Comparative study between Global Positioning System (GPS) surveying methods and Geographic Information Systems (GIS) - based flood volume for reservoir capacity determination in Makera marshland, Muhanga district, Rwanda

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Abstract: The main objective of this study was to compare the results got through the use of Global Positioning System (GPS) and Geographic Information Systems (GIS) to determine the reservoir capacity of Makera Marshland, Muhanga District in Rwanda. This study also aimed at collecting and identifying the flood volume capacity by using GPS, conducting GIS- based flood volume capacity of Makera marshland based on existing digital topographic map, investigating and identifying differences in the proposed techniques. The GPS surveying method revealed that the plannimetric area of Makera marshland is 447,840.122 m^2 with the reservoir capacity of 9,703,452.75 m^3 calculated above the base height of 1733 m. The GIS- based flood volume capacity of Makera marshland based on existing digital topographic map gave a plannimetric area of 1,914,988.688 m^2, while the volume capacity was 7,537,512.812 m^3. Then, the difference was 2,165,939.938m^3. Results indicated that there is a significant difference between the results obtained from GPS surveying and the existing digital map due to the atmospheric fluctuations, the multi path interferences and poor satellite signals. Therefore, the use of GIS- based flood volume is better than using GPS as far as reservoir capacity determination is concerned.

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1. Introduction

The hydrological regime of the marshlands in Rwanda is directly dependent on the particular drainage basin. An attempt to regulate the surface flow in a certain drainage basin should consider the entire basin and not only its separates area such as the marsh. The marshes play the role of natural storage reservoirs and maintain a stable base flow during the dry season. Marshes in Rwanda are divided into 3 categories as follows: marshes in high altitudes, medium and low altitudes. As the number of marshlands used as croplands continues to increase in Rwanda, the irrigation is considered as a very important factor for increasing the production (MINAGRI, 2010).

The estimated total area of marshes in Rwanda is 275,169 ha, of which 55,896 ha are fully protected, 204, 198 ha are not protected but with limited access while 15,595 ha are not protected without any limited access. The latter two categories are added up to 219,793 ha covering the marshland potential for irrigation. 41% of the aforementioned marshlands are covered by natural vegetation, 53% (148,344 ha) are under cropping and about 6% are fallow fields (Muhanga master plan, 2010).

Flash floods occur periodically in Makera marshland, due to several factors including its rugged topography and geological structures. Hence, precise assessment of floods becomes a more vital demand for its management. Therefore, a GIS-based flood volume method has been used for quantifying and spatially mapping the flood characteristics. Additionally, the computation of flood volumes was carried out by digitizing the existing soft topographic map containing Makera marshland. Digitizing is the process of encoding geographic features in digital forms as x, y coordinates. It is carried out in order to create special data from existing hard copy or soft copy maps (Davaine, 1999).

For irrigating such a marshland, it requires the hydraulic structures and canal supply. Among irrigation structures, reservoir should be included and its capacity has to be determined (Meigh, 1995; Mugabe et al., 2004). The methods to be used include GIS- based flood volume or Global Positioning System (GPS). A reservoir or an artificial lake is used to store water. Reservoirs can be used in a number of ways to control how water flows through downstream waterways. Makera marshland management was initiated in 1987 by the PAG (Programme Agricole de Gitarama) and QWMDP

(Quick Win Marshland Development Project) inaugurated in 2011 aiming at rehabilitating these hydraulic structures. The main purpose of two projects was to design and construct the hydraulic structures excluding the design and construction of reservoir capacity to store water for irrigation and the flood volume. In Makera marshland, there is a problem of water stress for crops during dry season because the storage reservoir is not adequately determined nor exceeding flood volume during the rainy season because they have not been designed. Water distribution canals and reservoirs are required to distribute, raise and divert water in the farmers' plots (Muhanga, 2010). Unfortunately, the reservoir is not provided in that project. Another issue is that the surveying techniques used during the design of Makera marshland management were various and gave different results. All techniques used did not solve the problems of water stress for crops and the flooding. This led to the mismanagement of the marshland which caused problems to designers (main canal and secondary canals). Therefore, this study aims at determining the reservoir capacity which can be used to store water by using GPS surveying technique and GIS- based flood volumes by digitizing the existing soft topographic map.

