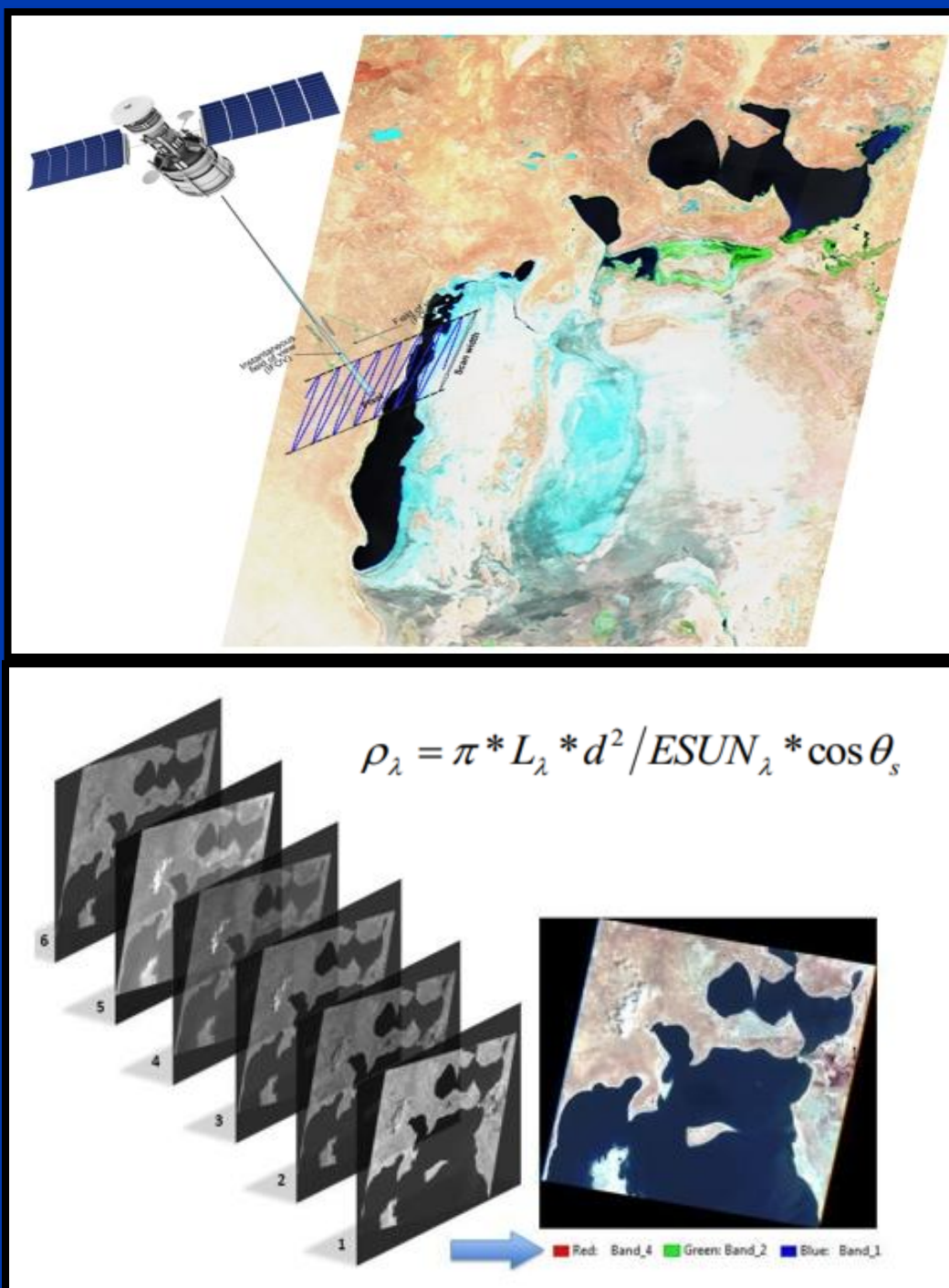# Z.A.Gafurov, D.Nazaraliev, F.S. Kattakulov, G.U. Jumabayeva

SPATIAL-TEMPORAL ANALYSIS OF ARAL SEA USING EARTH OBSERVATION

(Масофадан зондлаш маълумотлари ёрдамида Орол денгизининг фазовий ва вақт мобайнидаги ўзгариши таҳлили)

$$\rho_\lambda = \pi * L_\lambda * d^2 / ESUN_\lambda * \cos\theta_s$$

Red: Band_4   Green: Band_2   Blue: Band_1

Tashkent – 2020

Z.A. Gafurov, D.Nazaraliev, F.S. Kattakulov, G.U. Jumabayeva

SPATIAL-TEMPORAL ANALYSIS OF ARAL SEA USING EARTH OBSERVATION

(Масофадан зондлаш маълумотлари ёрдамида Орол денгизининг фазовий ва вақт мобайнидаги ўзгариши таҳлили)

/MONOGRAPH/

Tashkent – 2020

This research aims to analyze water surface dynamics of the Aral Sea in Central Asia which has lost enormous amount of surface area in the last few decades. The data for this purpose was obtained from remote sensing, particularly from Landsat data which provides high resolution images of earth surface observation. The remote sensing images were prepared for 6 different years and from these images water surface was delineated using supervised classification methodology. Using the classified images, it was then possible to carry out change analysis of Aral Sea starting from 1973 to 2018. The results of this study show how the Aral Sea surface lessened during different time periods. In general, for whole period between 1973 and 2009 the Aral Sea lost about 86 % of its surface than in 1973.This was maximum loss and after 2009 water covered are has gradually increased. Taking this into account, the water surface shrinkage between 1973 and 2018 amounted to 67 % which is very dramatic. The results of this study may be a great use to decision makers or scientists who deal with Aral Sea and its consequences after it has lost huge surface area.

Abbreviations

AOI	Area of Interest
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
DEM	Digital Elevation Model
DTM	Digital Terrain Model
EMR	ElectroMagnetic Radiation
ETM	Enhanced Thematic Mapper
ETM+	Enhanced Thematic Mapper Plus
GDEM	Global Digital Elevation Model
GRS	Geodetic Reference System
JAXA	Japan Aerospace Exploration Agency
METI	Ministry of Economy, Trade, and Industry
MSS	Multi Spectral Scanner
NASA	National Aeronautics and Space Administration
RBV	Return Beam Vidicon
RGB	Red, Green, Blue
TM	Thematic Mapper
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WGS	World Geodetic System

Introduction

Water has always played an important role for human being, for the life and for our beautiful environment. Water resources in Central Asia are very much important for many sectors. With the increase of central Asian demography and potential to climate change, we as human being should more actively act to ensure the life for tomorrow's generation in this region. When we look back into the second decade of 20th century, we can observe negative developments of sustainable water resources management in this area. The Aral Sea crisis is a main example to this point, which has lost its water almost completely as a result of misuse of water resources. The Aral Sea was the fourth largest inland water body in the world before 1960th [15]. It started to lose its water volume after the extension actions of cotton fields in Central Asia started during the Soviet time. As a result of agricultural extension, the sea surface of Aral Sea was reduced enormously that it impacted even local climate in the region. After about 1980s, the negative consequences of Aral Sea shrinkage were clearly visible. Figure 1 illustrates two satellite images of the Aral Sea that qualitatively show the amount of water lost in Aral Sea between these two time spans. From this point it is clear that the policy of Soviet Union did not think about the consequences of Aral Sea and now, the new generation is suffering and struggling from the natural disaster which has happened as a result of arrogant human engineering.

Once we were proud of talking about Aral Sea as it was fourth largest lake in the world by its surface area. It has equalized the weather extremes of Central Asia but now it has lost more than 80 % of water volume and surface area. The main reason of disappearing of Aral Sea was to extend agricultural field with irrigation in Central Asia for the purpose of mainly cotton production and its exportation to the world. Two rivers which were flowing to the Sea were diverted into deserts in order to start agriculture production. The consequences of overusing and mismanagement of water consumption resulted hazardously in Central Asia e.g. climate change records

(increase of mean air temperature), increasing unemployment and economic hardship, destroying fishing industry and mainly number of illness and disease has come to shocking level [21]. Now, taking into account all above mentioned problems we obviously should look back and understand how the changes over past periods has resulted in that area in order to learn Aral Sea water dynamics. Although there were some researches carried out in this direction and came up with different opinions according to their individual assumptions, this study focuses to make specific analysis which will demonstrate and show the changes of Aral Sea for six years over past periods. The change dynamics illustrated in this paper will help us to better understand what the size of Aral Sea was in fact in the past and how the sea dynamics developed with time. It is of advantage to have Sea dynamics analysis in order to make proper decisions that should mitigate possible negative changes of Aral Sea in the future if further irrigation extension is required. Considering all above mentioned issues with Aral Sea, this study was carried out where the outcome can be useful information in several sectors dealing with Aral Sea and the mitigation of its effects into the nature. Since the glance of the world headed to save the Aral Sea and also because of present harmful situation of Aral Sea was a great challenge to the author in carrying out this study which should also act as a supportive material that will be serving for saving the Aral Sea and develop sustainable water management practices in this region.
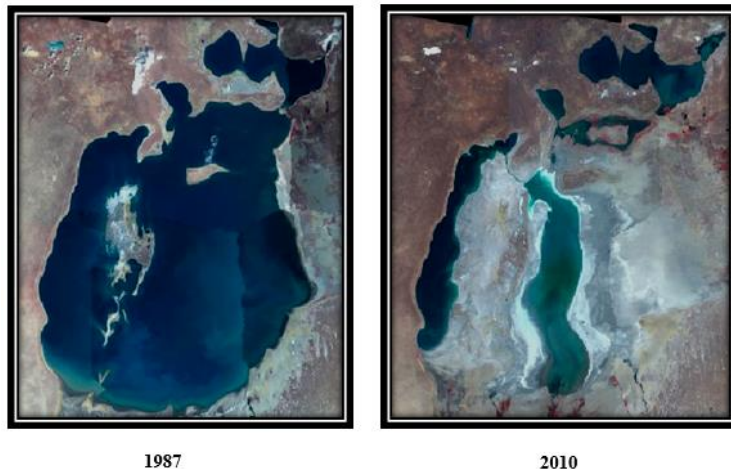

1987   2010

Figure 1. Aral Sea in two periods

CHAPTER-1. OBJECTIVES AND THE ROLE OF GEOGRAPHICAL INFORMATION SYSTEMS (GIS) AND REMOTE SENSING IN WATER SECTOR

1.1. Objectives of this study

The main objective of this study is to do sequential change analysis of the Aral Sea. The analysis will be made on the basis of water surface area calculations for different years. This will give an overall understanding of the water surface area changes in Aral Sea which can show more detail picture of the changes of water coverage over last nearly 50 years of time span. Aral Sea played a key climate balancing role in the past and now disappearing of the sea has changes the climate in the region as well. I order to understand the extend of the changes there is a need for accurate quantifying of the losses which will help us to further take an action to mitigate and adapt for future potential changes in the context of changing climate. Study area of this research is located in Central Asia. This section is aimed to shortly enlighten the Central Asia, which consists of five countries; Kazakhstan, Uzbekistan, Kyrgyzstan, Turkmenistan and Tajikistan. These countries were part of the former Soviet Union since about 1920s until break down of Soviet Union in 1991 when each country achieved its independence. The Central Asia mainly bordered with Russia from north, China from east, Afghanistan and Iran (although some small parts of these countries are regionally in Central Asian area) from south and Caspian Sea in the west. Figure below shows the location of Central Asia and its border countries. The area of Central Asia is approximately 4 million square kilometer and around 72 million people live in this region. Independence created more opportunities for each region to work and protect their own countries. Capacities and expertize levels are increasing especially in Uzbekistan and innovative technologies are being introduced in many

sectors to better understand the current situations and develop smart strategies for sustainable development of the country.

Figure 2. Central Asia

Aral Sea is located in Central Asia and covers the area in two of Central Asian countries namely Uzbeksitan from the south and Kazakhstan from the north part of the Sea. It has two major inflow rivers which are Amu-Darya in south west and Syr-Darya in north east. Water in this reivers accumulated mainly from the upstream glaciers and seosanal precipitations accross the basin. The Aral Sea itself is a closed sea which has an inflow from above mentioned rivers and no outflow as a river. The water balances of the Aral Sea consists inflow from two rivers and outflow as evaporation or infiltiration. Thus, those two inflowing rivers act as equalizer of the Aral Sea with respect to its water surface, water quality and salt concentration. After

diverting inflowing water from Amudarya and Syrdarya into deserts for cotton production in 1960s, the sea started to lose its balance and water shrinkage has started immediately. After water shrinkage as a result of evaporation without inflow, the territory which was covered with water turned into enormous saline wasteland. Aral Sea was then given a local name "Aralkum", which is "Aralsand" when translated into english. Also ships that were used to transport goods from one to another side of the lake are now waiting for water and staying as a monument at the seabed [1].
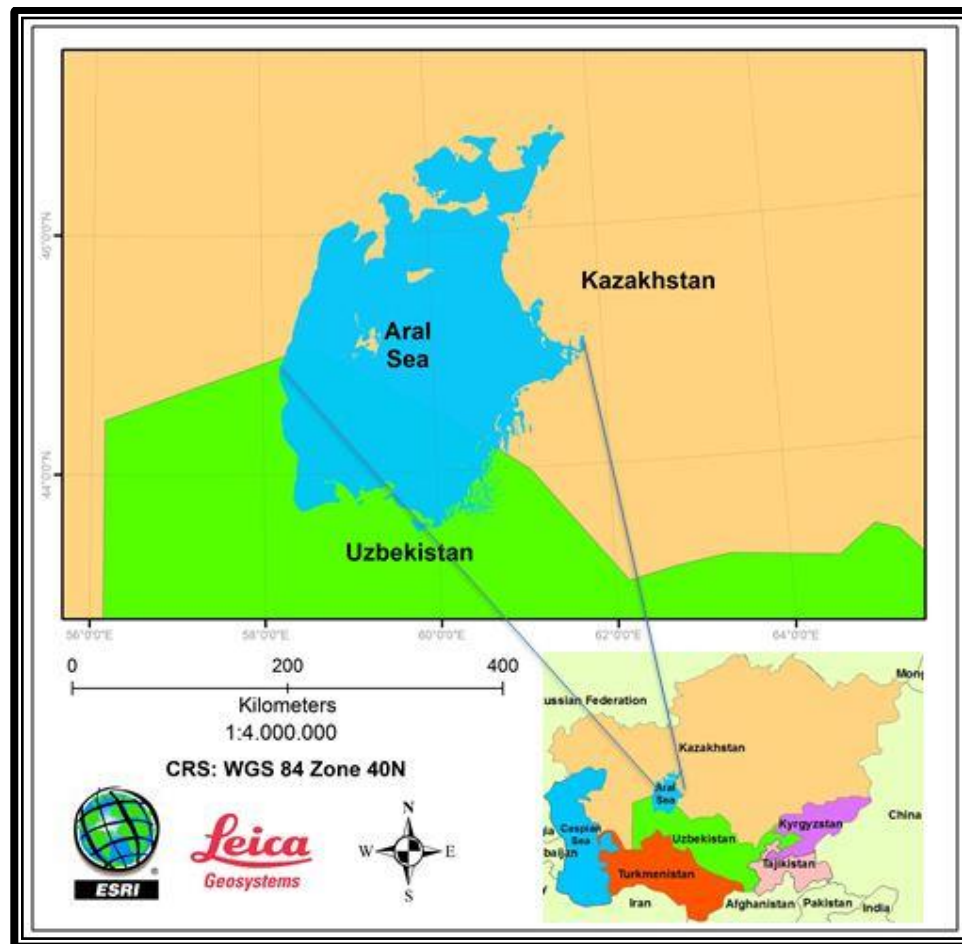
Figure 3. Aral Sea

In order to understand the temporal change of the Sea surface, we have used satellite data and we looked at the history. This gave us to visually interpret the changes and make detail analysis of the changes. But as many other research activities, this research also has some limitations and minor issues occurred during the process.

Assessment of water surface has lacked in certain months due to cloud coverage. Therefore in this study sequential analysis was done according to the data availability.

