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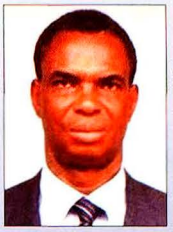

Development of Indigenous Nigerian Tide Tables

The Challenge Before the Developing Nations

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Abstract

Tidal analysis and prediction have become subjects in which a number of institutions located in coastal nations are involved, either for the improvement of knowledge of the environment or for purely commercial purposes. This paper discusses the effort being made in some developing nations particularly in Nigeria, towards joining other nations in developing their own tide tables. It shows that a lack of awareness of the importance of tidal information by the policy makers and the difficulty of obtaining cooperation from the developed nations. It goes on to discuss the approach taken by the University of Nigeria to develop Indigenous Nigerian Tide Tables.

Résumé

L'analyse et la prédiction des marées sont désormais des questions dont s'occupent un certain nombre d'instituts situés dans des pays côtiers, que ce soit pour améliorer la connaissance de l'environnement ou bien à des fins purement commerciales. Cet article traite des efforts actuellement fournis, dans certains pays en développement et notamment au Nigéria, dans le but de participer, avec d'autres pays, à l'élaboration de leurs propres tables des marées. Il montre le manque de conscience des responsables politiques face à l'importance des informations marégraphiques et la difficulté d'obtenir la coopération des pays développés. En outre, une discussion porte sur l'approche adoptée par l'université du Nigéria pour développer des tables de marées nigérianes.

Resumen

El análisis y la predicción de las mareas se han convertido en temas en los que están implicadas un número de instituciones que se encuentran en naciones costeras, ya sea para mejorar los conocimientos del medio ambiente o a efectos puramente comerciales. Este artículo trata sobre el esfuerzo que se está efectuando en algunas naciones en vías de desarrollo, particularmente en Nigeria, para unirse a otras naciones en el desarrollo de sus propias tablas de mareas. Muestra que existe una falta de conciencia de la importancia de la información sobre las mareas por parte de los responsables de tomar las decisiones y una dificultad en obtener cooperación de las naciones desarrolladas. Continua para discutir el enfoque adoptado por la Universidad de Nigeria para desarrollar las Tablas de Mareas Nigerianas Nativas.

The study of tides is employed in various fields of life including the following:

- Surge prediction and monitoring.
- Marine traffic control.
- Reduction of bathymetric data.
- Industrial and domestic water supply.
- River pollution studies in estuarine and coastal waters.
- Determination of Mean Sea Level.
- Definition of maritime baselines.

An example of a real time tide gauge was an old wooden station which was installed at Fort Hamilton, New York in 1897. The tide was observed by mariners with the aid of binoculars in which a pointer indicated the present level of tides while the vertical arrow gave an indication of falling or rising tide.
Based on the principles of harmonic motion which were postulated by Eudoxas in 356 B.C, Sir William Thomson (Lord Kelvin) devised the method of reduction of tides by harmonic analysis about the year 1867.

Several researchers such as Laplace, Dr. Thomas Young, Sir George Airy, Sir William Thomson and many others contributed in various ways to development of the theory of tidal analysis by the harmonic method.

Earlier approaches in tide analysis tried to deduce only times and heights of high and low waters but later studies were able to compute the water level values at any required intervals.

Tide predictions tables were previously computed by means of auxiliary tables and curves constructed from results of observations at the different ports. From 1885 this was accomplished with the aid of tide-prediction machines until the advent of digital electronic computers in 1966. All these have been replaced today by fast computers that are able to carry out tide analyses and separate several constituents within a short period of time.

The process of tidal analysis has made it possible to separate the various constituents that make up the complex tidal curve. Currently, more than two hundred constituents have been identified and different methods of analysis have been employed.

The harmonic method has however stood as the most common method of tidal analysis. The method requires physical observation of tides and is therefore most commonly used for locations where water level data can be directly or indirectly observed. The desire for a more detailed understanding of tidal phenomenon has continued to grow due to its importance to other fields of study in the marine environment.