2. Materials and methods

Study area description

Makera marshland is located in Muhanga district, Southern Province of Rwanda. Muhanga District occupies an area of 647.7 km^2. The rain fall ranges between 1100 mm and 1200 mm per year and it is at 1733-1782 m a. s. l. This area is characterized by two major seasons: a short rainy season (September to December) and long rainy season (February to May).

Materials

The materials used include the topographic map of Rwanda, Arcview GIS 3.2, Covadis software, and Global Positioning System (GPS).

Methods

(1). Determination of volume capacity by using Geographic coordinates taken by GPS. This operation consisted of creating the contour map (generating triangulated Irregular Net work (TIN) to grid data for Digital Elevation Model (DEM), determining the volume of contained water by establishing the proposed levels as datums).

(2). Digitizing the contours of topographic map with Arcview GIS 3.2: This operation consisted of obtaining the contours and determining the contained water from digitized map.

(3). Comparing two volumes

3. Results and discussion

3.1 Determination of flood volume capacity by using data collected by GPS

The figure 1 below shows different geographic positions taken from Makera marshland.

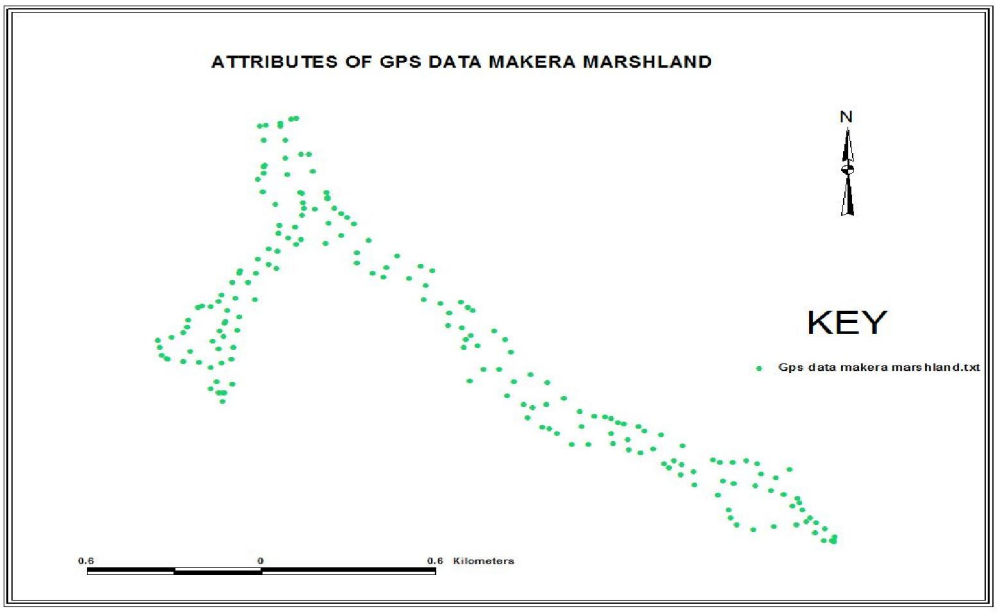

Figure 1: GPS-based attribute data in Makera marshland

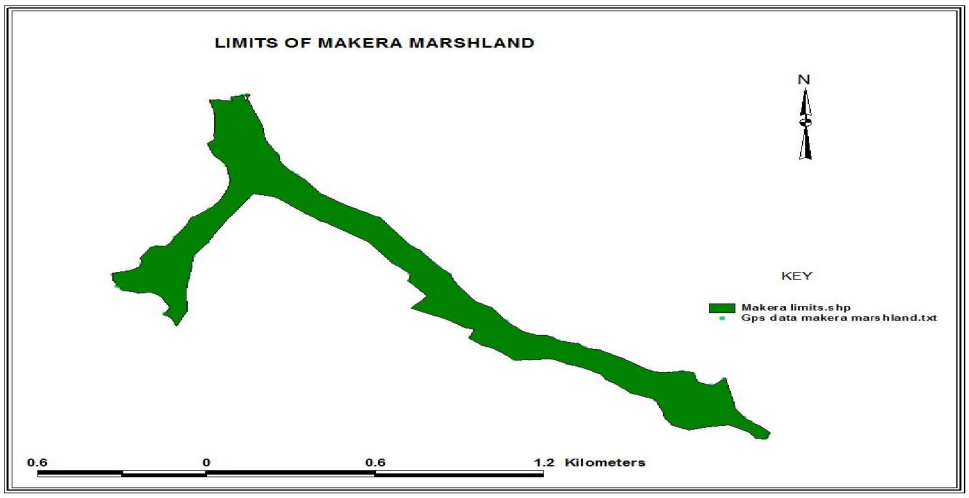

Figure 2: Boundaries of Makera marshland The highest level of the elevation of the Makera marshland is 1782 m and the lowest is 1733 m and the interval between contours is 1 m.