1.2.   General background information of GIS

New and innovative technologies such as GIS are becoming more and more important of our everyday life. These tools are making the complex tasks economically efficient and timely management of all resources on earth. On the most basic level, geographic information systems technology is used as computer cartography, that is for straight forward mapping (GIS Lounge, n.d.) but today the Modern GIS is a computer-based tool for mapping digitizing and analyzing objects that exist and events that happen on earth [22]. Today, GIS technologies are widely used in the world as well as in Uzbekistan. Using this tool scientists and decision makers are interested to create new models in both spatial and temporal character to identify and solve existing issues and challenges in order to make timely decisions.

GIS is a set of technical software and information tools providing input, storage, processing, mathematical and cartographic modeling and image processing that represent the geographical locations and correlation with attributive data to solve the problems of territorial planning and management [8]. The main components of GIS are shown in below figure 4.
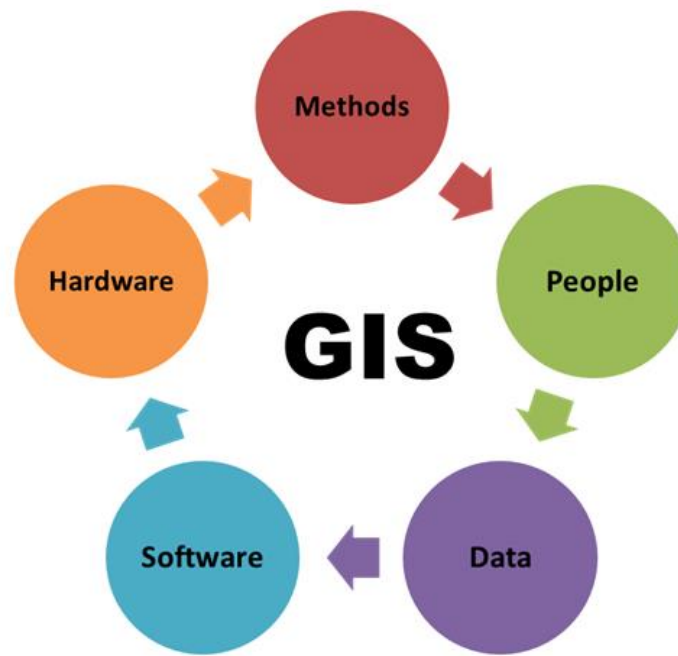
Figure 4. Components of GIS [13]

Today, in science and technology still unfortunately in most cases using outdated system such as working on paper maps to analyze the process of geographical changes. Analysis, descriptions for their use is done manually. It is difficult and challenging to transform from old system to the new approaches and it requires appropriate specialists and time. But it is taking place especially in Uzbekistan and the government is realizing the benefits of new method and of course it is started penetrating the use of GIS in all areas and showing that its future is bright. So, transformation is taking place, and the government, research and academic institutes are understanding the advantages it this system. It is due to that the people all around the world working more efficiently because of using this advanced technology [24].

GIS can easily handle multiple dataset analysis at once and categorizes the results based on the commander's criteria. It has a capacity to consider several layers and read the background attribute information to make proper analysis of the geographically coordinated maps. This way, it is possible to analyses its thematic and spatial characteristics to obtain a better knowledge of this zone [6]. There are many instruments and tools available to make analysis of GIS. Some of them open source

tools whereas some are commercial. ArcGIS tool is one of the commercial one and it is one of the best in the market to make GIS analysis. While technologies are fast in development, there is another tool which is open source so called Quantum GIS (QGIS) and this tll is becoming as powerful as ArcGIS and being able to handle similar jobs like ArcGIS does. Advantages of using both ArcGIS and QGIS is in one hand it generated maps in digital format so that each colors corresponds to certain digital numbers of the image, in another hand GIS maps are easy to transform from one to another computers systems and continue working. Both instrument has an opportunity working with several image layers and consider many layers at once to get required results. This layer can be as vector data which represents of lines, points and polygons or it can also be raster format layers consisting of any pixel sizes. It can easily read background digital information and combine with other layers to provide the results. Below image shows an illustration and understanding of layers which is used in a GIS instrument.
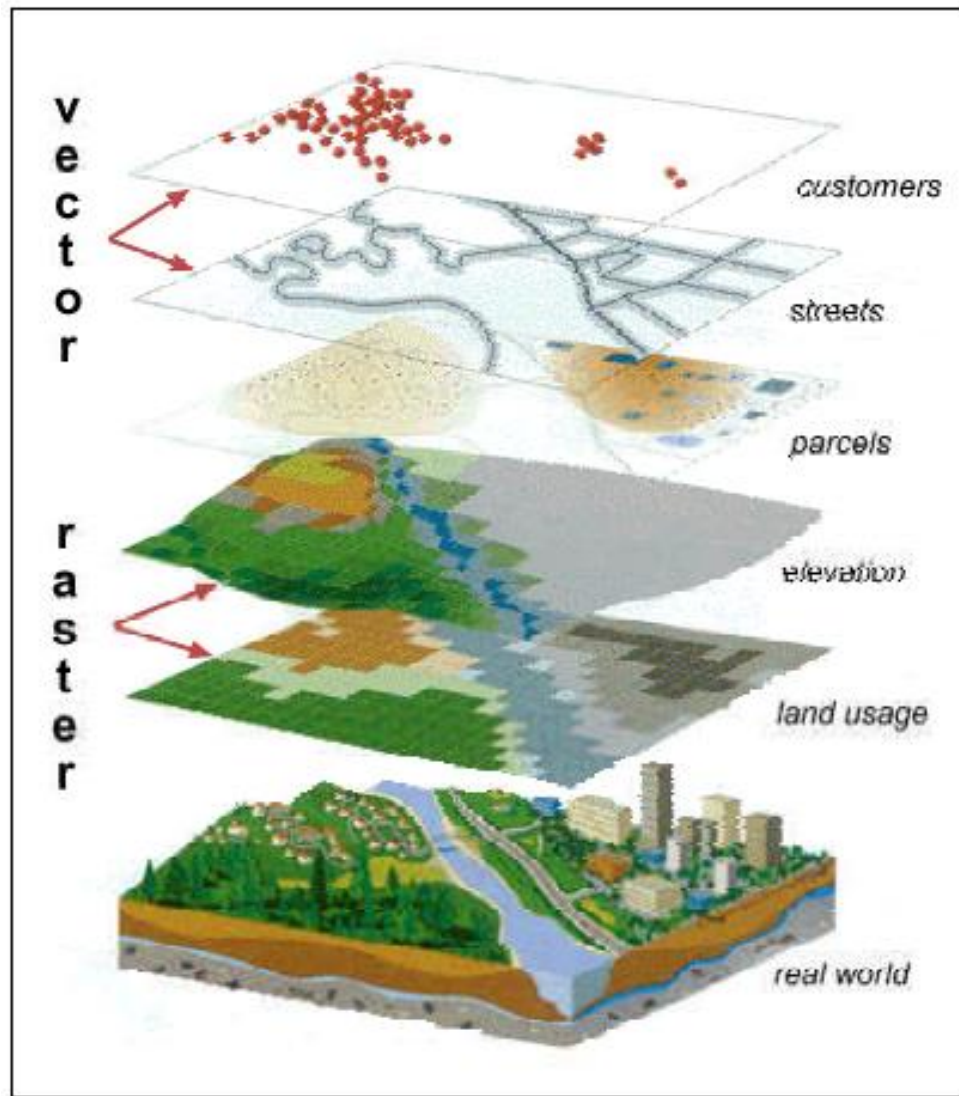
Figure 5. The concept of layers (ESRI)

GIS mainly manages the Raster and Vector datasets. Raster datasets are meant of images taken from satellites, aero, drones or all other images which are geographically coordinated or not coordinated or even scanned maps. Raster data consists of a matrix of cells (or pixels) which is generated as rows and columns with a values representing information of for example temperature, precipitation and etc.. Raster's are digital aerial photographs, imagery from satellites, digital pictures, or even scanned maps. Vector datasets are a structure of information which are used to store spatial data. Vector data is comprised of lines or arcs which has a beginning and

end points. Vector datasets are features which are defined by their boundaries only and curved lines are represented as a series of connecting arcs [6].

1.3. Principles of Remote sensing

The principal objective of remote sensing is to capture the reflected or emitted electromagnetic radiations (EMR) coming from different materials on the face of the earth. According to Howard, 1985, Remote Sensing is "concerned with the collection of data by a sensing device not in contact with the object being sensed, and the evaluation of the collected data, which is then termed information and is presented in map form or as statistics". Satellite images are widely used in remote sensing. Radiations reflected or emitted by an object on earth have to pass through the thick layers of atmosphere in order to reach to the satellite. The earth's atmosphere is made up of different layers i.e. Troposphere, Stratosphere, Mesosphere, and Thermosphere consisting different kinds of gases, dust particles and pollutants. The tiny particles and gases of the atmosphere have an influence in the form of reduced radiations reaching to the sensor on specific ranges of reflected or emitted radiations of an object. This influence can be seen in the following diagram represented by absorption at different wavelengths of EMR.
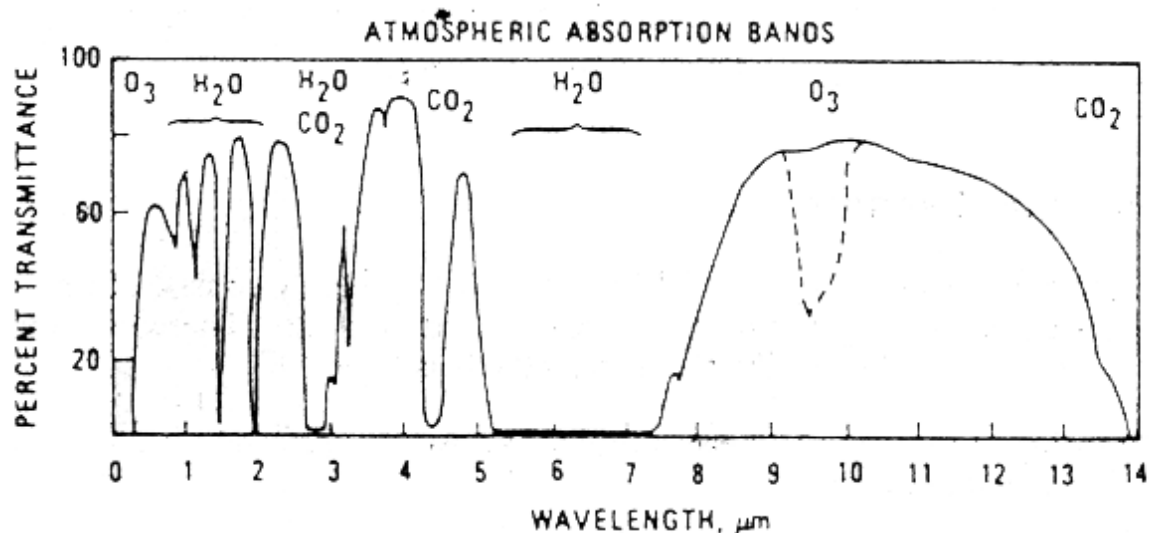
Figure 6. Transmittance against wavelength of EMR [14].

When EMR is incident on different materials of the earth, every material behaves differently in EMR spectrum. Each material has a specific reflectance or emittance in different portions of EMR known as spectral signature. This signature is repetitive and predictable for a specific material. Spectral signatures of various natural materials are depicted below.
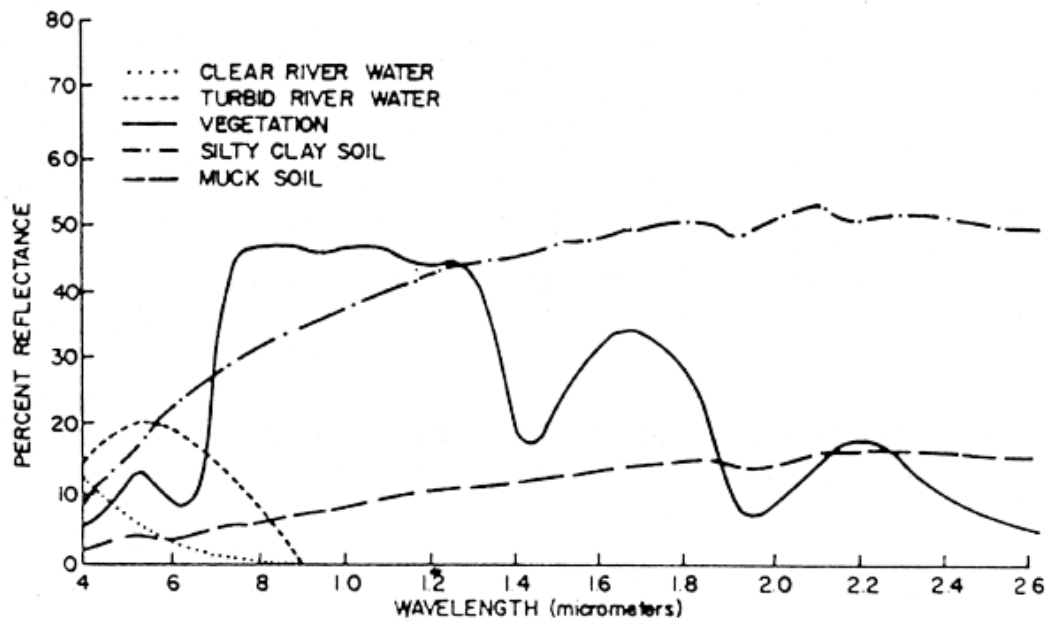

Figure 7. Spectral Signature of Various Natural Surface Features [14].

Spectral signatures of a particular material can alter a bit depending on the spatial location, growth of material (e.g. vegetation) and topography etc. [14]

CHAPTER-2 DATA AND USE OF REMOTE SENSING TO CLASSIFY OBJECTS ON EARTH

2.1. Data

The data available for the study is so called Landsat data. Landsat mission has started its mission early 1970th and has good amount of temporal data. In addition to this, Landsat data use good to apply in water surface delineation in lakes and reservoirs which good accuracies. It is an advantage of using remote sensing data to classify water covered areas and calculate the coverage area.

2.2. LANDSAT PROGRAM

Landsat program initially called as Earth Resources Technology Satellites started the mission in 1967 under NASA with the cooperation of the U.S. Department of interior. The main objective of the program is to observe and continuously record of earth surface for the purpose of business, science, education, government, and national security.

The mission of Landsat program is to provide repetitive acquisition of high resolution multispectral data of the Earth's surface on a global basis. United States Geological Survey (USGS) launched different satellites namely Landsat-1 to Landsat-7 which were carrying different remote sensing sensors for capturing data. Sensors used in Landsat satellites were divided into mainly three groups. Landsat 1-3 were carrying Return Beam Vidicon (RBV) and Multispectral Sensor (MSS). Thematic mapper (TM) and MSS were mounted on Landsat 4-5. ETM and ETM+ were used on Landsat 6 and Landsat 7 respectively. Detailed information of Landsat and sensors is described in the following table. Landsat 6 is not mentioned because of malfunction in launching and it was not able to reach its orbit.

Table 2.1.

Landsat generations

Satellite	Sensors	Launch date	End date
Landsat 1	RBV & MSS	July 23, 1972	January 6, 1978
Landsat 2	RBV & MSS	January 22, 1975	February 25, 1982
Landsat 3	RBV & MSS	March 5, 1978	March 31, 1983
Landsat 4	MSS & TM	July 16, 1982	June 15, 2001
Landsat 5	TM	March 1, 1984	June 24, 2013
Landsat 7	ETM+	April 15, 1999	Present
Landsat 8	OLI	February 11, 2013	Present

The data from different Landsat sensors have been used to monitor water quality, glacier recession, sea ice movement, invasive species encroachment, coral reef health, land use change, deforestation rates and population growth. Figure below shows the main components of Landsat-7 satellite.
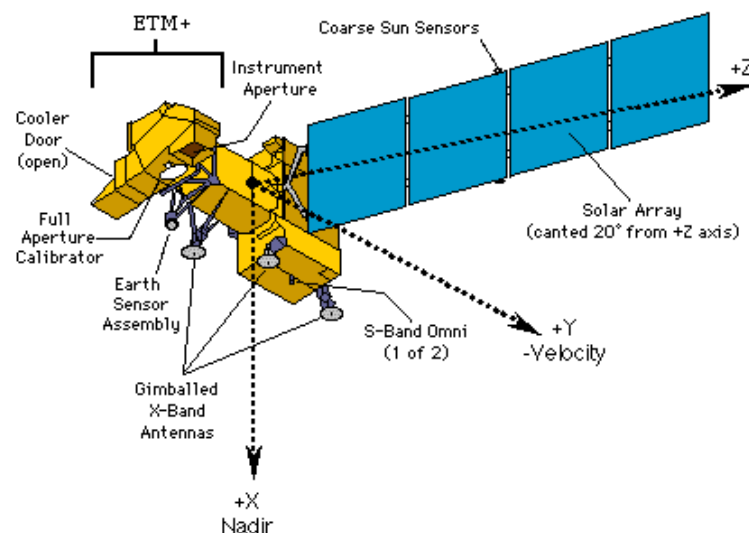
Figure 8. Landsat 7 Satellite [23].

