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Deducing the digital evaporation loss model of high dam reservoir

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ABSTRACT

Evaporation is the most negative phenomenon, causing huge losses in the water capacities of reservoirs. For example, evaporation at the High Dam (HD) reservoir (the water resources bank of Egypt that supplies Egypt with about 97% of its freshwater needs) which is characterized by its large water surface area (about 6000 km2 at water level 178 A.M.S.L). This reservoir, due its geographical location, is exposed to a range of climatic factors which increase evaporation rate annually, and consequently, increase the total loss of its capacity (about 10 Billion m3 of the HD reservoir capacity is lost annually due to evaporation phenomenon). Many organizations rely on an evaporation chart that gives the value of evaporation loss according to some climate variables. With respect to the problem of malfunctions of some stations, or in case of lack of data for any reason, it is important to have a digital evaporation loss model that gives the missed evaporation loss in the High Dam reservoir directly, according to two factors; the given month and the average monthly water level. This paper will explain how to get benefit from the available data of hydro-meteorological stations distributed within the High Dam reservoir, to predict the digital evaporation loss surface using the GIS prediction and conversion tools.

Keywords: GIS- Interpolation- Raster to points- Calculate geometry- Selection by attribute.

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1. Introduction

High Dam reservoir is known as one of the largest man-made fresh-water reservoirs in the world. It is about 500 km long and extends from Aswan to the south of Wadi Halfa in Sudan. The High Dam average width is about 12 km at level 178 A.M.S.L [1]. The highest recorded water level so far was 181.60 m A.M.S.L in November 1999, while the lowest level recorded so far was 150.62 m A.M.S.L in July 1988. The reservoir total capacity is about 162 billion m3 at level 182 A.M.S.L. The maximum and minimum depths have been recorded during the surveying missions are 130 and 15 meters respectively. The measured annual evaporation loss ranges between 10 and 16 billion m3 depending on water level and month, which is equivalent to 1/8.4th-1/5.25 of the annual discharge of the Nile River estimated at Aswan upstream High Dam.

2. The problem to be solved

The annual evaporation loss in High Dam reservoir is calculated from the data collected from Eight floating evaporation measurement stations distributed within the reservoir as shown in figure (1). These stations are exposed during the year to several external factors that may lead to missing some or all of the data, such as standing birds or their residues on some sensors [2]. Sometimes some sensors are stolen, but then legal action is always taken. Sometimes the installation chain breaks and the station may be lost until it is found again. The loss of these data may result in inaccuracy of the total evaporation loss to be calculated [3]. On the other hand, this problem could be solved by deducing a digital model that accurately reflects the three dimensions of the evaporation phenomena of the reservoir, i.e., month, water level and evaporated quantity.

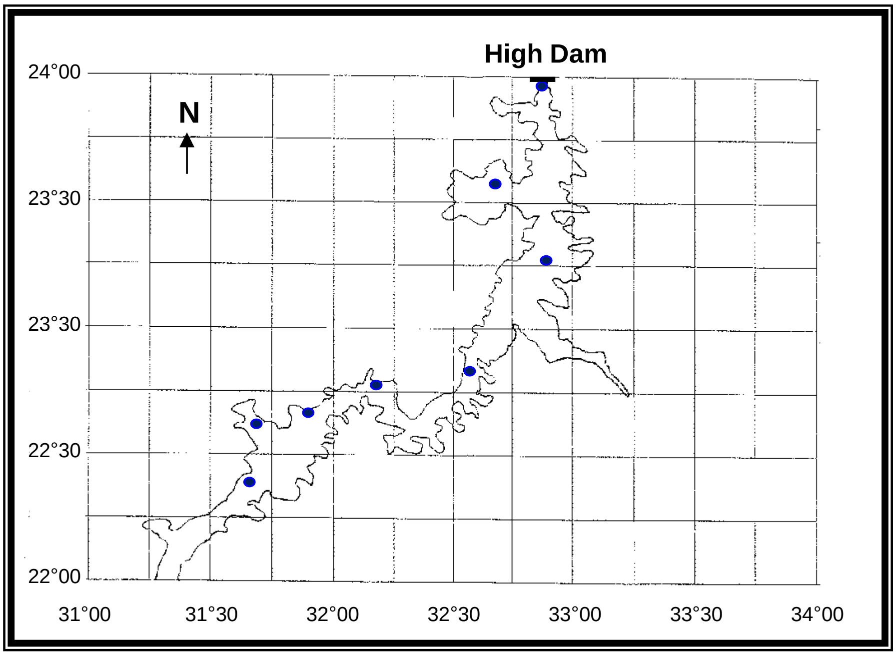


Figure 1. Distribution of evaporation measurement stations within high dam reservoir

3. Conceptual framework

The conceptual framework depends on re-formatting the evaporation data in a 3D database which could be arranged as follows:

X field: represents the months, and is labeled from 1 to 12.

Y field: represents the monthly average water levels.

Z field: represents the monthly evaporation loss in billion m3.

This database could then be treated using GIS to obtain the digital evaporation model based on the analytical tools of the GIS environment.

4. Assumptions

We have observed that the rate of change in the evaporation loss values to the water levels during the same month is very little. Therefore, this study assumes that temperatures during the year could be expressed in terms of months. Table (2) shows a sample of the records during February for different years; as we can notice, from water level 173 to 179.3 there is only about 0.1 billion m3 change in the evaporation loss.

Table 1. The month could be a term of the temperature

FID	Shape*	x	y	z
78	Point ZM	2	173.02	0.748349
66	Point ZM	2	174.23	0.799
90	Point ZM	2	174.71	0.657192
54	Point ZM	2	175.74	0.822372
42	Point ZM	2	179.31	0.829937

5. Methodology

By arranging evaporation data in a 3D database, it be ready to be converted to a shapefile. The problem of no spatial reference will not affect the results, instead, units must be defined as "points". This will make it easier to control the distribution of the output evaporation points shapefile [4]. Figure (2) shows the flow chart of our methodology.