Contour map of Makera marshland

The contours are added to the map as shown in the figure 3**.**

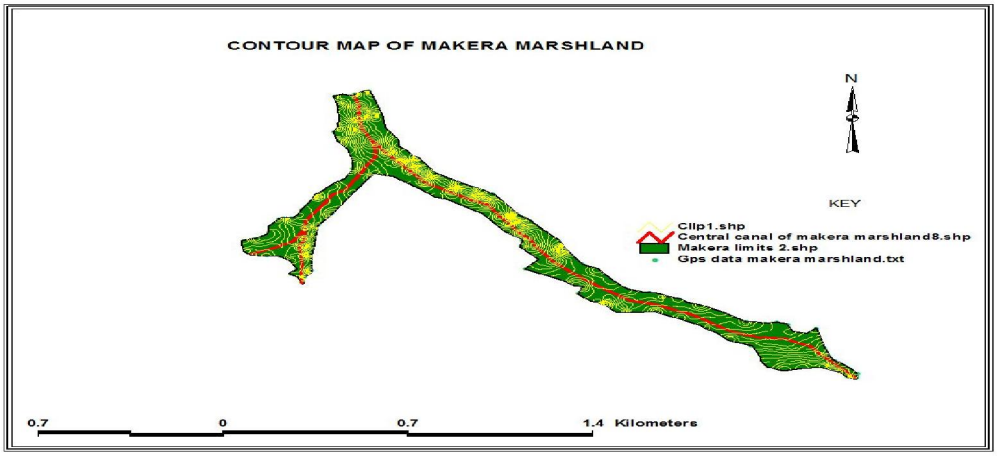

Figure 3: Contour map of Makera marshland

The corresponding areas calculated were 1,759,360 m^2 but the corrected areas were 447,840.1223m^2.

The figure 4 shows that the highest elevation is located between 1776.556 and 1782 m while the lowest is between 1733 and 1738 m. The green color indicates the area with lower elevation whereas the whole areas covered by the Gray colors occupy the higher elevation in the marshland. This topographic map was used to determine the reservoir capacity of Makera marshland. The corrected plannimetric area of Makera marshland is 1,914,988.688 m^2, and reservoir capacity of 30,150,051.248 m^3. By using Covadis software, we obtained 447840.1223 m^2 representing the limit covering polygon area of the Makera marshland. The TIN covering polygon area is known (1,759,360 m^2). For obtaining the factor of difference: N=1,759,360 m^2/ 447840.1223 m^2=3.928 ≈ 4 times. Therefore, the volume = V_{TIN}/ N=38,813,811m^3/4= 9,703,452.75 m^3 which is the reservoir capacity of Makera marshland calculated from GPS surveying method.

