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Water Resources Management Using Satellite Remote Sensing (Case study in Lake Tana and Lake Nasser)

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Abstract

Water is the main component of the integrated and sustainable development, the expansion in various fields is linked to the ability of countries to provide the water needed for this expansion. In recent years may be caused increasing people and economic request, water supply issues are creating unprecedented pressures. Irrigate agriculture represented about 70 % of global water consumption. The economics of water use and its long-term future requires the search for alternatives and determine the amount of available water resources at the present time. Egypt and countries that share the Nile Basin show interest in studying how to determine manage and develop water resources. Managing demand is request accurate data on the water balance about the components of lakes and reservoirs and also, it is necessary for Satellite information is useful in supply a wide location extent from temporal coverage and natural resource management. Mapping using remote sensing and various traditional domain survey is provides access to extensive historical data archives for retrospective. Also In-situ hydrological measurements of reservoirs are usually not publically available. In this paper, Water balance equation and its components illustrated and focused on how open-access Satellite Remote Sensing measurements data can be used replacing field measurements. Then an assessment of TRMM (Tropical Rainfall Measuring Mission) data with respect to rain gauge data within Lake Tana in the period from 2000 to 2002 and the result have a good performance with RMSEr about 25 mm within period of high precipitation about 500 mm in August and finally Satellite Radar Altimetry data were supported by directly than the space station Radar altitude Information based water levels with the in-situ water levels from measurements over Lake Nasser prepared from Nile Research Institute of the Ministry of Water Resources and Irrigation (NRI) over three different years 1993-2000-2009 period, RMSEr equal to 0.99 m, 0.88 m and 0.46 m, respectively.

Key words: Water Balance, Satellite Remote Sensing, Satellite Altimetry, Tropical Rainfall Measuring Mission, Precipitation, Lake Nasser, Lake Tana.

INTRODUCTION

Since the 1990's, in the Earth system have become monitoring and design the water cycle is very important job (Stakhiv and Stewart, 2010). Civilization manufacturing and environmental change exert greater pressures on water use therefore, Water management will become even more important in the future (OECD, 2012). Uses three approaches: in-situ measurements, modeling, and remote-sensing observations could be water resources monitored on a global scale (Jorgensen *et al*., 2005; Harding and Warnaars, 2011; Hall *et al*., 2011 and Duan and Bastiaanssen, 2013). During the coming decades has become a major goal in hydrology for measuring water stages by remote sensing and especially by space station (The Ad Hoc Group on Global Water Datasets, 2001; Alsdorf *et al*., 2007; Duan and Bastiaanssen, 2013).

Risk evaluation has been increasing over the last few decades for the regional changes of water storage in rivers and lakes (Guha-Sapir and Vos, 2011). Moreover, the significance of measurements, the orgenal place stations controlling flow emptying is reducing. Therefore, river is provided period series which decreased from 7300 to 1000 stations between 1978 and 2013 (Global Runoff Data Centre, 2013). Reservoirs are artificial lakes created back a dam or between dykes. Also, the lakes are formed when depressions are filled with water and there are about nine million lakes in the world, and they cover a total surface area of about 1600,000 km². The total water storage in these lakes is about 230,000 km³ (Bengtsson *et al*., 2012). Based on various data sources, Chao *et al*. (2008) assembled a comprehensive list of 29,484 reservoirs constructed in the world since 1900, and the total nominal capacity is about 8,300 km³. Uses lakes and reservoirs are many purposes such as for domestic and industrial water supplies, flood control, hydroelectricity generation, irrigation, recreation, navigation, fishing, atmospheric cooling, leaching of saline water intrusion, dilution of polluted water and provisional services to coastal ecosystems. Lakes and reservoirs have a key function in storing excess water from periods of high rainfall to provide water during dry spells. The water stored in lakes and reservoirs play a vital role in the economic development and many services that contribute to the well-being of communities up to kilometers downstream (even across administrative borders) and in close proximity to lakes and reservoirs (Medina *et al*., 2008; Singh *et al*., 2010). The gross storage capacity of Lake Nasser in Egypt is for instance 168 km³, two times the annual flow of the River Nile at Dongala. It is the major source of water for Egypt. The growing need for food will induce additional demand for new irrigation systems, and thus more dams. Savenije *et al*. (2014) comprehensively discussed the importance of water resources and evolving relation between water and human beings.

The demand for water resources is increasing, and storage of sufficient water to meet water demand during dry seasons and below-average rainfall years is becoming increasingly important. Lakes and reservoirs thus require a comprehensive and effective water management and planning strategy. Water quality assessment and preservation is also inextricably linked to the water balance of lakes and reservoirs (Ferguson and Znamensky, 1981). In addition, assessment of the long-term water balance of lakes and reservoirs provides a quantification of human effect on water resources and improved knowledge of regional and global climate change (Cretaux and Birkett, 2006; Velpuri *et al*., 2012; Bracht-Flyr *et al*., 2013; Sutcliffe and Petersen, 2007). In a recent paper, Mahe *et al*. (2013) described the changes in river flow in Africa due to climate change and anthropogenic modifications. These changes in river flow affect the size and volume of water stored in lakes and reservoirs, and the authors concluded that river flow is a witness of climate change.

A solid understanding and quantification of the water balance of lakes and tanks is effective water management strategy. Many global hydrological models have been created during the last 10 years. They describe the earthly water balance at continental levels, and they are increasingly used for earth climate influence estimateand more recently also for water scarcity analyses. The driving forces for developing global hydrological models are multiple, and reservoir management is one of these driving forces. Some common Global Hydrology Models are PCR-GLOBWB (van Beek *et al*., 2011), WaterGap 2 (Alcamo *et al*., 2003), LPJmL (Bondeau *et al*., 2007), HO8 (Hanasaki, 2010), WBMplus (Wisser *et al*., 2010) and GWAVA (Meigh *et al*., 1999). Space station obtain something from data supply serious information about water bodies advantage as channel geometry, water surface region, water levels, Precipitation Measurement and formed mainly of river extension (Rokni *et al*. 2015; Schumann and Moller 2015; Smith 1997). Swenson and Wahr (2009) estimated the outflow from Lake Victoria using satellite remote sensing data and limited ground measurements. In their study, the changes in lake level were estimated from satellite altimetry data; precipitation over land catchments and the lake were estimated from TRMM-3B43 monthly data; lake evaporation was estimated using the bulk aerodynamic formulae, and all required input were parameterized using surface pressure from ECMWF operational analyses and satellite-derived wind speeds, sea surface temperatures, and near-surface atmospheric humidity; lake surface inflows were modeled as being proportional to precipitation and lake subsurface flows were modeled as being proportional to the water storage changes derived from GRACE data; during modeling of lake surface and subsurface inflow, the measured outflow were used to determine several associated coefficients. After the coefficients were determined, the authors further estimated Lake Outflow as a residual in the water balance, but they found large errors in the estimated outflow and concluded that currently available satellite data were not sufficiently accurate to estimate the outflow from Lake Victoria as a residual.