2.3. LANDSDAT DATA

The Landsat data was obtained from United States Geological Survey [22] webpage. A good amount of data can be downloaded without any cost merely for the purpose of research. The temporal resolution of Landsat data is 16 days and the spatial resolution is 30 meters. The data used in this study has an interval of between 8 to 14 years. Available data for most recent years was also downloaded to check the change in recent years and current condition of the study area. The swath of one Landsat image is about 185 km which does not cover the entire Aral Sea surface. Therefore several images are required to completely cover the study area of a particular year [22].
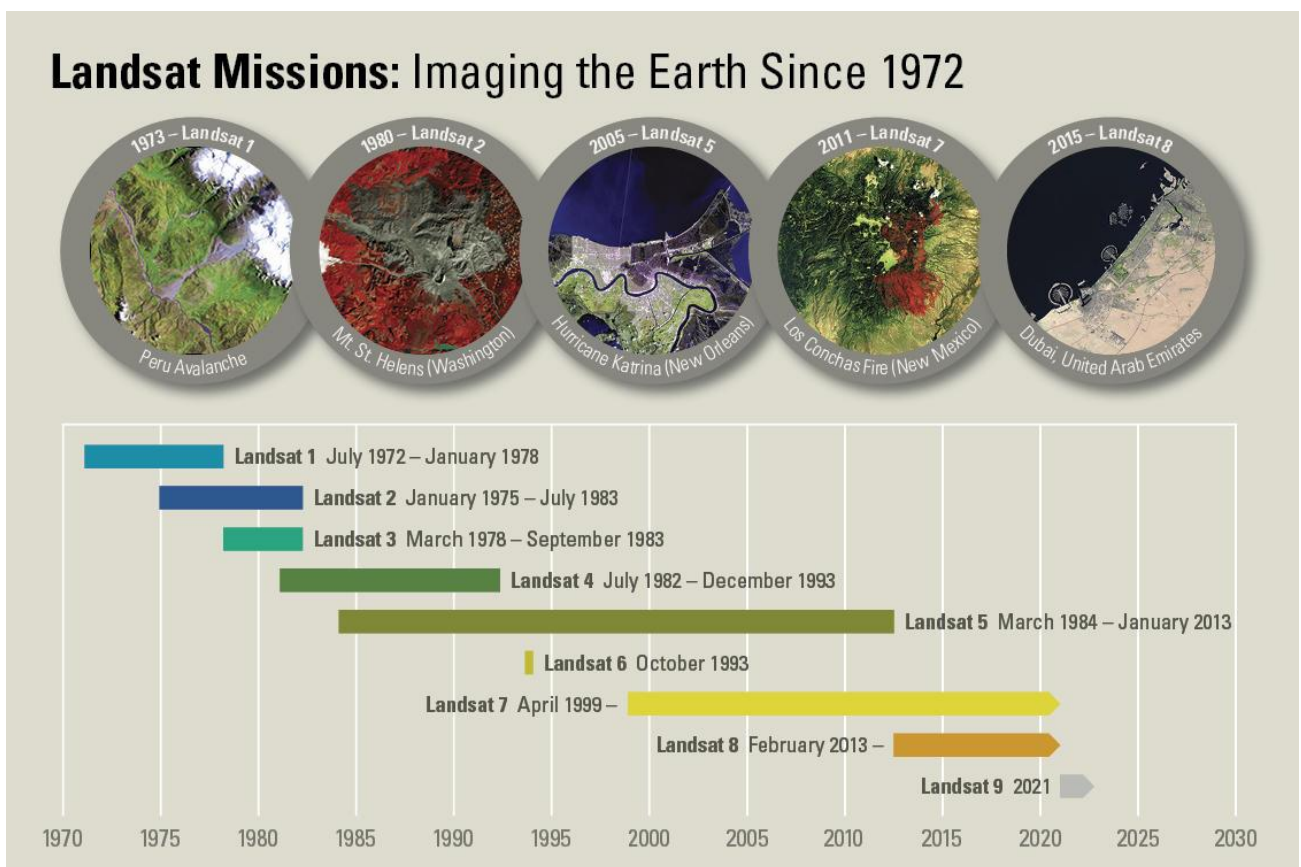
Figure 9. **Three decades of continuing Earth imaging service provided by Landsat** [23].

Image above shows the entire Landsat mission indicating start of the mission which is in 1970th and it is present mission and future plans as well. Main application of Landsat datasets are Land use, agriculture, forestry, geology, water resources,

mapping, etc. Landsat data are particularly suited to long-term estimation and monitoring of standing vegetation biomass, biological productivity, and the movement of fragile ecosystem boundaries [10].

Also for comparison purpose of the yearly change it was made sure to have the same seasonal data of each year and to have the data from the same sensor for a particular year to overcome the variation in the results because of different resolutions. In conclusion, the scenes downloaded vary from June to September of the same sensor for a specific year. The table below demonstrates the capturing year of Landsat imagery used and satellite it belongs to.

Table 2.2.

Available data

Serial No.	Number of scenes used	Year	Satellite
1	5	1973	Landsat 1
2	6	1987	Landsat 5
3	7	1999	Landsat 5
4	8	2007	Landsat 7
5	9	2009	Landsat 5
6	4	2010	Landsat 7
7	5	2013	Landsat 5
8	5	2014	Landsat 8
9	6	2015	Landsat 8
10	5	2016	Landsat 8
11	6	2017	Landsat 8
12	7	2018	Landsat 8

The characteristics of the data used are described in the following below table.

Table 1.3.

Available data characterictics

Year	Format	Resolution (m)	Sensor
1973	GeoTIFF	80	MSS
1987	GeoTIFF	30	TM
1999	GeoTIFF	30	TM
2007	GeoTIFF	30	ETM+
2009	GeoTIFF	30	TM
2010	GeoTIFF	30	ETM+
2013	GeoTIFF	30	TM
2014	GeoTIFF	30	OLI
2015	GeoTIFF	30	OLI
2016	GeoTIFF	30	OLI
2017	GeoTIFF	30	OLI
2018	GeoTIFF	30	OLI

The figure below depicts the user interface of the USGS website from where data can be downloaded. One the left side of the window vital information about the data exists i.e. path/row of the satellite, latitude/longitude, capturing date, cloud cover and quality of the data etc. On the right side of the window it shows how a particular image looks. On top is the information whether a scene is downloadable (in red) indicates that it is ready for download in another hand if information is not there, it means one should order and the system will generate this data to make it available for downloading. Of course USGS data portal is not the only source to download satellite data, there are many others such as earthexplorar, Landsat viewer, European Space agency and so on. USGS portal is one of the user friendly and easy to download

portal, therefore in this study we used this portal to get an access for time series images for this entire Aral Sea area.
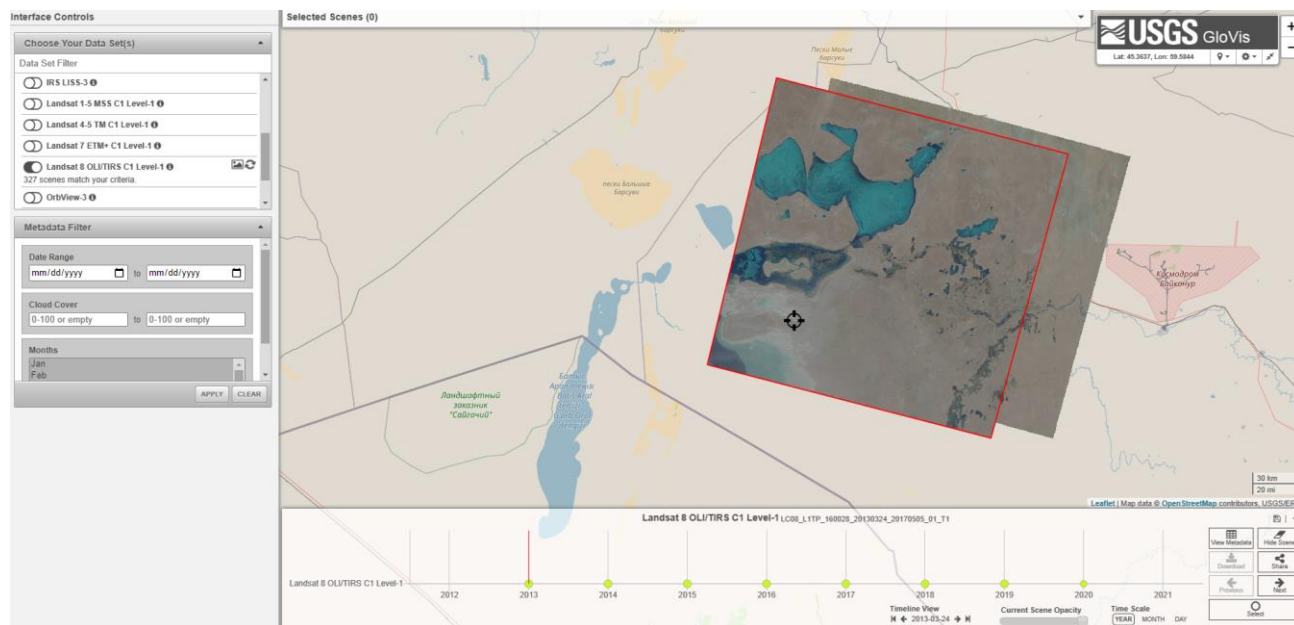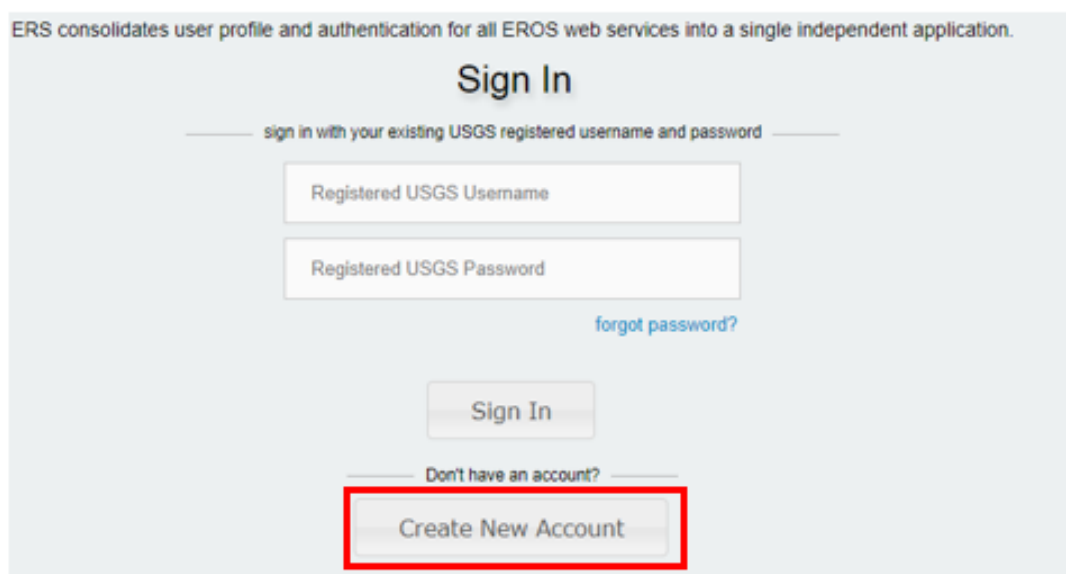

**Figure 10. User interface of the USGS data archive**

Step by step data downloading instructions are given below, please follow the red color rectangle on the images to be able to follow for downloading of images.

1. https://glovis.usgs.gov/app?fullscreen=1

2. Register on the site / log in to your account.

3. Select the territory where you want to download data:

- Add lat/Long, Scene ID or location
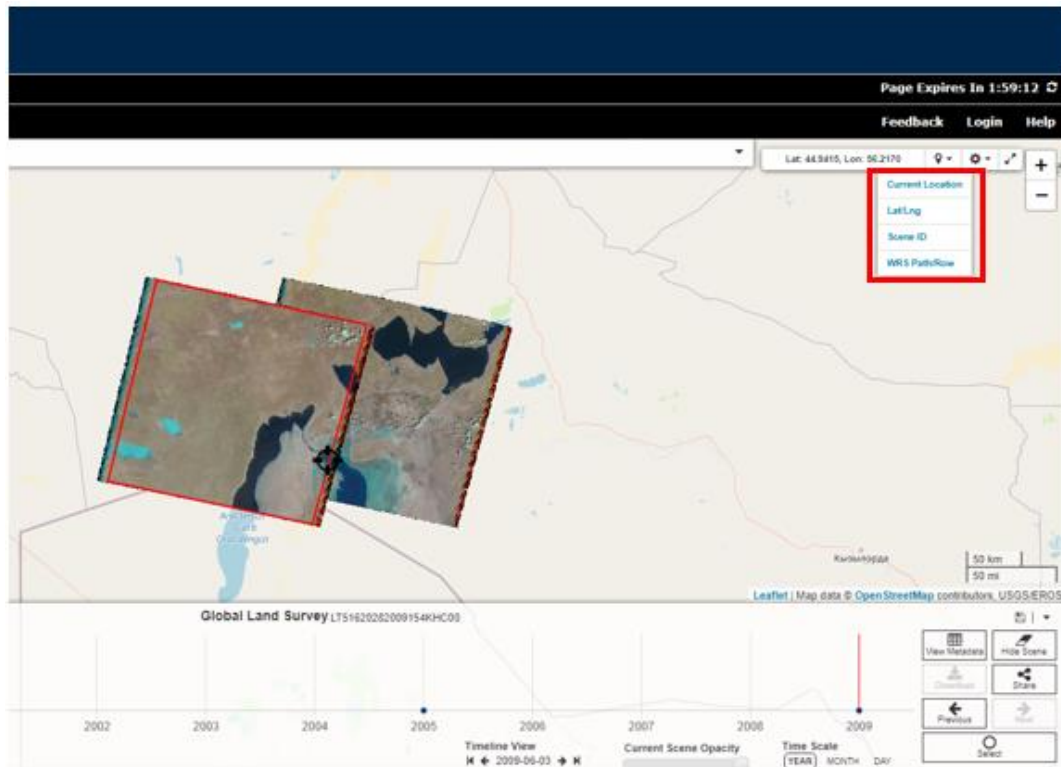
- By entering the name of the place or address in the address bar (after clicking Show, a table appears with the results of your query; clicking on the address in the table displays a marker on the map)