Determination of water volume

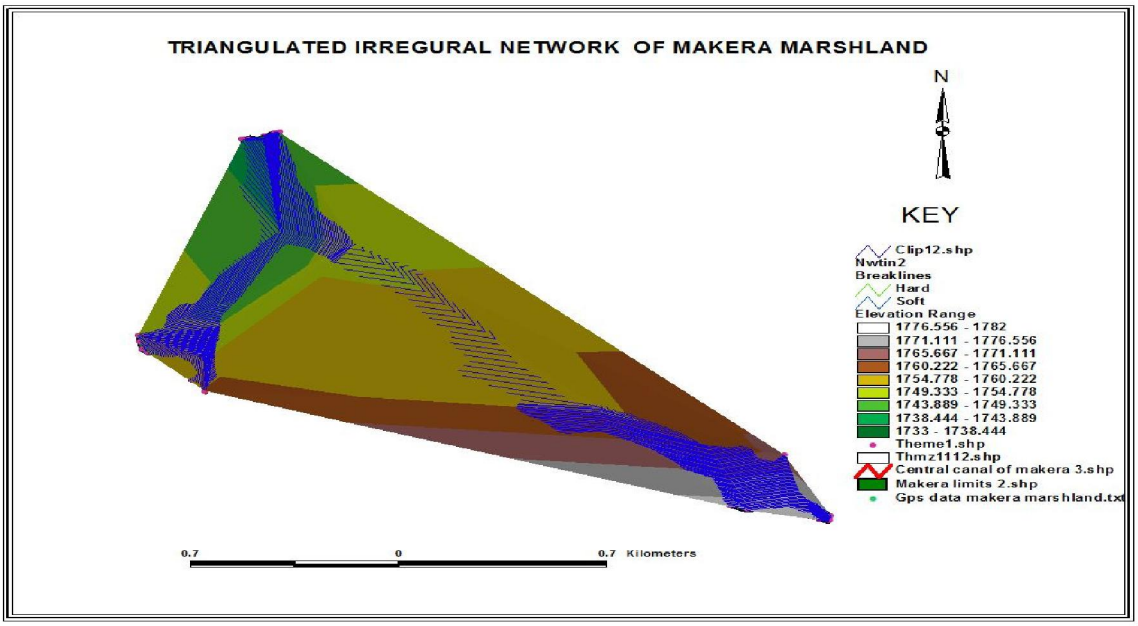

Figure 4: Triangulated irregular net work

Grid map of Makera marshland

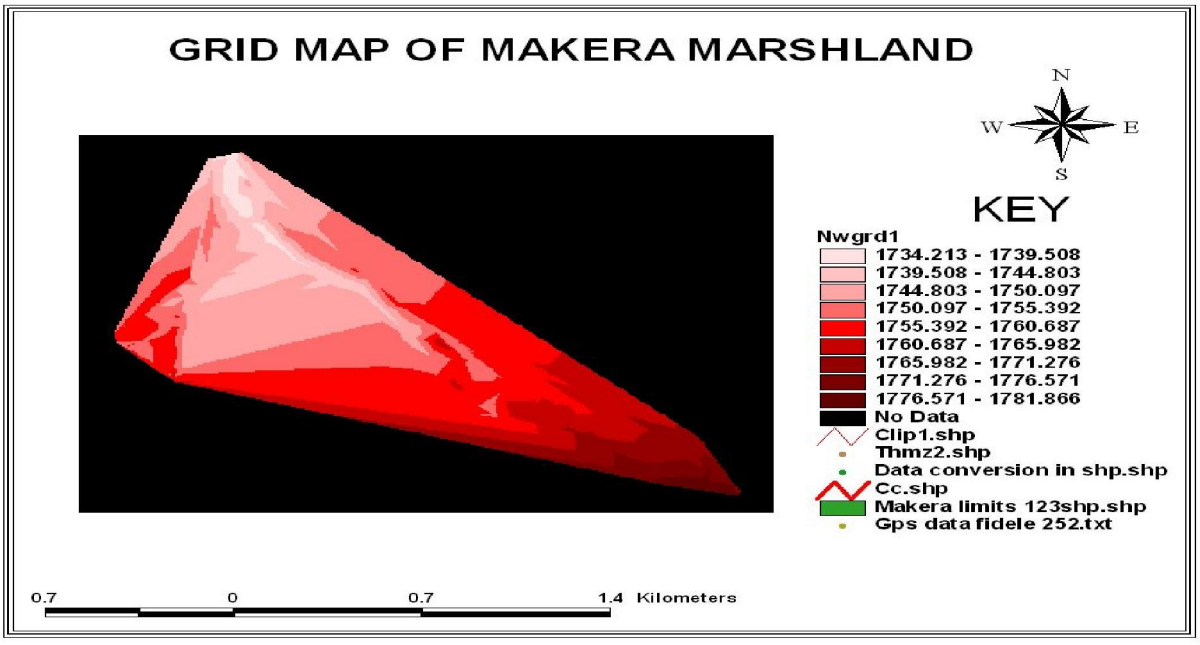

Figure 5: Grid map of Makera marshland

Final layout of topographical map of Makera marshland