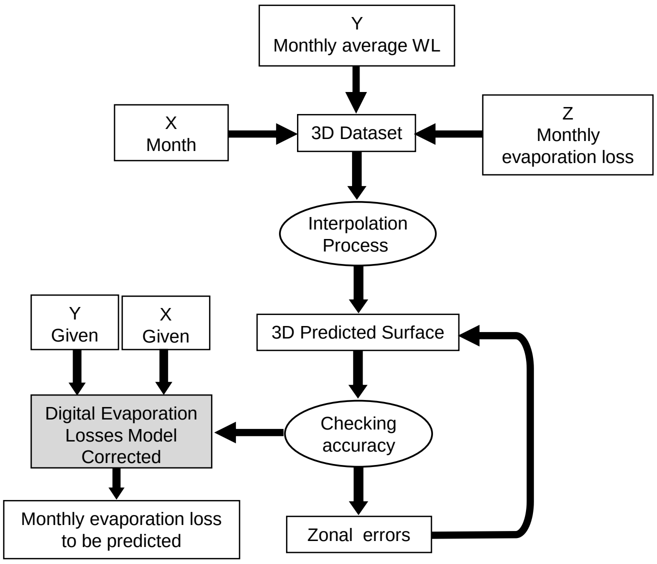


Figure 2. Methodology

6. Study area

Our study area contains the entire reservoir in both of Egypt and Sudan which extends between longitudes 31.141 & 33.101 and latitudes 21.72 & 23.968 degrees as shown in Figure (3).

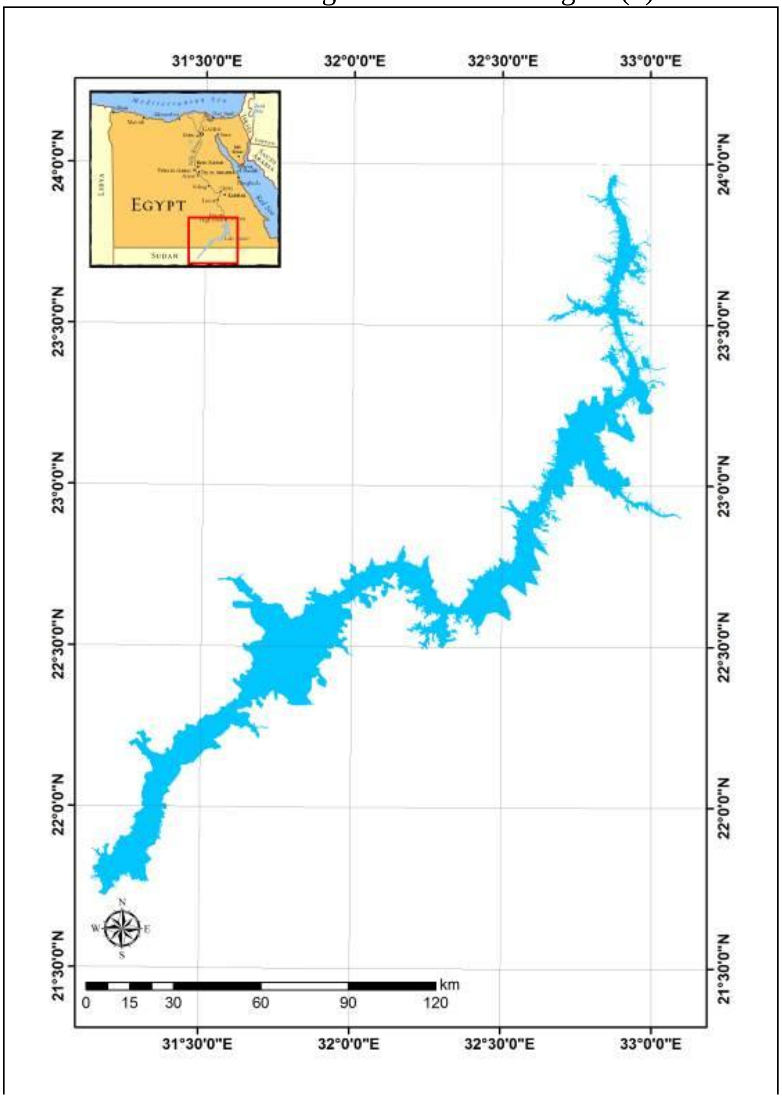


Figure 3. Study area

7. Dataset

Our dataset has been collected during the period from 1998 to 2016, the date of the last scientific mission. Many records are missing for the reasons stated before. The dataset contains X, Y and Z fields as follows:

- X field represents months in unique values and ranges from 1 to 12.
- Y field represents the average monthly water levels; minimum, average and maximum values are 168.89, 175.33 and 181.21 meters respectively as figure (4-A) shows. So, we do not have a spatial extent below level 168.68 m.

Z field represents the monthly evaporation loss; minimum, average and maximum values are 0.66, 1.19 and 1.98 billion m3/month respectively as figure (4-B) shows.

