Final Report

Reconstructing the Ganga of the Past from Corona archival imagery

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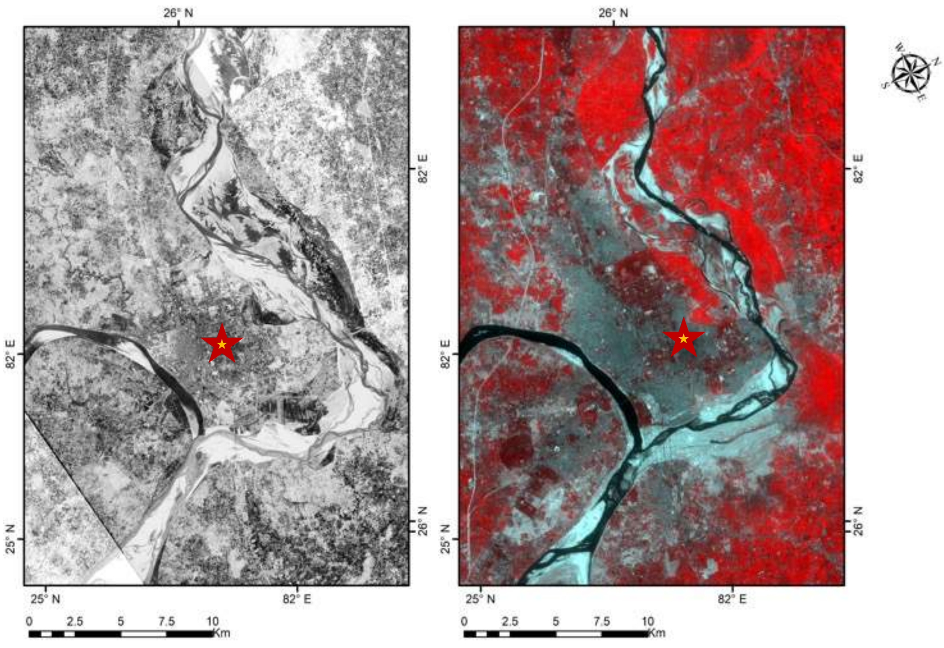

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Executive Summary

This report summarizes the protocols for georeferencing of the Corona images with the basic objective of reconstructing the reference condition of the river Ganga during 1965-66. the river Ganga has a long history of human impacts particularly in the last 4-5 decades. However, the most severe impacts began in the middle of the 20th century when the independent India began to intensify agriculture, hydropower development and industrial activity in order to support food security, energy security and economic development. In conjunction with rapid population growth and urban development, these multiple stressors have caused significant disturbances in flow regime, sediment transport and significant degradation of water quality. There is now a renewed interest in restoring this river basin which is home to nearly 7% of humanity (ca. 500 million inhabitants). Any such restoration effort will need to define an end-goal and establish a reference status which can be realistically achieved through restoration. Suitable geospatial data relating to the Ganga are somewhat difficult to obtain. While modern satellite imagery can now be used to infer a range of variables such as land-use, river geometry and even river discharge, the lack of availability and lower quality of satellite data for 1980s limits the usefulness of such approaches. Declassified imagery acquired as early as 1961 by the CIA and having resolutions from 1.8 to 7.5 meters offers the unique opportunity to extend the data window of civilian satellite imagery by two full decades. However, these images are characterised by a lack of geographic reference and severe spatial distortions which render the raw product unsuitable for quantitative analysis. In this project, we present a workflow that allows users to process and analyse declassified imagery of riverine environments at minimal cost and using open source softwares. Our approach is accessible to end-users who are not specialised in any programming languages, advanced remote sensing, and GIS. We also demonstrate the use of corona imagery in establishing a reference condition and the use of modern remote sensing datasets to evaluate the land use land cover dynamics between the 1960s and recent time.

1.0 Introduction

The Ganga basin in northern India is the most populous river basin in the world with nearly half a billion inhabitants. In the 66 years that followed Indian independence in 1947, population expansion and human interventions have left the ecosystem of the Ganga in a severely damaged state with dwindling water levels polluted by human activity and natural sediment transport severely perturbed by dams and barrages. Fortunately, there is a growing recognition by Indian authorities and NGOs such as the World Bank and the World Wildlife Fund (WWF) that the restoration of the Ganga to a healthier status, closer to its original unperturbed state, would set a strong foundation to future, greener, economic growth in Northern India. However, given the past six decades of fast development, efforts to restore the Ganga to its original condition are faced with a fundamental question: **What was the original state of the Ganga?** Answering this question will require some knowledge of the former course of the Ganga and of the farming and urban density of the surrounding plains before the impacts of human disturbance could be felt. Whilst challenging, this can be achieved thanks to a unique dataset of declassified intelligence satellite photography. The Corona spy-satellite program collected a large number of earth observation photos in the 60s. These photos, now declassified, offer us a unique view of the Ganga at the very early stages of intense development and thus before the worst ecological damages occurred.

In a recent report, the World Bank concluded that environmental degradation in India is costing USD 80 billion per year (World Bank, 2013). This report also concludes that water supply is crucial to development in India, and it highlights a lack of information and data on the state of India's main rivers. Chief among these, the Ganga has been declared the 'national river' by the Indian government and it is the only Indian river with this status. The restoration of a heavily degraded large river such as the Ganga to a reasonable ecologic functionality is a challenging prospect. In order to have a clear goal, this process of restoration must be informed by some knowledge of a 'reference condition' i.e. the status of the river before the ecological damages. Ordinary maps are of limited usage since channel banks are approximate and no information on channel depth is available and seasonal effects (i.e. changes in the channel at high versus low water levels) are not represented. However, good quality aerial photography is in fact capable of delivering much of the needed information and of providing a good approximation of the reference condition. Unfortunately, aerial photographs are restricted to military uses in India. This leaves satellite imagery as the only source of data capable of giving scientists and managers a complete view of the entire Ganga. Since development began to accelerate in the 50s and 60s, data from Landsat-1, the first civilian imaging satellite launched in 1972 is too recent. However, the Corona images provide spatial resolutions below 10 meters which is competitive even by current standards. Probably due to its proximity to China, the Corona archive contains over 8000 images of the Ganga basin, declassified and provided to the public by the US Geological Survey.

Corona images are valuable to document the history of earth surface and can be useful in many scientific applications. In spite of its enormous value of scientific application in terms of very high spatial resolution, its application has been limited due to severe problems with the positional accuracy of these images. Corona satellite design was developed for the reconnaissance mission with stereoscopic capability and there was an analog gamma rectifier that corrected all positional distortion on the final image. This mission was designed for the purpose of Spying and was used by CIA, much of the information about corona project remains classified. The analog image rectifying instrument working principle is still not declassified and not translated to any present commercial or open-source software, which makes rectifying corona images a challenging task. Mostly piecemeal application of rectified images has good positional accuracy. Therefore, actual usage of these images poses significant technical challenges. In the design of the Corona cameras, very high resolution comes at the cost of extreme distortions. Furthermore, we have no information on the exact position and orientation of the satellite at the time of image acquisition so an accurate projection of the image into conventional map coordinates is not straightforward. For this reason, Corona imagery has remained an underused resource and much new science could be enabled if the georeferencing process (i.e. minimizing distortions and projection into standard map coordinates) could be made available to a wide user-base as opposed to the current handful of specialists.