The major component of the hydrological cycle is precipitation and it was a natural phenomenon thus in a sense dominate of a natural resource water a stock that affect economical, environmental and agricultural (Bohnenstengel *et al*. 2011; Marzano *et al*. 2010). Traditional accurate measurement is essential cannot supply for enough and safe locative exemplification caused to the comparatively sparse dealing out of measure networks (Javanmard *et al*., 2010).

Since 1997, Tropical Rainfall Measuring Mission (TRMM) precipitation information have been widely estimated with the best achievement (Kummerow *et al*., 2000 and Dinku *et al*., 2007) and it was used as hydrological design (Li *et al*., 2012; Su *et al*., 2008; Swenson and Wahr, 2009), overflow forecast (Li *et al.*, 2009), the fall of rain evaluation (Vrieling *et al*., 2010) and the climatologically studies (Islam and Uyeda, 2007). A researcher has observed the highest changes of the little scales precipitation (Krajewski *et al*., 2003). Collecting satellite to greatly improve the accuracy of rainfall evaluation rainfall data with rain gauge data (Boushaki *et al*., 2009; Cheema and Bastiaanssen, 2012 and Li and Shao, 2010).

Many large reservoirs have been constructed recently to store fresh water from lakes and reservoirs and make it available to household, manufacturing, agriculture, hydroelectric power, wetlands and environmental water. (Avakyan and Iakovleva, 1998 and Gleick, 2003). Distribution of water is balance achieved between water available in lakes, tankes and the water request from differences sectors. The best understanding of the environmental changing impacts is constant and control of storage differences in lakes and tanks is fundamental for fair and impartial water division to water section and environment services system (Birkett, 1995; Crétaux and Birkett, 2006 and Crétaux *et al*., 2011).

The measurement of height for space station Radar/Laser can be used to evaluate water standard of unlock water organism. Moreover, the measurement of height for space station Radar can be work under all weather conditions and environmental (Birkett and Beckley, 2010). The measurement of height for space station Radar is work continuously until 35 days. In1974 with Skylab is first appeared the measurement of height for Satellite Radar. In 1975, the GEOS-3 the measurement of height for Radar was designed to monitor ocean surfaces, followed by the SEASAT (1978) and GEOSAT (1985-1989) function. The measurement of height for Radar was come in a before for use stage in 1992 to 2001 with the space stations different. Also, measuring the level of the ocean through a collection of a Radar technique define the measure from the space station to the reflecting surface and a space station status technology characterize the accurate position of the space station as shown in Figure (1).(Bercher, 2008). Moreover, the usage of these technique had acceptable controlling of the inland waters (Aladin *et al*., 2005), lakes (Birkett, 1995, 2000; Birkett *et al*., 2002; Crétaux and Birkett, 2006) and big rivers (Birkett, 1998; Mercier, 2001; Maheu *et al*., 2003). The measurement of height for space station Radar had been utilized comleting to come water standard of continental flatten water bodies as inland water, lakes and rivers (Calmant *et al*., 2008; Crétaux and Birkett, 2006). Morris and Gill (1994) and Birkett, (2000) observed that the over other world lakes indicated Root Mean Square Error (RMSEr) was greater than 10 cm for Lake Chad and also, approximately 5 cm for Issyk Kul Lake, Kyrgyzstan; and 10 cm for Chardarya Lake, Kazakhstan (Crétaux and Birkett, 2006).

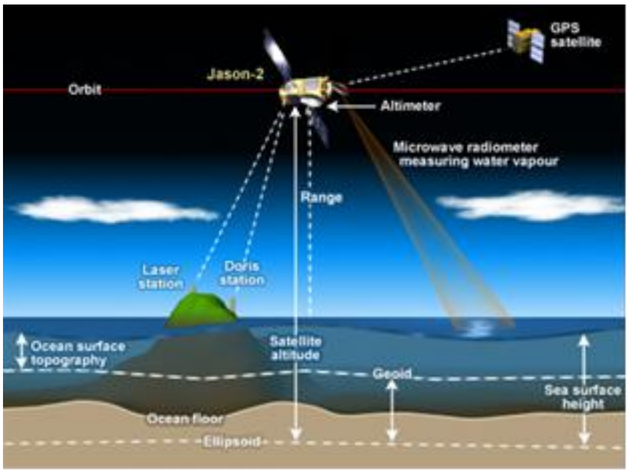

Fig. 1: Satellite Altimetry Working Technique.

Birkett *et al.* (2002) and Bercher (2008) studied that the selection of rivers and floodplains in the Amazon Basin using the measurement of height for Satellite Radar. Essential wrong were observed with RMSEr values between 40 cm and 1.1m. ICESat-GLAS derived water levels in lakes showed that better than 10 cm with Lake measure information (Bhang *et al*., 2007; Zhang *et al*., 2011). The ICESat-GLAS level 2 Global Land Surface the measurement of height for space station Radar information (GLA14) was used to conclude water levels for lakes (Phan *et al*., 2012; Swenson and Wahr, 2009; Zhang *et al*., 2011, 2011). Table (1) illustrated the measurement of height for Satellite Radar function up to date. At the present, there are three databases depended on the measurement of height for Satellite Radar for selected water areas are operationally able to be reached : the Global Reservoir and Lake Monitoring (GRLM) database, the River Lake Hydrology (RLH) database using The River and Lake Project, and the website database. These databases had contained five measurements of height for Satellite Radar. Moreover, the measurement of height for space station Radar was collected with space station imagery to obtain volume differences of surface water in big river basins such as the Negro River Basin (Frappart *et al*., 2005, 2008, 2011), lower Mekong River Basin (Frappart *et al*., 2006b) and Lower Ob' Basin (Frappart *et al*., 2010). Crétaux *et al.* (2005) observed that the build volume differences in the in lake Big Aral Sea by digital the deeplymetry sample and water levels take from T/P the measurement of height for Satellite Radar information. Peng *et al.* (2006) obtained that from the water level volume relationship for Fengman Tank, China, using original place water levels and surface regions obtained from Land sat imagery information. Zhang *et al.* (2006) transform the water standard obtained from T/P the measurement of height for Satellite Radar information to water stock in Lake Dongting, China, by the water level-stock connection which was determined from T/P altitude water standard and original place water stock measurements. Smith and Pavelsky (2009) calculated water stock changes in nine lakes at Canada by place water levels and remotely sensed regions. Medina *et al.* (2010) evaluated that the water size differences in Lake Izabal by the original place water standard and the measurement of height for Satellite Radar (RA-2) and Advanced Synthetic Aperture Radar (ASAR) images. The obviously procedure depend completely on the accessibility of passing maps or original place water volumes which are non-present for most remote lakes. Meanwhile, the space station gravimetric has been measurement of height for Satellite Radar and studies the water volume differences in the very big inland water bodies (Singh *et al*., 2012).

Table 1: Satellite Mission and Operating Characteristics of Altimeters.