The study of the tidal regime has grown from a simple investigation in order to understand the tidal processes to a fully developed subject and a commercially driven market. Many developed nations have not only undertaken the detailed study of tides of their coastlines and estuaries, but have made their products commercially available to the public. Among the published commercially available tidal works include the publications of the British Admiralty, Land Information New Zealand and the US NOAA ..

Some nations and institutions have gone beyond the confines of their territorial limits and now provide services for different parts of the world. Consequently many of the developing nations which have enjoyed such services have settled for the option of other organisations and countries providing the tidal information and have not made serious efforts towards the development of their own national tidal studies. Nigeria is one such country that has benefited tremendously from the services of the British Admiralty Hydrographic Office and the Proudman Oceanography Laboratory.

Tidal Work in Nigeria

The tidal work in Nigeria was spearheaded by the British Admiralty as part of its global studies on tides. Publications resulting from such work included the Admiralty Tide Tables – Atlantic Ocean and West Africa. The information provided for Nigerian territory included the following

- Predictions of High and Low water for Bonny which has so far remained the only internationally recognised standard port in Nigeria.
- Tidal constants (g and H) for secondary ports along the coastline and some estuaries.
- Time and height differences between Bonny as the standard port and more than 30 secondary ports including the following- Lagos Bar, Lagos town, Koko, Escravos, Warri, Forcados river bar, Forcados, Akassa,

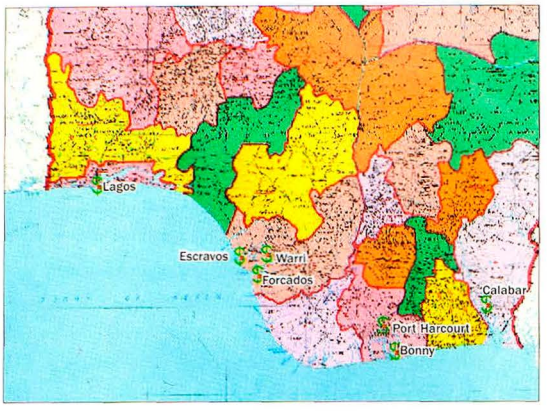

Figure 1: Locations of some proposed tide stations in Nigeria.

Figure 1 shows the locations of some of these ports. Some of the secondary ports are referenced to Bonny as the standard port, while others are referenced to the standard port at Takoradi in Ghana.

Various attempt made so far in the study of tides in Nigeria have often ended in the determination of mean sea level. However some projects on tidal analysis have been undertaken for commercially oriented purposes by some oil companies and other companies in related fields of studies. These projects have often been executed for a particular purpose and the result of such tidal studies have most often been treated as classified documents by the respective bodies. Some academic institutions have also made different ventures into tidal work as part of their research projects.

However, all the studies so far carried out are uncoordinated and efforts have resulted in duplication and some of the energy dissipated. There have also been few published predictions of tides from these studies, and, where this has been done, the predictions have often been unreliable.

The Committee of Experts

In an effort to bring more attention to tidal studies in Nigeria the Hydrographer of Nigerian Navy convened a meeting of professional hydrographic surveyors in 1987. The membership of the resulting committee was drawn from institutions of higher learning, Ports Authority and other related government agencies. At one of the earlier meetings held on February 1987 the committee was informed of an earlier attempt towards solving the problem of tidal observation and analyses in Nigeria. The earlier attempt which was made in 1984 culminated in visits to 18 proposed sites for the establishment of tidal stations. Out of this number 13 sites were finally chosen. The project was however abandoned due to financial constraints. About ten meetings of the above committee were subsequently held between February 1987 and October 1988. A summary of the problems which needed attention were enumerated as follows:

i. Some of the tide predictions contained in the existing tables were inaccurate.
ii. Correct value of MSL needs to be determined for many of the published ports.
iii. There was a need for an organized tide observation programme.
iv. Tidal analyses and prediction software are not readily available to Nigerian scholars.
v. The previously selected 13 locations need to be scaled down to 5 to accommodate scarce resources.
vi. Need for coordination of efforts of the various institutions and agencies involved in tidal work.
vii. Serious financial constraints
viii. Inaccessibility to data held by some agencies.
ix Lack of tide gauges
x. Unavailability of appropriate personnel.
xi. Absence of the BMs to which the current tidal predictions are referred.
xii. Uncertainty of the chart datum (CD) to which the predictions in the tide table are referred

Solutions

In addressing the problems posed above, the committee decided on the following lines of actions

i. Scaling down of the earlier number of proposed tidal station from 13 to 5. Further deliberations saw the need to select only 3 stations which would serve as standard ports. The stations selected were Bonny, Forcados and Lagos.
ii. Installation of more gauges as phase II of the project. The stations for the second phase were chosen as Aiyetoro, James town, Calabar, Warri, Port Harcourt and Naval base and the target was to complete installation at these locations by the

end of March 1988. This later choice superseded the earlier choice of secondary ports, which included Makun (Nigeria/Benin border) Aiyetoro, Ogidigbe, Brass, Opobo, James town, Calabar, Port Harcourt, Warri and Sapele.

iii. Creation of sub-committees for the various operations were as follows:

a) Standing committee on data collation to be domiciled at the secretariat of the Hydrographer of the Navy
b) Sub-committee to visit the existing tidal stations and assess their reliability and functionality. The stations included Lagos and Forcados installed by Nigerian Ports Authority, Bonny installed by Shell and Opobo by Rivers State University of Science and Technology.
c) Subcommittee on information gathering from oil companies.
d) Subcommittee on installation of tide gauges.
e) Subcommittee in charge of levelling tide gauges to BMs.
f) Subcommittee on logistics
g) Subcommittee on data-bank

The number and functions of the above subcommittees indicates that every effort was made to ensure that this project succeeded. Progress was recorded when at a meeting of the enlarged body held in 1988, it was reported that the subcommittee on tide gauge installation had successfully installed gauges at Bonny and Escravos. The later choice of Escravos in place of Forcados appears to have been due to logistic reasons.

Operational Constraints

Unfortunately the valuable installation of the tide gauges was short lived due to the following problems.

i. The funds needed to maintain the personnel at the gauge stations were not readily available.
ii. Technical experts needed to maintain the gauges were not available.
iii. The expendable materials needed to run the gauges could not easily be sourced.
iv. The proper datum and bench marks for the gauges had not yet been established.
v. Absence of software for the analysis of the expected tidal data.

By the end of October 1988 and resulting from the above problems it was reported that the gauges were no longer functioning.

All efforts to get financial or technical assistance from government agencies and commercial interests to continue the project were not successful. Evidently the concerted effort of the Hydrographer and his committee to provide Nigeria with some tidal capability had not achieved the desired result. It subsequently became difficult to proceed with that vision. No further action was taken until 1993 when another meeting was convened by a new Hydrographer of Navy.

The meeting which was convened in November, 1993 recognised the earlier problems. It was further reported that the fate of the three previously established tide gauges was not known. Evidently the whole project had returned to the original unsatisfactory situation.

The new body of experts decided as follows:

- Naval personnel were to man and monitor any established tide gauges.
- Data collation and processing were to be undertaken by the office of the Hydrographer of the Navy.
- Institutions of higher learning offering hydrography were to oversee the operations of the gauges closest to them.
- Relevant Government Institutions and Institutions of Higher learning to be requested to donate tide gauges when necessary.
- Software held by individuals and institutions to be made available to the committee.

