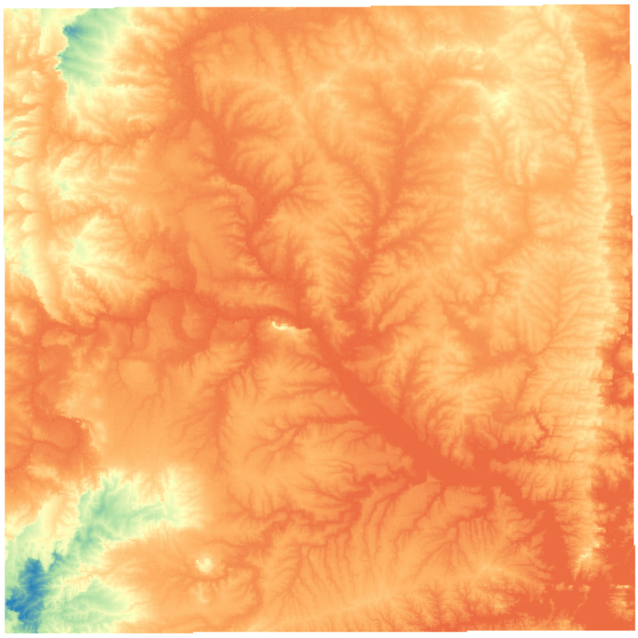


Figure 3.12: Digital elevation model

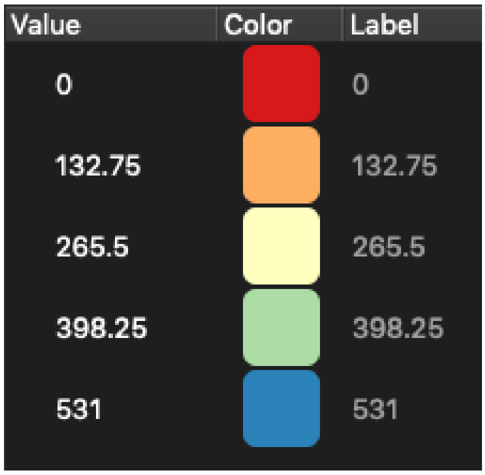


Figure 3.13: Digital elevation model image legend

Table 3.2: AHP scoring scale

Score	Interpretation
1	Equally important
3	Slightly more important
5	Strongly more important
7	Very strongly more important
9	Absolutely more important

3.5 Creating Suitability Map

This analysis shows that elevation will be weighted as most important, then slope, then NDWI and NDVI respectively. The preference for a rainwater harvesting site is one