Altimeter	Launch	End	H (km)
Seasat	26 Jun 1978	Oct 1978	800
Geosat	12 Mar 1985	Jan 1990	800
ERS-1	17 Jul 1991	Mar 2000	784
Topex	10 Aug 1992	Jan 2006	1336
Poseidon	10 Aug 1992	Jan 2006	1336
ERS-2 Sep 2011	21 Apr 1995	Sep 2011	784
GFO	10 Feb 1998	Sep 2008	800
Jason-1	7 Dec 2001	Jul 2013	1336
Envisat	1 Mar 2002	May 2012	784
ICESat	1 Jan 2003	Aug 2010	600
Jason-2	20 Jun 2008	Present	1336
CryoSat-2	8 Apr 2010	Present	717
HY-2A 15	Aug 2011	Present	971
SARAL/Altika	25 Feb 2013	Present	800

(AVISO, 2016; NASA, 2016; Vignudelli *et al*., 2011)

This study demonstrated the high potential of satellite remotely sensed data and consist of three parts, part one focus on illustrating water balance equation and its components and how Satellite Remote Sensing data can be used replacing traditional data in different water balance components. Part two deals in detail with precipitation, one of the most important components in water balance and an assessment for TRMM satellite data with respect to rain gauge data within Lake Tana has been done. Finally, part three, Satellite Radar Altimetry data verified with In-situ water level measurement and used to monitoring Lake Nasser water level.

Table 2: Available Rain Gauge Data.

YEAR/Month	2000	2001	2002
JAN	0.0	0.0	0.0
FEB	0.0	0.0	1.2
MAR	0.3	1.0	8.2
APR	27.0	22.7	15.9
MAY	61.2	54.8	33
JUN	153.7	257.3	437.2
JUL	314.2	379.6	461.8
AUG	512.2	522.1	395.0
SEP	225.8	142.5	154.9
OCT	179.3	86.7	17.8
NOV	27.8	2.5	0.5
DEC	0.0	12.5	1.0
Annual Precipitation (mm/year)	1501.5	1481.7	1495.5

2. Available Data Used:

2.1Rain Gauge Data:

Monthly total rainfall information, for Lake Tana Basin from rain measure stopping place at the southern part of Lake Tana were obtained from the Ethiopian National Meteorological Agency. From 2000 to 2002 the available information for three years are shown in Table (2). The rain gauge analysis is showed that during 2000-2003 the medium yearly rainfall was about 1490 mm/year.

2.2 In-Situ Water Level Measurement:

The collected data form Nile Research Institute of the Ministry of Water Resources and Irrigation (NRI) for River Nile Basin, these data are In-situ water level monthly measurement collected from a number of gauging stations within Lake Nasser in south part in Egypt. These data are in Excel sheets from 1993 to 2009.

2.3 Version 7-TRMM 3B43 Data:

In November 1997 was began a collection project by National Aeronautics and Space Administration (NASA) and the Japanese Space Agency (JAXA) by the Tropical Rainfall Measuring Mission (TRMM). An area of products from TRMM is came about and freed for free uses during many websites. The TRMM Multi-space station Precipitation Analysis (TMPA) was prepared to collect from obtain downpour information collection from different space station sensors and monthly surface rain standard information to give better evaluation of downpour at locative decision of 0.25° (Huffman *et al*., 2007). The TRMM 3B43 monthly information is one of TMPA products and it was used in this study for three years from 2000 to 2002. The final Version 7 was freed during May 2012.

2.4 Satellite Altimetry Data from Global Reservoir and Lake Monitor (GRLM):

Actually, GRLM provide a association of T/P, Jason-1 and Jason-2 (TPJO.1 version) time-series related with water level different with estimate to the mean 9-year T/P level at 10-day period for 80 lakes/tanks. At a recent time database was ENVISAT space station to observe time-series of water level differences for just vow about 228 of the world's the biggest lakes and tanks in a near-real time method of ready for use. The data of version TPJO.2.3 including water levels and estimated errors for Lake Nasser from GRLM were used in this study. A 10-day temporal resolution for 1993, 2000 and 2009 years used to observe the comparative difference in surface water level in Lake Nasser. The relative lake height differences calculated from Jason-2/ and TOPEX.

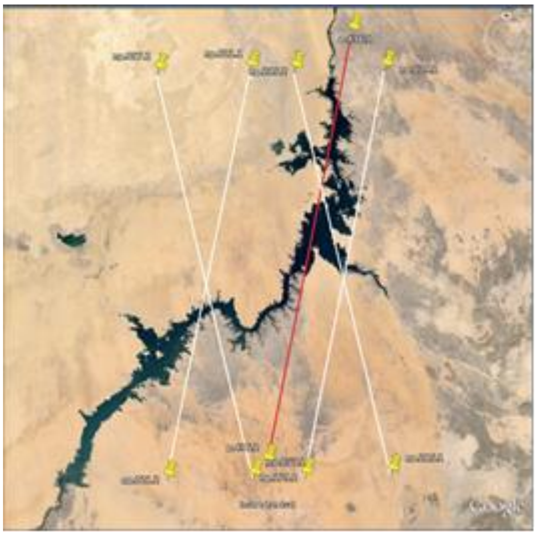

Fig. 2: Sample Altimetry Tracks Over Lake Nasser in Egypt.

3. Study Area Under Investigation:

3.1 Lake Tana Basin:

Lake Tana Basin is located in the northwestern highlands of Ethiopia. The water region was about 3100 km² and its high ranges from 1791 to 4084 m above mean sea level. The weather is wet monsoon (June-September) and a dry monsoon (October-March). The mean annual temperature is 20°C (Setegn *et al*., 2011). The upper Blue Nile Basin is believed to be the biggest and economically essential water resources for Ethiopia due to including Lake Tana Basin (Taye and Willems, 2012). Moreover, Lake Tana is the source of the Blue Nile River and it was gifted more than 60% of total flow water into the River Nile at Aswan - Egypt (Uhlenbrook *et al*., 2010).

3.2 Lake Nasser:

Lake Nasser lies in the extreme southern part of Egypt occupying a considerable area behind the High Aswan Dam. Due to the large area of extent and the huge mass of water in this lake, it is the second big artificial lake in the world. The Lake is based fundamentally on relating to granitic land and extends southward at Egyptian-Sudanese border. High Dam Lake is bounded by latitudes 24°N in Egypt and 21°S in Sudan. Lake Nasser water is a main source for drinking, agriculture, and household purpose in Egypt The shoreline of Lake Nasser at 160 m (AMSL) is 5416 Km and at 180 m (AMSL) level is 7875 Km length. The length of eastern shoreline is almost double that of the western shoreline.

4. Methodology:

4.1 Water Balance Components for Lake:

In general, the water balance equation for a lake or reservoir can be written as (Ferguson and Znamensky, 1981; Sokolov and Chapman, 1974):

$$dV_{lake}/dt = R_{land} + A_{lake}\,(P_{lake} - E_{lake}) + G_i - G_o - O_{lake} + \varepsilon \qquad (1.1)$$

Where:

- Vlake: is the water volume stored in a lake or reservoir,
- dVlake/dt: is the change in lake water volume over the time period dt,
- Rland: is the surface inflow into the lake or reservoir from the surrounding landbased river basins,
- Alake: is the surface area of the lake or reservoir which is a function of water level,
- Plake: is the precipitation over the surface of the lake or reservoir,
- Elake: is the evaporation from the lake or reservoir,

- Gi and Go: are the groundwater inflow and outflow into the lake or reservoir, respectively,
- Olake: is the surface outflow from the lake or reservoir,
- ε: represents the accumulated errors from all components in Eq. (1.1) and other factors such as abstraction and human water use. These factors usually cannot be accounted for directly and has been assumed to be zero in many water balance studies (Sene, 2000).