Unfortunately, no fund was reported to have been budgeted for this project which was expected to be costly and all the above decisions were therefore not backed up by financial commitment. Consequently the renewed effort could not even go as far as its predecessor. By now it has become clear that the problem of Tidal Studies and other aspects of hydrographic surveying cannot be solved by committees but by organized institutions or bodies who are dedicated to such assignments.

The committee of experts was also informed on several occasions that efforts were being made to finalize legislation establishing the National Hydrographic Services. It was hoped that this body will spear

head the hydrographic operations in the nation and subsequently tackle all the existing problems including that of tidal measurement and prediction. This legislation is still awaited and interest in pursuing the various objectives appears to have waned.

Revitalising Interest in Tidal Studies

By 1994, it has become clear that the study of tides in Nigeria required a fresh coordinated approach. In addressing these problems, it became obvious that a systematic approach was needed to carry out the following objectives.

i. Acquisition of water level observation data.
ii. Development of tidal analyses and prediction programmes.
iii. Verification of obtained results with existing data
iv. Customising all results to fit the local conditions in Nigeria.
v. Convincing the government on the need to adopt the locally produced results and developed software.
vi. Personnel development to ensure continuity for future tidal studies. This is a very important aspect of the objective due to apparent lack of interest in this field of study in Nigeria.

At that time tidal predictions for Nigeria were produced in two publications viz:

a) As part of the Admiralty tide tables Vol. 2, Atlantic and Indian Ocean by the Hydrographer of the Navy, Taunton, Somerset (UK). This contained only predictions for high waters and low waters for Bonny, while data such as time and height difference relative to Bonny were given for other ports.
b) As predictions from the Proudman Oceanographic Laboratory, Bidston (UK). published by the Hydrographic of Navy, Nigerian as Nigeria Navy Tides Tables. Predictions for HW & LW were covered for Apapa, Lagos Bar, Escravos Bar, Forcados Bar, Bonny town, Kwaibo River entrance, Calabar Port, Akassa and Brass.

Progress at the University of Nigeria

Efforts were subsequently made at the University of Nigeria, Nsukka (UNN) to contribute to the study of tides in Nigeria. The Shell Company was kind enough to make available some tidal data to some students who were working in related tidal projects as part of their degree programme. This data later became valuable as initial data needed for tidal analysis.

It was however soon discovered that help was not easy to come by from both outside and inside the country as seen from the following:.

i. A request for a table of constants from a developed country came back with the offer to analyse the data free-of-charge as only one copy of the table was said to be available and therefore could not be dispensed with.
ii. A request from an oil company for financial aid to establish and harmonize tide gauges and datum was also turned down on the premise that an institution has been contracted to do same. The result of that contract, if available is yet to be known by the hydrographic community in Nigeria.
iii. A request for financial support from an International Hydrographic body was referred to Nigeria and subsequently not recommended.

The reason for the above actions may be summarized as follows:

i. Hydrographic data and especially tide prediction data has become highly commercialized and producers wish to retain their market.
ii. Oil companies are profit oriented bodies and may not readily invest where financial gain is not immediately obvious.
iii. Awareness of policy makers on importance of such specialized projects is very low or non-existent in the developing nations.

Working with Available Data

It became evident that the university study cannot expect to receive external support and must proceed independently. This programme has therefore proceeded with the development of software for tidal analyses and prediction. An analysis for a period of one year at one month interval was concurrently embarked on as a degree project under the supervision of the author. This was done by the semi-graphic method of harmonic analyses and therefore proved physically exhausting. The outcome of the project

M2	S2		K1		O1			
	g	H	g	H	g	H	g	H
UNN	148	0.70	186	0.22	26	0.13	324	0.02
ATT	149	071	186	0.23	19	0.13	342	0.02

Table 1: Tidal constants from UNN programme and from ATT

was however encouraging as it helped to add validity to the various sets of data which were computed in the process since the value of the computed tidal constants agreed closely with the accepted published values in the Admiralty Tide Tables (ATT).

