Use of water table as a benchmark for leveling groundwater forest: The case of Jozani Groundwater Forest, Zanzibar, Tanzania

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ABSTRACT: *Leveling techniques, including the use of levels, theodolites and GPS are less applicable under forest canopies. In addition, the "Light Detection and Ranging" (LIDAR) technique is sophisticated, expensive and not readily available in developing countries. The current study therefore attempted the use of water table as an alternative method for leveling the Jozani groundwater forest (JGWF) of Zanzibar, Tanzania. The "Height of Instrument" method was used to determine reduced level (RL) of the water table (RL_{WT}) of JGWF from local wells. Then, through temporary wells (TWs), RL_{WT} was used as a wide benchmark to determine other RLs on the ground surface along 32 transect lines. The height from the water table to the ground surface (floating height (FH)) was then measured. Benchmark number 205 and SOKKIA C.3.2 level were used to determine the RL_{WT}. Soil auger was used to open TWs, and cellphone timer and floating rod tape were used respectively to determine time of water settlement, and FH in a TW. GARMIN GPS Model Etrex 10 and ArcGIS 10.1 were used for geo-referencing and mapping. Elevations of ground surfaces were computed by summing the RL_{WT} and FH at a particular point and were then used to produce digital elevation model (DEM) of JGWF. It is concluded that, use of water table for leveling the groundwater forest is feasible and an alternative method.*

Key words: *Benchmark, groundwater forest, leveling, reduced level, water table, Zanzibar*

I. Introduction

Topographic maps show a wide range of land information, and for decades, they have been used broadly for land planning, management and development [1]. Information on the terrain conditions and topography beneath trees canopy is important to the forestry industry and natural resources management [2]. The Jozani groundwater forest (JGWF); the dense canopy's multi-storey forest [3], needed such information not only for what [1] and [2] listed, but as a tool for studying soil, water, flora and fauna conditions and their distributions within the forest.

The JGWF is located within the 62 km^2 of Jozani-Chwaka Bay National Park (JCBNP) [4]. The forest is on a trough lying between Uzi and Chwaka bays and is the lowest inland point in Zanzibar [5]; [6]. The trough was first observed in the Zanzibar topographic maps of Department of Survey (DOS). The maps were among the series of DOS 208 of 1980s sheets no. 10/4404 and 10/4410 of Pete and Charawe, respectively. In the said area, there were few randomly spotted points with less than 5 m elevation above mean sea level (AMSL). Since there were a number of features and conditions that differ within the JGWF and with its surrounding areas, the DOS maps were of little use in revealing the underlying factors affecting soils and water, and their interrelationships which influence the distribution of plant species and communities in the forest. Therefore, study of generating digital elevation model (DEM) and related features of JGWF is key to a number of pressuring agendas related to management and research in the forest.

The use of dump levels, theodolites and related surveying techniques for production of contours and DEM requires a series of instruments' setup along the surveying route using sensitive levels and geo-referencing systems [7]; [8]. Surveys with the use of levels are valid only if the instruments' setups were linked to each other and all of them were referred to a datum [8]. On unstable grounds of multi-storey high canopy forests, leveling with the said instruments and GPS receivers were highly obstructed and poorly signaled [9]; [10]; [11]. Such scenarios were experienced during surveying operations along Jozani-Wangwa trail to characterize the water table of the JGWF. Surveying operations were tedious as they were carried out while upholding the "Zanzibar Forest Policy" cautions [4], [12] insisting that any activity in the JGWF shall be carried out in a manner that ensures intact maintenance of the flora, fauna and environment. Therefore, surveying with such technologies for elevation of the JGWF was not possible.

LIDAR (Light Detection and Ranging) technique is most useful for mapping-out heights of vegetation and elevation of ground surfaces under forest canopies [2]; [13]. Therefore, the use of LIDAR outweighs the use of levels and theodolites [14]. However, LIDAR requires sophisticated equipment and highly qualified expertise; it is expensive and yet has limitations [15]. Hence, in developing countries even with the need of the use of LIDAR, it is yet economically inappropriate and unaffordable. When such conditions are in place, as it is the case for JGWF; an alternative way of making the topographic information available is inevitable.