Fig. 3: Lake Tana in Ethiopia.

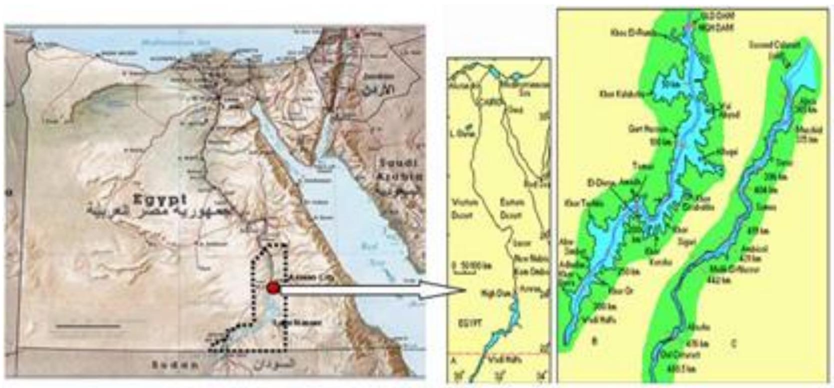

Fig. 4: Lake Nasser in Egypt.

The term Rland links a lake or reservoir with the water yield from the surrounding catchments. The simple water balance equation of catchments feeding lakes and reservoirs can be written as:

$$dS_{land}/dt = P_{land} - ET_{land} - R_{land} \quad (1.2)$$

Where:

- dSland/dt is the change in land total water storage Sland,
- Pland is the precipitation over the river basin,
- ETland is the actual evapotranspiration over the river basin.

Figure (5), presents the general water balance components of a lake or reservoir and its catchment areas. The relative importance and the need to consider each individual component in the water balance equation can vary, depending on the type and dimensions of a lake. For example, some lakes (the Caspian Sea, Lake Chad and the Dead Sea) are terminal lakes with no outflow; some kettle lakes are part of the groundwater system with only groundwater inflow and outflow (Bengtsson *et al*., 2012). For lakes with a relatively small drainage basin, precipitation and evaporation over the lake surface are usually the dominant water balance components.

To close the water balance equation of a lake or reservoir, all components should be measured or estimated independently (Sokolov and Chapman, 1974). The common usage of the water balance equation is to estimate the unknown component as the residual. In this respect, the accuracy of the estimated component depends on the accuracy of each known component and will include the accumulated errors from the other known components. It is thus necessary to improve the quantification of each water balance component independently.

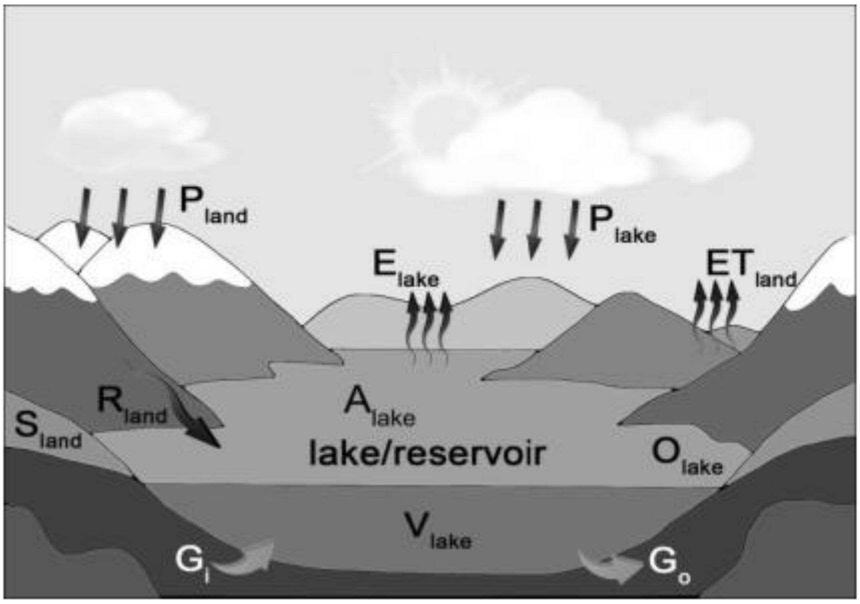

Fig. 5: The General Water Balance Components of a Lake or Reservoir.

4.2 Using Remote Sensing to Estimate Water Balance Components:

From the previous water balance equation, in-situ measurements of each water balance component should provide a complete understanding of inflow, storage changes and outflow of a lake. But in reality it is difficult to direct measure all these components or always data are incomplete and inadequate to represent the real average values over a lake and surrounding catchments or data are of poor quality and not shared with the public. With Satellite Remote Sensing technology that plays an important role in water balance studies estimating the key water balance components of lakes, the below steps explore in general the use of Satellite Remote Sensing methods to estimate each water balance component.

4.2.1 Surface Inflow into Lakes and Reservoirs (Rland):

The surface inflow into lakes can be determined by measurements of runoff from the contributing catchment. However, in most cases, upstream sub-basins are partially gauged; fifty percent of catchments contributing to the inflow to Lake Tana (Wale *et al*., 2009) are ungauged, which makes it difficult to estimate the total inflow water of the lake. And in most cases estimates of inflow involve rainfall-runoff modeling and need more studies on runoff prediction with respect to lake evaporation and lake interaction with groundwater which are very difficult to assess, and can only be obtained by accounting for all other flows with a high accuracy. The reality is thus that the water balance of lakes and reservoirs are usually incomplete. So, there are no direct satellite measurements available for runoff but can be inferred from water balance components (precipitation, evapotranspiration, soil moisture, total water storage) that can be measured independently by satellites, and more and more satellite products are becoming available to the public.

4.2.2 Precipitation over Water Surface of Lakes and Reservoirs (Plake):

Precipitation can be measured by installing rain gauges over lakes and reservoirs and for large lakes, more than one gauge is needed to determine the spatial average precipitation. However, such measurements are often lacking and no gauging stations installed over the surface at all. As a result, it is still common practice to use precipitation measured in the nearby land or shoreline to determine lake precipitation. For this purpose either directly measured precipitation data from one land-based gauge station or interpolated precipitation from several available nearby stations is used (Rientjes *et al*., 2011). Satellite Remote Sensing can provide precipitation data over a water surface by measuring the atmospheric conditions in terms of perceptible water.

Satellite precipitation data as Tropical Rainfall Measuring Mission (TRMM) data generated by Climate Prediction Center which can be used, but its requires a local calibration using rain gauges installed over water surfaces, Therefore, the associated errors in estimating precipitation over lakes and reservoirs are not well known and ignored in most studies. The difficulties with installing and maintaining rain gauges over a water surface for long-term periods are not easy to overcome satellite precipitation data may thus be the best available data for water balance studies of lakes and reservoirs.