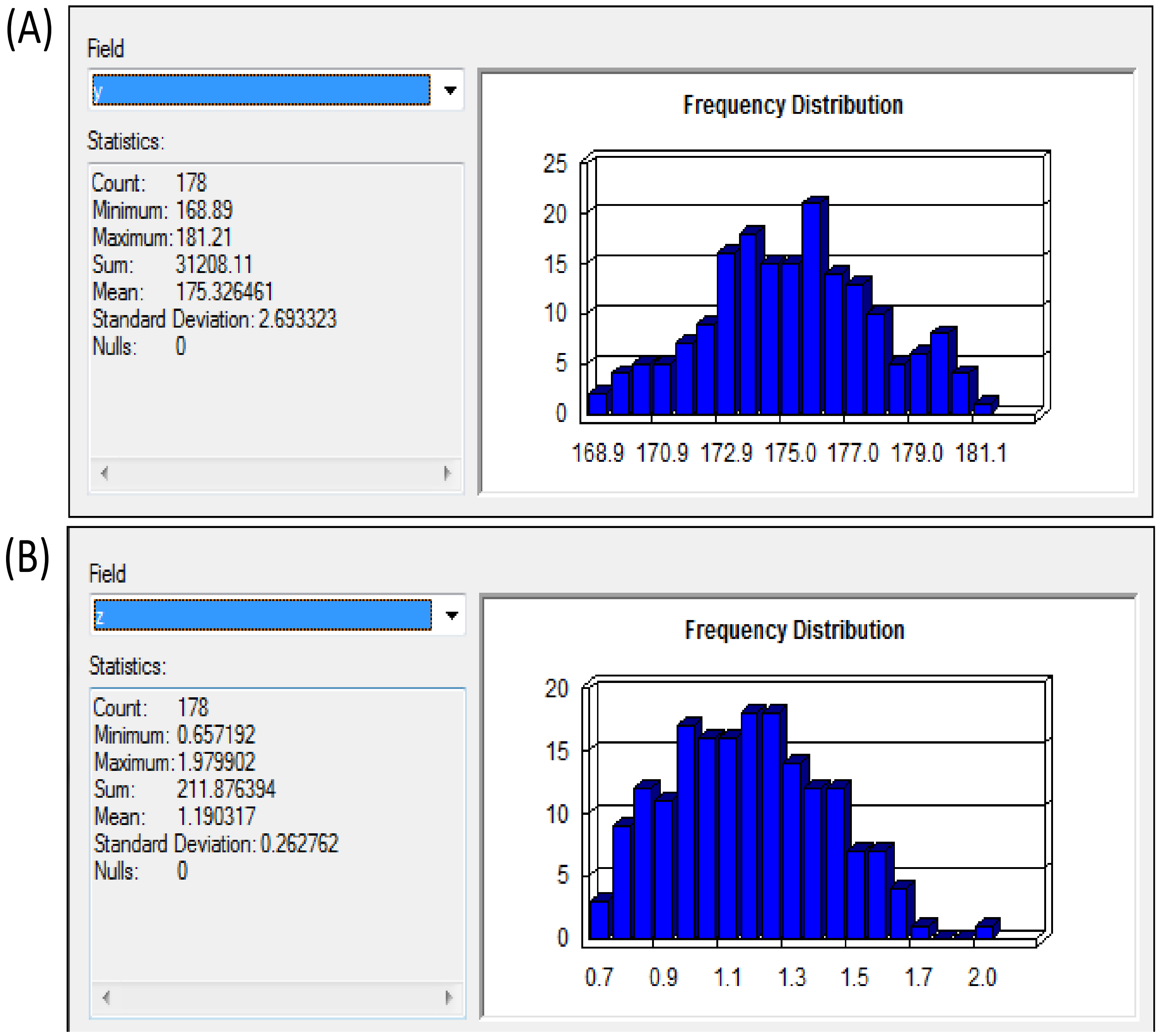


Figure 4. (A) The statistics of Y field, and (B) the statistics of Z field

From the extent of the measured records shown in Figure (5), it reflects the inverse relationship between the amount of evaporation loss and temperature in both summer and winter months. And shows also the extent of No Data we have.

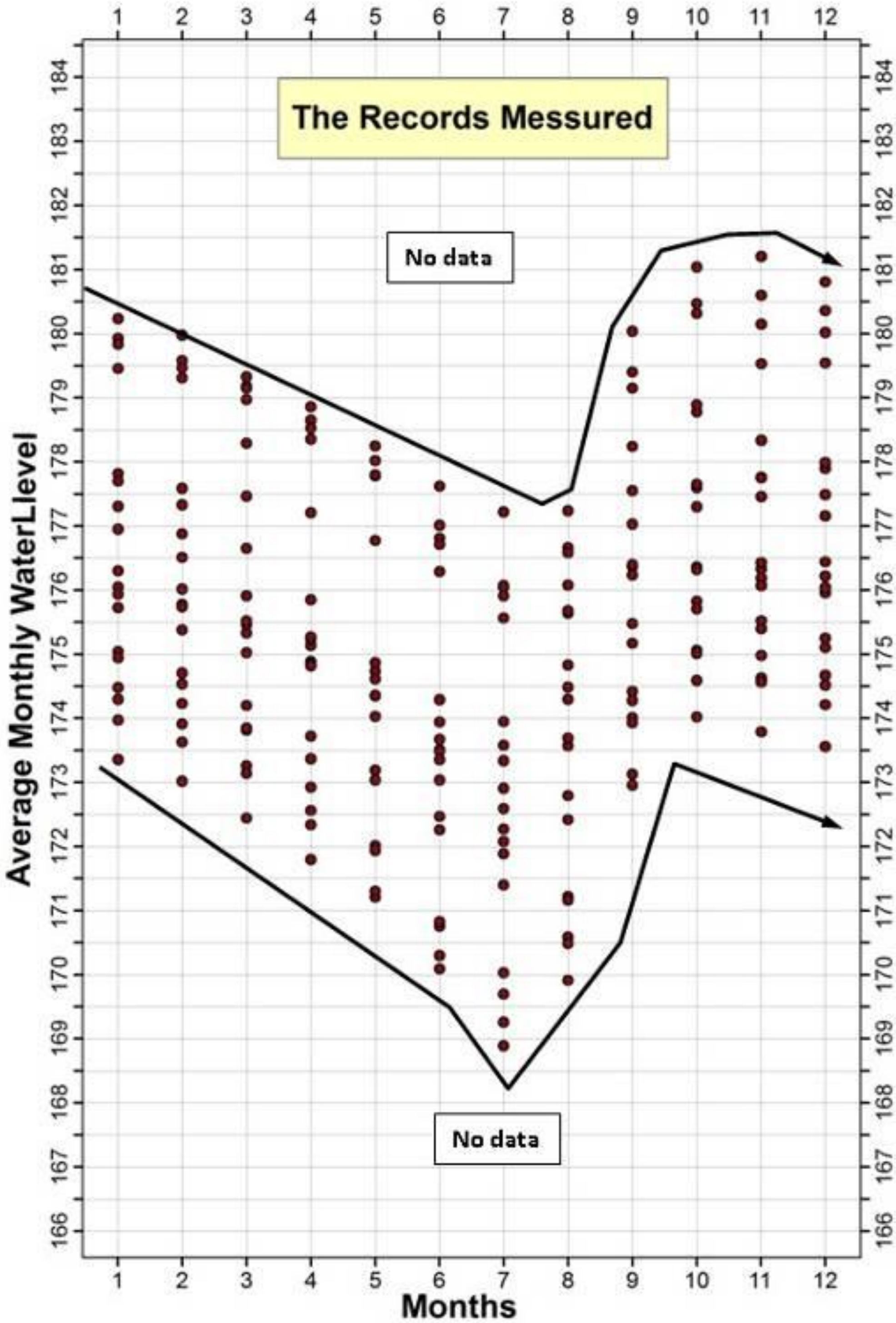


Figure 5. The extent of records measured and no data

8. Interpolation process

Mean Prediction Error value (MPE) as a difference between the measured and the predicted records [5], helps us choose the most accurate interpolation method to be used. By carrying out many interpolation processes, it is certain that the Radial Bases Function with completely regularized spline and Four neighbor records, is the best interpolation method that could be used in this very application.