A number of survey technologies are used to prepare maps of water tables and static water levels from measurements obtained from well-log records of private wells [16]; [17]. Such measurements result into a production of depth-to-water table maps, such as isobaths [16]. For decades, many, if not all publications used the word "water table" (WT) to express the top/upper surface/level beneath in-land earth surface saturated by water; and "static water level" (SWL) to express the water level in a well before water has been pumped out. According to The Columbia Electronic Encyclopedia [18], The Great Soviet Encyclopedia of 1970s went further on the term water table as referring also to the water surface of rivers and lakes. However, the word "float/floating" was often used when it was referring to specific use of the water bodies rather than the WT alone. Again, the SWL was used to refer to a WT, but was confined to its uses in engineering and water pumping studies and applications. With such context, the terms poorly expressed the water surface when it acts as a line/level floating the mass/objects above it. Therefore, in this study "water floating level (WFL)" has been used instead of "water table". The term was defined as an imaginary reference line/level horizontally laid on the upper surface of an in-land water body above which all masses/objects were floating and it was used as a wide floating benchmark.

1.1 Basic principle of the use of WFL

When a WFL acts as a benchmark (BM), heights from it to soil surface (floating heights (FHs)) can be measured from every point (floating point (FP)) of the surveyed area. In this case a FP was a geographic point of the measured FH. Since WFL as BM was referred to the mean sea level (MSL), all reduced levels (RLs) of FPs were also referred to the MSL (Fig 1).

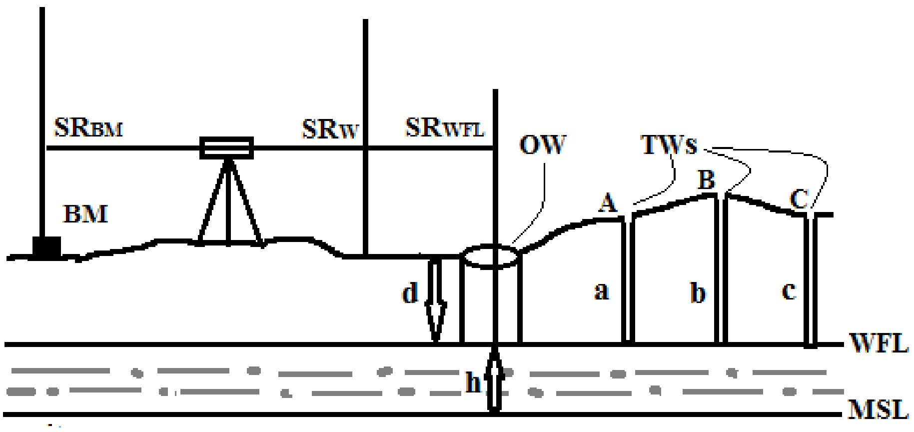

Figure 1: A basic principle of leveling with the use of water floating level (WFL)

Fig. 1 illustrates that the RL of the WFL (RL_{WFL}) in observation well (OW) was determined from surveying by the “Height of Instrument (HI)” method from a nearby BM, formula 1, 2 and 3 apply as per [7]. While the RL of $FP_{A, B, C}$ were then obtained by separately summing the RL_{WFL} and FH $_{a, b, c}$, Formula 4 and 5.

$$HI = BS + RL \quad (1)$$

$$RL = HI - SR \quad (2)$$

$$RL_{WFL} = HI - SR_{WFL} = h \quad (3)$$

$$RL_{W} = HI - SR_{W} = RL_{WFL} + d \quad (4)$$

$$RL_{A, B, C} = RL_{WFL} + a, b, c = h + a, b, c \quad (5)$$

Where HI; height of the instrument, BS; back sight, RL; reduce level, SR; staff reading, BM; benchmark, SR_{BM}; SR at BM, WFL; water floating level, RL_{WFL}; RL of WFL, SR_{WFL}; SR on WFL, RL_{W}; RL of soil surface at the OW, SR_{W}; SR on the soil surface at the OW, MSL; mean sea level, h; height of WFL AMSL, d; depth from soil surface to WFL, a, b, c; measured depths from soil surface to WFL at point A, B, C, and $RL_{A, B, C}$; are RL at $FP_{A, B, C}$.