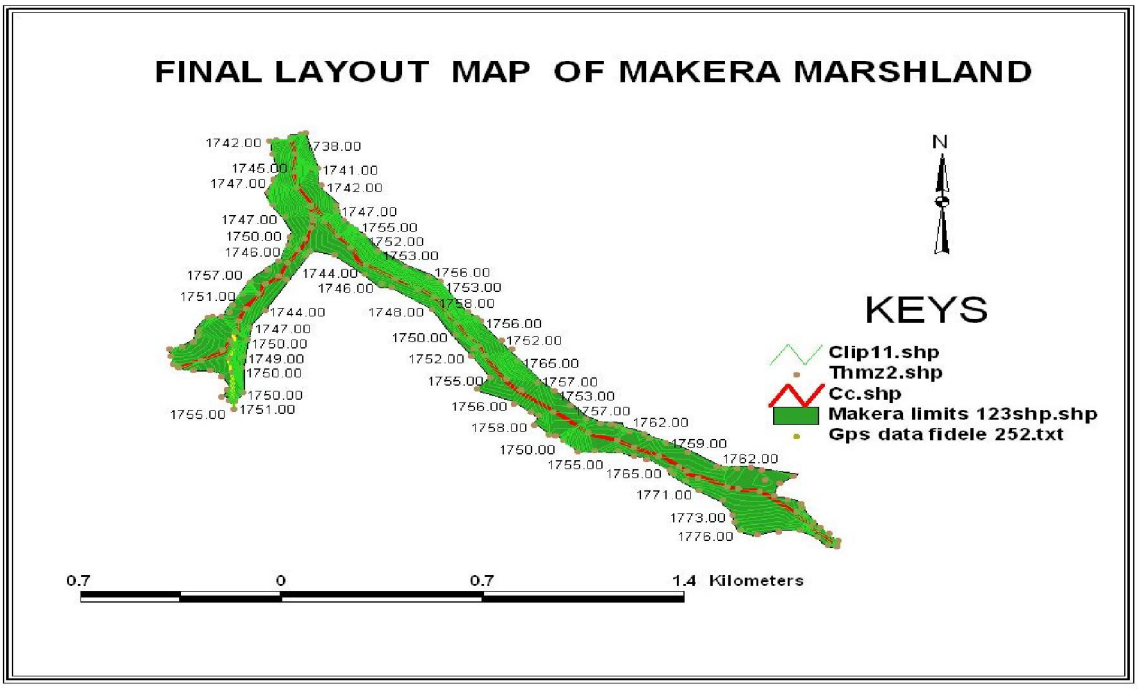

Figure 6: Final layout of Makera marshland

3.2 GIS- based flood volume capacity of Makera by using existing digital topographic map.

Topographic map showing the area of study (Makera marshland)