The major objectives of the project were envisaged as follows:

- Make all processed Corona images available for upload on public portal such as Bhuvan
- Develop an Atlas of the Ganga River showing a comparison between 1960s and present
- Establish the reference condition of the Ganga river and quantify the changes in morphological characteristics and landuse/landcover within the Ganga valley between 1960s and present
- Propose a policy document on 'desirable' landuse within the Ganga valley
- Capacity building for Corona image processing through training workshops including development of a working manual. These workshops will aim to accelerate the processing of declassified imagery for the whole of India.

2.0 The CORONA Project: an important resource for uncovering historical images

This section provides an overview of Corona satellite images, its importance, limitation, rectification process and algorithms to rectify corona images based on remote sensing/GIS techniques. Previous works on methods and applications of Corona image correction procedure have been reviewed extensively. Special attention is directed towards application of GIS for the geomorphic feature extraction, which reflects the time prior to the human intervention on river Ganga.

The CORONA project was a covert satellite program launched by the USA during the cold war era and it was operational from 1958 to 1972. President Eisenhower endorsed the project on 8th February 1958 (Hall, 1995). After 14 failures, the first successful mission occurred on 18th August 1960, when the first CORONA image of an intelligence target was acquired during mission 9009 (McDonald A., 1995). After 2 days, the film capsule was recovered undamaged.

The cameras used for capturing the aerial view of Earth are commonly called "Key Hole" (Analogous to a person looking at the other side of the locked door through a keyhole). There was a succession of cameras, each more advanced than its predecessor. The naming convention extended from KH-1 to KH-4, KH-4A & KH-4B (Richelson, 1998). The mission went on until the end of 1972. Within this period project CORONA acquired over 800,000 frames of photographs, covering at least 600 to 750 million square nautical miles. In the history of mankind, this was the first time that the Earth was mapped so extensively using photo-reconnaissance (Galiatsatos, 2004). On the 22nd of February 1995, President Bill Clinton declassified these images under the executive order 12951. This intelligence satellite was equipped with ultra-high-resolution cameras capable of spatial resolutions below 10 meters, which is competitive even by current standards. Probably due to its proximity to China, the Corona archive contains over 8000 images of the Ganga basin, declassified and provided to the public by the US Geological Survey. Though the imagery is available as stereopairs, most of the data is catalogued incorrectly with image footprints not matching the actual position of the imageries.

One of the earliest studies using both Corona and recent multispectral imagery was done by georeferencing several KH-4A strips to a Landsat 5 TM image to digitize geological structures (Lorenz, 2010). Another study includes the application of corona images to study glacier changes, where four Corona KH-4A image strips, were used in conjunction with Landsat 5 TM and ASTER images (Bolch et al., 2008). They geo-registered Corona strips to a thematic map and used ASTER Digital Elevation Model (DEM) to rectify Corona and ASTER images with a Root Mean Square Error (RMSE) of <20 m and <30 m, respectively. Early studies have stressed upon the difficulties and challenges while handling Corona images because of the inherent image distortions (Sohn et al., 2004).

2.1 The CORONA images

With every subsequent mission, improvements were made on the lenses, films, vehicle stability and boost capacity of the rockets. One should keep in mind that each CORONA satellite had a limited supply of film. It remained in orbit only for a few hours to a few days, thus requiring that a new CORONA satellite be launched each time a new set of photographs was needed. Thus, CORONA did not keep the whole world under constant surveillance, but instead ran a series of reconnaissance missions with specific goals. Approximately 120 CORONA satellites were flown before being replaced in the early 1970s by the larger and more sophisticated film-return satellite, the KH9 HEXAGON (Sohn et al., 2004).

CORONA images were all panoramic in nature. Renowned companies like ITEK, Eastman Kodak, Fairchild Cameras and Instruments worked together to produce the improvements required by the missions (Ruffner, 1995). They made the film, which was a few thousandths of an inch thick, rolled onto a structure of 7 inch width and a thickness of 1 inch so as to increase the number of shots ("The NRO Declassified," 1967).

The CORONA images used in this work comes from two camera sources, the KH4A (CORONA J-1, Aug 1963 – Oct 1969) and KH-4B (CORONA J-3, Sep 1967 – May 1972). These cameras provide the best resolution available for the intelligence missions. Both the camera systems consist of two dual panoramic cameras with a focal length of approximately 61 cm. The resulting ground resolution of the photographs varies across the scan direction of the film. With the best resolution of about 1.8 m at nadir, it provides a ground view of 217 km X 16 km. The flying height varied with each mission. But a nominal height of 145 km was common. The dual cameras had a common mount and tilted 15 degrees from the vertical, towards each other. This enabled them to take two simultaneous images designated as aft and forward. The camera is thus designated as forward-looking and aft-looking. The ground clearance between the two photographs were around 100 km (Ruffner, 1995).

The reason for using two panoramic cameras was to obtain a suitable combination of high resolution and wide-angle coverage of the Earth from the space. Exposure of the film was done by a slit in front of the cylindrical photographic film (Wolf, 1978). Since the images were panoramic, they contain large amounts of geometric distortion, which increase towards the distant edges. Traditional photogrammetric methods do not produce such distortion (Sohn et al., 2004). Worst of all, since the CORONA project was originally developed for the intelligence department, the images do not come with any calibration data (fiducial coordinates, lens distortion coefficients, point coordinates) or ancillary data (position, velocity vector's altitude angle). This makes it extremely difficult to reconstruct the images and use them for mapping. The only spatial data available is the coordinate of the four corners and the center of the image. Many times, they are provided with wrong spatial data. This makes it difficult to properly georeference them, compared to the conventional approaches of georeferencing (Hackeloeer et al., 2014). All of these factors have made the use of CORONA data limited to only photo-interpretation. To properly use it for mapping or similar situation where accuracy is essential, georeferencing is needed.

3.0 Material and methods

3.1 Corona images

The corona archival imageries procured from the USGS web portal of earth explorer (URL: http://earthexplorer.usgs.gov/). The corona images available under the tab of declassified imagery -1. These images were originally used for reconnaissance and to produce maps for U.S. intelligence agencies. The Corona program was officially classified top secret until 1992. The photos taken by the Corona satellites, and also by two contemporary programs (Argon and KH-6 Lanyard) were declassified in 1995. The key dataset used for the current project is **KH4A**, which has spatial resolution of 9 feet. As the project proposed for the River Ganges from the origin part in Uttarakhand to Farakka, dataset acquired from the USGS in multiple order made through online portal with single image cost at $30.

These images come with very limited metadata information with only four corner and central coordinate information, when this information used for the georeferencing of the corona image, the result produced barely project the image at approximate location on the globe with huge positional error. Also, the cataloguing of the images and most of the footprints do not match the original position of the images, confined to the Ganga region.

3.2 Bing Images (Web Map Service)

Now the question arises what kind of secondary images we can employ to rectify the corona images for image-to-image registration method. Considering the high spatial resolution of the corona the secondary data which supplies the high spatial information is required, all high-resolution images from the commercial satellite has limited swath and priced very expensive. This project covers River Ganga, from her origin at Gangotri to downstream up to Farakka and the distributary-Hooghly portion of West Bengal. As corona has a very high swath, rectification for this stretch with SPOT, IKNOS, Quickbird, GeoEye & Cartosat -2 would incur high cost. At present few of the GIS software, they incorporate the online Web Map Services, which provides free high-resolution images for visualization purpose. A Web Map Service (WMS) is a standard protocol for serving georeferenced map images over the Internet. where a map server generates services using data from a GIS database. In this project, we have employed Bing images, which is a web map service of Microsoft Corporation. This can be accessed using the Web map Services plugin in the QGIS database. (Ubukawa, 2013) has compared Bing images vs google images with the high-resolution satellite data and found better positional accuracy on Bing image. Bing uses single projection for entire world, Mercator projection and follows the spherical form instead of ellipsoidal projection form. Bing Map Service can be accessed in different geospatial software programme and found useful for image rectification with limited accuracy. Though the positional accuracy is almost comparable for the Google Earth imagery and Bing imagery, we found the overall image rendition of Bing imagery to be of better quality and used it for our purpose.