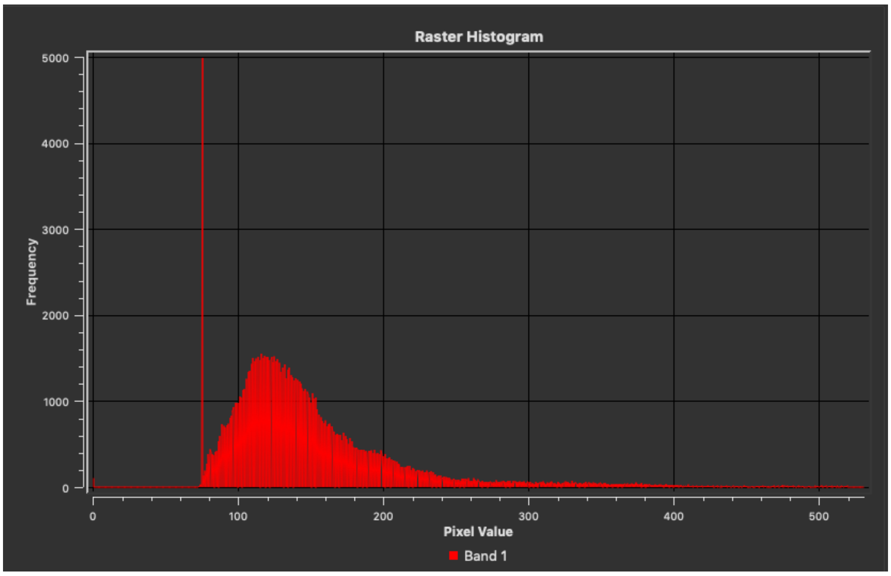


Figure 3.14: Histogram of elevation values

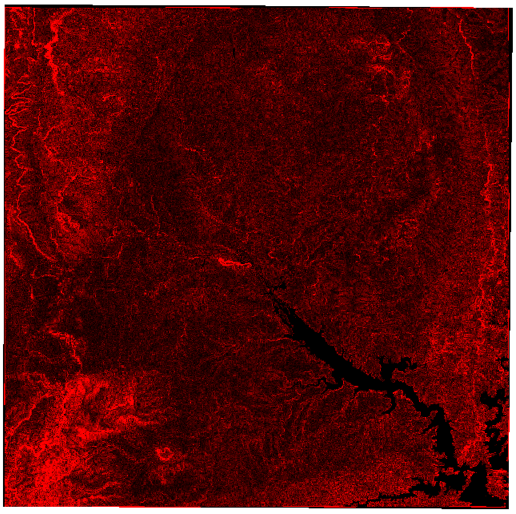


Figure 3.15: Slope

Table 3.3: Pair-wise comparison of criteria

	NDWI	NDVI	Elevation	Slope
NDWI	1.00	3.00	0.14	0.20
NDVI	0.33	1.00	0.11	0.14
Elevation	7.00	9.00	1.00	3.00
Slope	5.00	7.00	0.33	1.00

with low elevation, near-flat slope, medium range NDWI and high NDVI. Using the priority weights determined after pairwise comparison, separate rasters were calculated for:

1. Low elevation: This was determined as elevation values which fell below the twentieth

Table 3.4: Determining priority vectors (Weights)

	NDWI	NDVI	Elevation	Slope	Priority Vector	Rank
NDWI	0.08	0.15	0.09	0.05	0.09	3
NDVI	0.03	0.05	0.07	0.03	0.04	4
Elevation	0.53	0.45	0.63	0.69	0.57	1
Slope	0.38	0.35	0.21	0.23	0.29	2

percentile of elevation values [3]. These were all areas with elevation <106m.

2. Near-flat slope: The best slope for water catchment has been found to be those with less than five percent gradient. A new raster layer was calculated for all areas with slope <5%.

3. Medium range NDWI: Previous studies suggest a medium range NDWI is best for water catchment rather than high or low values. Values used as medium range were all NDWI values $\geq$ -0.02 and $\leq$ 0.02.

4. High NDVI: Higher NDVI values indicate optimality for water catchment. All NDVI values above the ninety-fifth percentile were determined as "high" and separate raster calculated. These were all NDVI values >0.249.

Suitability maps were then generated by summing the products of the weights and criteria which had been subset to the new rasters.

[3] Percentile values were calculated with the Python console plugin in QGIS.

Chapter 4: Results

4.1 Suitability Analysis and Discussion

The suitability maps generated (figures 4.1 and 4.3) showed that, in the region under consideration, areas bordering the Volta River were most suitable for rainwater harvesting.