9. Effect of the interpolation process coefficients

9.1. Effect of sector type and number of neighbor records

Figure (6) shows a comparison between many MPE values according to the number of neighbor records (Four neighbors with Four sector, eight neighbors with Four sector, four neighbors with One sector and Six neighbors with one sector respectively), where the first model gave the lowest MPE value.

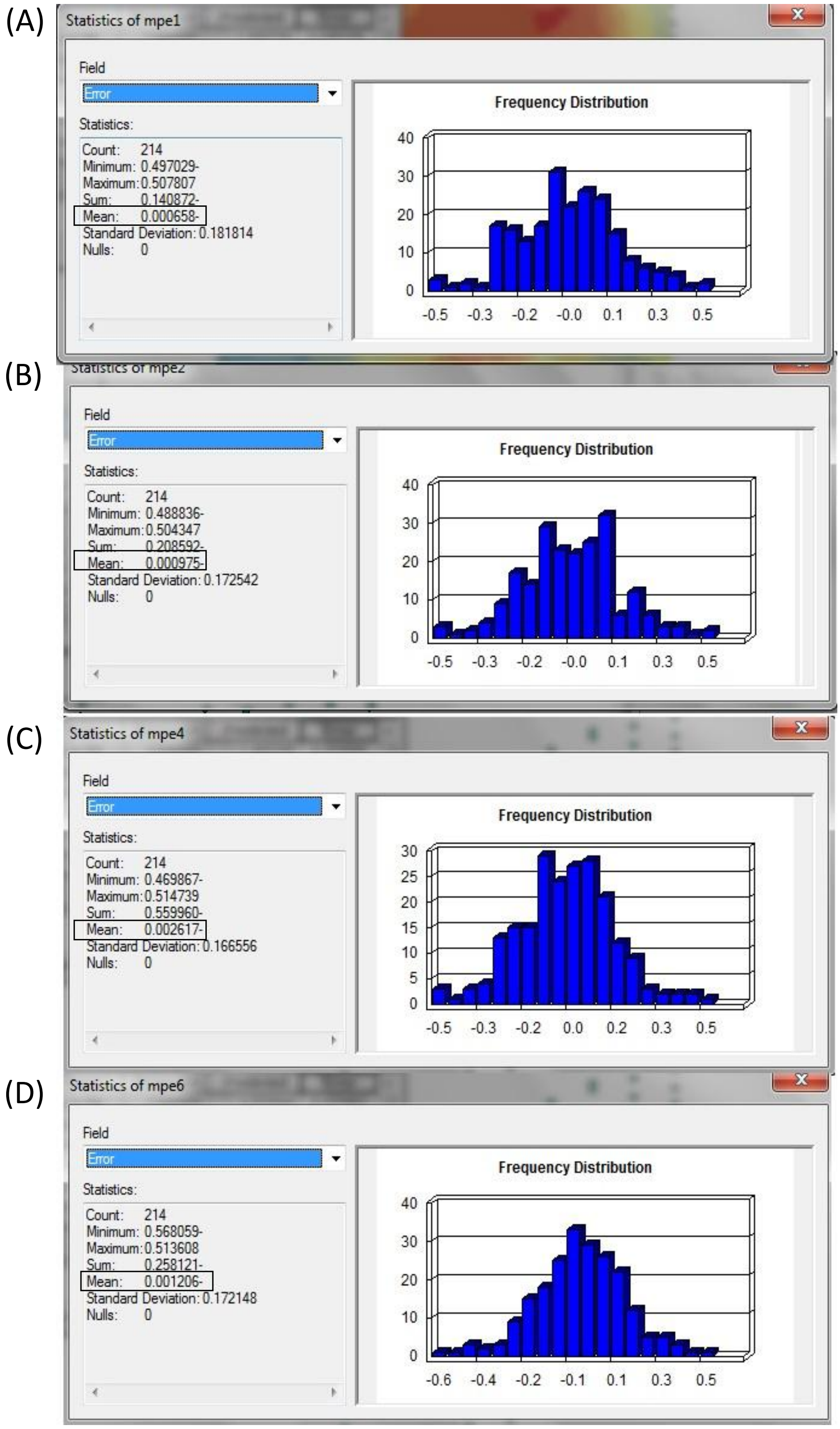


Figure 6. MPE values and frequency distribution for several RBF methods

As a result of the previous figure, we can deduce the correlation between MPE values and the number of neighbor records, where the most accurate model in such applications does not need us to increase the number of neighbor records as shown in Figure (7).

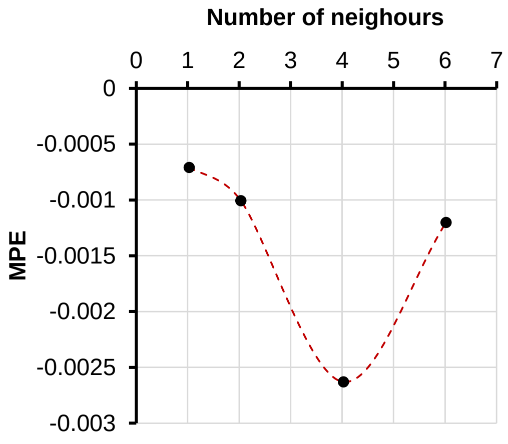


Figure 7. Correlation between MPE values and the number of neighbor records

9.2. Effect of the cell Size

As it's known, the smaller the cell size the more accurate of the simulation process. But, at the very time we seek the highest accuracy, we also seek the lowest number of cells, which will be converted later to points. So, by comparing the results for each of the default values and the modified values of the cell sizes, there is almost no difference as shown in Figure (8).