4. Below the criteria for a territorial request are the criteria for a temporary request. Fill in the Data Range field for which you want to receive data (months can be selected separately; by default, all are selected).
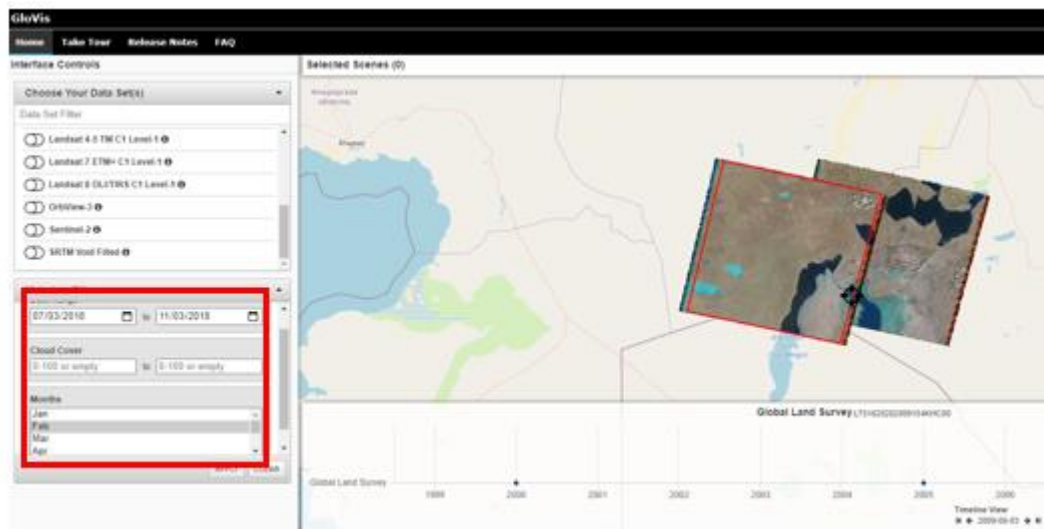
We can select time series over years and select exact months as well.
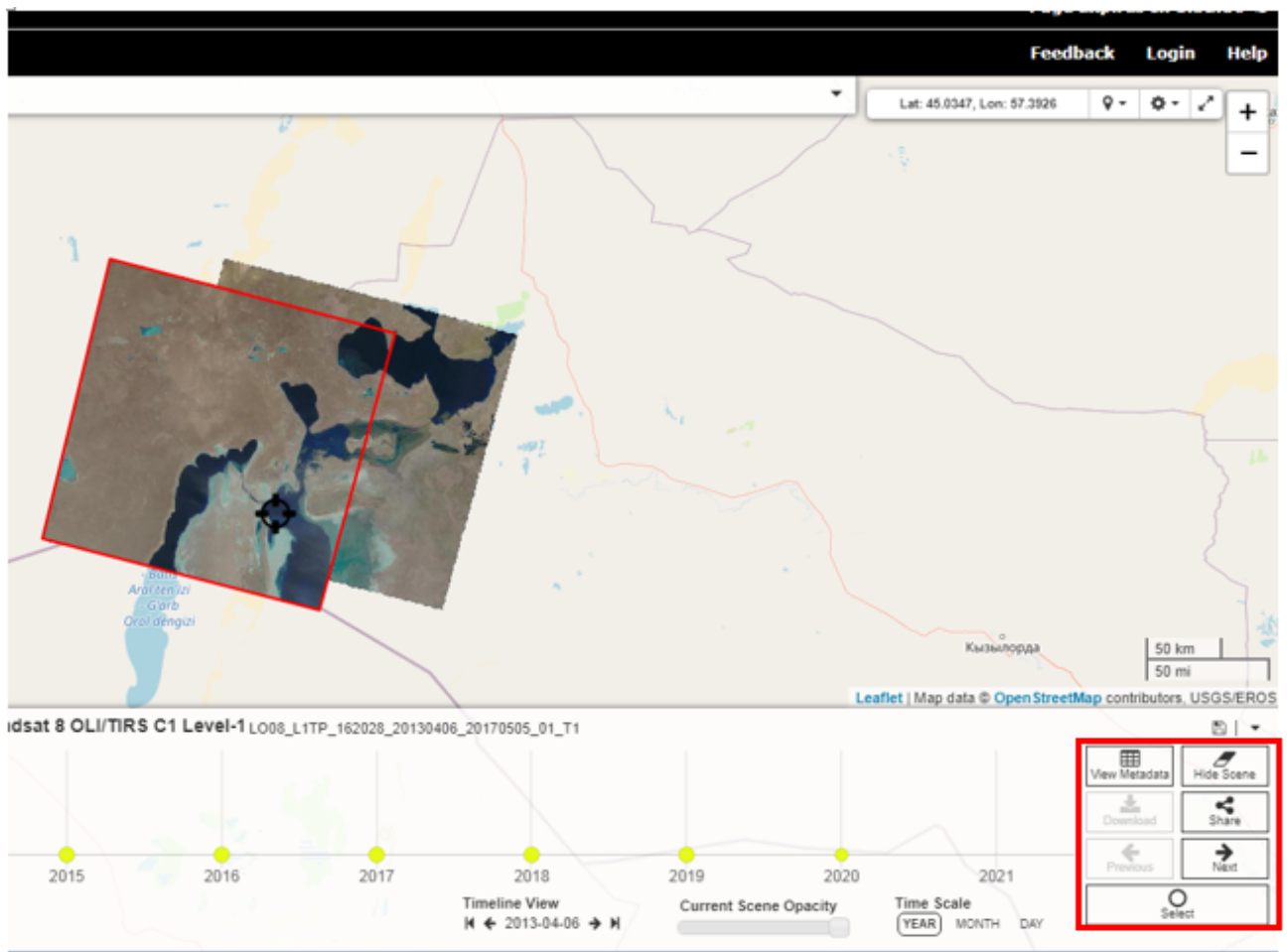
Depending on what data you need, select a particular line of the list (one or several):

- Landsat 1-4 – L1-5 MSS;

- Landsat 4-5 – L4-5 TM;

- Landsat 7 – L7 ETM+ SLC – on (1999-2003)

- {data – L7 ETM+ SLC – off (2003-present) "damaged", damaged pictures, with black stripes };

- Landsat 8 – L8 OLI/TIRS.

It is possible to see metadata of the current images and some other parameters. If data is good enough, we can then download this images which is also on the right below corner.

5. If the picture satisfies you in every way, then click download

- A window will appear
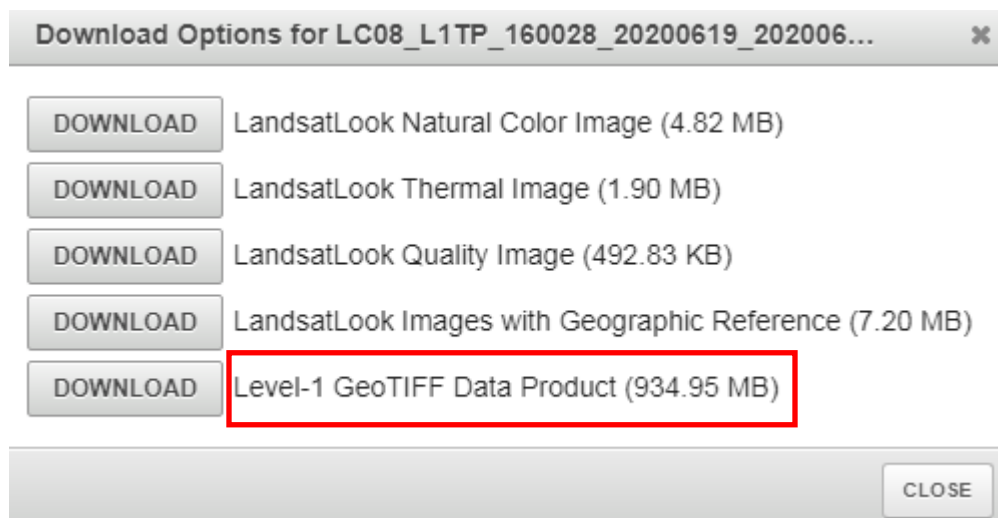
Download the heaviest file. In the above example (above), this is **Level 1 GeoTIFF Data Product (934.95 MB)**. All other files are for quick looks, allowing to visually look at pictures in various syntheses to finally decide if we need this or not.

6. Click on Download and wait for completing the process of downloading
7. The downloaded file is an archive. The archive will have the tar.gz extension (but maybe something other format). Before you start working with pictures, you need to unpack it.

Comments

Sometimes the Download button for the selected image may be inactive. Therefore you should first login to have download button as active. But sometimes the data is went into some kind of post processing. They will be available, but through a certain period of time (waiting time can be calculated in days or weeks). Usually, on the portal you can find an informational message with a warning, or it will be announced in front of you at the request generation stage that you should wait.

2.4. CLASSIFICATION

In most cases human eyes automatically recognize the type of land belongs to which class, but in order to recognize these patterns in computer system it is necessary to train software to differentiate the spectral response of pixels in a meaningful way. Mainly two types of classification methods exist in image classification, namely supervised and unsupervised classification. The purpose of both classifications is the same to find land cover types and set them into classes. The main difference between these two classifications is discussed below.

For unsupervised classification one should concentrate to the mathematical behavior of the image and their reflectance. According to mathematical setup one will create classes and signatures which enable the image to be represented from this segmentation of the area. Supervised approach is quite different then unsupervised as training samples should be designed for this type of classification. According to these samples the selected algorithm will try to find other pixels in the image that belongs

to spectral reflectance of those samples. These training samples are discussed below in detail.

2.4.1 SUPERVISED CLASSIFICATION

In supervised classification, samples of the different land cover types in an image are taken before hand. These samples are also called "Training sites". Each sample has a statistical data and has a spectral signature. These signatures are compared with available spectral signature libraries. The sample having similar signature to a certain land cover is then assigned to that class. This training site is then used to classify all the areas having similar spectral responses in an image. It is not always possible that the spectral response of a certain land cover exactly matches with the spectral library. The spectral response of a certain land cover type can be affected by several factors like seasonal changes or health of vegetations. Therefore several supervised classification techniques are used today to differentiate these spectral responses into land cover classes. Most famous methods are Maximum likelihood classifier, Minimum distance to mean classifier and Mahalanobis distance classifier (Tangjaitrong, Supichai).

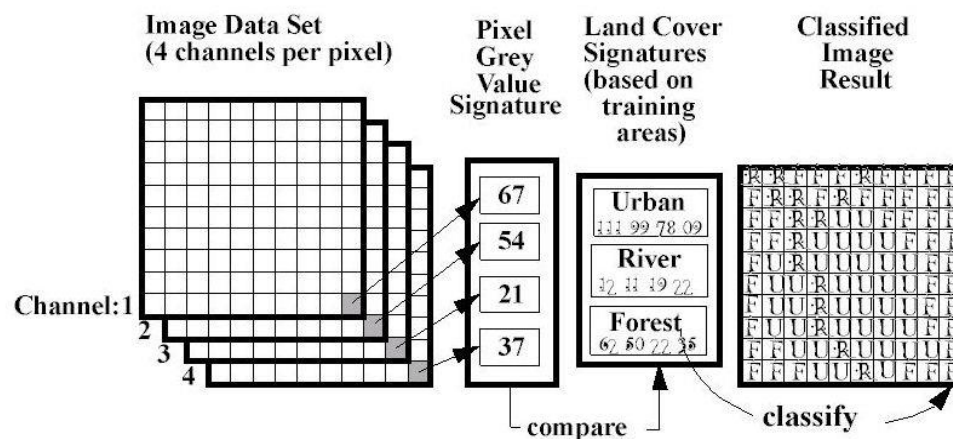Figure below illustrates how the classes are sorted into land cover types.

Figure 11. Steps in supervised classification [20].

2.4.2 MINIMUM DISTANCE CLASSIFIER

In minimum distance to mean classification method the mean or average spectral value in each spectral band for each class, based on training sets, is calculated. Then it determines the Euclidean distance of an unknown pixel to the mean value of each class. After calculating the distances the unknown pixel is assigned to class which is closest to the unknown pixel. If the pixel is not within the user defined distance then it remains unclassified.

Minimum distance to mean classifier is simple and quite fast. But it lacks the ability to take into account the variability of the each spectral class. Because of this huge draw back this classification is not widely used specially where the spectral classes are close to each other in scatter plot and comprise high variance [12].

2.4.3 MAXIMUM LIKELIHOOD CLASSIFIER

The Gaussian Maximum likelihood classifier takes into account the variance and covariance of each class, having similar spectral values, while classifying an unknown pixel. The classifier assumes that dispersal of each class training data is normally distributed and estimates the probability of an unknown pixel belonging to the each class. The pixel is finally allocated to the class that has the highest likelihood or probability. If the probability threshold is not defined then all the pixels are classified otherwise pixels that do not match the criteria will remain unclassified [12].
The equation for maximum likelihood classifier is given below

D = ln(ac) - [0.5 ln(|Covc|)] - [0.5 (X-Mc)T (Covc-1) (X-Mc)]

Where:

D = weighted distance (likelihood)

c = a particular class

X = the measurement vector of the candidate pixel

Mc = the mean vector of the sample of class c

ac = percent probability that any candidate pixel is a member of class c

(defaults to 1.0, or is entered from a priori knowledge)

Covc = the covariance matrix of the pixels in the sample of class c

|Covc| = determinant of Covc (matrix algebra)

-1/Covc = inverse of Covc (matrix algebra)

ln = natural logarithm function

T = transposition function (matrix algebra)

(Erdas field guide)

The major advantage of maximum likelihood classification is its capability to take variability of classes into account by using the covariance matrix which yields quite accurate results. Whereas the major disadvantage of maximum likelihood is the computation of extensive equations to classify a single pixel. These computations take a long time as compared to other classifiers. This becomes more problematic when dealing with numerous spectral bands. The second drawback is the immense dependence of maximum likelihood on normal distribution of data in each spectral band [12].

2.4.4 MAHALANOBIS DISTANCE CLASSIFIER

The Mahalanobis Distance classification overcomes some of the limitations of minimum distance to the means classifier by considering the direction in addition while classification. It presumes that the covariances of all the classes are equal. This assumption helps the classifier to be fast as compared to maximum likelihood

classifier. If the pixel is not within the user defined distance threshold then it remains unclassified otherwise all the pixels in an image are classified to the closest class [17].

CHAPTER – 3 METHODOLOGY OF WATER SURFACE DELINEATION AND RESULTS

3.1 OVERVIEW OF WORKFLOW

Methodology that is implemented in this work is described in steps. Major approach of this work was to apply supervised classification for extracting features from satellite images with satisfactory results. Methodology is a framework that allows humans knowledge to progress. Therefore methodology implemented in this research was divided into four main parts by analyst consisting of several sub parts. Following diagram shows these major portions as they feed one another.
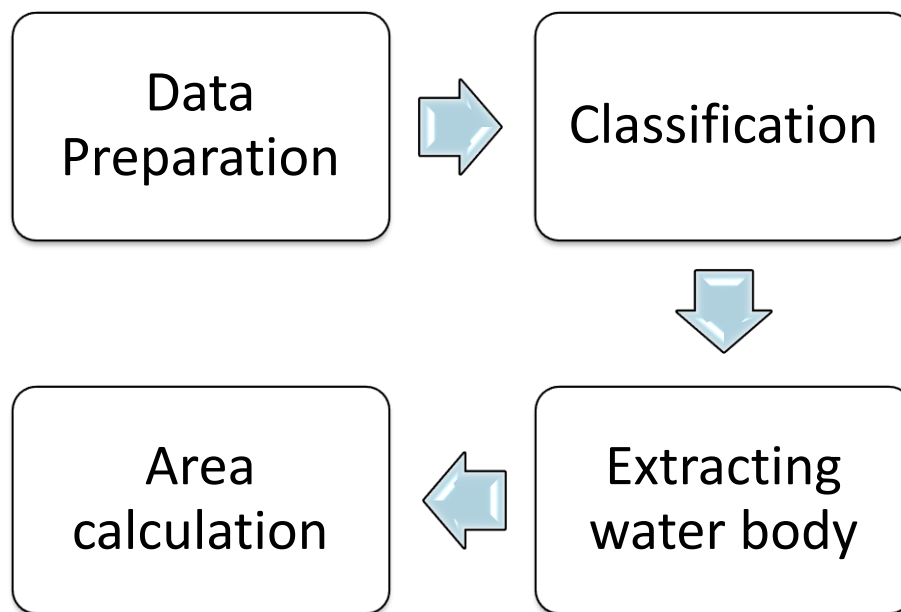
Figure 12. Complete workflow

All these processes were supposed to be carried out in "ILWIS" software but they were done in "Erdas Imagine" software due to couple of problem ensues in data

preparation. One is the inability of "ILWIS" to stack more than three bands in an image and the other one is its incapability to produce seamless mosaic.

Data preparation consists of seven sections and each has a particular method to grip them. As far as data preparation done, classification will be carried out which includes two sections. Thereafter extraction of water body and area calculation will be carried out.