3.3 Software packages used

3.3.1 Microsoft ICE: Microsoft Image Composite Editor is an advanced panoramic image stitcher made by the Microsoft Research division of Microsoft Corporation. The application takes a set of overlapping photographs of a scene shot from a single camera location and creates a high-resolution panorama incorporating all the source images at full resolution. The stitched panorama can be saved in a wide variety of file formats, from common formats like JPEG and TIFF. The ICE stitched corona 4 sub-images and post rectification makes a single strip which has an approximate swath of 200Km x 19km.

3.3.2 Adobe Photoshop: Adobe Photoshop is a raster graphics editor developed and published by Adobe Systems. Photoshop files sometimes has a file extension. PSB, which stands for "Photoshop Big" (also known as "large document format"). A PSB file change to the proprietary PSD file format if the data size exceeds the limit of 4GB, increasing the maximum height and width to 300,000 pixels and the length limit to around 4 Exabyte's. Even the panorama generated in Microsoft ICE tends to be in PSB format and has to be later transferred to Adobe Photoshop for conversion to a TIFF format. The Adobe Photoshop software has also been used for flattening the image and finally converting it into grayscale imagery. This reduces the heavy corona image to a significant level to approximately 800MBs

3.3.3 QGIS is a user-friendly Open Source Geographic Information System (GIS) application software licensed under the GNU (General Public License). QGIS is an official project of the Open Source Geospatial Foundation (OSGeo).The QGIS is an alternative GIS application software which can also cut down the 2 step rectification with 3rd order polynomial of corona images. It offers the Thin plate spline (TPS) algorithm, which is a more modern Georeferencing method, able to introduce local deformations in the data. This algorithm is useful when very low-quality originals are being georeferenced. Mostly QGIS is used for georeferencing the single corona stripe, with the 3rd order polynomial in two step rectification process. Geomorphic mapping over corona images performed inside with file geodatabase. Basic functionality for the geomorphic mapping was on screen image interpretation and vectorization of the digitally processed corona images.

4.0 Pre-processing of the Corona Imagery

The workflow developed for this project is shown in Figure 1. The specific components of the workflow are discussed in the following sections.

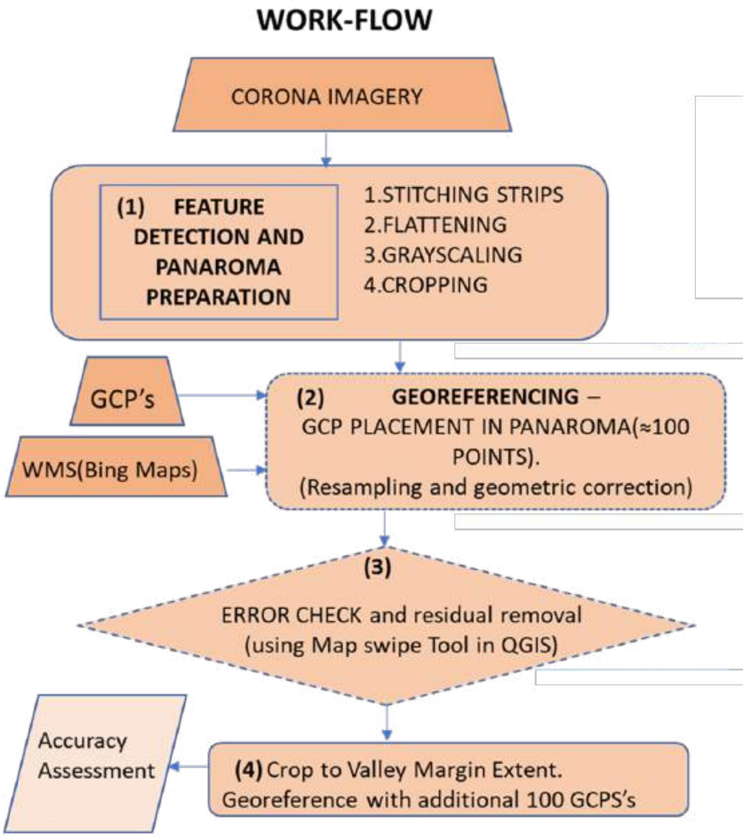


Fig 1. Methodology involved in preprocessing of the Corona imagery.

4.1 Corona Image stitching with Photoshop

The images acquired through USGS data distribution site "Earth Explorer" in tiff file format (4 parts for a single image). Images were processed for stitching and flattening before the geometric correction performed over it. These activities were performed in "Photoshop" software. Processed images were rectified using web map services (Bing Map).

In our first attempt to stitch corona images, we used Photoshop software which uses auto merge function to align the subsets of corona (Figure 2). Further processing involves 'flatten image' and conversion to grayscale image. The output image is used in ArcGIS for geo-referencing.

Figure 2 Corona Image stitching in Photoshop 13.0

4.2 Corona Image Rectification with QGIS

Mathematical models, such as Polynomial, Thin Plate Spline, use ground control points (GCPs) to calculate a transformation that will warp the raw image to the ground coordinates (Figure 3). The warping the raw image is known as geometric correction. The quality of the geometrically corrected image is directly related to the quality and number of the GCPs and the math model that you choose. Selecting the wrong math model, collecting too few GCPs, or inaccurately collecting the GCPs may result in a geometrically corrected image that does not suit your needs.

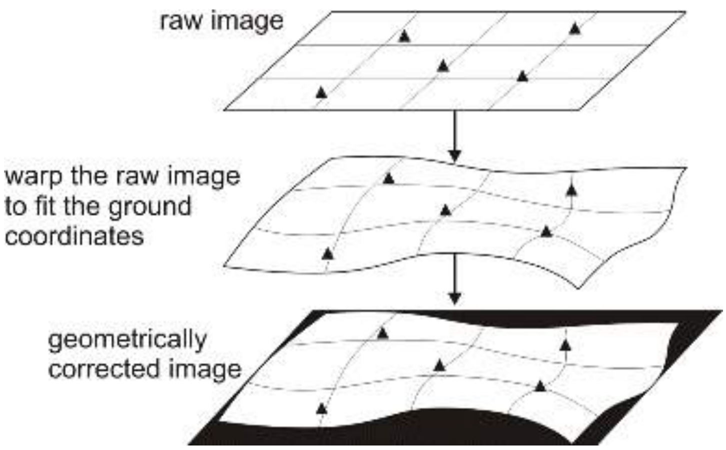


Figure 3. Geometric correction procedure

Sine panoramic cameras were used to obtain a suitable combination of high-resolution and wide-angle coverage of the terrain from space. Exposure of the film is made by a slit in front of the cylindrical photographic film (Wolf, 1978). Due to this typical feature, the photographs that were obtained with the CORONA camera system contain several types of image distortions which are not present in the normal metricframe camera, as shown in Fig. 4.

Ample care has to be taken while georeferencing these images to avoid these distortions to affect the final output.