Elevation of soil surface at a particular floating point (Elv_{FP}) was therefore, identified by summing the RL_{WFL} of the area in a particular day of surveying and measured FH. A floating metric tape was used to measure the FH through a geo-referenced temporary well (TW). If FPs were many enough and were obtained from transects covering the studied area, they are the inputs for DEM production with the use of a digital mapping tool such as ArcGIS.

The current study explored the possibility of using a close to soil surface WT referred to as WFL for the JGWF DEM production. The WFL acted as a wide benchmark and was used to determine elevation of several points within the JGWF. A close to soil surface WT was a unique opportunity in this method. The method cuts down the costs of leveling under forest canopies using modern technologies. The map produced can be used in a number of academic and management programmes such as soil and water inter-relationships, plant species distributions, biodiversity, and environment and ecotourism conservation.

II. Materials and Methods

2.1 Description of the study area

The study was conducted in about 8 km^2 area of JGWF located between the Chwaka and Uzi bays and was within the JCBNP area, Zanzibar, Tanzania. The park of about 62 km^2 lies within Universal Transverse Mercator (UTM) Zone 37S coordinates between N 9 305 880 to 9 317 855 and E 539 100 to 549 000 [4] (Fig. 2). The park has a tropical sub-humid climate and receives about 1400 mm annual average rainfall from the rainy season (*Masika)*; March to May and the short rainy season (*Vuli)*; October to November [6]. The JGWF has a closed to the soil surface WT [3]; [19]. During the rains, the WT often emerged above the soil surface and form temporary marshes [20].

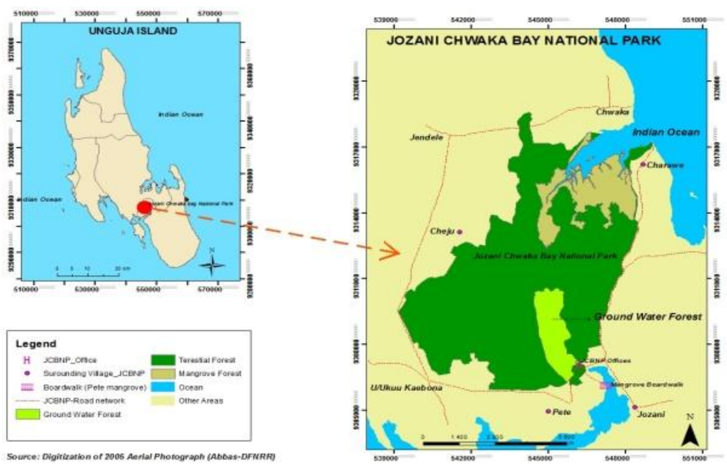

Figure 2: Location map of JGWF, Zanzibar, Tanzania. Source: Abass DFNRR, 2014.

2.2 Survey to characterize WFL of JGWF

As cited in [16], a water level in a well has a height of the WT of a particular water body. Hence existing wells offer ready-made sites for water level observations. During the reconnaissance survey, a total of eight wells; two on the southern end (Jozani) close to datum no. 205, four along the *Jozani-Wangwa* trail, and two on the northern end (Wangwa) were identified. These wells were used as OWs for WFL characterization. The survey to characterize the WFL was done for two consecutive days in October 2014 as suggested by [16]. He suggested that, measurement for WT determination should be done within a short period of time. The HI/Collimation method [21] by the aid of SOKKIA C.3.2 level was used to determine the WFLs through the OWs. During the survey, temperature ranged between 30 and 32^{o}C as recorded from Tanzania Meteorological Agency (TMA) stations at Kisauni, Zanzibar. Therefore, to minimize errors associated with the aluminum reading staff, a wooden reading staff was used. According to [10], aluminum reading staffs are affected by temperature above 27^{o} C. Datums numbers 205 and 210 with RL of 2.134 and 5.621 m, AMSL located respectively at 546 217 E, 9 306 943 N and 547 685 E, 9 310 846 N both within UTM 37S, were used. These datums were installed in 1976 and revisited in 2013 by the DOS office. For convenience of data collection, the surveying process used UTM 37S coordinates system, regardless of the citation made from [22] which noted that the World Geodetic System of 1984 (WGS 84) was the most used system. GARMIN Etrex 10 GPS receivers were used for geo-referencing of OWs. From datum no. 205 at Jozani, the leveling process continued to Wangwa and then from Wangwa to datum no. 210 at *Mapandani* along *Charawe* road. The RLs were computed in Excel spread sheets by Formulas 1 and 2 given above. Arithmetic error and slope of WFL (between Jozani and Wangwa) were calculated as proposed by [8] and [23], using Formulas 6 and 7, respectively.