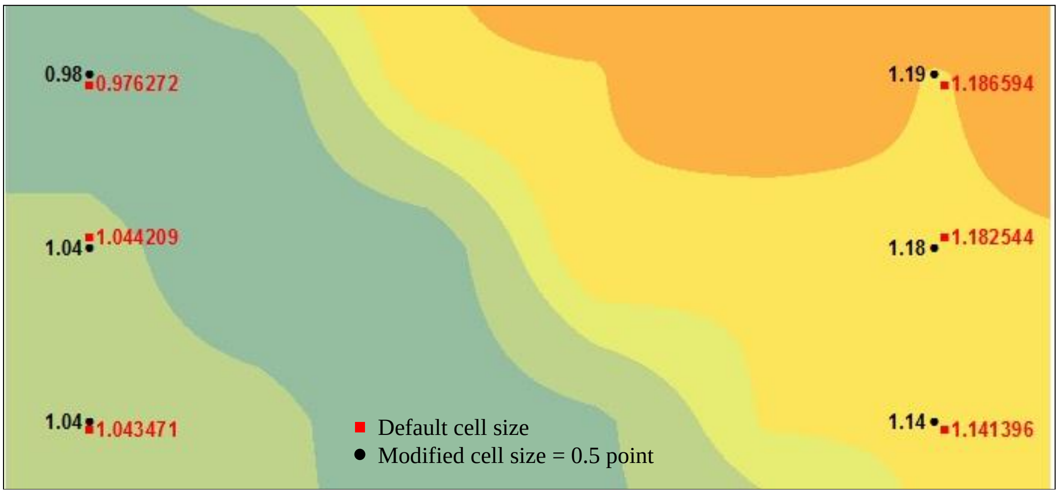
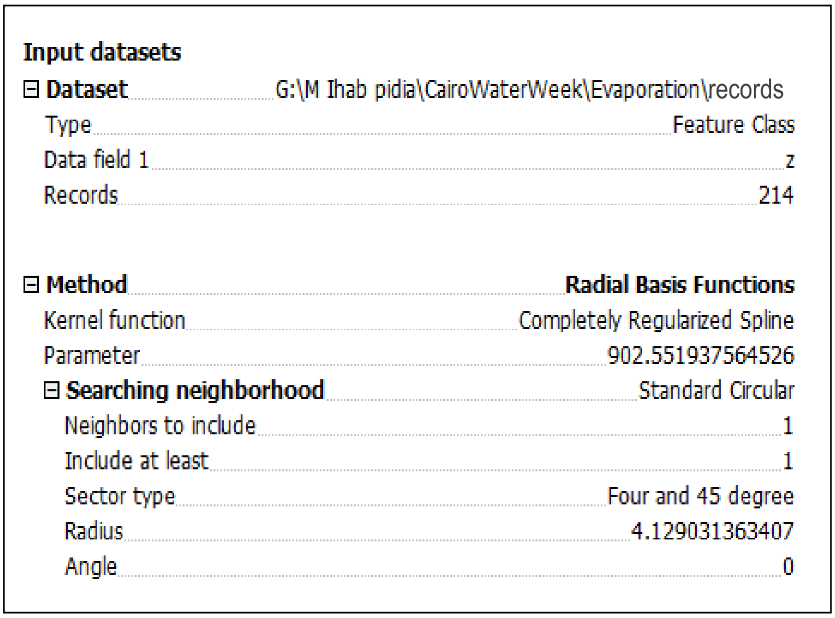


Figure 8. Difference in cell value between the default and the design Cell Size

By the end of this part, our model parameters should be as shown in Figure (9).

10. The output of the interpolation process

Figure (10) shows the output of the RBF interpolation process; The Digital Evaporation Loss Model (DEvM). The values of evaporation losses range between 0.61 and 1.84 billion m3/month. Maximum evaporation loss, where the red color concentrates, lies at the zone of summer months and high-water levels, and then gradually fades into blue, where the zone of winter months and low water levels lies. According to this scientific fact, it is clear that our model has many errors due to the lack of data and other factors mentioned before. But the greatest errors are still always within the no data areas.



Input datasets	
Dataset	G:\M Ihab pidia\CairoWaterWeek\Evaporation\records
Type	Feature Class
Data field 1	z
Records	214
Method	**Radial Basis Functions**
Kernel function	Completely Regularized Spline
Parameter	902.551937564526
Searching neighborhood	Standard Circular
Neighbors to include	1
Include at least	1
Sector type	Four and 45 degree
Radius	4.129031363407
Angle	0

Figure 9. Final RBF parameters

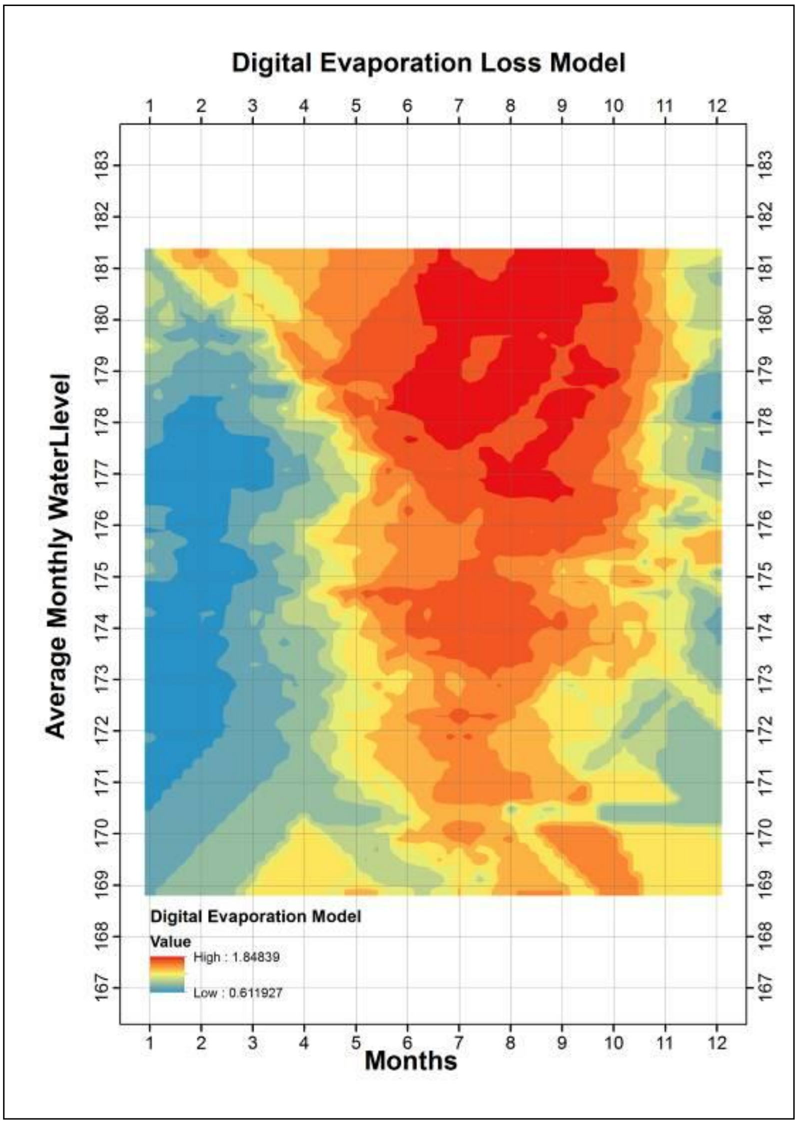


Figure 10. The output DEvM

11. Discussion

11.1. Checking the accuracy of the DEVM

By extracting out the predicted values and comparing them to the measured values, we will get the following table.