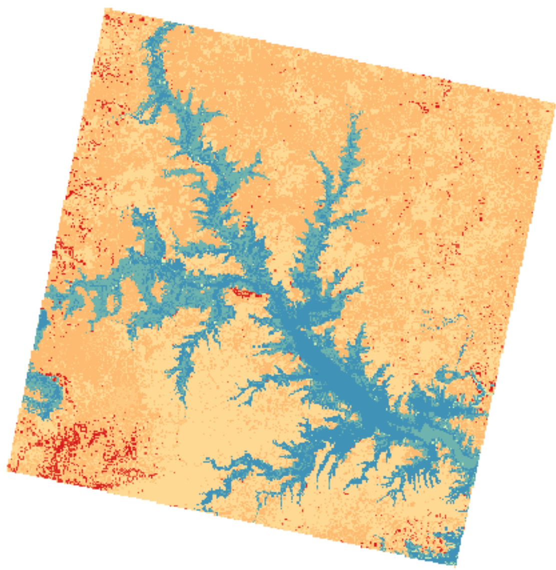


Figure 4.1: Suitability map with values in equal intervals

Figure 4.2: Legend for equal interval suitability map

Very few regions were found to be not suitable at all for rainwater harvesting. Suitability analysis using equal intervals (figure 4.1) shows most areas as being just suitable

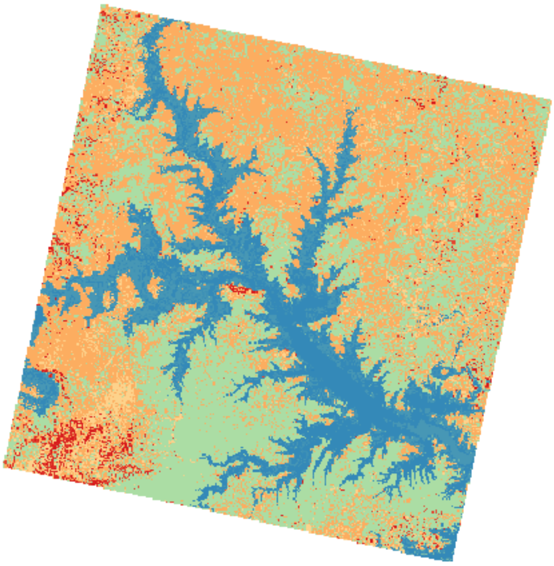


Figure 4.3: Suitability map with values in quantiles

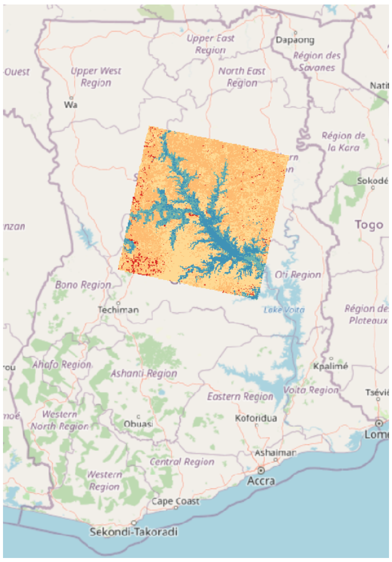


Figure 4.4: Suitability map (with values in quantiles) scaled to show its position in the country

enough or least suitable, and these are those further away from the Volta River. Using quantiles (figure 4.3), more regions a bit further away from the Volta River were found to be good enough or very suitable for rainwater harvesting, though not necessarily the best. In both cases, the areas showing non-suitability were few, scattered and closer to the bottom left border of the region being studied.

Figure 4.5: Legend for quantile values suitability map

4.2 Results Validation

There is limited data on existing rainwater harvesting sites in Ghana [11], causing difficulty in validating the results of the experiment. In an attempt to validate these results, the locations used by D.A. Barnes in his study, ”Assessment on Rainwater Harvesting in Northern Ghana” [5], were used to identify places where rainwater harvesting was already being practised. The limitation of this data is that it was curated in 2009, which means this data may be outdated. This was made apparent when it was noticed that some of the places assessed had relocated. Barnes made an assessment of nine locations, six of which were community sites and three household sites.