Before making any analysis using Landsat data, there is a need for making atmospheric corrections or cleaning the image from from any disturbances. Each single layer which will be used for calculation should be converted to top of Atmosphere Reflectance to get fine image (so called atmospheric disturbances). Two levels of conversion equation to be used to get fine image.

1.   Digital number to Radiance

2.   Radiance to Atmosphere

Digital numbers to radiance

Since reflectance is calculated using radiance data, It is necessary to convert DN to radiance beforehand. Mainly two formulas exists to convert DN to radiance, it depends to the user and metadata file. One method uses Gain and Offset or Bias values from metadata file. The other one is longer equation which uses LMin ans LMax spectral radiance scaling factors (Landsat_DN_to_Reflectance). Conversion to radiance was done using second formula (longer equation). Metadata file provides all necessary information for this equation. The formula is as shown below. As mentioned earlier, the data preparation consists of seven steps, starting from original Landsat layers visualization. The figure below shows the workflow for data preparation.

DN to Spectral radiance formula

Result of digital number conversion has to be further used for calculating reflectance values. Following equation is used to get top of Atmosphere reflectance.

$$L_{\lambda} = \left(\left(LMAX_{\lambda} - LMIN_{\lambda}\right)/\left(QCALMAX - QCALMIN\right)\right) * \left(QCAL - QCALMIN\right) + LMIN_{\lambda}$$

Where:

L_{λ} is the cell value as radiance
QCAL = digital number
$LMIN_{\lambda}$ = spectral radiance scales to QCALMIN
$LMAX_{\lambda}$ = spectral radiance scales to QCALMAX
QCALMIN = the minimum quantized calibrated pixel value
    (typically = 1)
QCALMAX = the maximum quantized calibrated pixel value
    (typically = 255)

Result of digital number conversion in then to be used for calculating reflectance values. Following equation is used to get top of Atmosphere reflectance.

Radiance to Top of Atmosphere

$$\rho_{\lambda} = \pi * L_{\lambda} * d^2 / ESUN_{\lambda} * \cos\theta_s$$

Where:

ρ_{λ} = Unitless plantary reflectance
L_{λ} = spectral radiance (from earlier step)
d = Earth-Sun distance in astronmoical units
$ESUN_{\lambda}$ = mean solar exoatmospheric irradiances
θ_s = solar zenith angle

Earth to sun distance in astronomical units is provided by NASA in Landsat handbook (Landsat_Handbook)

Table 3.1. Earth to sun distance in Astronomical units

Earth – Sun Distance in Astronomical Units

Table 11.4 Earth-Sun Distance in Astronomical Units									
Day of Year	Distance	Day of Year	Distance	Day of Year	Distance	Day of Year	Distance	Day of Year	Distance
1	.98331	74	.99446	152	1.01403	227	1.01281	305	.99253
15	.98365	91	.99926	166	1.01577	242	1.00969	319	.98916
32	.98536	106	1.00353	182	1.01667	258	1.00566	335	.98608
46	.98774	121	1.00756	196	1.01646	274	1.00119	349	.98426
60	.99084	135	1.01087	213	1.01497	288	.99718	365	.98333

Table 3.2.

Mean solar exoatmospheric irradiances also provided by NASA

Sensor	Band 3	Band 4
Landsat-5 TM	1557	1047
Landsat-7 ETM+	1555	1047

Solar zenith angle can be taken from the metadata file of each image.

Image below illustrates difference between before correction and after correction of the images from left to fight.
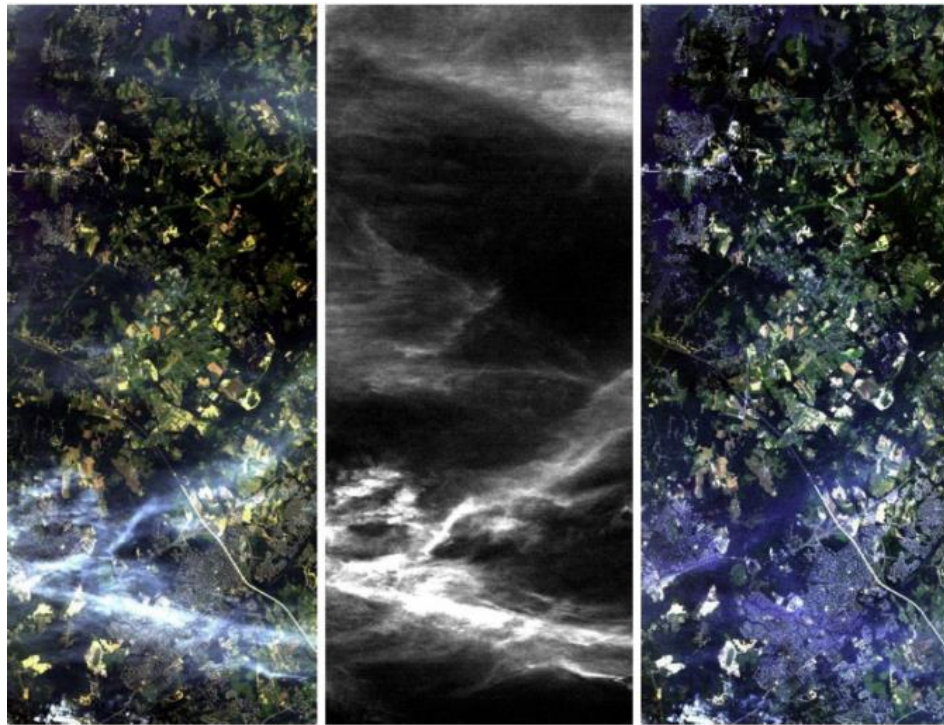
Figure 13. Example of atmospheric correction [7].

Converted output of radiance to reflectance is then used for further image processing steps.
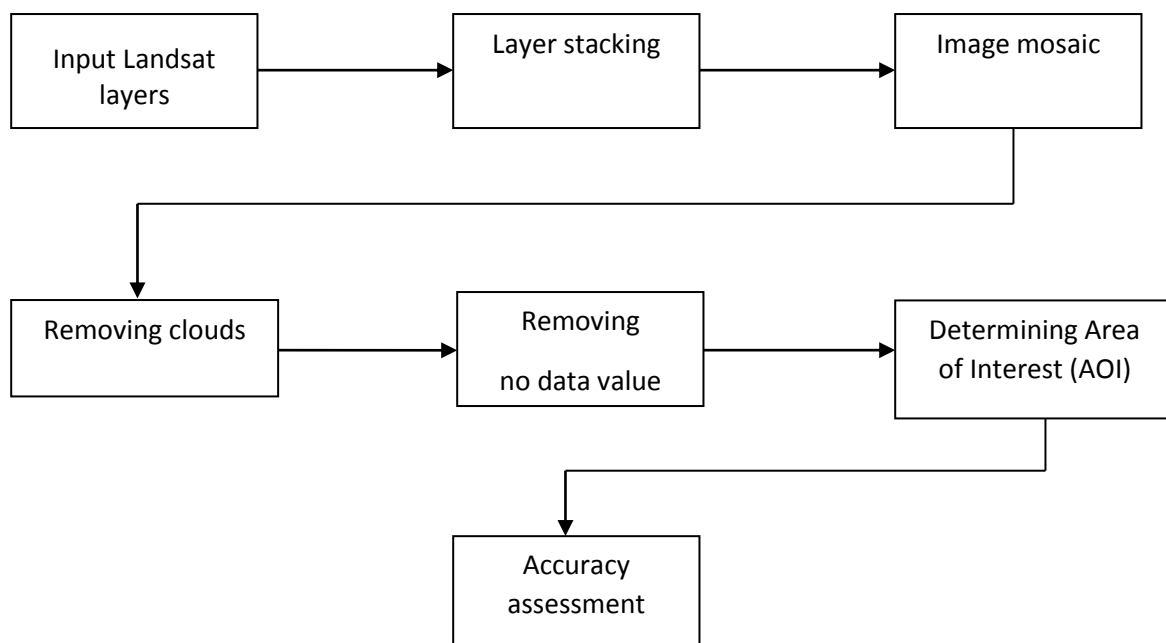
3.2. DATA PREPARATION

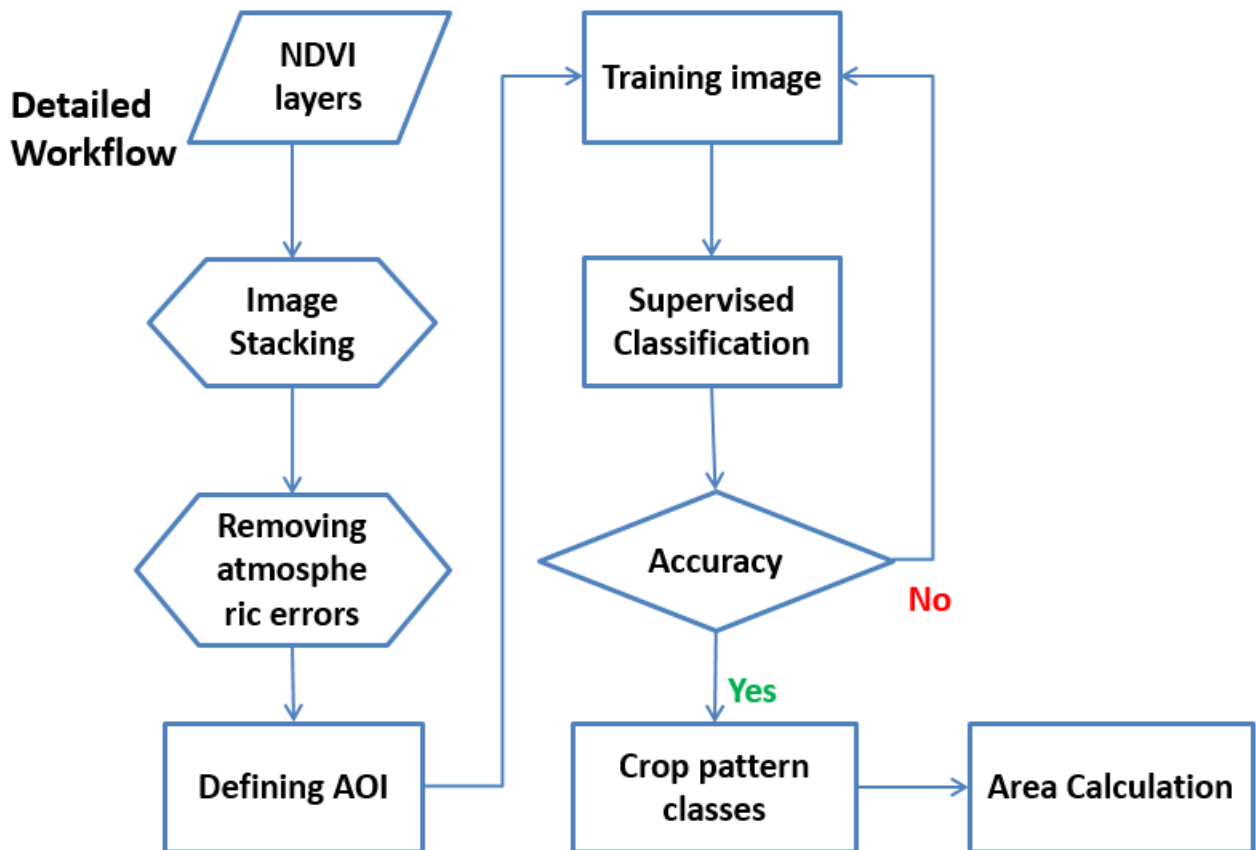**Figure 14. Complete data preparation workflow**

Figure 15. Detailed workflow

3.2.1 LANDSAT LAYERS

Remote sensing information is available in several layers reflected or emitted in electromagnetic spectrum of light having grey values. Combination of these bands enables human being to see them as they appear in nature if true color combination has been used i.e. layer reflected in red wavelength is assigned as red band, the green wavelength as green band and the red wavelength as red band. Except thermal layers, all other layers available for a particular scene were taken into consideration in this study. Different bands are important or appropriate for different types of applications.

For delineating water bodies, 1st, 2nd, 3rd and 4th bands are the most significant ones as it is depicted in spectral signature figure.

One of the disadvantages of remote sensing data is that it can be affected by atmospheric conditions e.g. clouds. This is why the layers were first loaded to "Erdas Imagine" software in order to check if they contain clouds or not. It was found tha some of layers contains clouds and no da values. Clouds and no data can be removed before stacking as well but they were removed after stacking and mosaicking because it is easy to remove clouds and replace no data values once the layers are stacked. Also some of the clouded or no pixel area can be coved by other cloudfree good quality images while mosaicking.
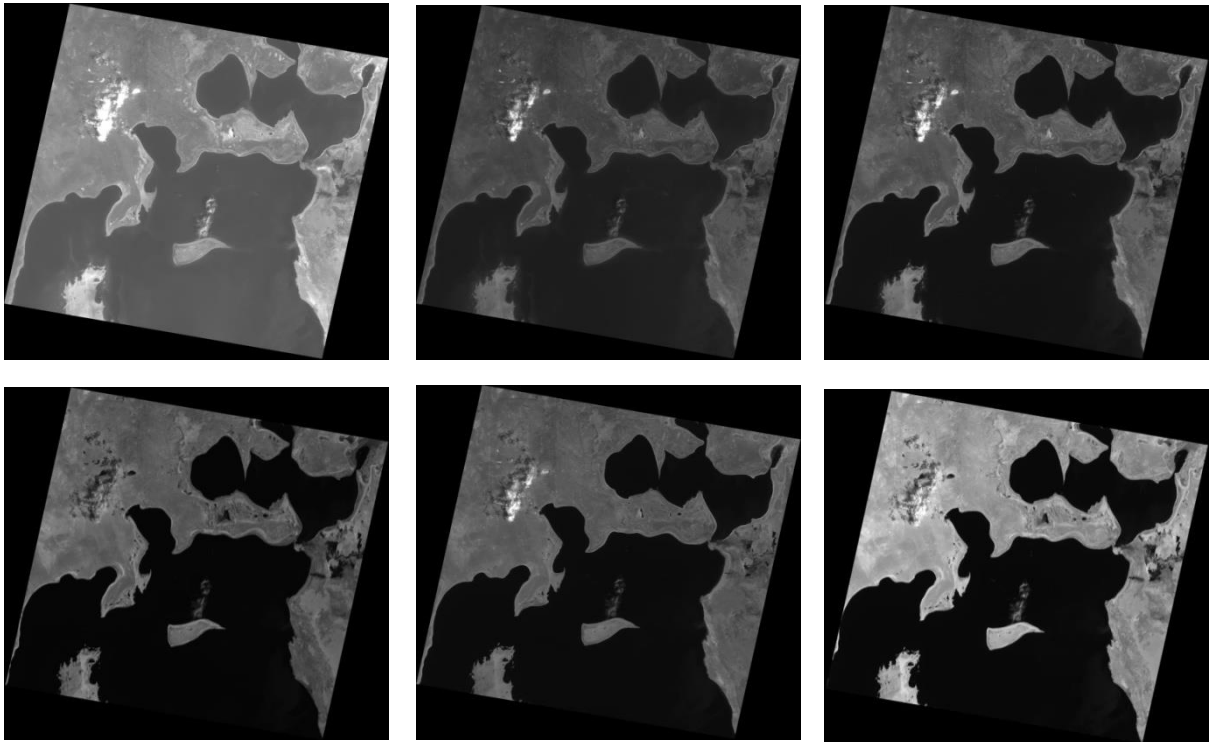
Figure 16. Landsat bands 1, 2,3,4,5 and 7

The above figure shows different layers of a Landsat image. In order to process these layers simultaneously for classification they have to be combined and/or stacked.