Table 2. Percent of accuracy

Percentage of Accuracy (Measured/Predicted) *100	No. of records	Percentage of the record to the total records
60-65	2	0.9
65-70	2	0.9
70-75	1	0.5
80-85	8	3.7
85-90	25	11.6
90-95	55	25.5
95-100	123	56.9
Total	**216**	**100.0**

Table (2) shows that there are 93 out of 216 records which have an accuracy < 95%. The error zones are shown in Figure (11-A).

11.2. Correcting the DEvM errors

Working with raster in GIS provides many tools that help modify raster widely. Our mission is to modify our DEvM to meet the inverse proportionality between the water level and the evaporation loss. The spatial analysis steps could be summarized as follows [6]:

- Digitizing the areas of error into an analysis mask as shown in figure (11-A).
- Changing the DEvM symbology to the classified symbology.
- Calculating the average value for each classified range.
- Converting the analysis mask shapefile to raster based on the z value of the corresponding classified range.
- Replacing the areas of error with the corrected raster mask.

Figure (11-B) shows the corrected DEvM

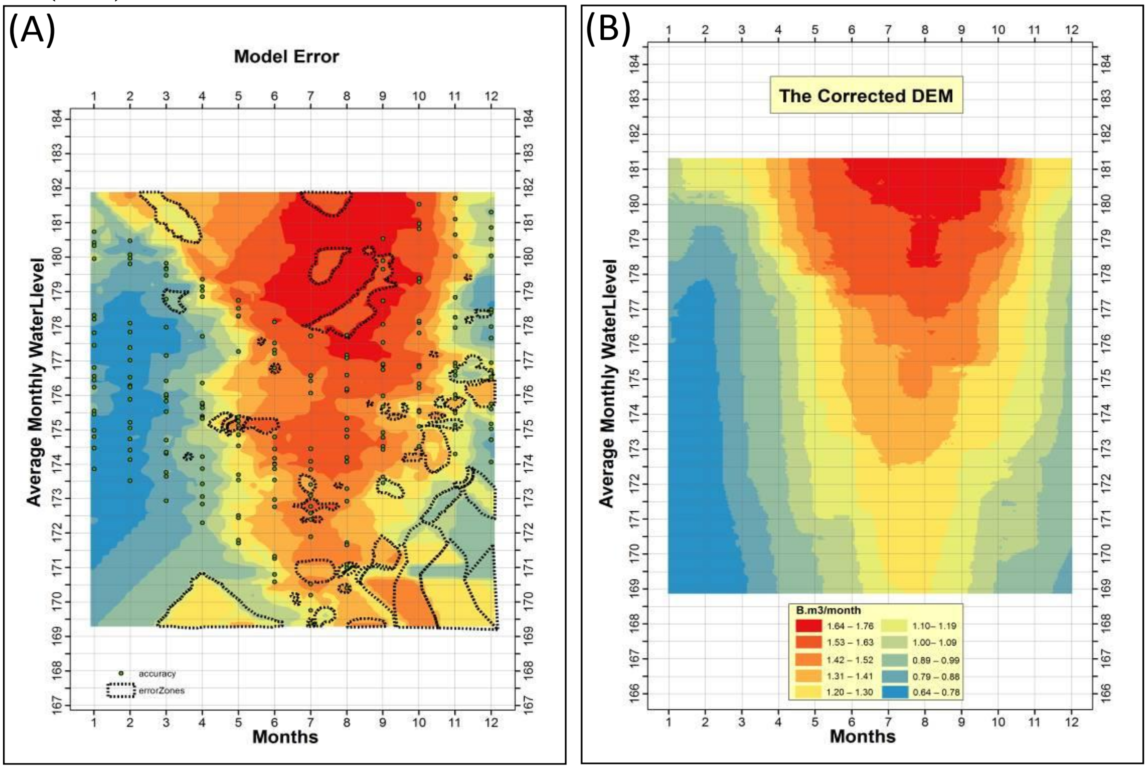


Figure 11. (A) Error zones shapefile, and (B) the corrected DEM

11.3. Distribution of evaporation loss

Figure (12) shows the distribution of evaporation loss contour lines through the year.