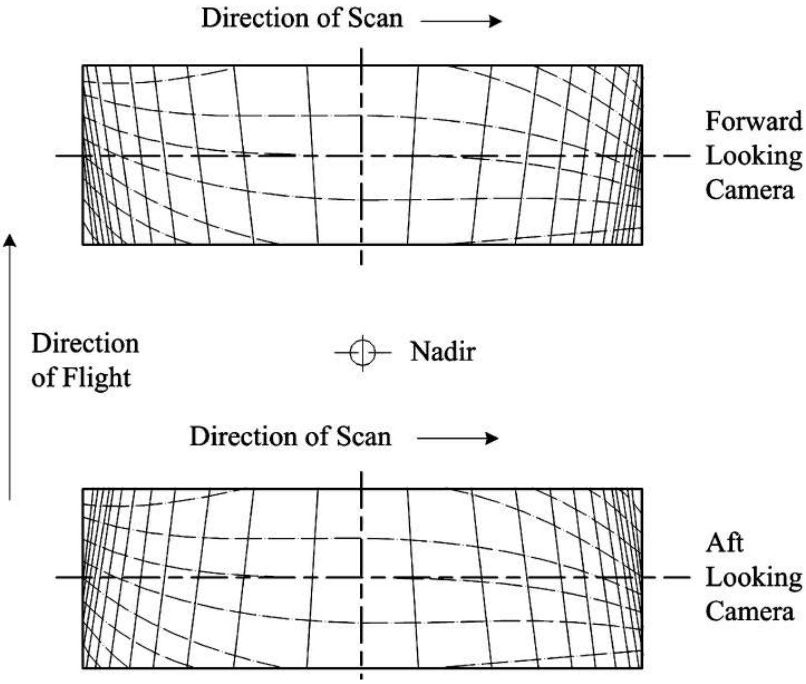


Fig. 4. Diagram of image grid obtained with panoramic cameras in the Corona mission (Sohn et al., 2004)

Accessing WMS: - Bing Map is a web mapping service of Microsoft. Bing images can be accessed directly in QGIS for GIS mapping. The Bing images has different satellite sensor images to cover the entire globe.

Prior to access the Bing images in QGIS environment, Quick Map Services plug in has to be installed (Fig 5). After acquiring the contributed pack from the plug-in settings, one can access a list of open-source WMS layers (Fig. 6). These are faster than ArcGIS and map rendering is efficient for using as a background layers for collecting ground control points.

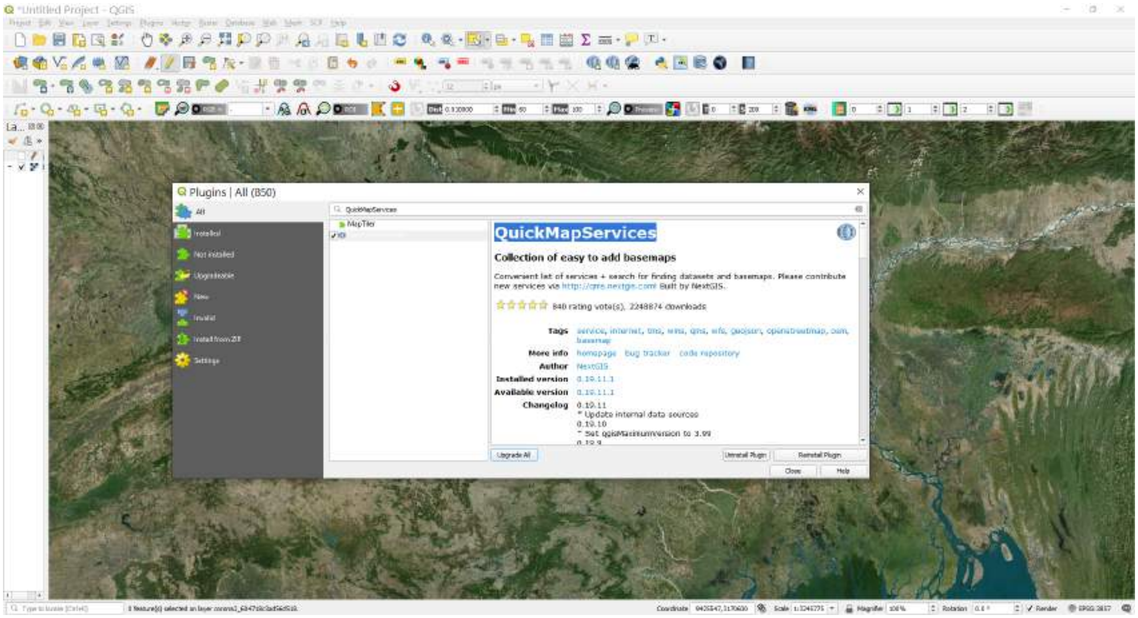


Fig. 5. User interface of QGIS with the Bing Maps option in the plugin layers.

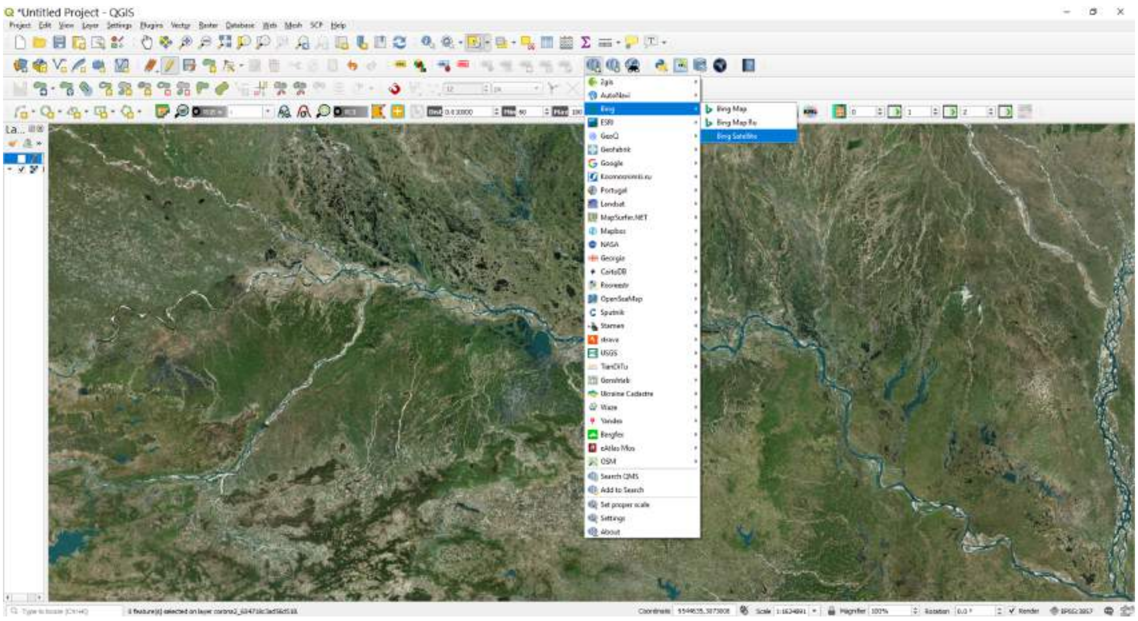


Figure 6. *Bing images at global scale*

5.0 Georectification

5.1 First stage of Geo-rectification

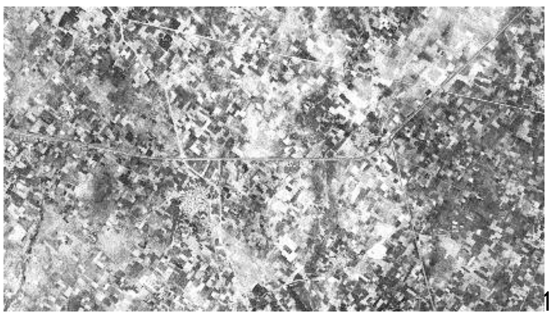
Corona images are nearly half century old, during this time period landscape has changed drastically, and therefore, finding good GCPs remains very challenging. Good GCPs can be identified as road & canal intersection, but one should check their alignment prior to collecting GCP points. Mountainous terrain remains challenging for GCP collection as in 1960-time road infrastructure was not very developed and only un-metaled road network are present.