3.2.2. LAYER STACKING

These layers obtained are already georeferenced having Geodetic Reference System (CRS) UTM zone 40 datum WGS 84. All available Landsat layers except the thermal band were considered for stacking to get one image.
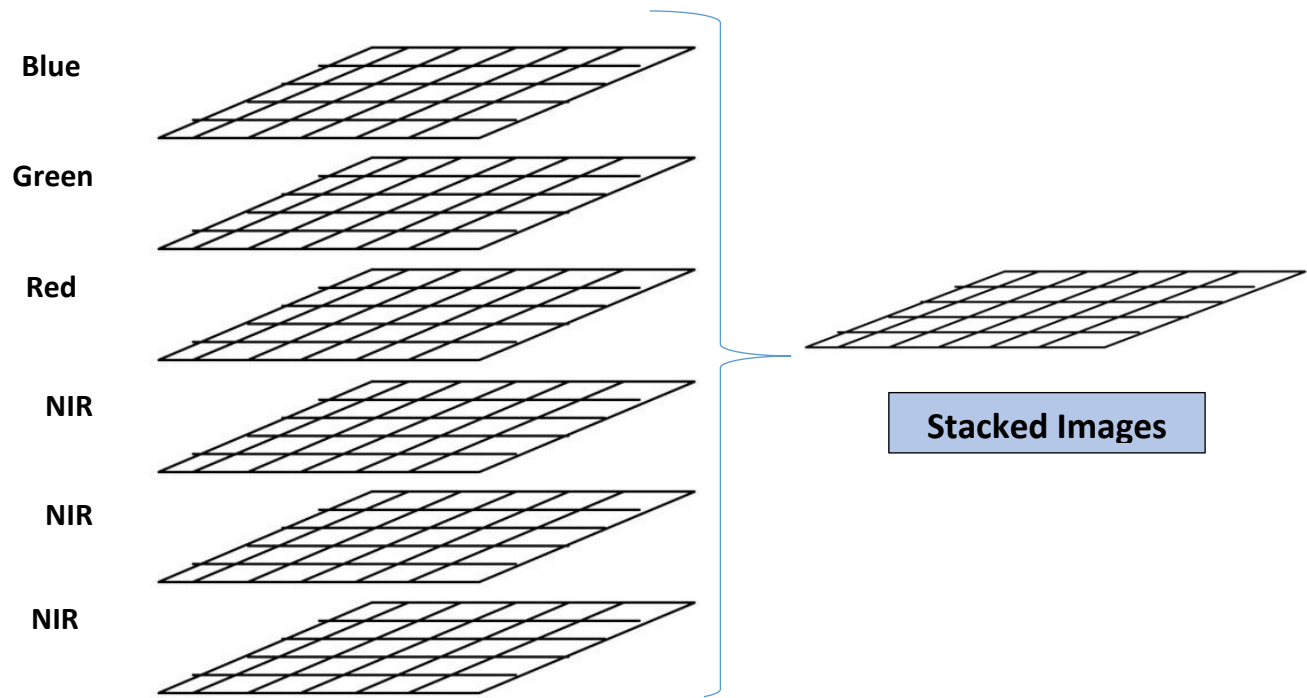

Blue

Green

Red

NIR

NIR

NIR

Stacked Images

Figure 17. Different Layers

Below is an example of a stacked image displayed in 421 bands as RGB.
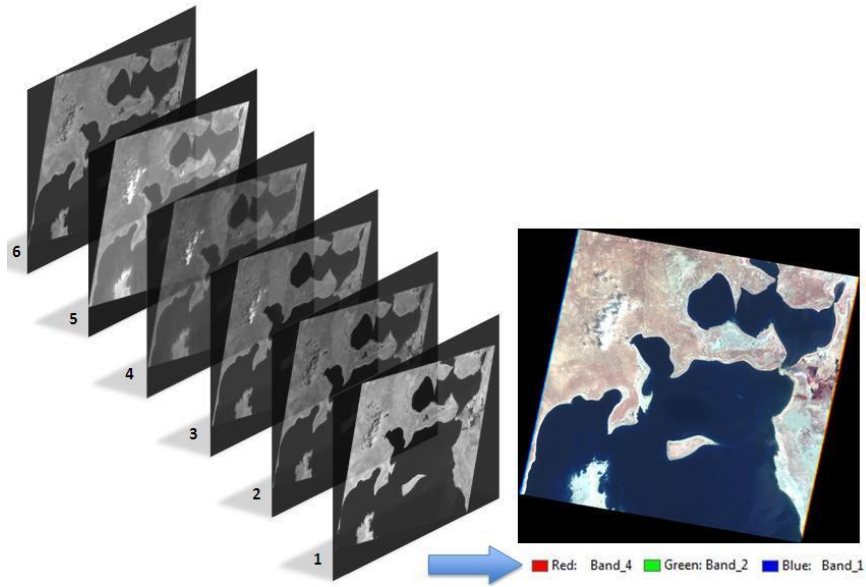
Figure 18. Stacked image

Landsat data has a swath width of approximately 185 × 170 km but the study area is larger than this swath. Therefore, complete study area is covered in several image files. In order to get a unique image that covers complete study area, it is necessary to combine several images. This was done by mosaicking images with each other.

3.2.3 IMAGE MOSAICKING

Image mosaicking is the process of stitching several adjacent images together in order to get one large desired image. In the past, mosaicking was done by analog methods, which combined images manually. Computers using digital data carry out digital image mosaicking.

It is important that all the images overlap. If the images don't overlap then there will be gaps/holes in the output mosaic. Below are the images that are going to be mosaicked.
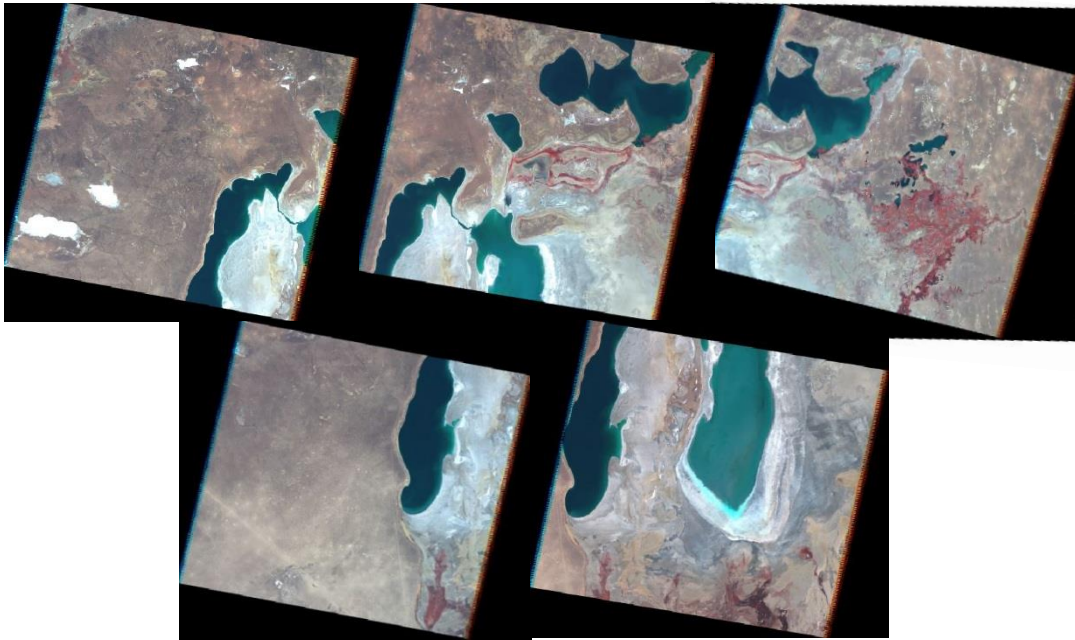
Figure 19. Scenes for 2007

These images to be loaded to the software for producing one large image using mosaic tools. As they are loaded to the software the images come to each other as overlapped, so this overlapped area will be merged using some seam line editing.
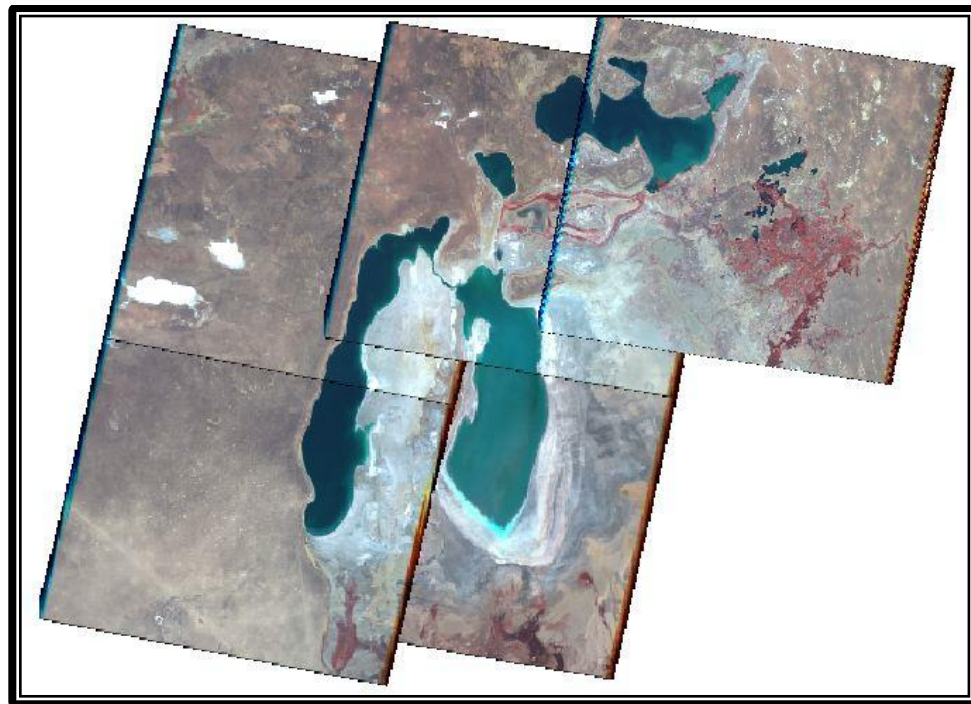

Figure 20. Overlapped images

The images were overlaid and it can be seen that images have good overlapping area. Seam lines are used to merge these overlapping areas. Seam lines can be produced manually by digitizing or fully automatic way. Automatic method allows the software to find the best possible regions for seam lines. Automatic seam lines were generated and it was found there is a need for some editing. That is why wherever required some manual editing was done in all the mosaics.
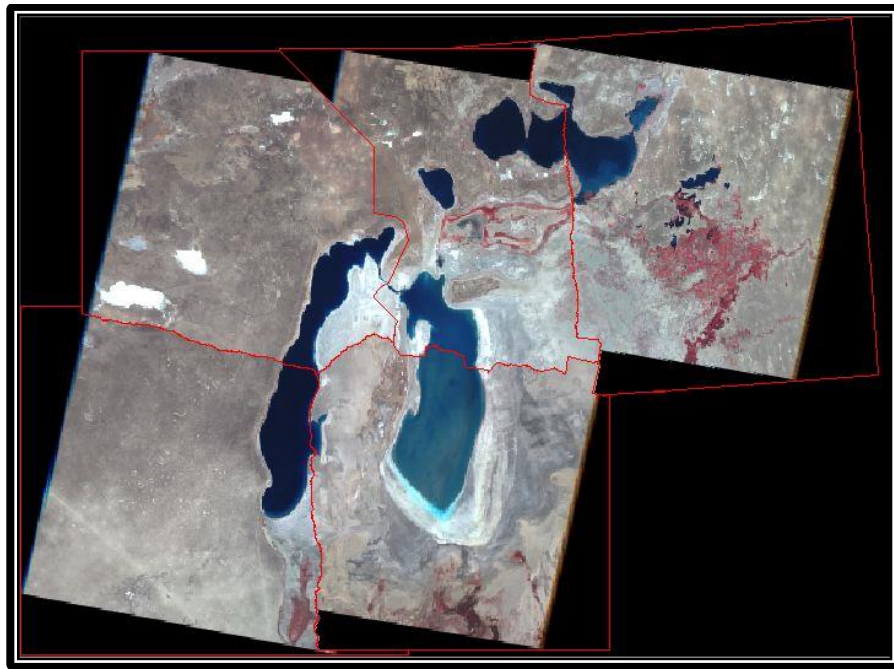

Figure 21. Seam line

This way image will be prepared for the mosaicking, so this seam lines editing connects all images to each other with the best way to generate clean image.
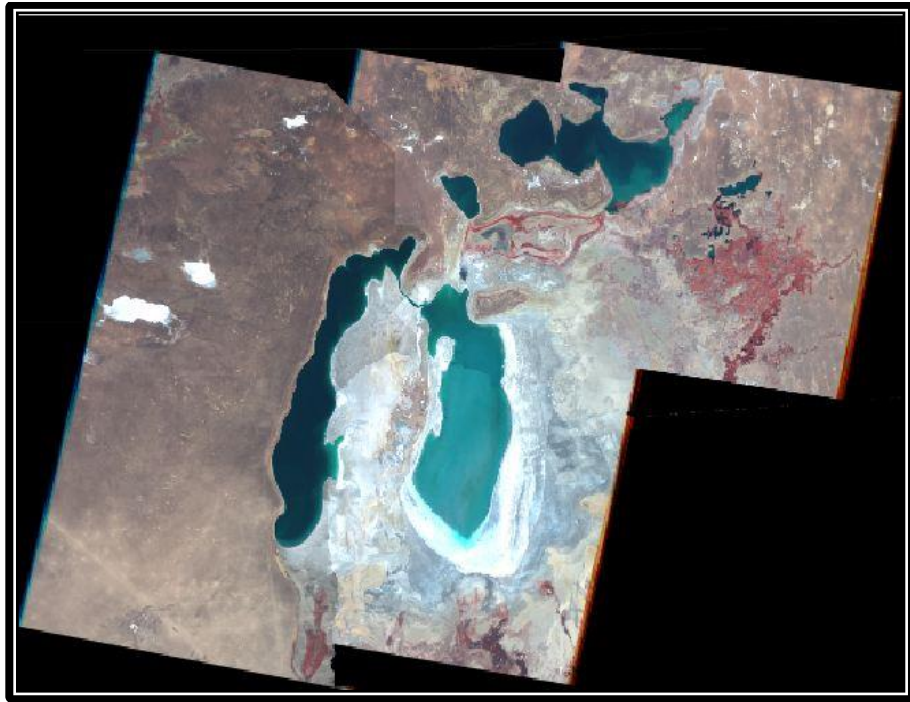
Figure 22. Mosaic result

After all the images were mosaicked successfully for one year, the same steps were used to mosaic the other years as well. In some images few no data value area and also clouds on the top of the water was found. These blunders have to be removed before hand. Image below illustrates this small portion of cloud cover and no data area exists in the image.
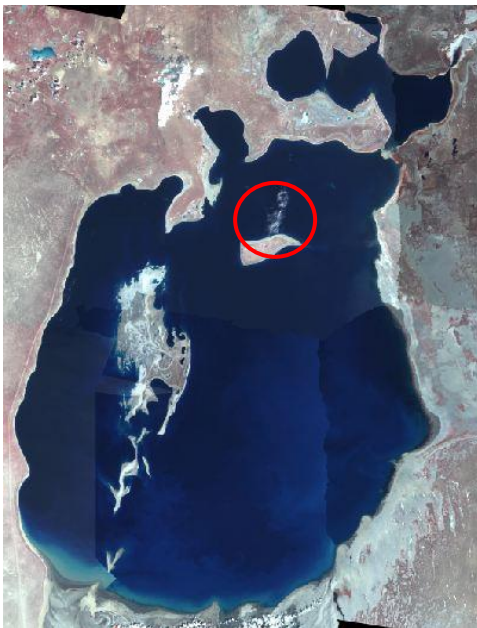
Figure 23. Image with cloud & no data value