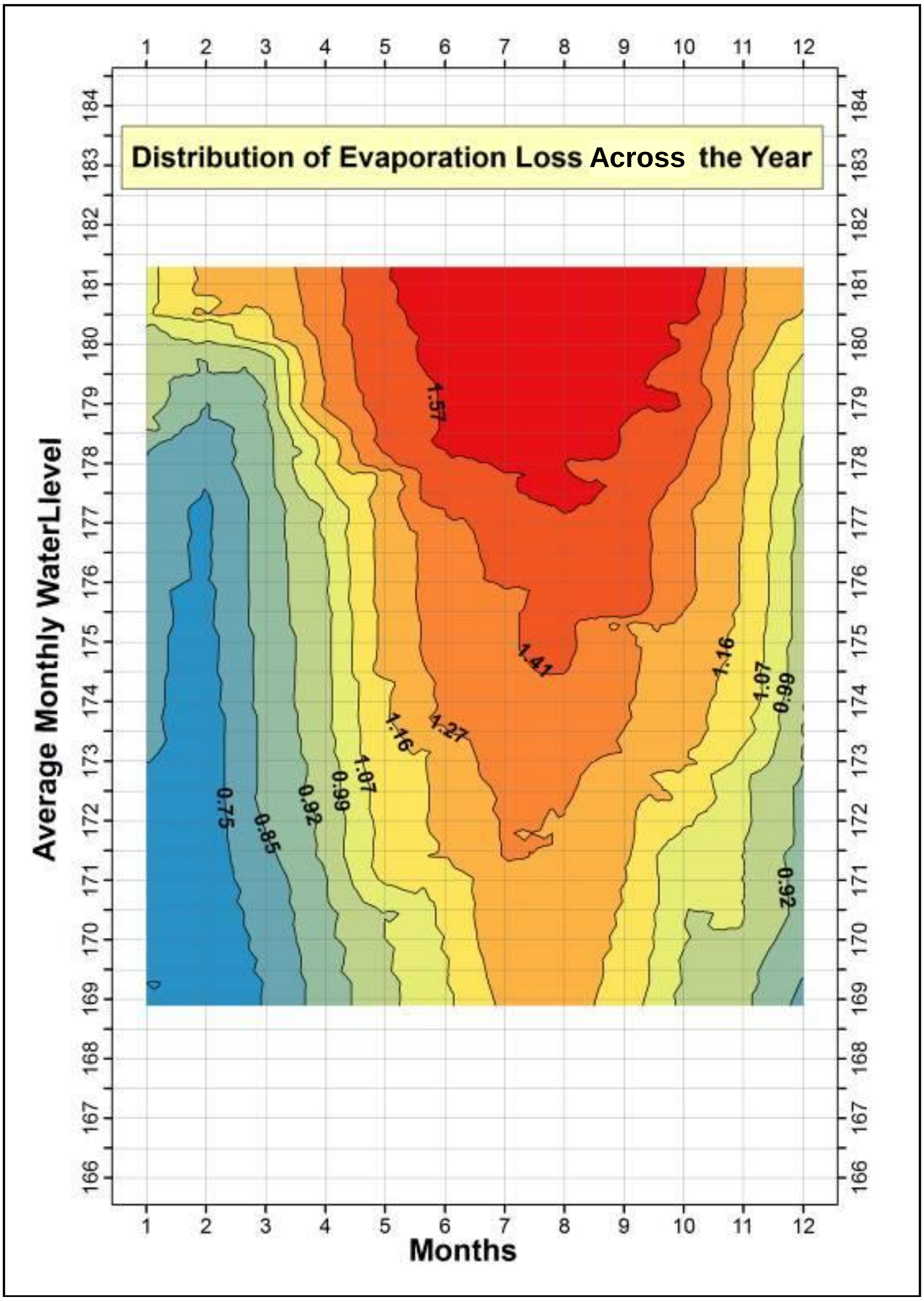


Figure 12. Distribution of the monthly evaporation loss through the year

12. Results

12.1. How to use the DEvM.

We can easily use the DEvM chart to get the monthly evaporation loss [7] if X and Y values are given as shown in figure (13).

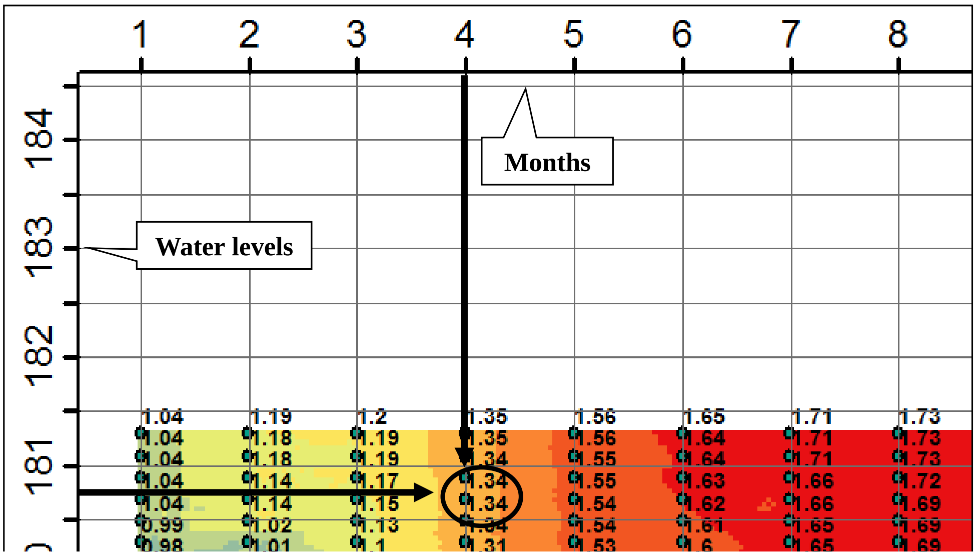


Figure 13. How to use DevM chart

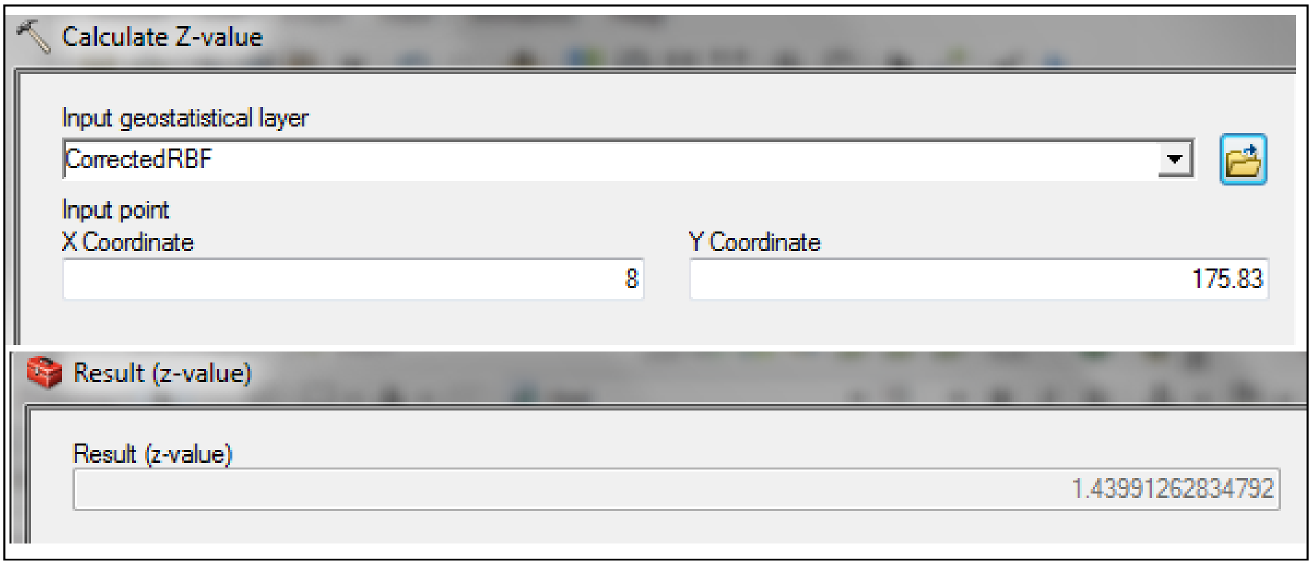


Figure 14. Using GIS Model Builder in calculating evaporation loss

12.2. Maximum, minimum and Average annual evaporation loss

As our DevM covers only the extent of high-water levels, it is easy to plot the maximum monthly water levels that occurred (see figure 15-A) and calculate how much the maximum evaporation loss could be [8]. And as our DEvM does cover the extent of water levels below 169 m, the average and minimum monthly evaporation loss could be only estimated.