4.2.3 Water Volume of Lakes and Reservoirs (Vlake):

The volume of water stored in lakes or reservoirs is the water directly available for downstream users and it cannot be measured directly to determine water volume requires water level and water surface area information. Traditionally, the water volume is estimated based on in-situ water levels and bathymetry maps. Water levels can be measured with in-situ gauging stations and bathymetry map can be obtained from hydrologic surveys, using sonar sensors to measure the underwater topography. Based on the bathymetry map, a functional Area-Level and Volume-Level relationship can be derived. The water volume and surface area for a given water level can then be computed. Bathymetry maps are usually non-existent or difficult to obtain. In addition, the number of in-situ gauging stations has decreased in recent years around the globe (Alsdorf *et al*., 2007; Calmant *et al*., 2008; Cretaux and Birkett, 2006), which makes in-situ water levels more scarce.

Satellite Radar and Laser Altimetry have been used successfully to estimate water levels of open water bodies with an accuracy better than 10 cm (Calmant *et al*., 2008; Cretaux and Birkett, 2006; Zhang *et al*., 2011a) as Global Reservoir and Lake Monitoring (GRLM), River Lake Hydrology and Hydroweb. Satellite imagery data are available for water surface area determinations at a range of spatial and temporal resolutions; it used to extract the water surface areas (Frappart *et al*., 2005; Liebe *et al*. 2005; Medina *et al*., 2010; Peng *et al*., 2006; Smith and Pavelsky, 2009). Various land use/cover classification methods (Song *et al*., 2012) used for extracting water surface extent and further calculation of the surface area. Therefore, it is feasible to combine satellite altimetry and satellite imagery data to derive water volume without using any in-situ measurements

4.2.4 Evaporation from Lakes and Reservoirs (Elake):

Evaporation is generally considered to be the largest water loss for many lakes (Kizza *et al*., 2012). Evaporation can be measured by Bowen Ratio or Eddy Covariance techniques (Assouline and Mahrer, 1993; Blanken *et al*., 2000; Stannard and Rosenberry, 1991). Many methods have been proposed for estimating evaporation as Water Balance method, Mass Transfer method, Energy Balance method and Combination method (Lowe *et al*., 2009), these methods depends on different data as net radiation, heat storage changes, air temperature, relative humidity and wind speed. The two major difficulties in measuring these data are the meteorological and the heat storage effect. Satellite Remote Sensing can provide data for several variables related to estimation of evaporation: solar radiation, surface albedo and surface temperature. According to Swenson and Wahr (2009), satellite data can also provide near-surface wind speed and direction, near-surface atmospheric humidity and temperature over water bodies. Satellite surface temperature data as Moderate Resolution Imaging Spectro-radiometer (MODIS) have been used for many lakes and have been shown to be in good agreement with measured lake surface temperature (Reinart and Reinhold, 2008; Sima*et al.*, 2013).

4.2.5 Ground Water Flows of Lakes and Reservoirs (Gi and Go):

Groundwater inflow into and outflow from lakes and reservoirs are probably the most difficult water balance components to evaluate due to the requirements of laborious and costly measurements (Ferguson and Znamensky, 1981). There are three methods to quantify groundwater inflow into or outflow from a lake or reservoir (Crowe 1993); field-oriented method, a numerical simulation and a water balance method. Water balance method estimates the groundwater component as the residual in the water balance. The application of satellite remote sensing in groundwater studies appears to be limited. But can provide several relevant surface variables as inputs, or supporting information to groundwater models. Leblanc *et al.* (2007) used satellite imagery data to map recharge and discharge areas, and then imported the map into a groundwater model. Satellite soil moisture data have potential to support inferring groundwater dynamics, and can be used with in-situ discharge to calibrate groundwater models (Sutanudjaja *et al.*, 2014). Gravity Recovery and Climate Experiment (GRACE) data used to monitor groundwater storage changes at large basin scales greater than 200,000 km2 (Rodell and Famiglietti, 2001). Becker *et al.* (2010) mentioned that the latest GRACE data have improved spatial resolution and allow for studying smaller basins. GRACE basically measures the terrestrial water storage changes including changes in surface water, snow water equivalent, canopy water, soil moisture and groundwater components (Proulx *et al.*, 2013).

4.2.6 Surface Outflow from Lakes and Reservoirs (Olake):

The surface outflow from lakes and reservoirs is the water released to downstream multiple sectors. It can be estimated using water level (h) and the predefined level-outflow functional relationship Q (h) or rating curve (Nicholson *et al.*, 2000; Piper *et al.*, 1986). The Q (h) relationship pertains to site-specific hydraulic structures such as gates, weirs and turbines. Historical in-situ measurements of Q and h are needed to reconstruct the rating curve. The Q (h) relationship is usually not available for lakes and reservoirs. In addition, the Q (h) relationship may change over time for the same lake or reservoir due to hydraulic modifications and clogging features. In the absence of a locally calibrated Q (h) relationship, the universal method for estimating outflow is to quantify independently all other water balance components of lakes and reservoirs and then compute outflow as a residual term in the water balance.

4.3 TRMM Satellite Precipitation Assessment over Lake Tana:

In this part, Version 7-TRMM 3B43 monthly precipitation data 0.25°x 0.25° in NetCDF format were obtained from: **http://mirador.gsfc.nasa.gov** for the period from 2000 to 2002. These data converted to Raster layer using make NetCDF to Raster layer tool from Multidimension toolset in ARCGIS tool box, the output for each month will be a Raster layer as a grid with precipitation value stored as pixel value, as shown in Figure (6).

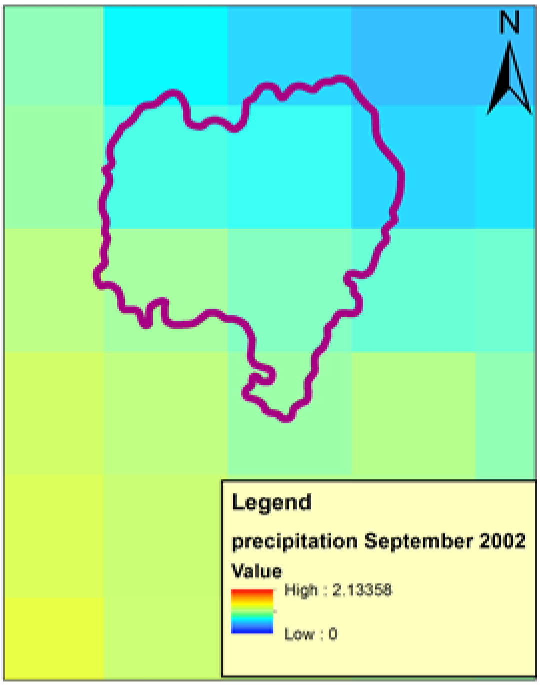

Fig. 6: Lake Tana Precipitation in September 2002.

Monthly total rainfall data from three rain gauge stations at the southern part of Lake Tana were obtained from the Ethiopian National Meteorological Agency for the same period (2000-2002) and compared to the above TRMM data, as shown in Figures (7), (8), (9).