$$\text{Arithmetic Error} = \Sigma \text{ Back} - \Sigma \text{ Fore} \qquad (6)$$

$$\text{Slope (gradient)} = \text{Rise/Run} \times 100 \qquad (7)$$

Where Σ Back is sum of all back sights, Σ Fore is sum of all fore sights, Rise is vertical height, Run is horizontal distance between the two points and 100 is factor of expression in per cent.

2.3 Transecting and WFL slope determination

In areas where the WT is smoothly sloped, OWs can be spaced farther apart [16]. With this regard, it was estimated that, in JGWF the height of WFL m, AMSL was the same within a radius of about 200 m from the OW. Therefore, transects were spaced at 200 m apart aimed at evenly distributing the slope of the WFL. This transecting was done with expectation that, through transects across the forest length the RL_{FP} will be properly captured. These transects were running east-westwards. Along transect lines, the TWs were opened for FH measurements. One of the OWs at 545 987 E, 9 306 659 N was used as reference well (RW), and for the convenience of transecting, its northern coordinate was rounded to 9 306 600 N. Hence, the area of the first three southern transects (9 306 400, 9 306 600 and 9 306 800 N) had the same RL_{WFL} as recorded at RW and was indicated as T_0. Therefore, the first transect affected by WFL slope was 9 307 000 N indicated as T_{200} (200 m from T_0) and the last transect was 9 312 600 N, indicated as T_{5800} (5800 m from T_0). Therefore, the run (length) of about 6 km was subdivided into 32 transects.

The primary references at water level recording stations are a set of datums [16]; [21]. So, WFL on a particular day of transect walks was determined by surveying from datum no. 205 to the RW (about 372 m apart) using HI method with SOKKIA C.3.2 level. The identified WFL was used as BM for FH probing during transect walks. Formula 8 was used to nullify the WFL slope (S) along T_X aimed at obtaining FHs that were free from the S effects.

$$WFL_{TX} = WFL_{RW} \pm (S \times T_X), \text{ m} \qquad (8)$$

Where WFL_{TX}; was WFL (m) at a given transect (T) with X distance (m) from T_0, WFL_{RW}; WFL at RW in a day of transect walk, S; slope in per cent (%) a constant. The sign was negative when the T_X runs down the slope and positive when T_X runs up the slope.

2.4 Transects walks

GARMIN Etrex 10 (GPS) receivers set into UTM 37S were used to direct the teams along transect lines during the walks. The transect walks for probing involved four teams of four people, each consisting of two villagers with at least secondary school education, skilled park attendant, and diploma-holder surveyor. Each of the team walked on two transects per day and the walks were for four consecutive days. The task of each of the teams was to identify the FPs on a T_X where the measured FH coincided with the one indicated in the field book for a given elevation (Elv). Thereafter, the eastern coordinates (E) of the identified FPs were recorded. It was experienced that in JGWF it is impossible to walk on a straight line along indicated T_X (northern coordinates (N)). So alteration of about 5 m from a given T_X was allowed.

2.5 Determination of floating heights at selected points

From observations made on DOS maps, it was decided that, JWGF could be surveyed at 0.25 m vertical interval as that would give more detailed elevation map. So the elevations comprised: 0.50, 0.75, 1.00, 1.25, 1.50, 1.75, 2.00 and 2.25 m, AMSL. The FH_{TX} were calculated and recorded in the field book with their respective Elv before the transect walks. A field book consisted of partial pre-printed separate sheets with table. The table was indicating N coordinates, Elv and their respective FH for the T_X. Value of FH for a given Elv on T_X was calculated by Formula 9.

$$FH_{TX} = Elv - WFL_{TX}, \text{ m} \qquad (9)$$

Where, FH_{TX}; was FH along T_X, Elv; elevation and WFL_{TX}; WFL along T_X at a given distance from RW.