3.2.4. REMOVING CLOUDS

For the removal of clouds, interpolation methodology of "Erdas Imagine" was used. This interpolation method allows editing the displayed raster layer in order to correct defects on it. This is accomplished by operating on an AOI that encloses a defective portion of the layer. Thereafter inside of selected AOI will be interpolated in order to get best approximation of a pixels color and intensity based on the values at surrounding pixels.
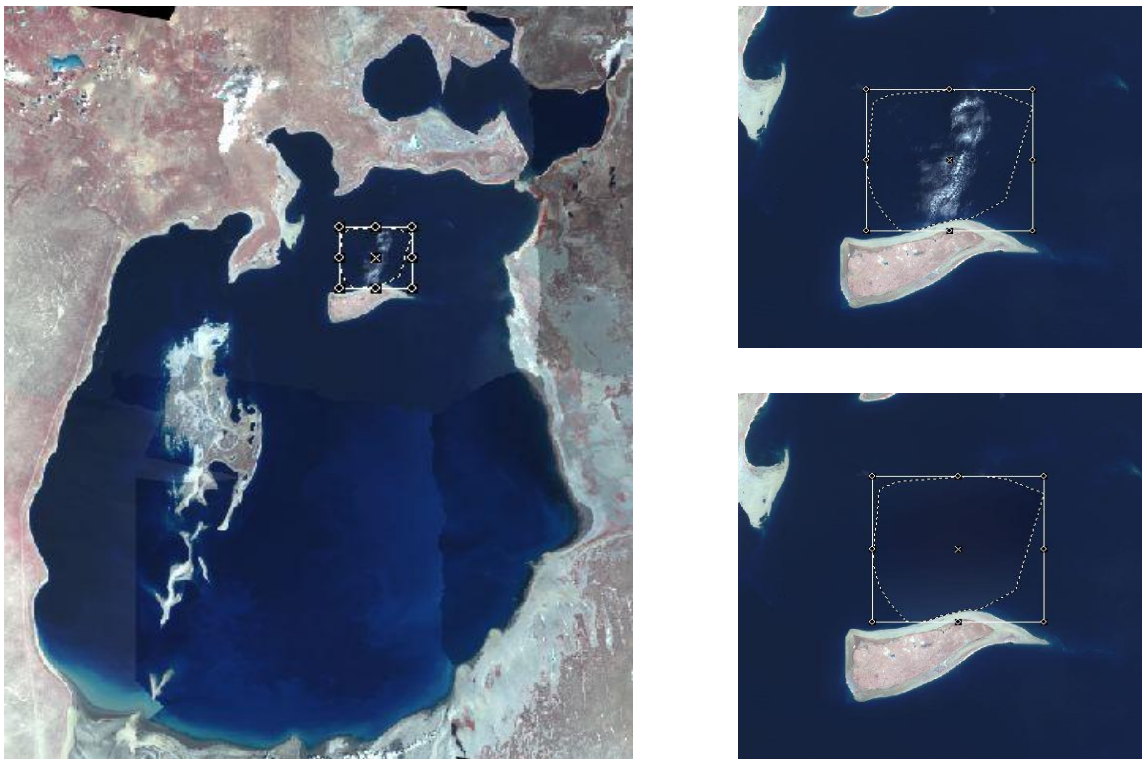

Figure 24. Cloud removing

Interpolation is a function to add some pixels that do not really exist in the defected area for making the image relatively accurate. There are number of interpolation algorithm exists and they are applies depending on how this interpolation method will affect to the image quality. Usually series of mathematical computations are done within the interpolation. Interpolation algorithm looks at one pixel and all the pixels

surrounding area and then decides what pixel to change. This way clouds and no data value areas were corrected and brought to the similar pixels as water (Randy Glass).

3.2.5 REMOVING NO DATA VALUES

Additionally to cloud covered areas in the image, some area contain no data values which should also be corrected. These gaps in the image were also handled with the same method that is shown above. Same interpolation method is applied and eliminates those defects. The problem with no data values occurred only in one image which was captured in 1973. These no data values were visible as small lines on water surface area. It is very important to know the land cover under cloud covered areas or on no data values in order to process the image.
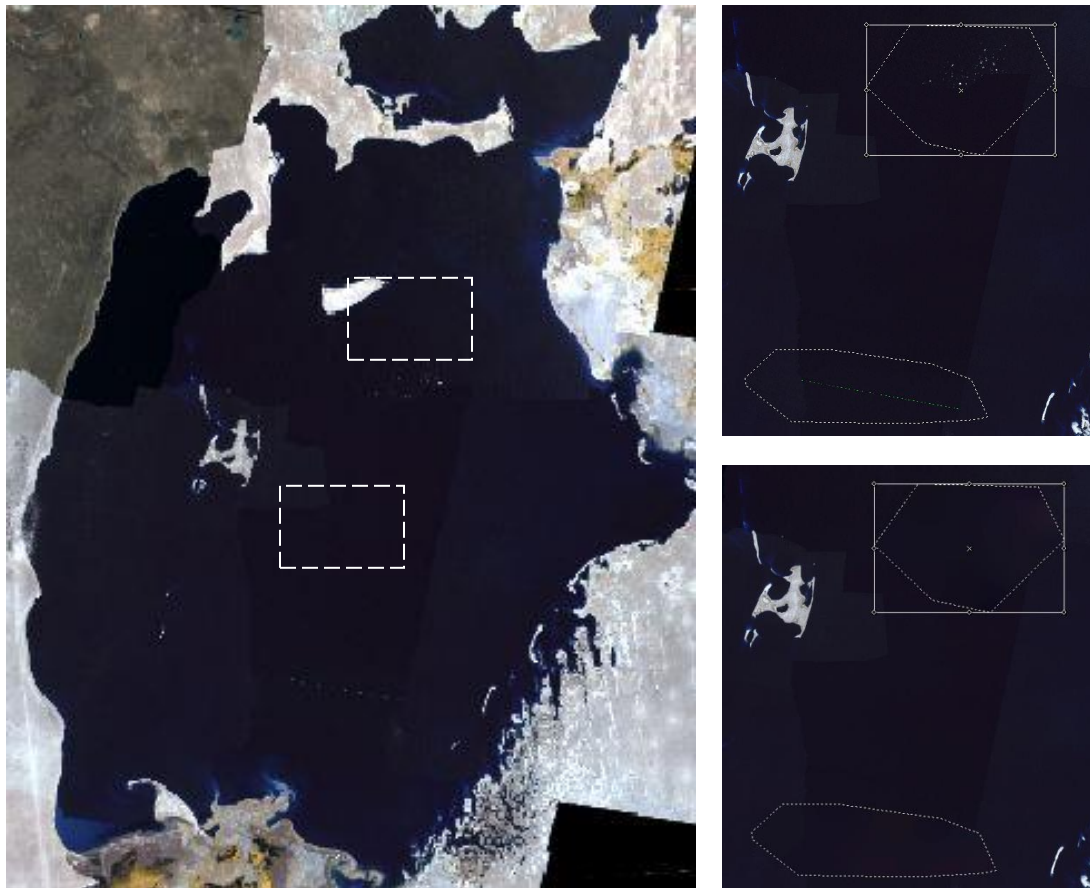

Figure 25. No data value removing

Meanwhile all blunders were removed and clean image was generated, there is a need for data accuracy assessment of all the prepared mosaics in order to check if there is any shift in the mosaics or not. This assessment can be done by overlaying one image to another and verify whether a certain feature in different images laying in the same point or not, this is so called registration assessment.

„Registration is the process which makes the pixel in two images precisely coincide to the same points on the ground" [18]. Thus there is a need for assessment of the data if there is some shifts between different images. It can be done by overlaying images one to another and using swipe method it is possible to check the quality.
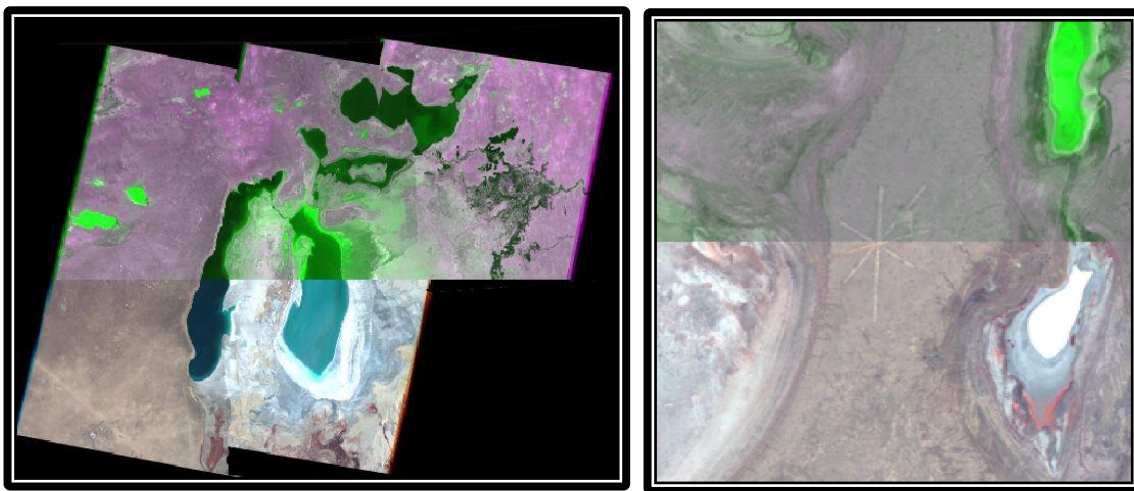

Figure 26. Data accuracy assessment

The above figures show two overlaid mosaics for different years. Using the swipe function of "Erdas Imagine" it is possible to check them how well these images fit together. On the right image above, the plane landing area is visible which is located in the island of former Aral Sea and has a size of approximately 2 kilometers. Using this point it is possible to check the quality fitting. Using such quality assessment of images, it was found that all the data are well georeferenced and there is no shift in images. Above shown overlaid images have different band combinations so that the difference between two images is visible.

3.2.6 DEFINING AREA OF INTEREST

In order to take only area of interest in those images into consideration, only the area around Aral Sea was taken for further analysis. The area of interest was defined not only to speed up the processing time by neglecting the unnecessary regions but also to eliminate the pixels at the borders of each mosaic that have similar spectral response as water and may disturb computation. In the test run of classification it was found that these border pixels were considered as water although they were not water surfaces in reality but have similar spectral response as water. Such small areas would increase the water area of Aral Sea causing incorrect results. For this reason it was vital to eliminate these error pixels. Area of Interest was generated for all mosaics and the classification was done only for this area.

Image below illustrates the area of interest that was selected for further analysis.

Figure 27. Area of Interest

3.3 CLASSIFICATION OF IMAGE

To extract the water bodies from the different land images there are several kinds of methods available. The most basic technique is visual interpretation of the images. This method is too primitive and time consuming. Other method is classification which is also fairly old but still yields very good results over large areas in short time. There are two broader types of classification having further subtypes. One is unsupervised classification and other is supervised classification. In this study supervised classification was exercised because of its high accuracy and ability to integrate the user's knowledge while implementing the classification.

3.3.1 TRAINING IMAGES

"Training is the process of defining the criteria by which these patterns are recognized" [9]. Sample selection in supervised classification is done manually. This process will categorize the pixels into different land cover features that are visually recognizable. This recognition is done by observing to the image and having an extra knowledge about the land cover types in the study area. By this sample identification, software is given certain classes for which all pixels in the image should be classified.

In this study, 4 main classes were categorized. These are vegetation, water body, soil, and salt.

"Erdas Imagine" software enables different methods to identify training samples and they are as listed below.

- Using a vector layer

- Defining a polygon in the image

- Identifying a training sample of adjoining pixels with similar spectral response

- Identifying a training sample of adjoining pixels within a certain area, with or without similar spectral response

- Using a class from a thematic raster layer from an image file of the same area

The second method (Defining a polygon in the image) was used to select samples in an image. These samples were selected using AOI tools in "QGIS". Defining a polygon enables digitizing the polygon. It is very easy and convenient as the user has the freedom to effortlessly choose the area for sample selection. The signature file is also created at the same time for corresponding training samples.

Figure 28. Training images

It is not necessary to make a lot of training sites, as there is not many land cover types exist in the study area. However, as many samples are takes as more precise the classification. In this case different samples were taken into account to detect the shallow water pixels as they also can be misclassified as soil. Taking samples also from very shallow water surfaces lead to sharp seashore edges of Aral Sea. So there is

a need for having several samples of variations in the same land cover if the results of classification are not satisfactory according to predicted land cover types.

Different types of polygons were created in the image as a sample to sort the type of feature in figure 28. From this generated polygons it is necessary to extract the information in the pixels to the signature in order to check the distinctions of several classes from feature space. From following diagram one can see all pixels of different classes in band two at x-axis and band four at y-axis.
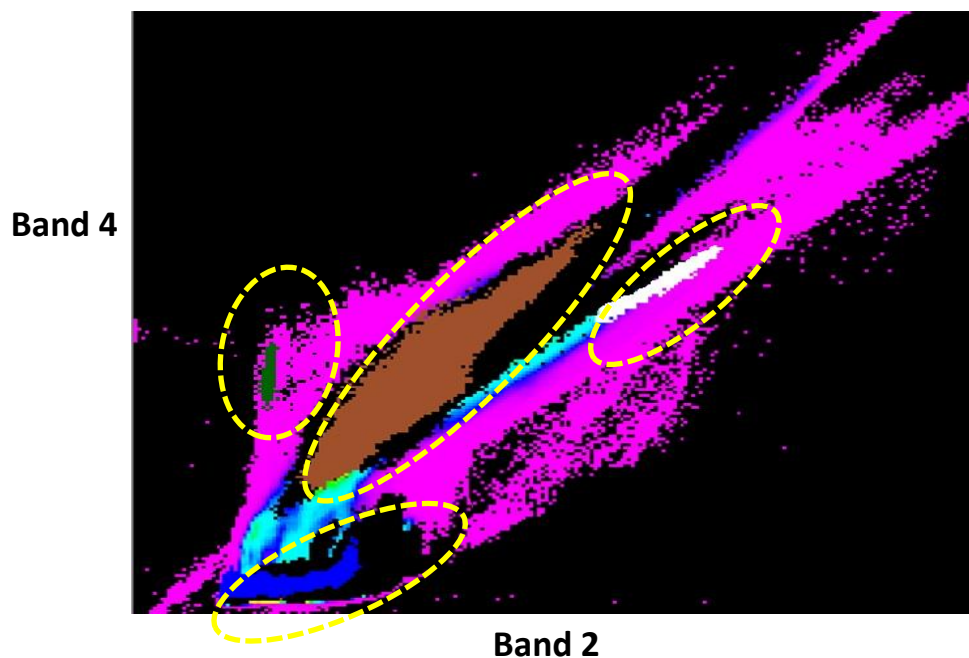
Figure 29. Feature space

Above shown scatter gram illustrates the combination of band four and band two and the reflectance of samples in these bands. It is important to select bands for visualization of images that have minimum correlation between them and also it is easier to differentiate the desired land covers in those bands.

Supervised classification is then applied to sort classes, in the section AOI layer or samples will be used for the purpose of sorting different types of features. Using that AOI layer and corresponding signature set classification process is carried out.

Supervised classification has different decision rules that can be used. These rules are non-parametric and parametric rules.

Non-parametric rule contains two other main rules which are overlap rule and unclassified rule. These rules are used if there is overlapping of classes which will mainly happen in crowded images. These kinds of cases guide through these rules and apply them to find the best solution.