The processed corona images were added into QGIS software for the georectification. This process required the zoom and pan for appropriate area selection and to initialize the georeferencing task. After alignment following a placement of 2-3 GCP's, the image gets registered with respect to the base map layer. The raw corona image is set for the collection of GCPs and user should collect spatially distributed GCPs and number of ground control point should be more than 100, all ground control point can be saved as text file (for later use).

In the following section, we discuss the good GCP selection as these images are nearly 60 years old. Due to inherent nature of distortion of corona images, it's very hard to rectify these. The Gangetic plain region is topographically flat and area offers a well-distributed point for potential GCP selection (Fig. 7 a, a', b & b') but the user should be careful before making a final choice for good GCP. In contrast, higher vertical exaggeration and scale difference in the hilly terrain make the identification of good GCPs very difficult, also because of the less infrastructure and human settlement (Fig.7 Image c, c').

A

a'



b b'

c c'

Figure 7. Good vs Bad GCPs point location (Corona vs Recent). *Selection criteria for distinguishing Good vs Bad GCPs on Corona and Recent images (WMS Bing Image), Figures a & a' show a geographic location, which clearly depicts change in the man-made structure, Figure b & b' shows ideal condition like road intersection & Canal (User must check their alignment before considering it as Good GCPs). Figures c & c' show extremely bad GCP point collection over hilly terrain (Road network over hills sometimes serves as an aid for rectification)*

After alignment of the corona image, one can start collecting the GCPs based on previously mentioned criteria of selection of good & bad GCP. User must take care of distribution of the GCPs point, as corona image offers very good spatial resolution and once the user starts looking for GCPs in their current image extent, they will find many, and user will be tempted to collect all possible GCPs. But, it is more important to add points on all four edges of the image which are well distributed inside the four edges of the corona image. Figures 8 gives an impression to the user, how the points should be arranged on the corona image.

The user can see that there are lesser number of points in the densely forested and hilly terrain area, it's just because the non-availability of good GCPs in those areas. User may find exceptional GCPs, if the road network is developed or there are sharp turns in mountains. We followed the protocols by Donovan et al. (2019), following the protocols for choosing ground control points (Fig. 8).

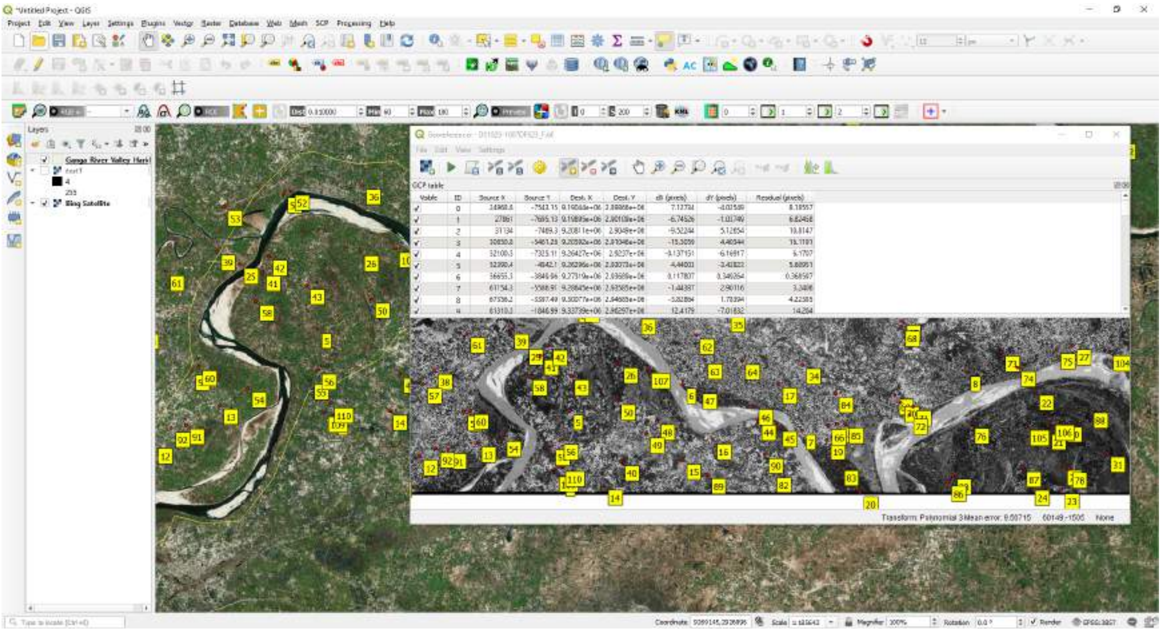


Figure 8. Protocol for GCPs (Ground Control Point) collection

After distributing the GCP evenly, we applied 3rd order polynomial transformation with the target projection system of UTM WGS 84. The corona image gets broadened at the edges and squeezes a little in the central part. Fig 9 shows the user interface within the QGIS georeferencer tab, to perform the georeferencing process.

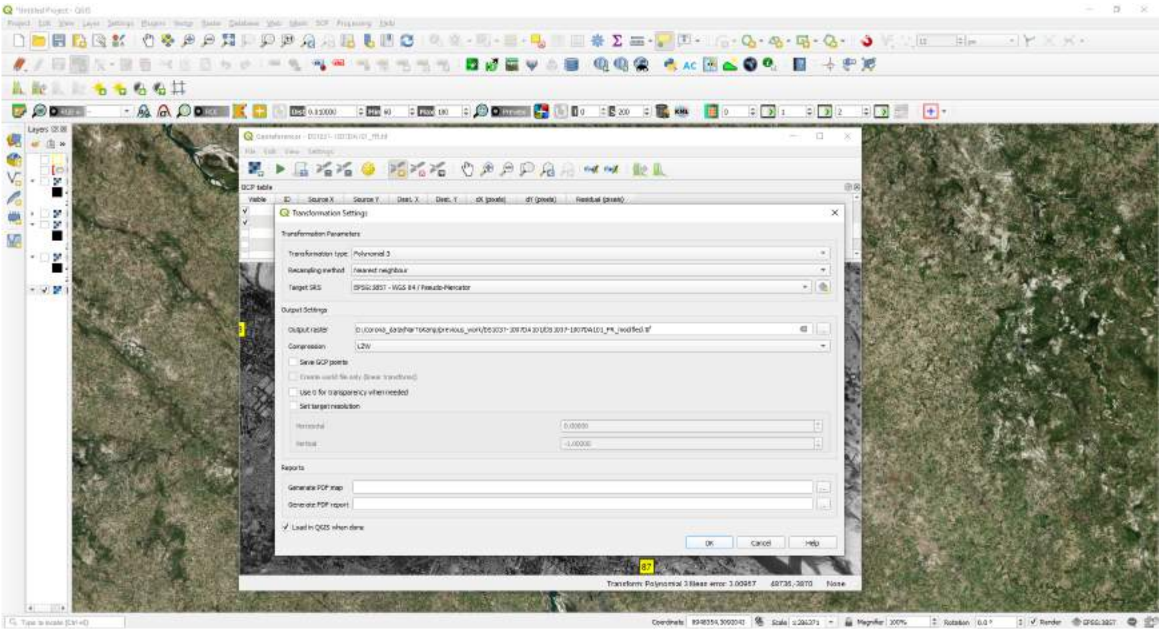


Figure 9. Georeferencer tab and interface for selection of transformation settings.