2.6 Probing

To minimize the number of probes while maximizing the time use efficiency during transect walks, the surveying members were trained on how to perform the task. Transect probing was carried out for 4 days of late November, 2014. The probing was performed mainly when a team found a sort of sharp or gradual slope, depression or rise along transect. Drilling, depth measurements and data recording were done as suggested by [16]. Soil auger of about 0.08 m diameter and up to 2.0 m long was used to open the TWs to reachable depths. The floating measuring rod was inserted down the TW just 2 minutes after drilling. The team members' individual cell phones were used as timers. Following several observations made on JGWF, it was recommended that measurement should be done in 5-6 minutes time after drilling. Data for FH were observed from the metric rod at the cap slot at soil surface. The E coordinates of given FP were recorded in field book. However, it was difficult to obtain FP with exact metric figures of FHs as given in the field book for a given Elv. Therefore, alteration of ±0.05 m from given FH value was allowed. On the selected point about 3-4 probes for a particular FH were recommended. However, an FP was recorded when its measured FH fall upon Elv range indicated in the field book for a particular T_X.

2.7 Mapping

The FPs with their respective FHs were used to produce DEM of JGWF with 0.75 to 2. 25 m height range. ArcGIS 10.1 was used for mapping as per [24].

III. Results

The WFL was at varying depths from the soil surface and no rains were recorded during the surveying and probing time. A summary of the performed instrumental leveling process from Jozani to Wangwa to characterize the WFL in the forest is presented in Table 1. Table 2 shows the recorded WFL_{TX} for a T_X after having nullified slope based on the WFL_{RW} obtained from surveys carried out from datum no. 205 to the RW on the day of transect walk.

Table 1: Leveling for WFL characterization in JGWF, October 2014

OW and Datum	Coordinates		RL		Arithmetic	Slope	
IDs	UTM 1960 37 S		Surface	WFL	error	Surface	WFL
	Eastern	Northern	m	m	m	%	%
OW at JCBNP office	545 732	9 306 309	4.721	0.780			
Reference well (RW)	545 987	9 306 659	1.477	0.781			
Datum no. 205	546 217	9 306 943	1.967	-			
First OW along trail	546 176	9 307 148	2.330	0.699			
Second OW along trail	545 892	9 307 545	1.275	0.660			
Third OW along trail	545 808	9 307 848	1.106	0.643			
Fourth OW along trail	545 519	9 312 091	4.642	0.637			
OW at Wangwa (Eastern)	545 000	9 312 000	0.765	0.635			
OW at Wangwa (Western)	544 459	9 312 174	0.770	0.635			
Mean				0.688	0.063	0.023	0.0028

Table 2: Values of water floating levels for various transects during probing

Day1		Day2		Day3		Day4	
T_X	WFL_{TX}	T_X	WFL_{TX}	T_X	WFL_{TX}	T_X	WFL_{TX}
RW	0.732	RW	0.732	RW	0.730	RW	0.728
T_0	0.732	T_{1600}	0.687	T_{3200}	0.641	T_{4800}	0.594
T_{200}	0.726	T_{1800}	0.682	T_{3400}	0.635	T_{5000}	0.589
T_{400}	0.721	T_{2000}	0.676	T_{3600}	0.630	T_{5200}	0.583
T_{600}	0.715	T_{2200}	0.671	T_{3800}	0.624	T_{5400}	0.577
T_{800}	0.710	T_{2400}	0.665	T_{4000}	0.618	T_{5600}	0.572
T_{1000}	0.704	T_{2600}	0.660	T_{4200}	0.613	T_{5800}	0.566
T_{1200}	0.699	T_{2800}	0.654	T_{4400}	0.607		
T_{1400}	0.693	T_{3000}	0.648	T_{4600}	0.602		

A total of 453 FPs on Elv ranging from 0.75 to 2.25 m, AMSL were recorded in the field books. The FPs were geo-referenced with E and N coordinates from 544 430 to 546 400 and from 9 306 600 to 9 312 400, respectively. As an example; Table 3 shows the data recorded on T_{1200}. The DEM of the JGWF in raster format produced is presented in Fig. 3**.**

Table 3: The recorded field book for the transect line T_{1200}.