Max. = 15.74 b.m3 (calculated from DEvM).
Avr. = 10.54 b.m3 (estimated).
Min. = 5.34 b.m3 (estimated).

13. Conclusion

It is easy to model even non-spatial phenomena in the GIS environment if it is possible to reformat the data in a 3D databse.
High Dam Digital Evaporation Model could be successfully used to get the monthly and annual evaporation loss in the High Dam reservoir by knowing both the month and the monthly average water level. See Figure (15-B).

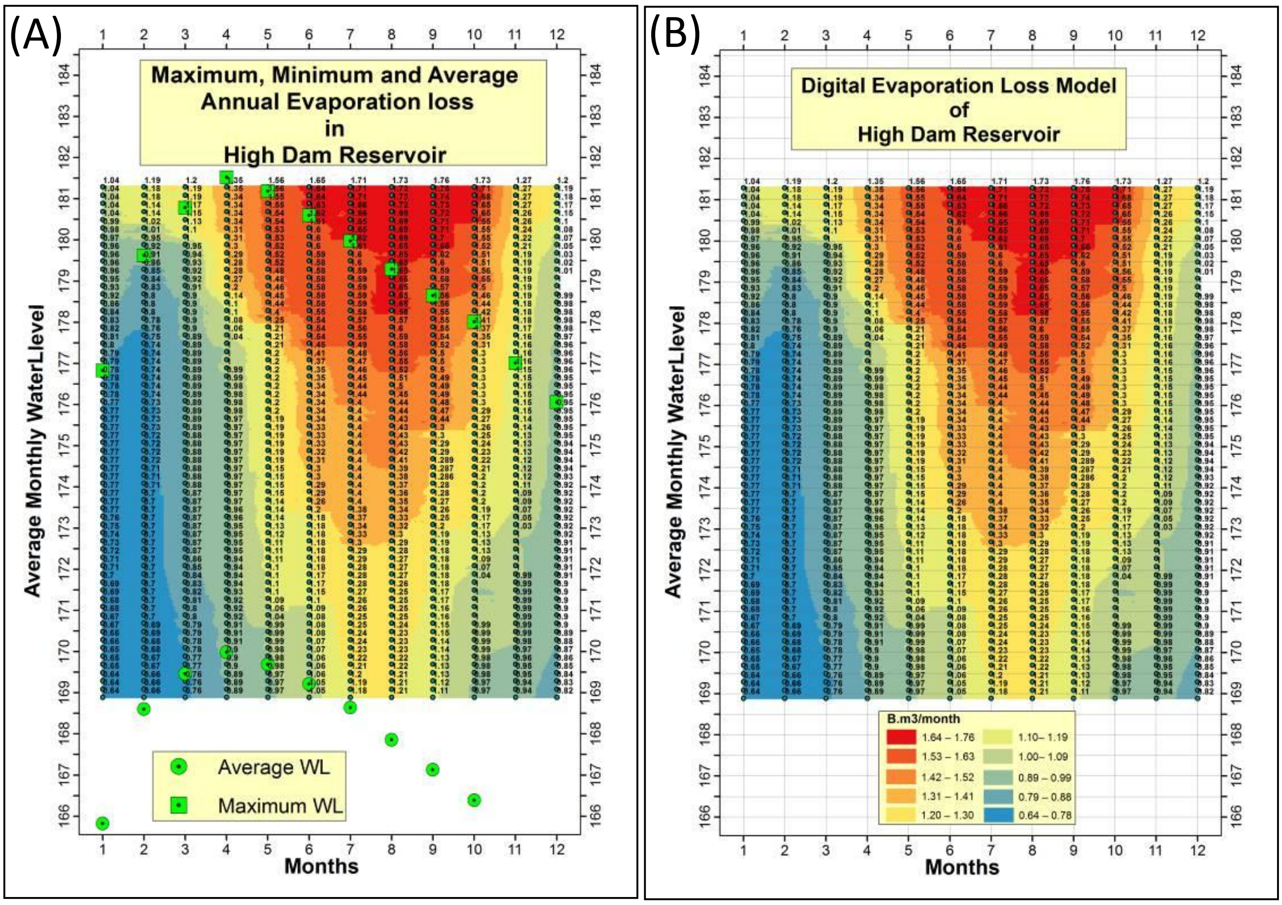


Figure 15. Our data extent doesn't cover the ranges of average and minimum water levels, and (B) High Dam DevM of High Dam reservoir

14. Recommendations

I recommend continuing research efforts to complete the DEVM to cover the no_data zone below water level 169, to reflect the full scale of evaporation loss in High Dam reservoir.

References

[1] Estimating Actual Evapotranspiration Using RS and GIS, Vajja Hari Prasad. Indian Institute of Remote Sensing.

[2] Ahmed Hassan, Sherine, Evaluating evaporation rate from high Aswan Dam Reservoir using RS and GIS techniques.

[3] Abou El-Magd and Alib, Estimation of the evaporative losses from lake Nasser, Egypt using optical satellite imagery, 2012.

[4] M. Hassan, Evaporation estimation for Lake Nasser based on remote sensing technology, *Ain Shams Eng. J.*, vol. 4, no. 4, pp. 593-604, 2013.

[5] Spatial modeling of reference evapotranspiration using adjusted Blaney-Criddle equation in an arid environment, Hossein Tabari, P. Hossein zadeh Talaee.

[6] GIS Application in Water Balance Modelling, Hassan A. Eltoum.

[7] Praveen Rathod, V. L. Manekar, Estimation of Pan Evaporation and Actual Evapotranspiration Using GIS and Remote Sensing.

[8] Mohammed Ihab Salah, Daril Ma'arifah, Practical Applications in GIS, Cairo 2009.