We have applied this process on corona images on desired reach length from Haridwar to Gangasagar city (Fig. 10). The number of acquired images are more than eighty which includes stereo pair too. Our objective is to rectify these images as they are not easy as other conventional and recent satellite images (their extent and spectral nature is entirely different from others).

Despite the application of image-to-image rectification, the user will find the positional error on the rectified image. The amount of error gets higher on both edge from the central part. As this data was to be further processed for mapping and to achieve higher positional accuracy, we developed a methodology to rectify these images and achieved high positional accuracy on a subset of first phase of rectified images.

Our main focus remains on the Ganga river and geomorphological mapping from the archival imagery (Corona). In these images, the Ganga river channel belt and its valley margin cover 20 to 25 percent of the image. On the entire corona image strip, the positional error after rectification process remained quite high. Here, we have employed the valley margin of Ganga river, which was previously extracted from the SRTM digital elevation model in a Govt. of India project entitled “Ganga River Basin Management Plan project”.

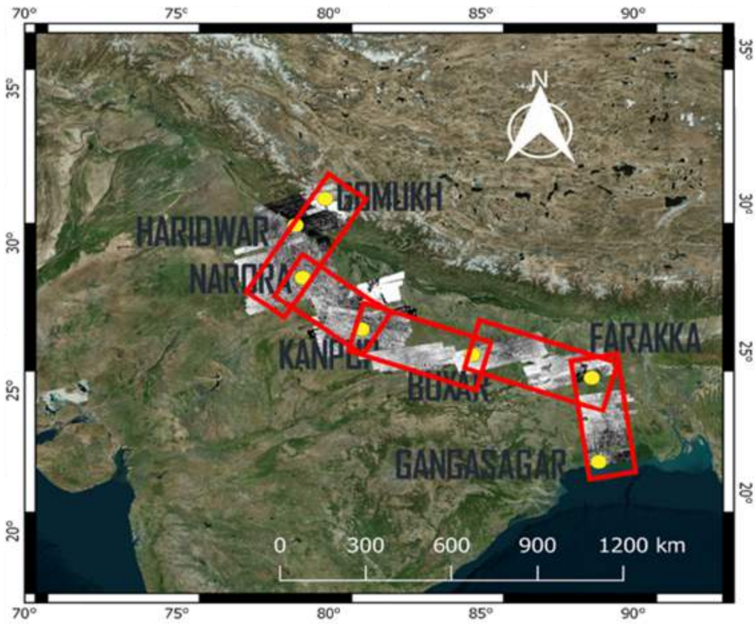


Figure 10 shows the 1st stage rectified Corona images.

Number of images on which 2nd stage rectification is performed are different, as the stereo pairs were excluded. The selected images were used for seamless mosaic preparation and for Geomorphic feature extraction of 60s for the River Ganga.

Now, the second level of rectification is performed by overlying valley margin on first level rectified corona image, an appropriate buffer of 80x19 Km subset is prepared to subset the corona image. A new feature class is created inside the QGIS with common projection system (UTM 43N WGS84) assigned. The clipped image was subjected to second stage rectification process, which is discussed in the following section including respective figures.

5.2 Second stage of Geo-rectification

This stage of rectification starts with the selection and preparation of the AOI, to make a subset of first stage rectified corona image. Figure 11 displays the selection of AOI feature class with reference to the Ganga valley margin. The Subset was prepared with image extraction by mask command, and the resultant image was subjected to second re-registration with Bing image. Approximately 50 GCP were required, but again, GCPs must be equally distributed. User can use the GCPs selected at the time of first stage points as GCPs.

The detailed process of 2nd stage of geo-rectification can be illustrated in figures 12-13. Figure 12 shows the GCPs on the AOI and Figure 13 displays the rectified clipped images after 1st stage that will be processed further for 2nd stage using (UTM WGS 84) & 3rd order transformation.

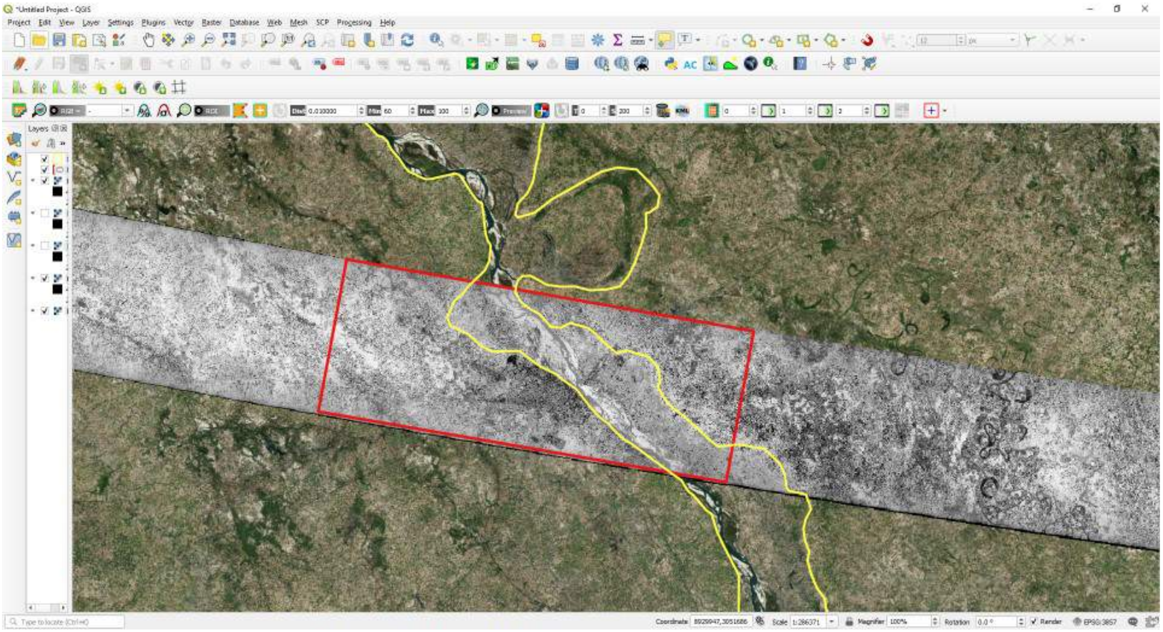


Figure 11 Selection of AOI over Ganga valley margin. (Kanpur region).

In most of the cases significant change will be found especially inside the valley margin region with respect to the position of the active channel and geomorphic changes in the last 60 years. Therefore, a careful observation of the hard points has to be done in collection of the GCPS's since this is our primary region of interest, to check the change in the river morphology and the shift in channel position in the last 60 years.

The best hard points include the bridge sites, road crossings and the agricultural fields, where most of the boundaries still remain the same or has not seen and major change in the last 60 years.