Elv	FH ± 0.05	T_{1200}: 9 308 000 N			
m	m	Eastern coordinates of the floating points (FP)			
0.75	0.05	-	-	-	-
1.00	0.30	545 127	546 303	-	-
1.25	0.55	545 103	546 342	-	-
1.50	0.80	545 094	546 364	-	-
1.75	1.05	545 082	546 387	-	-
2.00	1.30	545 073	546 400	-	-
2.25	1.55	545 056	-	-	-

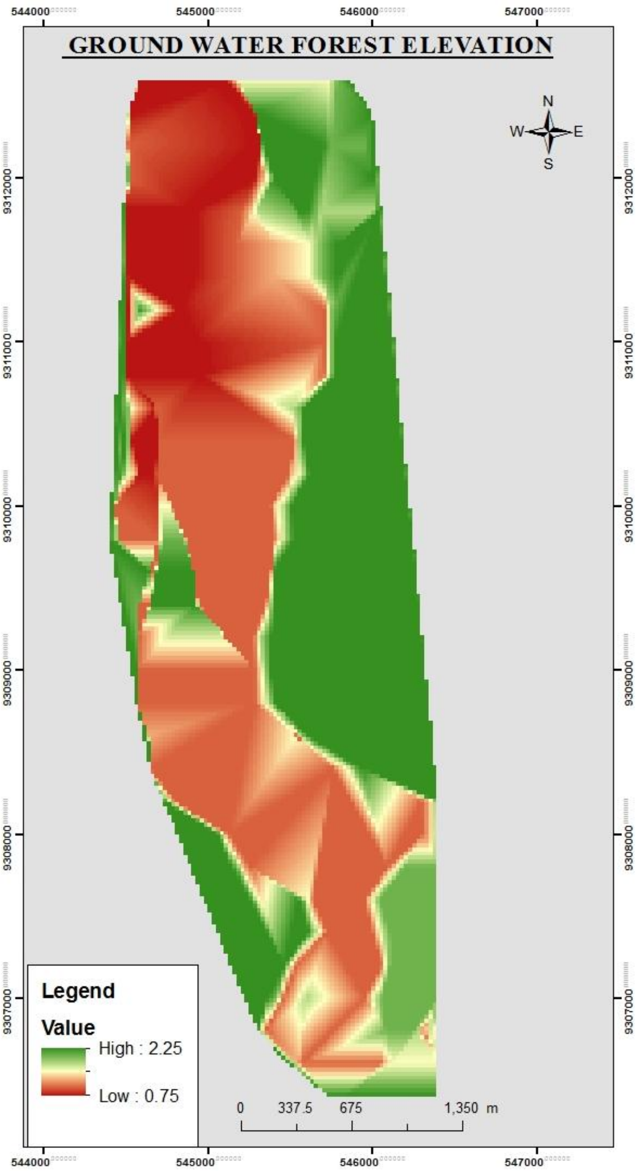

Figure 3: Digital elevation model (DEM) of Jozani groundwater forest (JGWF).

IV. Discussion

4.1 Geographical setting of the JGWF

From the DEM, the JGWF occupies the area between 544 400 to 546 400 and 545 000 to 544 459E on Jozani and Wangwa ends, respectively, and extends from 9 306 400 to 9 312 400N. The forest is also located beneath and confined within coral ridges and cliffs on the west and gently up-ridging on the east. Furthermore, the JGWF and narrowly opens towards Uzi creek and widely opens towards Chwaka bay.

4.2 General characteristics of surface elevation of the JGWF

Datum no. 205 was at the height of 2.134 m, AMSL (DOS, 2013), but the RL of the soil surface where the datum is located is about 2 m AMSL only. Again, the difference between Jozani and Wangwa soil surfaces (about 6 km run) was about 1.12 m, giving an average slope of about 0.023%. The surface elevations and slopes indicated that although JGWF has an altitude of about 2.25 m, AMSL and less, yet slope of the soil surface is decreasing from Jozani towards Wangwa.