We used Root Mean Square Error (RMSEr) as measures of performance or validation between TRMM satellite precipitation measurements and rain gauge stations measurements for the period from 2000 to 2002. The RMSEr is a measure of how far the estimated measures are from the truth values. It is defined as: (e.g., Nagler, 2004; Li, 2010)

$$\text{RMSE} = \sqrt{\sum_{i=1}^{n} \frac{(x_i - y_i)^2}{n}},$$

Where: xi is the TRMM data and yi is the rain gauge stations measurements.

From the previous figures we noticed that TRMM have a good performance in highest value around 500 mm and in lower values and the difference between rain gauge stations measurements to TRMM obtained data about 4 mm in year 2000.

4.4 Monitoring Lake Nasser Water Level using Satellite Altimetry:

The principle behind Satellite Radar Altimetry is as follows: the altimeter emits a radar pulse and measures the two-way travel time from the satellite to the surface. The distance between the satellite and the Earth's surface, the altimeter range (R), is thus derived with a precision of a few centimeters. The satellite altitude (H) with reference to an ellipsoid is also accurately known from orbitography modeling. Taking into account propagation delays from the interactions of electromagnetic waves in the atmosphere and geophysical corrections, the height of the reflecting surface (h) with reference to an ellipsoid or a geoid can be estimated as follows:

h = H − R − Cionosphere − Cdry troposphere − Cwet troposphere − Csolid Earth tide − Cpole tide

Where:

- Cionosphere is the correction for delayed propagation through the ionosphere,
- Cdry troposphere and Cwet troposphere are corrections for delayed propagation in the troposphere from pressure and humidity variations, respectively, and
- Csolid Earth tide and Cpolar tide are corrections that account for crustal vertical motions from the solid and polar tides, respectively.

In this part we used Satellite Radar Altimeter measurements from The Global Reservoir and Lake Monitor (GRLM) database in three different years (1993 – 2000 – 2009) for Lake Nasser, as shown in Figure (10), The relative lake height variations computed from Jason-2/ and TOPEX. Satellite Radar Altimetry measures water surface elevation with respect to the reference ellipsoid.

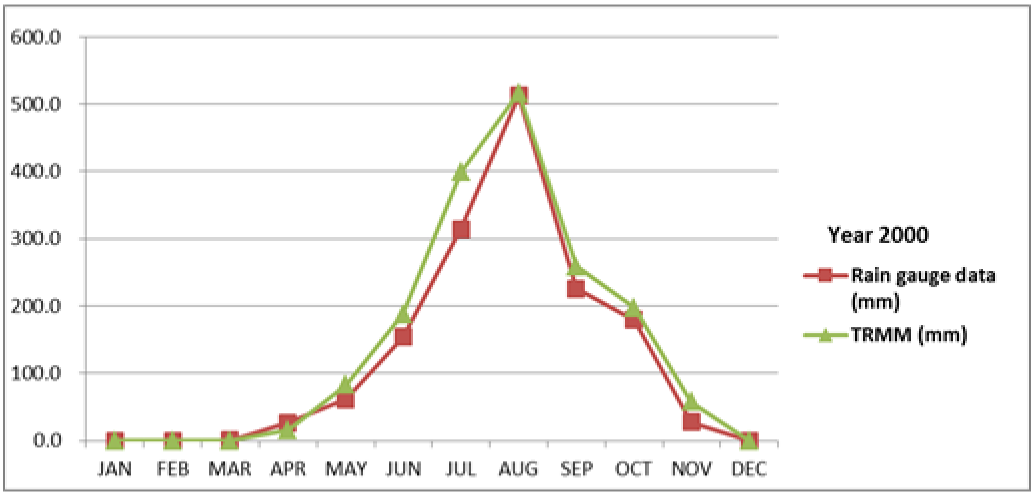

Fig. 7: Comparison between TRMM and Rain Gauge Data in year 2000.

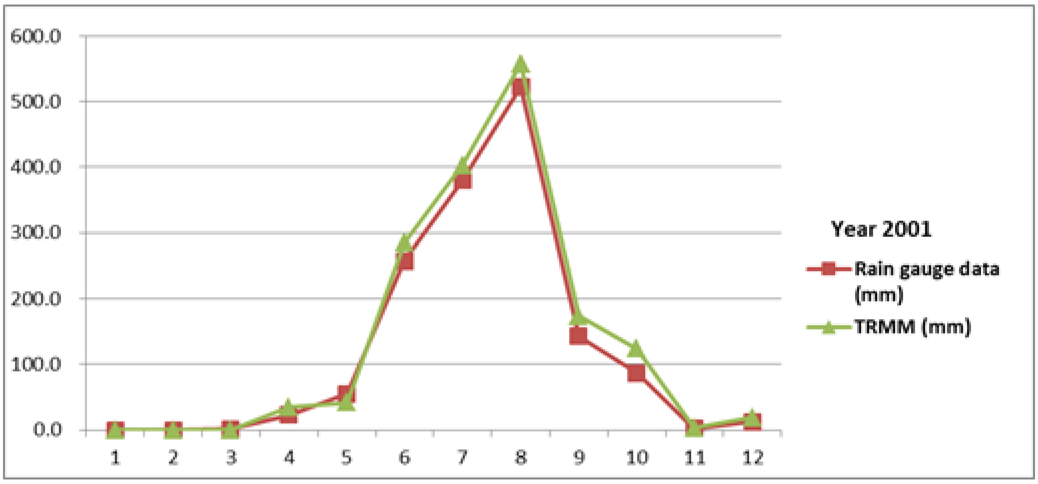

Fig. 8: Comparison between TRMM and Rain Gauge Data in year 2001.

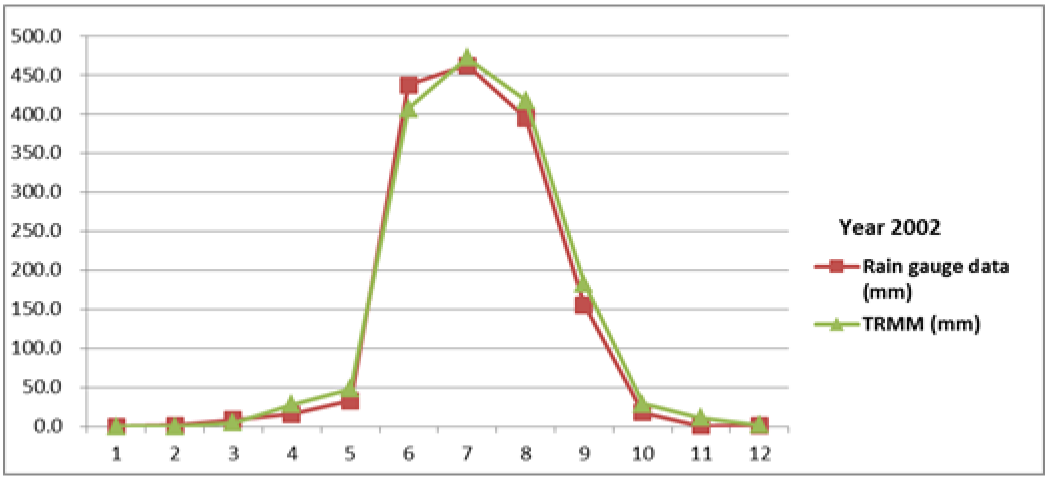

Fig. 9: Comparison between TRMM and Rain Gauge Data in year 2002.