The programme for harmonic analyses by the Fourier method was first developed. The computed values of Equilibrium Argument (E), nodal factors (f) and nodal correction for phase (u) were first compared with the values published in the ATT.

For short period analyses these were M_2, S_2, K_1, O_1 corrected for side band modulations as follows:

M_2 : MU_2, N_2, L_2, $2N_2$, V_2, LD_2
S_2 : T_2, R_2, K_2
K_1: M_1, J_1, P_1, SI_1, PH_1, X_1, PI_1, T_1
O_1: Q_1, MP_1, RO_1

For long period analysis, only 9 constituents were available in ATT viz. M_2 S_2, N_2, K_2, K_1, O_1, P_1, M_4, MS_4.
Agreement between the programme output and the published values indicated validity for this section of the programme.

The final stage of the software development involved the following:

i. Analyses of one month data for up to 60 constituents but only 29 primary constituents were printed for use.
ii. Vector averaging of the monthly analysis. This can be done for up to one year or above.

The process involves finding the average of the constants as follows:

$$x = \sum_{N}^{1} H_i' \sin g_i'$$

$$y = \sum_{N}^{1} H_i' \cos g_i'$$

$$H = \sqrt{x^2 + y^2} \text{ m} \qquad g = \tan^{-1}\frac{x}{y}$$

Where g', H' are the values of the individual constituents for each month of the analysis and N is the number of months analysed.

The above process of averaging is part of the program module.

iii. Tide prediction programme
iv. Tide interpolation programme
v. Programme to organize the prediction into table format for the end user as applicable in normal tide table

Since only the tidal constants for M_2, S_2, K_1, and O_1 are published in ATT. The output of the programme was therefore compared with these tidal constants for the Bonny standard port. The result is shown in table 1 and gave further confidence to the developed analysis software.

The programme has since been restructured from the Fourier method and now employs the Least Squares approach. All the above stages of the programme are organized in modules such that each stage can access the preceding modules.
Based on the above results, a tide table was produced in 1999 and the predictions were compared with those produced by the Proudman Institute of Oceanography for the Nigeria Navy.
Results of the comparison of the two values for Bonny standard port for January 1999 are shown in figures 2 and 3.

The period of comparison was chosen to cover spring and neap periods since it is expected that the maximum error, baring other non-astronomic factors, should be reflected within this cycle. The maximum difference in height and time are 0.14m and 24 minutes respectively. However the best fit polynomial of order 6 gives these values as 0.1m and 9 minutes respectively. The order of the polynomial also suggests that any noticeable errors must have been as a result of shallow water constituents. Efforts are on to address this apparent discrepancy by reviewing some aspects of the program. However, the necessary tidal observations which will be needed to

validate future results may pose constraints due to financial constraints.

The above results can further be evaluated from the following considerations:

- The IHO S44 standard for depth uncertainty for special order survey is given by

$$S = \pm\sqrt{a^2 + (bd)^2} \text{ m}$$

The values of the above parameters are given as follows: a=0.25m, b= 0.75% and maximum value of d=40m.
This gives the maximum allowable depth uncertainty as 0.39m
Accepting the predictions from Proudman as the correct values (this was the only available standard prediction by this time), with the maximum difference of 0.14m for the UNN predictions, it follows that the obtained results apparently meet any standard of survey for most navigational purposes.

- As a follow-up from above, the differences between the UNN predictions and the Proudman Predictions are therefore negligible for most practical purposes.

It therefore became obvious that both software and tide tables can be developed and produced locally. Consequently between 2000 and 2005 the author was commissioned by the Hydrographer of the Navy to produce the tide prediction tables for Nigeria.