4.3 General characteristics of WT in JGWF area

For good results of leveling with the use of WFL, time and duration of survey was crucial. Based on suggestion on WT recording period by [25], the surveying was done on appropriate time as there was no rain two weeks before and during the survey period. As reported by [16] and [17], the water table keeps changing due to precipitation, and in JGWF case, its rises and falls were related to a number of processes occurring in the forest including evapo-transpiration and drainage. Within the 4 days of transect walks, the WFL had an insignificant change of its level. A recorded drop of 0.004 m (0.001 m/day) indicated that JGWF never gets dry. During the dry period, the WT falls by few centimeters and rises during the rains. Hence, the forest is favored by close to surface wetness throughout the year. Many scholars including [26], [16] and [27], reported that like streams and rivers, in coastal areas, groundwater flows down slope in seaward direction. The recorded difference of 1.477 and 0.780 m of soil surface and 0.765 and 0.635 m of WFL between Jozani and Wangwa respectively, indicated that, although JGWF is located between the Uzi and Chwaka bays, ground water sloped and flowed towards Chwaka bay. Again, based on [16], the recorded 0.144 m difference between the WFLs of the two ends also indicated that, the water aquifer in the area was a single segment. Although [28] reported that, a WT is subjected to change seasonally, annually or after a period of time, according to [17], the slope of the WT will remain constant unless factors influencing abrupt change are in place. Since the slope was of about 0.0028% and was constant and smooth, the subsurface geology of JGWF is fairly uniform and only seasonal rain was the major factor behind the changes of WFL in the forest.

4.4 Applicability of the method

The method was a reverse process of surveying where the WFL was used to identify the surface levels instead of surfaces being used to identify the water levels. With the DEM produced, it was confirmed that, the method was feasible. One of the advantages is that in areas where the WT is not segmented, few OW and/or TW can be used to characterize the WFL and DEM production, respectively. The method uses ordinary instruments and can be performed in areas with many surveying obstacles. Again, the method is less time consuming and less costly. Furthermore, this method needs less data inventory and calculations, allows the use of less skilled personnel and the surveying processes can be done by separate groups working at a time. However, a major disadvantage of the method is that, it is applicable mainly in the presence of close to soil surface WT.

V. Conclusions and recommendation

The study concluded that JGWF has close to the ground surface water table that seasonally fluctuates. The aquifer of Jozani groundwater forest was on fairly uniform geological subsurface. The water table has constant gradient that is slightly sloping from Jozani towards Wangwa. The digital elevation model produced is a key tool for studies on soil, water, plant species distribution and the inter-relationships between them. The method nullifies the challenges of leveling under forest canopy and high costs of leveling with modern technologies. Therefore, the method of using water floating level is feasible, applicable and an alternative for conducting survey for elevation on a multi-storey high canopy groundwater forest.

References

[1.] R. Pradhan, S. Shikhar, R. Agarwal, M. P. Pradhan, and M.K. Ghose, Contour line tracing algorithm for digital topographic maps, *International Journal of Image Processing (IJIP),* 4 (2), 2010, 156-163.

[2.] B. Peterson, R. Dubayah, P. Hyde, M. J.B. Blair and J. Fites-Kaufman, Use of LIDAR for Forest Inventory and Forest Management Application, *Seventh Annual Forest Inventory and Analysis Symposium 19 USA,* 2005, 193 – 202. [http://originwww.nrs.fs.fed.us/pubs/gtr/gtr_wo077/gtr_wo077_193.pdf] site visited on 01/09/2015.

[3.] C. L. Nahonyo, L. B. Mwasumbi, S. Eliapenda, C. Msuya, C. Mwansasu, T. M. Suya and P. Kihaule, *Jozani-Chwaka Bay proposed National Park biodiversity inventory report* (DCCFF, Serikali ya Mapinduzi, Zanzibar, 2002).

[4.] Sustainable Management of Land and Environment, SMOLE II, *Zanzibar National Forest Policy Analysis* (Zanzibar, 2013).

[5.] R. Klein, *An edaphic landscape of Unguja Island, Zanzibar* (Turku University, Finland, 2008).

[6.] Z. Leonila, *Assessing the spatial and temporal characteristics of ground water recharge in Zanzibar,* (University of Twente, Netherland, 2011).

[7.] R. C. Brinker and R. Minnick, *The surveying handbook* (Springer Science & Business Media, 2012).

[8.] SaMeh, A precise methodology integrates low-cost GPS data and GIS for monitoring groundwater quality parameters in Majmaah region, KSA, *International Journal of Environmental Monitoring and Analysis,* 2(5), 2014, 279-288.