Citation: Ali El Sagheer, *et al.*, Water Resources Management Using Satellite Remote Sensing (Case study in Lake Tana and Lake Nasser). Australian Journal of Basic and Applied Sciences, 12(7): 1-13.

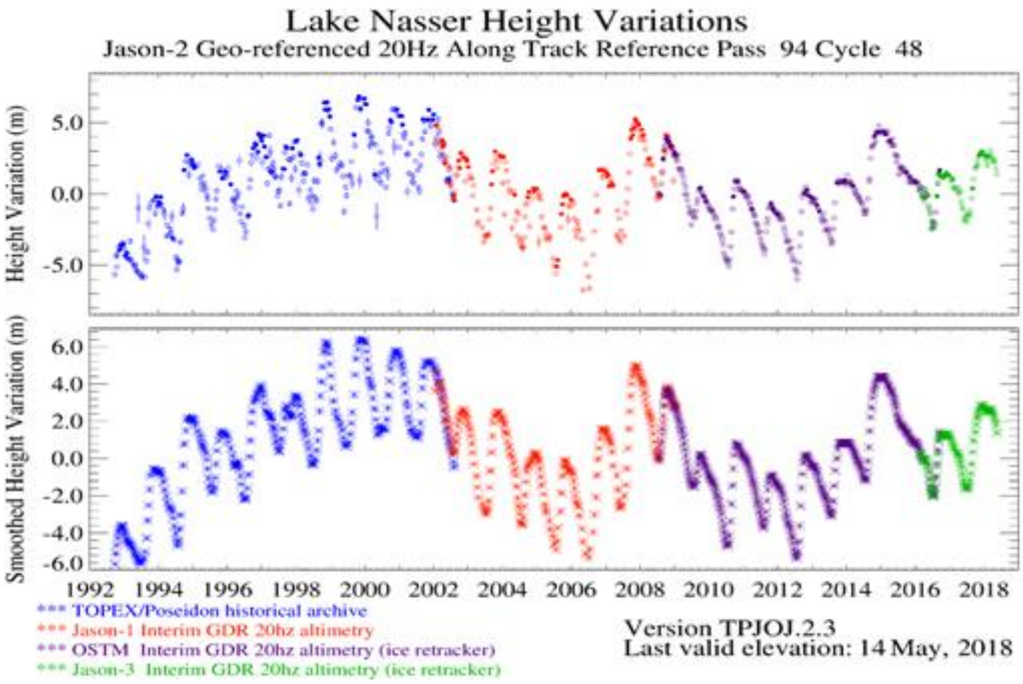

Fig. 10: Satellite Altimetry Data over Lake Nasser from Different Missions.
https://ipad.fas.usda.gov/cropexplorer/global_reservoir/gr_regional_chart.aspx?regionid=metu&reservoir_name=Nasser

The validation of satellite altimetry derived water levels is generally done by comparison with in-situ measurements from gauging stations (Birkett, 1995; Birkett and Beckley, 2010; Crétaux and Birkett, 2006), it should be noted that altimetry-derived water levels are average values along the ground tracks overflying the targets, and the tracks are usually some distance away from the gauging stations. In addition, in-situ water levels from gauging stations have their own reference datum (e.g. local mean sea level), while water levels from different satellite altimeter products are based on different geoids or references. The validation method used in this study is simply the altimetry derived water levels compared with in-situ measurements for Lake Nasser in three different years (1993-2000-2003). The Root Mean Square Error (RMSEr) of the water level differences are computed to signify error, as shown in Tables (3), (4), (5).

Table 3: RMSEr Calculation for Satellite Altimetry Data in year 1993.

year	month	Altimetry	In-situ water level	difference	square difference
1993	JAN	170.89	170.65	0.24	0.0576
1993	FEB	170.38	170.52	-0.14	0.0196
1993	MAR	170.21	170.12	0.09	0.0081
1993	APR	169.91	169.49	0.42	0.1764
1993	MAY	169.62	169.03	0.59	0.3481
1993	JUN	169.27	168.44	0.83	0.6889
1993	JUL	169.13	167.55	1.58	2.4964
1993	AUG	169.79	167.47	2.32	5.3824
1993	SEP	171.47	170.07	1.40	1.96
1993	OCT	173.85	173.05	0.80	0.64
1993	NOV	174.19	174.11	0.08	0.0064
1993	DEC	174.12	174.31	-0.19	0.0361
				total	11.82
				RMSE	0.992471662

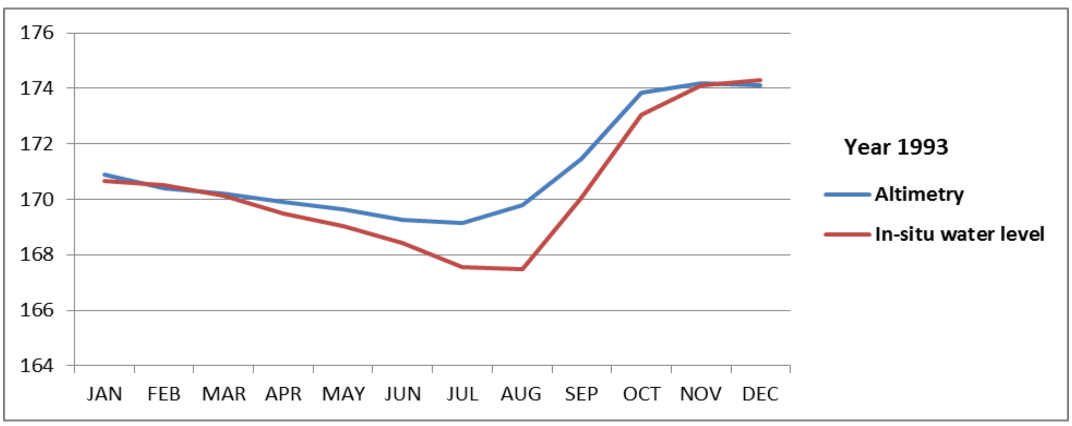

Fig. 11: Comparison between Altimetry Data and In-situ Water Level in year 1993.

Citation: Ali El Sagheer, *et al.*, Water Resources Management Using Satellite Remote Sensing (Case study in Lake Tana and Lake Nasser). Australian Journal of Basic and Applied Sciences, 12(7): 1-13.

From the previous calculation sheet and Figure (11), RMSEr between Satellite Altimetry water levels from Hydroweb and in-situ water level measurements in year 1993 was 0.99 m.