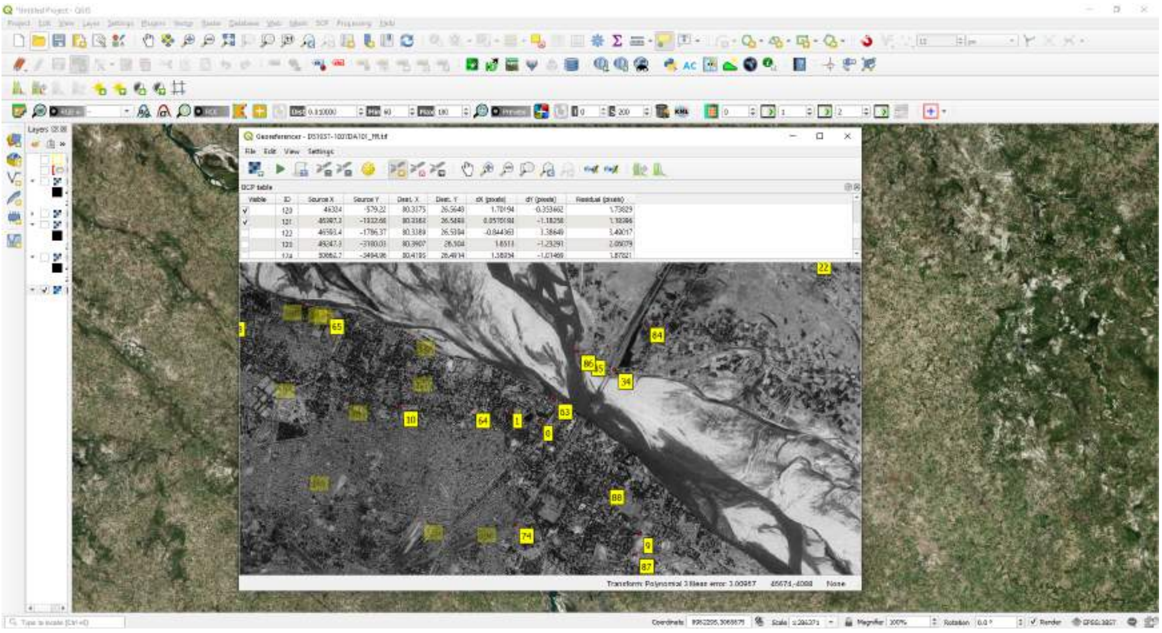


Figure 12 GCPs on clipped image (Rectified Corona)

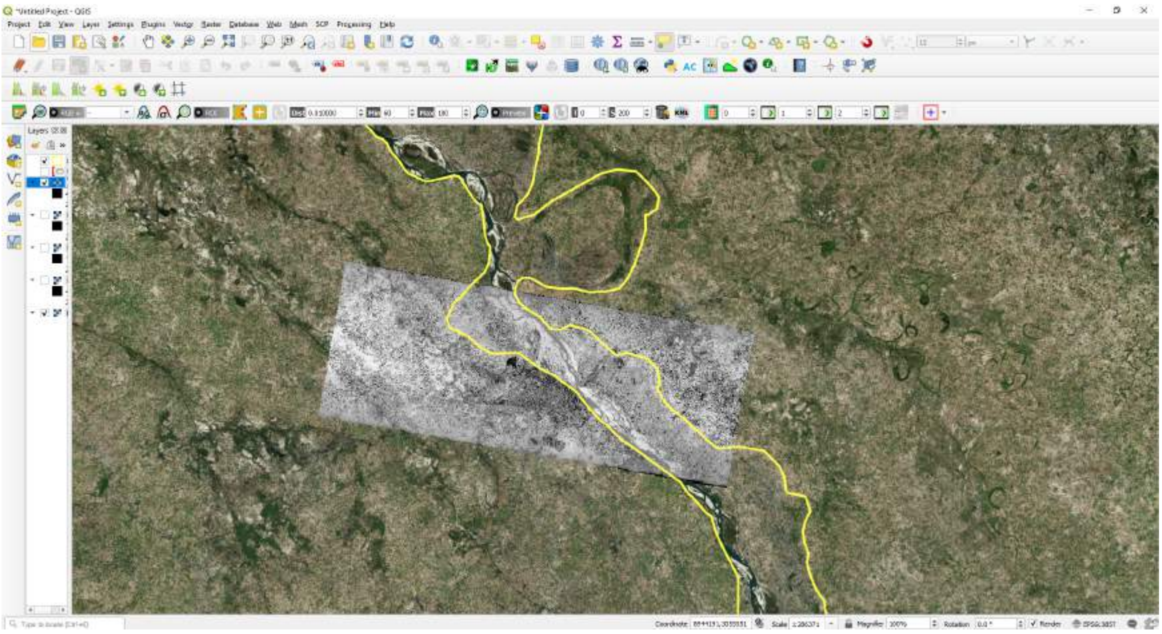


Figure 13. Clipped image of Corona

The cropped images are again loaded in the georeferencer tab and they were again cross checked using the map swipe tool that is preloaded in the plugins toolbar. The map swipe tool activates a base layer, with respect to which the temporary layer is swapped that can be used to see the difference in the position of the features in the two respective images (Fig. 14).

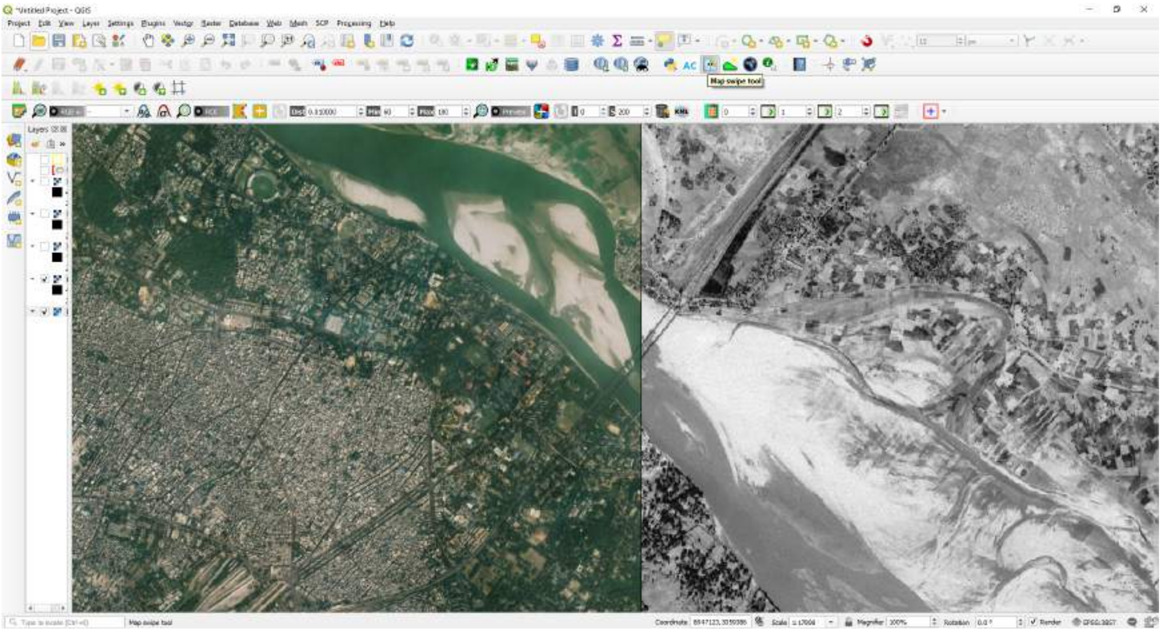


Figure 14 2nd stage geo-rectified Corona image swapped over Bing image (Kanpurr City)

We used approximately 50-100 GCPs (Figure 12) for the 2nd stage of rectification of the Corona image and achieved the positional accuracy of 20-30m. Higher positional accuracy (<=20m) was achieved at the central portion of the 2nd stage rectified corona image which was mostly within the valley margin, and lower accuracy (<=30m) outside the valley margin. Finally, the rectified images can be used in geoscience-related application and information extraction using remote sensing, GIS techniques. We found a fairly good RMSE, in 4 TEST SITES IN Haridwar, Narora, Kanpur and Prayagraj respectively, with most of the positional accuracy being in the range of 20 metres. (Fig 15).