[9.] B. C. Punmia, *Surveying. Vol. 1* (Firewall Media, LAXMI Publication Ltd, 2005).

[10.] A. Ceylan, C. Inal and I. Sanlioglu, *Modern Height Determination Techniques and Comparison of Accuracies* (From Pharaohs to Geoinformatics, Cairo, Egypt TS33.5, 2005).

[11.] S. K. Duggal, *Surveying* (Tata McGraw-Hill Education Private Ltd, New Delhi India, 2013).

[12.] Zanzibar Revolutionary Government, *Zanzibar Woody Biomass Survey Preparedness for REDD+ Phase: Biophysical Inventory Report, Using Zanzibar Woody Biomass Survey in Policy and Planning Processes, Working Paper* (Indofood, Forest Intelligence and Norwegian Embassy, Zanzibar, Tanzania 2013).
[13.] W.A. Staats, *Use of LIDAR–Derived terrain and vegetation information in a deciduous forest in Kentucky*, master of science diss.,University of Kentucky UK, 2015.
[14.] M. A. Wulder, C.W. Bater, N.C. Coops, T. Hilker, and J.C. White, The role of LiDAR in sustainable forest management, *Forestry Chronicle,* 84 (6), 2008, 807-826.
[15.] V. R. Mandla and J. Kamal, Digital Elevation Model Accuracy Aspects, *Journal of Applied Sciences,* 8, 2008, 134-139.
[16.] N. A. Ridder, Groundwater Investigations, In H. P. Ritzema (Ed), *Drainage Principles and Application, 2* (International Institute of Land Reclamation and Improvement ILRI Wageningen, The Netherlands, 1994) 16, 33-75.
[17.] R.H. Rowley, T. McClain, and M. Malone, Static water level mapping in East Central Michigan, *Journal of the American Water Resources Management Association (JAWRA),* 39 (1), 2003, 99–111.
[18.] The Columbia Electronic Encyclopedia®, *Water table* 2013 [http://encyclopedia2.thefreedictionary.com/water+table] site visited on 31/08/2015.
[19.] Zanzibar Revolutionary Government, *Zanzibar Woody Biomass Survey Preparedness for REDD+ Phase: Biophysical Inventory Report* (Indofood, Forest Intelligence and Norwegian Embassy, Zanzibar, Tanzania 2013).
[20.] L. M. Salum, Ecotourism and biodiversity Conservation in Jozani-Chwaka Bay National Park, Zanzibar, *Africa Journal of Ecology,* 47, 2009, 166-170.
[21.] NIWA, *Leveling and Surveying* (Pacific Island Hydrology Course, Fiji, 2004), [http://www.whycos.org/fck_editor/upload/File/Pacific-HYCOS/Surface_Waters/Levelling_and_surveying.pdf] site visited on 3/09/2015.
[22.] R. Welch, and A. Homsey, Datum shifts for UTM coordinates, *Photogrammetric engineering and remote sensing,* 63 (4), 1997, 371-375 [http://www.asprs.org/a/publications/pers/97journal/april/1997_apr_371-375.pdf] site visited on 01/09/2015
[23.] M. Cavanagh, *Trigonometry from a Different Angle (*Australian Mathematics Teacher 64.1, 2008).
[24.] J. M. Schaeffer, *Working with ArcGIS for environmental analysis: Core GIS skills and analysis* (Juniper GIS services Inc. Tanzania, 2012).
[25.] M. G. Dalton, B.E. Huntsman and K. Bradbur, *Acquisition and interpretation of water-level data* (The Essential, 2006).
[26.] C. A. J. Appelo and D. Postma, *Geochemistry, groundwater and pollution*. (A. A. Balkema Publishers, Amsterdam, Nertherland, 2005).
[27.] J.T. Zhu, J. Yu, P. Wang, Q. Yu, and D. Eamus, Variability in groundwater depth and composition and their impacts on vegetation succession in the lower Heihe River Basin, north-western China, *Marine and Freshwater Research CSIRO Publishing* (65), 2014, 206-217.
[28.] M. Sophocleous, Interactions between groundwater and surface water, The state of the science, *Hydrogeology Journal,* 10 (1), 2002, 52-67.