Table 4: RMSEr Calculation for Satellite Altimetry Data in year 2000.

year	month	Altimetry	In-situ water level	difference	square difference
2000	JAN	180.99	180.93	0.06	0.0036
2000	FEB	179.6	180.25	-0.65	0.4225
2000	MAR	178.73	179.66	-0.93	0.8649
2000	APR	177.46	178.9	-1.44	2.0736
2000	MAY	176.45	178.41	-1.96	3.8416
2000	JUN	176.19	177.52	-1.33	1.7689
2000	JUL	176.44	176.45	-0.01	1E-04
2000	AUG	176.35	175.85	0.50	0.25
2000	SEP	178.19	177.96	0.23	0.0529
2000	OCT	179.96	179.97	-0.01	0.0001
2000	NOV	180.37	180.57	-0.20	0.04
2000	DEC	180.5	180.53	-0.03	0.0009
				total	9.3191
				RMSE	0.881244385

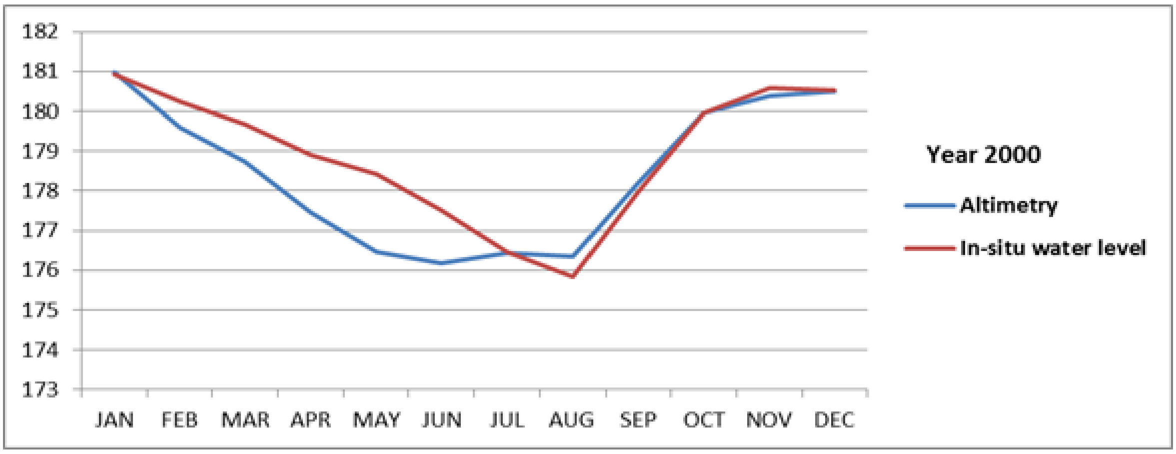

Fig. 12: Comparison between Altimetry Data and In-situ Water Level in year 2000.

From the previous calculation sheet and Figure(12), RMSEr between Satellite Altimetry water levels from Hydroweb and in-situ water level measurements in year 2000 was 0.88 m.

Table 5: RMSEr calculation for Satellite Altimetry Data in year 2009.

year	month	Altimetry	In-situ water level	difference	square difference
2009	JAN	177.44	177.81	-0.37	0.1369
2009	FEB	176.95	177.58	-0.63	0.3969
2009	MAR	176.4	177.03	-0.63	0.3969
2009	APR	175.58	176.23	-0.65	0.4225
2009	MAY	174.6	175.39	-0.79	0.6241
2009	JUN	173.76	174.29	-0.53	0.2809
2009	JUL	173.35	173.78	-0.43	0.1849
2009	AUG	173.46	173.3	0.16	0.0256
2009	SEP	174.47	174.51	-0.04	0.0016
2009	OCT	175.02	175.41	-0.39	0.1521
2009	NOV	174.64	174.7	-0.06	0.0036
2009	DEC	174.27	174.38	-0.11	0.0121
				total	2.6381
				RMSE	0.468872762

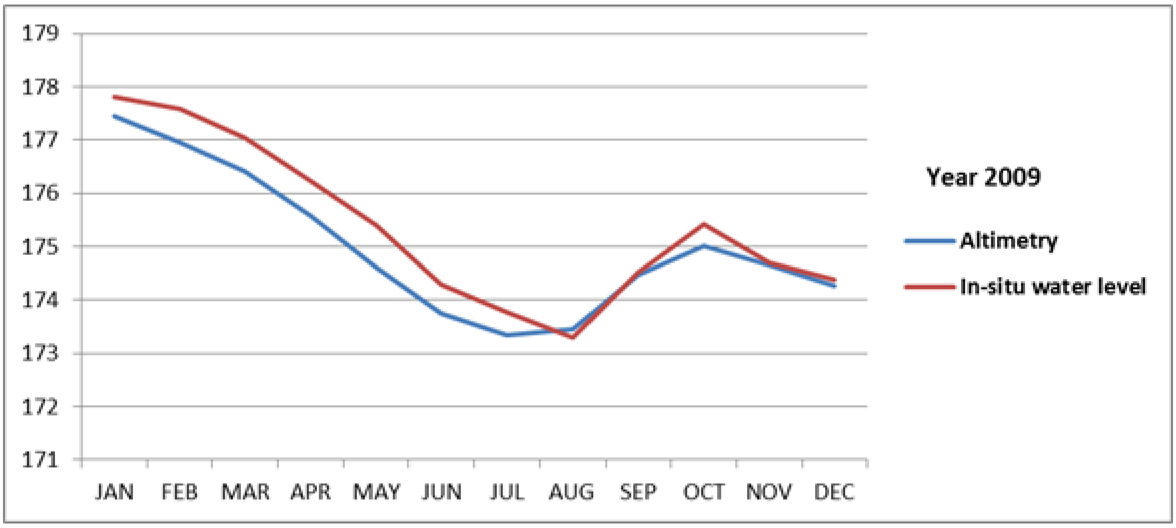

Fig. 13: Comparison between Altimetry Data and In-situ Water Level in year 2009.

From the previous calculation sheet and Figure (13), RMSEr between Satellite Altimetry water levels from Hydroweb and in-situ water level measurements in year 2009 was 0.46 m. As noticed from the previous calculation sheets and graphs the perform of Satellite Altimetry improved over time as in 1999 the RMSEr is 0.99m then in 2000 RMSEr changed to 0.88m and finally in 2009 it gives a better RMSEr 0.46m.

5. Conclusion:

Satellite information are found very useful supply locative and relating to time coverage different traditional domain scanning using remote sensing is not constrained by geopolitical limits. Therefore the uses of space station Remote Sensing have been certain to be an accurate and influential tool in ecological controlling and management. It is supply access to overall historical information archives for retrospective, up to date, cost effective, non-destructive and timely. TRMM data validated against rain gauge data within Lake Tana in the period from 2000 to 2002 and the result have a good performance with RMSEr varies from 4 to 8% from main precipitation value. This study demonstrated the high potential Satellite Altimetry observations for accurately monitoring water bodies levels, altimetry data were validated and compared with the in situ water levels from gauge measurements over Lake Nasser in three different years 1993-2000-2009 period. The RMSEr varies between 0.99 m, 0.88m and 0.46m, respectively. This result gives an overview on how Satellite Altimetry improvement over time as in 1999 the RMSEr is 0.99m then in 2000 RMSEr changed to 0.88m and finally in 2009 it gives a better RMSEr 0.46m. This part can be extended to get water volume within the lake by using free sources multispectral images to get surface area of the Lake then use bathymetric data derived from satellite images (proved in a previous study to have a good performance) to calculate total water volume in the lake.

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