1. Community sites
   (a) World Vision Ghana Rural Water Supply Office (5.5884704,-0.2317862)
   (b) Pong Tamale Health Clinic (9.066667, 0.833333)
   (c) Pong Tamale Vocational School Boys Correctional Center (9.066667, 0.833333)
   (d) Pong Tamale Health Center (9.066667, 0.833333)
   (e) Savelugu Hospital (9.616667, 0.833333)
   (f) Veterinary College (9.233333, 0.833333)
2. Household Sites

(a) Kakpaille (9.366667, 0.833333)

(b) Vogyili/Sakpalua (9.233333, 0.8)

(c) Pure Home Water House, Tamale (9.4182168,-0.8258508)

All the community site locations outlined by Barnes were outside the region being studied in this research. The Pong town itself is just at the border of the unsuitable areas in the region under study. Based on this, it can be extrapolated that it may be in a region which is not the most optimum for rainwater harvesting, which may support Barnes' [5] findings that RWH in these places was sub-par, badly maintained and rarely achieving the purpose for their construction. This study cannot however validate this claim with surety - other factors affect this phenomenon.

The Kakpaille and Vogyili/Sakpalua locations were also outside the region of study. However, the Pure Home Water House was found to be in a "Suitable" location.

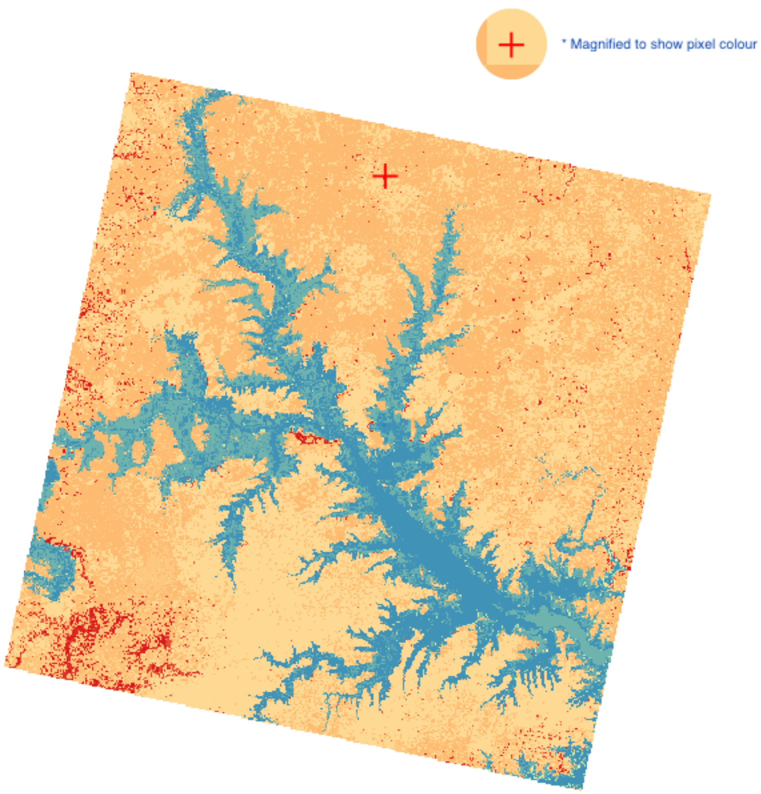


Figure 4.6: Location of Pure Home Water in Tamale

Although it is known that rainwater harvesting is practised in the region under study, almost no data exists on the locations of these places. This leads to a difficulty in asserting