Parametric rule contains different methods to apply in supervised classification. In the instrument Imagine Maximum likelihood, Mahalanobis and Minimum distance classifiers are available. For this research all three classifiers were tested. It was found that Maximum likelihood gives the best results for classification of water as compared to others. Therefore Maximum likelihood classification was applied in all the image mosaics in this research.
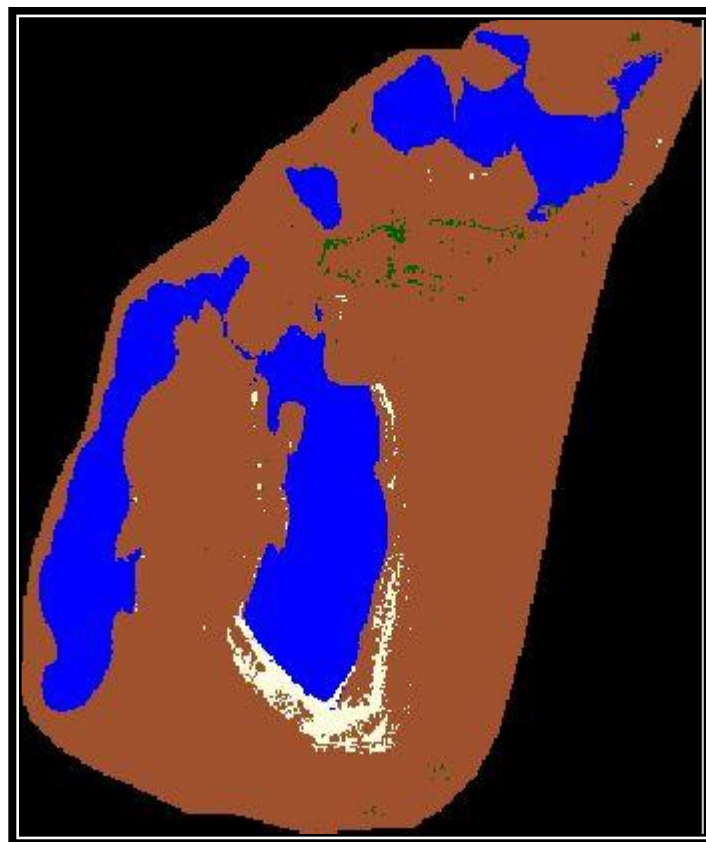

Figure 30. Image classification result

3.3.2 ACCURACY ASSESSMENT

Accuracy assessment can be carried out in order to check the quality of images comparing to ground truth or other information such as original Landsat images. Accuracy assessment is done by overlaying original image to the classified image in order to check if they are fitting well enough, especially in the regions of water border of the sea.
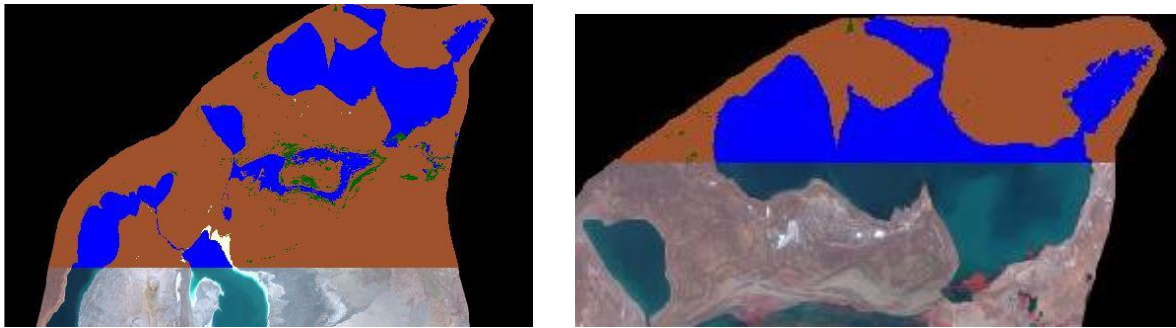

Figure 31. Accuracy assessment

Another accuracy assessment method is to extract region boundaries in order to overlay them to the image and see how sharp were the edges of the water area.

Figure 32. Accuracy assessment

From the above image one can clearly see that the edges are well extracted and the accuracy is good enough.

3.4 DELINEATION OF WATER BODY

These boundaries are in raster format. Using ArcGIS software conversion of raster layers to vector shape files is possible for further volume calculation. Additionally water surface sizes can be better compared having shapefiles of water bodies.

Figure 33. Water body in 1973

This is the extracted water body for the year of 1973 and this procedure is carried on all other images. This water surface delineation gives information for further calculation and management of our data and also the result of extraction process will be represented as polygons illustrate water area.

3.5 RESULTS

Classification was done for all image mosaics. These classification results show how the changes took place over past periods and help to make some analysis and make small prediction to the future. Figures below illustrate the area-calculated result for different years and illustrates the area calculated for each classified year. The numbers show that there is enormous water surface area lost since 1973. Two types of colors

have been used for each year's water and the blue color is the water that currently exists. More than half of the water area disappeared as compared to 1973 result. These changes are analyzed in the section below.

3.5.1. ANALYSIS

In this chapter the change analysis of Aral Sea water surface is discussed. The chart below illustrates how the surface changed exactly between 6 different years.
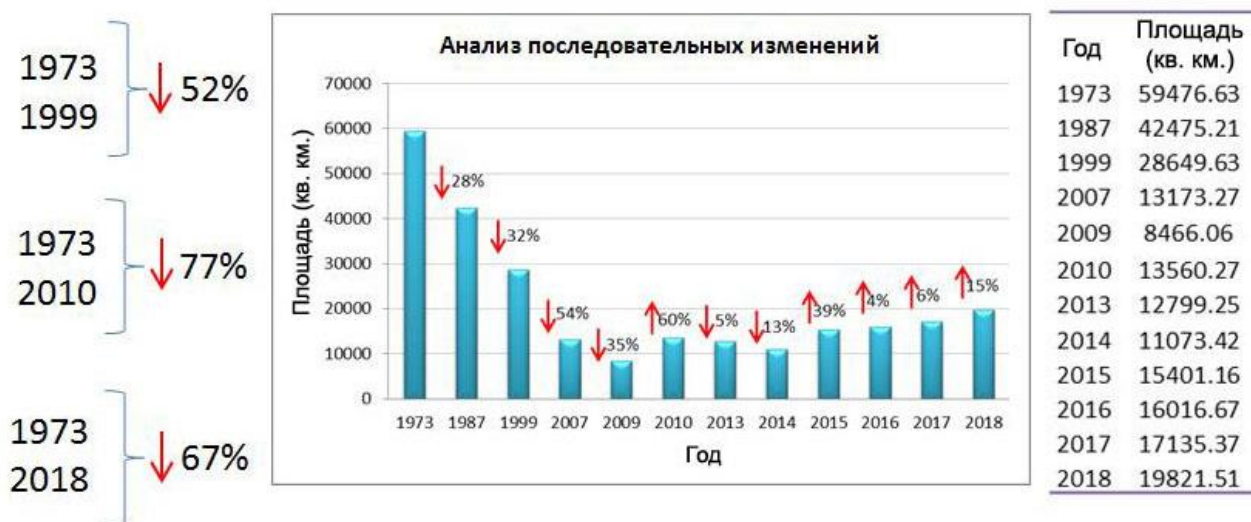

Figure 34. Analysis

As it is visible from the chart, the water surface of Aral Sea in 1973 was about 60000 km² and decreased with different rates afterwards. The percentage values between time spans show the amount of water lost between each period. For example, 28 % area was lost from 1973 until 1987. The decreasing of water surface continued until 2009. In 2009, southern part of Aral Sea was almost dried due to water shortage in this year. From 2009 to 2010 some water has arrived and increased the area by 60 % comparing to 2009. It is obvious that 60 % is big number but the coverage area is still very small as compared to previous decade results that are more important. Moreover, the Aral Sea is a shallow sea which leads to enormous water surface area even if the water volume was not that much. Huge lost was observed between 1973 and 2009, which resulted up to 86%. By 2010 this lost was decreased and the total lost for

existing data of Aral Sea is 77% which is still dramatic. The following image gives broad understanding of water lost in Aral Sea.
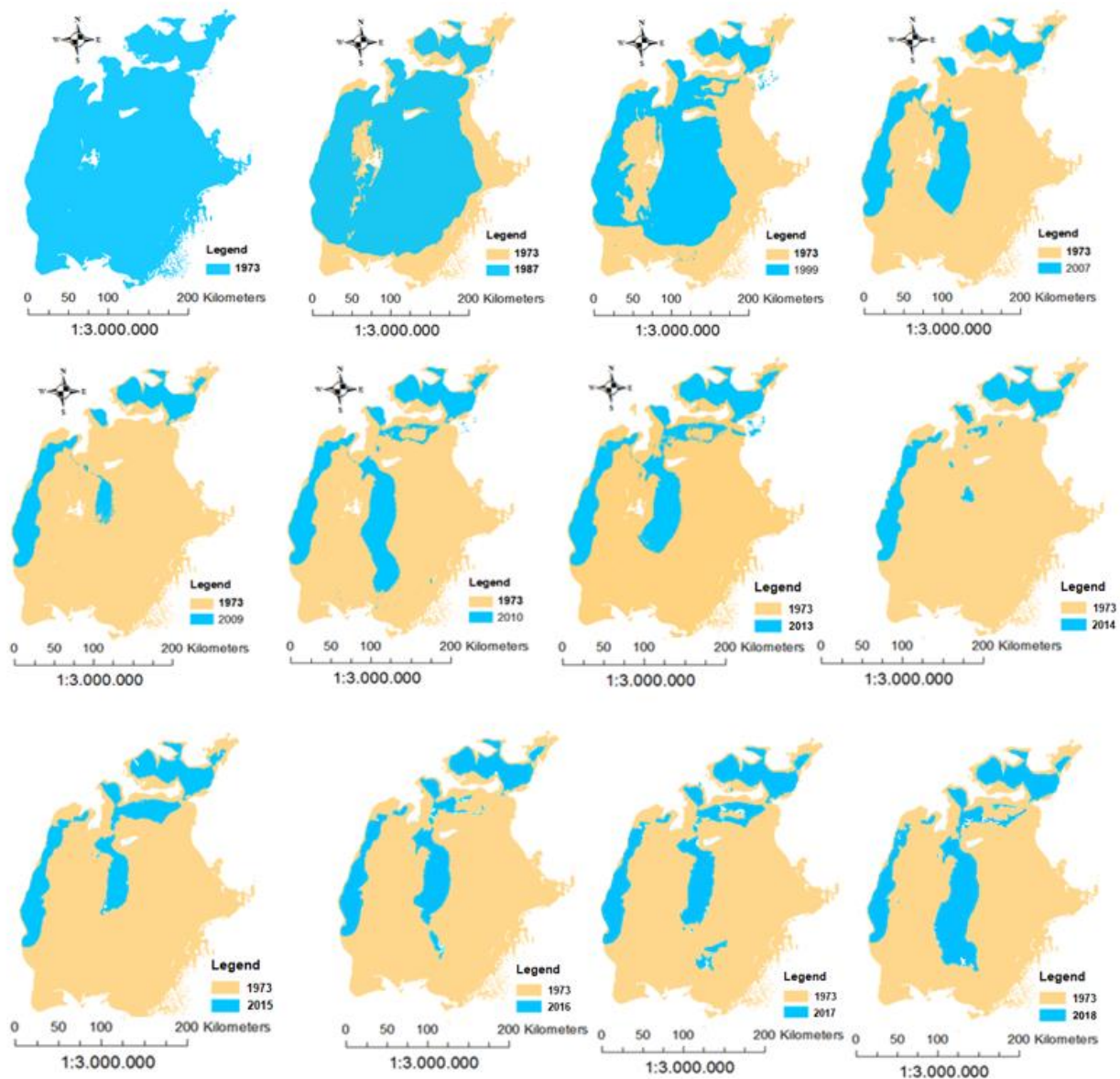

Figure 35. Changes of Aral Sea over time

There are two main reasons that water level has decreased so significantly in 2009. First reason is the effect of dam that was built in northern part of the sea, which is in the territory of Kazakhstan. This dam was built within the project for saving Aral Sea initiated by Kazakhstan in cooperation with World Bank in order to save at least one

part of the Sea. Another reason is that the year of 2010 was snow reach year which is melt in summer and reached the Aral Sea surface.

CONCLUSION

The main idea and the purpose of this study was to delineate water surface of Aral Sea to understand the changes of water resources in different time spans using publicly available remote sensing information. The results achieved in this study presented clear water surface changes for different years in the past. Through this study it was possible to demonstrate that using remote sensing information a historical view of the Sea can be clearly demonstrated in understanding of water surface change dynamics in the Sea. The automatic image classification approach was used and the result yielded with high efficiency in terms of making long term analysis and delineation of water surface for different years. Analysis demonstrates that huge water surface loss process started during last decade of the 20th century. One reason for water losses could be evaporation rate increase due to global warming and the other reason is less precipitation (increase of drought periods) in the mountainous zones. In addition to this water demand has also increased due to population increase in the region. Results of such study can be well used to better understand the behavior of the Aral Sea to different water availability scenarios. The software such as Erdas Imagine and ArcGIS is a powerful tool to carry out such analysis and to visualize all the changes clearly as a map in a spatial extent. The illustrations of water surface change in different years in this study can be very important in demonstrating the Aral Sea crisis in different sectors and at different level, internationally and nationally. The results and the approach of this study can be widely used in different research activities locally as well as globally. It is easy for decision makers to understand the extent of the changes and make necessary steps to adapt or mitigate the consequences of the changes.

REFERENCES

1. **Aral** 1995, *Aral Sea Loss and Cotton (Aral Case).* http://www1.american.edu/ted/aral.htm (Last cited March 2011)

2. **Aster Gdem:** Global Digital Elevation Model, http://www.gdem.aster.ersdac.or.jp/search.jsp available (Last cited April 2011)

3. **Aster Gdem**: Global Digital Elevation Model, *Final release announcement,* http://www.ersdac.or.jp/GDEM/E/4.html (Last cited April 2011)

4. **Aster Gdem:** Global Digital Elevation Model, Concept of ASTER G-DEM development, http://www.ersdac.or.jp/GDEM/E/2.html (Last Cited April 2011)

5. **Erdas Field Guide** 2005 Leica Geosystems pp 253-254

6. **Escobar F., Hunter G., Bishop I., Zerger A.,** Introduction to GIS, Department of Geomatics, The University of Melbourne, 2000

7. **Gastellu-Etchegorry J.P.** CESBIO, Atmospheric corrections – Fundamentals, 6th ESA Advanced Training Course on Land Remote Sensing, University of Agronomic Science and Veterinary Medicine Bucharest, Bucharest, Romania on 14-18 September 2015.

8. Geoinformatics and geographical information systems. Russia, 1998

9. **Hord, R. M**. 1982. *Digital Image Processing of Remotely Sensed Data*. New York: Academic Press.

10. **Herbert J. Kramer**, Landsat-1 to Landsat-3, Satellite-missions, "Observation of the Earth and Its Environment: Survey of Missions and Sensors" 2002

11. **JAXA** Japan Aerospace Exploration Agency, Earth observation research center, last modified 2006 http://www.eorc.jaxa.jp/en/imgdata/topics/2007/tp071226.html (Last cited April 2011)

12. **Lillesand, M. Thomas & Kiefer, W. Ralph** 2000 Remote Sensing and Image Interpretation. University of Wisconsin, United States of America. pp. 376-400 & 532-555. 0-471-25515-7

13. **Leena Kanickara,** Geographic Information Systems (GIS) Defined, Advisor Group ARC, 2018

14. **Meaden, J. Geoffery & Kapetsky, M. James** 1991 *Geographical information systems and remote sensing in inland fisheries and aquaculture.* Inland Water Resources and Aquaculture Service Food and Agriculture Organization Fisheries Department. Rome. 92-5-103052-9

15. **Micklin Philip and Aladin V. Nikolay.** 2008 *Reclaiming the Aral Sea*: Scientific American Magazine. http://www.scientificamerican.com/article.cfm?id=reclaiming-the-aral-sea&sc=rss (Last cited April 2011)

16. **Randy Glass.** 1999 Digital Imaging, Feather River Canyon News http://home.surewest.net/frcn/Interpolation.html (Last cited April 2011)

17. **Richards**, **J.A.** 1999, *Remote Sensing Digital Image Analysis,* Springer-Verlag, Berlin, p. 240

18. **Robert, A. Schowengerdt.** 2007 Remote Sensing: *Models and Methods for Image Processing.* University of Arizona Tucson, Arizona. ISBN 13: 978-0-12-369407-2, pp 355-400.

19. **Sabin**, **F**. **Floyd**. 2007 Remote Sensing: *Principles and Interpretation*. New York; W. H. Freeman and Company Press. pp. 69-91. 0-7167-2442-1

20. **Tangjaitrong, Supichai.** Enviremental Remote Sensing Courseware: *Image Classification* http://www.sc.chula.ac.th/courseware/2309507/Lecture/remote18.htm (Last cited April 2011)

21. **The Telegraph Journal** 2010, *Aral Sea 'one of the planet's worst environmental disasters'* http://www.telegraph.co.uk/earth/earthnews/7554679/Aral-Sea-one-of-the-planets-worst-environmental-disasters.html (Last cited April 2011)

22. **USGS,** Sciences for changing world, USGS Global Visualization Viewer
http://glovis.usgs.gov/ 2007

23. **U.S. Geological Survey,** 2016, Landsat—Earth observation satellites (ver. 1.2,
April 2020): U.S. Geological Survey Fact Sheet 2015–3081, 4 p.,
https://doi.org/10.3133/fs20153081.

24. **Understanding our world (what is GIS)** Why geography matters, Esri 2012

TABLE OF CONTENT