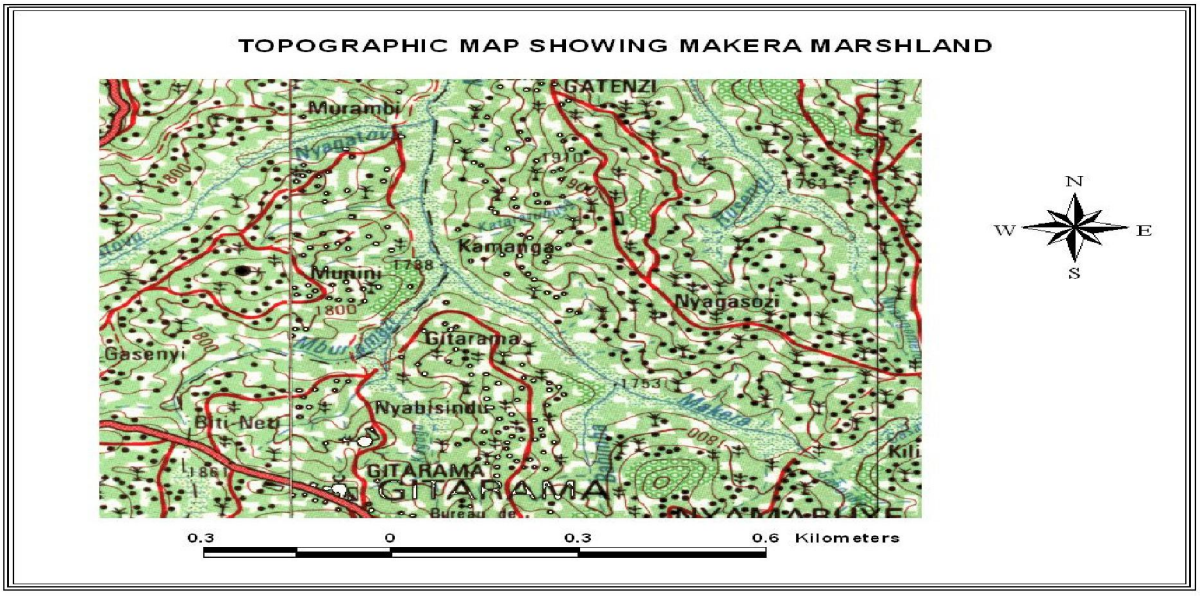

Figure 7: Topographic map of Makera marshland

Digitizing Makera marshland

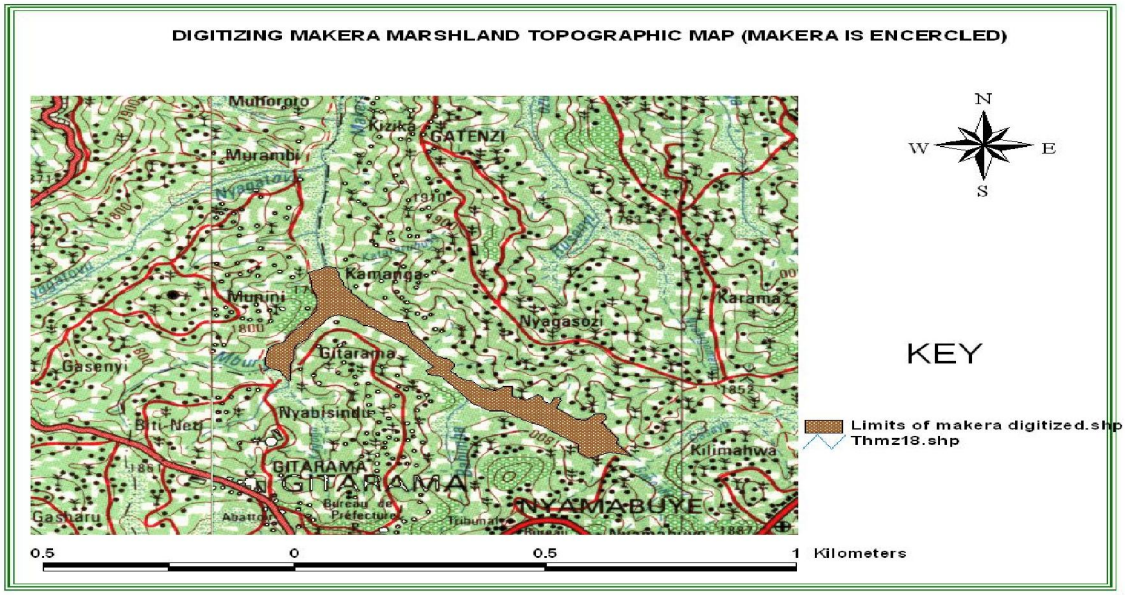

Figure 8: Makera marshland overlaid on topographic map

Digitized contour map

The planimetric area calculated was 1,914,988.688 m^2

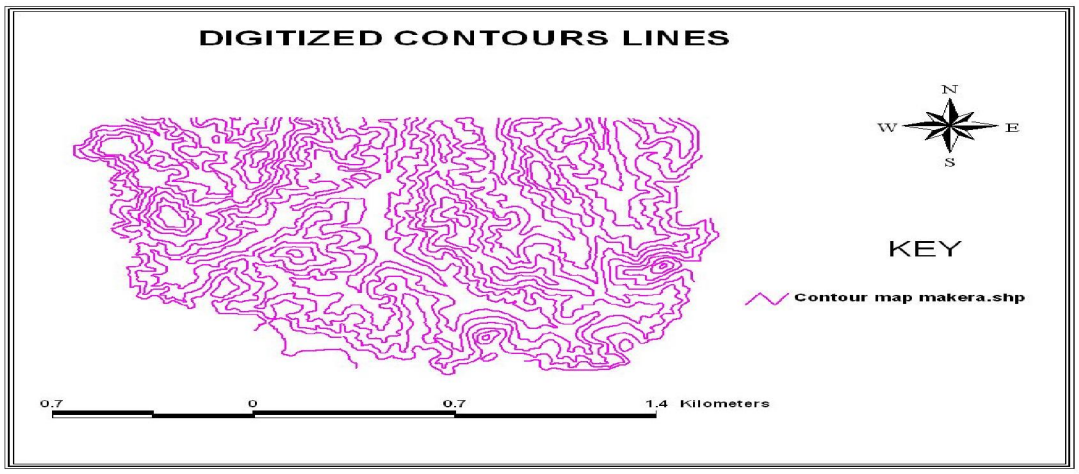

Figure 9: Digitized contour map

Determination of contained water from digitized map

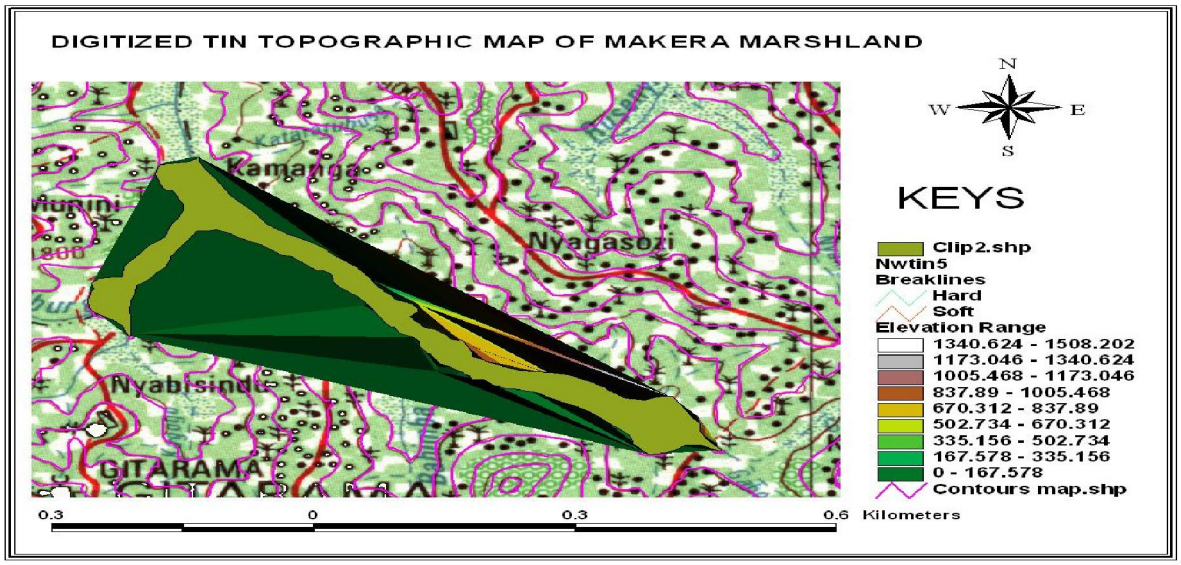

Figure 10: Digitized TIN of topographic map of Makera marshland

The flood volume of Makera marshland was about 30,150,051.248 m^3 and the planimetric area occupied by the flood volume was 1,914,988.688 m^2. Therefore, the planimetric area was calculated from the TIN covering all the limits of marshland and the external field as shown in the figure 10 above. 447840.1223 m^2 was found to be the limit covering polygon area of the Makera marshland. As the TIN covering polygon areas is known (1,914,988.688 m^2), to obtain the factor of difference N=1,914,988.688 m^2/ 447,840.1223 m^2=4.27 ≈ 4 times. Therefore, the volume = V_{TIN}/ N=30,150,051.248 m^3/4= 7,537,512.812 m^3 which is the reservoir capacity of Makera marshland calculated from digital topographic map.

4. Conclusion

This study revealed that the plannimetric area of Makera marshland is 447,840.1223 m^2, and reservoir capacity of 9,703,452.75 m^3 calculated above base height of 1733 m. The results also showed that the flood volume capacity of Makera marshland got from the existing digital topographic map was 7,537,512.812m^3calculated from the plannimetric area of 1,914,988.688 m^2. Those parameters were calculated above base height of 1733 m. By comparing two volumes, the difference was 2,165,939.938 m^3.

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