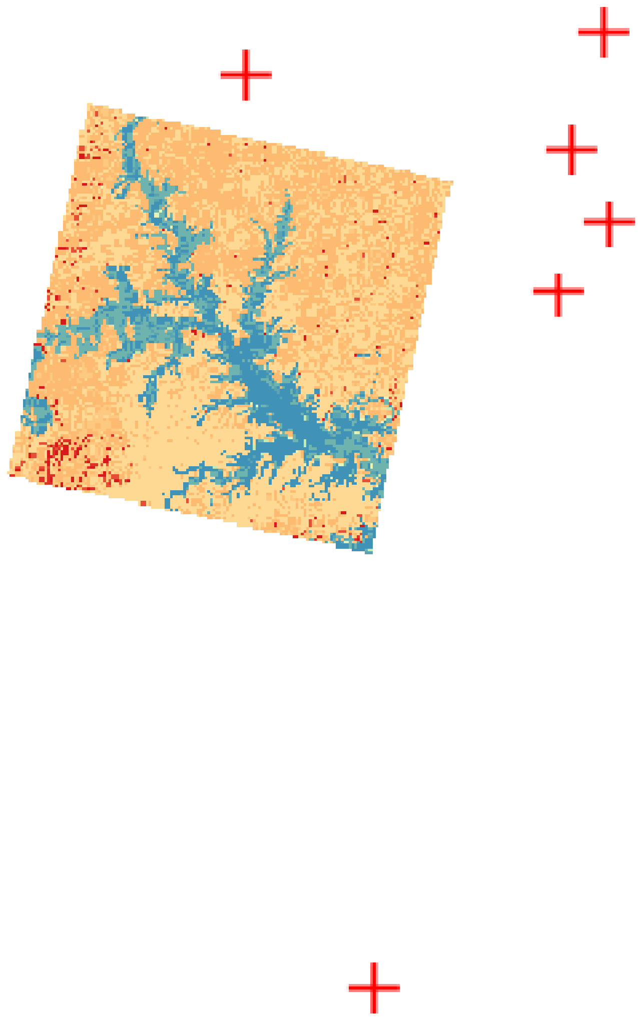


Figure 4.7: Other locations outside the study area

that the results of this research hold true. However, the identification of optimum sites near the river (blue regions in figure 4.3) opens up possibilities for dam construction.

Chapter 5: Conclusion

5.1 Analysis of Results

The results, while promising, are not validated appropriately. Only one location from the validation data was found to be in the area under study. No other data was found on rainwater harvesting sites in northern Ghana. However, in the absence of verifiable validation, this study has proven that geospatial analysis *can* be used to identify potential sites for rainwater harvesting in Ghana. Higher computational power and larger storage is needed to reproduce this work on a larger scale since aerial image datasets are data-intensive.

5.2 Limitations of This Study

One important criteria, socio-economic factors (such as a location being urban or rural, or its distance from pollutants), was not included in this study. Data on this could not be accessed at the time of research. Also, study does not include other helpful relevant criteria such as average rainfall, soil texture, runoff depth and stream order.

Again, the data that was used to validate this study is not current. There is a difficulty in accessing current data on the current locations of water harvesting. Although literature review showed that there was a major project by the USAID (United States Agency for International Development) to provide RWH systems for rural communities in 2012 (The Ghana WASH (Water, Sanitation and Hygiene) Project), they could not be contacted and the website which may have provided some information was no longer active.

5.3 Future Work

Selection of optimum locations should consider the entire country rather than one region. Other criteria should be examined, including the various socio-economic factors which affect the location of rainwater harvesting sites. Machine learning can be used to improve the results of this study: using a database containing satellite images mapped to attributes such as rainfall, soil type and elevation, models may be trained to attempt to classify these as optimal or non-optimal areas for rainwater harvesting. It would also be helpful to scale up the study to cover the entire country, and scaled down to find optimum locations within specific towns. Cloud capabilities should be explored to address the limitations of local storage in performing geospatial analysis.

5.4 Recommendations

This study revealed a need for data repositories to aid in climatological research in Ghana. Most of the data needed is hard to access and sometimes lost or outdated. Researchers carrying out the same study in other countries sourced most of their data from national data repositories which were freely available.

However, the results of this study show that exploring Geographic Information Systems and Remote Sensing shows potential as a viable means of locating optimum rainwater harvesting sites in Ghana. These results are applicable by agencies which are interested in providing water to areas in need, such as the WHO (World Health Organisation) and UNESCO (United Nations Educational, Scientific, and Cultural Organization). The government of the country and private individuals could also consider using such methodologies to correctly place rainwater harvesting storage tanks to minimise losses.

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