Problem

Some problems have however remained unsolved. These were highlighted in the submission of the data for the maiden edition of the indigenous tide table and have been consistently reflected in subsequent issues, as follows:

- The occurrence of negative values of predicted water levels at some tidal stations and the high values of the annual lowest heights at other stations show that chart datum at many locations need to be adjusted.
- Regular comparison between observed and predicted values is necessary to facilitate the correction for the datum and also to verify the accuracy of the predicted heights.
- Most of the Reference Bench Marks are no more in existence. New Bench Marks should therefore be established as aid in the fixing and recovery of the gauge zeros.
- Fresh tidal observations and analysis are necessary to asses the stability of the tidal constants at these locations and hence the reliability of the tidal constants currently in use.

Challenge of Modern Technology

Many Institutions and developed nations have advanced in their tidal work and are currently publishing and marketing their products on the web. Such institutions and nations include the United Kingdom, New Zealand, Canada and the USA NOAA, etc.

These nations have well organized Hydrographic offices involved in data collection and analysis. This is far from the case of many developing nations where it has not so far been possible to set up hydrographic offices or to have any organized system of tidal studies. The UNN software is in Fortran language but efforts are being made to make it more user friendly. The problem of catching up with the rapidly advancing technology of the developed nations remains a challenge to researchers in developing nations.

Conclusion

As technology advances, the challenge of catching up with new trends in data collection and management continues to be an increasing concern to the developing nations in a competitive world.The drive for increased profit continues to pose constraints in the willingness of the developed nations to partner with less privileged nation. Sharing of data, software and other modern technologies between the developed and developing nations continue to be elusive. The NOAA of the USA has however made some contribution in transferring knowledge by providing access to academic tide packages on the web. This has not however completely bridged the wide gap in this field of study. The Nigerian case has shown that with very little encouragement, the developing nations can contribute much in solving the global problems in the maritime world. The IHO is therefore expected to view this wide gap as a global problem since the safety of navigation depends on the safety of all waters through which the vessels are expected to navigate in the course of their voyage. A concerted

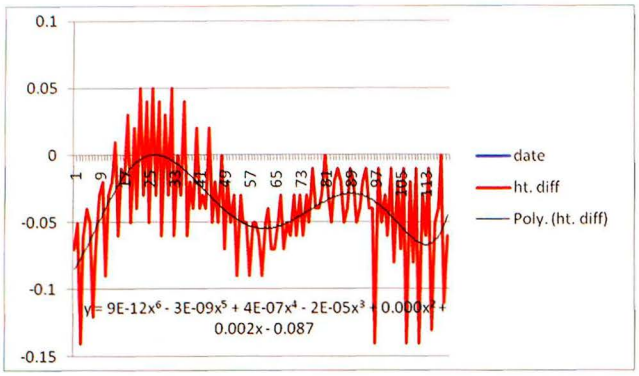

Figure 2: Curve of height differences of predictions (UNN –Proudman) in metres. From Fr. Jan1 1999 to Jan 31 1999. Location Bonny.

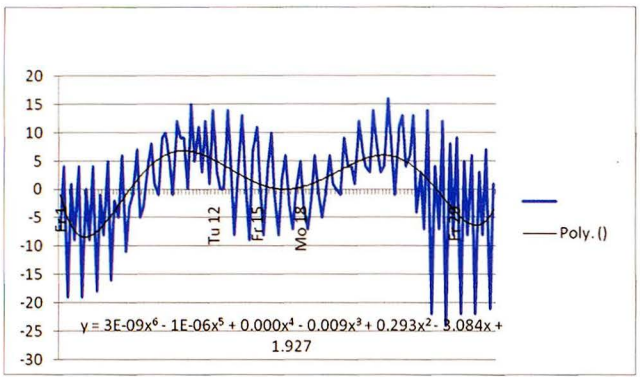

Figure 3: Curve of Time differences of predictions (UNN-Proudman) in munites From Fr. Jan1 1999 to Jan 31 1999. Location Bonny.

effort is therefore necessary to ensure this safety at all points by facilitating the development of every arm of hydrogaphy in the less privileged nations.

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