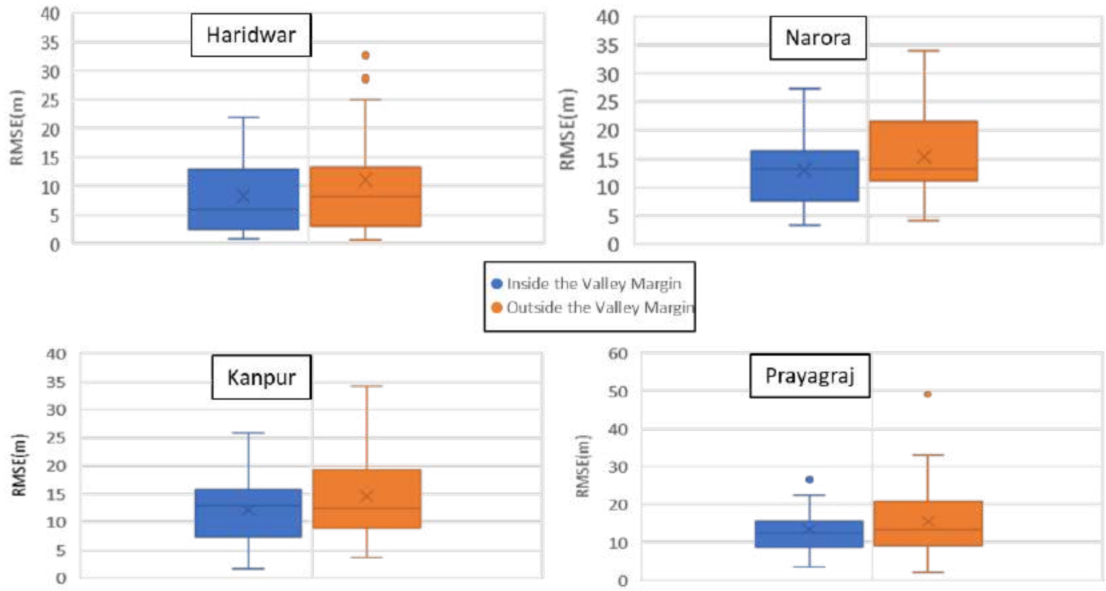


Figure 15 RMSE errors obtained for the seleced windows in Haridwar,Narora, Kanpur and Praygraj region, respectively.

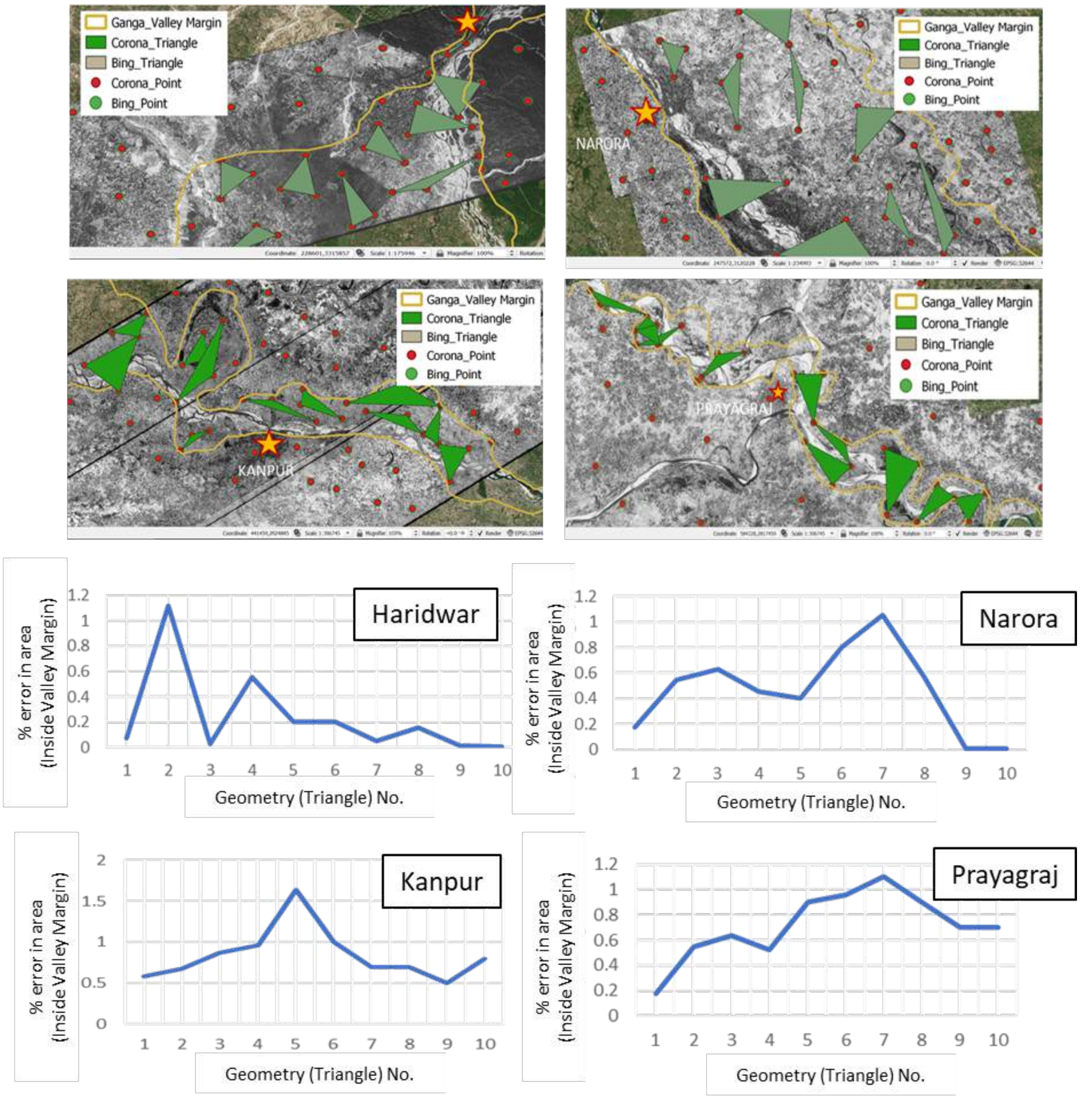


Figure 16 Selection of polygons and comparison of % change in area for Haridwar, Narora, Kanpur and Prayagraj respectively.

Before proceeding with the planform mapping a test of the robustness of the georeferencing had to be performed. Since planform mapping includes vectorization of the in-channel features and floodplain features respectively, therefore it's essential that there need to be a comparable amount of accuracy in both the images, in relation to the projection system used. We selected 10 polygons(triangles in this case) and calculated the area for both Corona imagery and Bing imagery respectively. Fig 16 shows that we found that the change in area in comparison with the two polygons of respective years was less than 2% for the respective windows.

6.0 Establishing the reference condition – geomorphic and LULC changes

Figure 17 shows the workflow for mapping the geomorphic and LULC changes by comparing the corrected Corona images with the recent Landsat images.

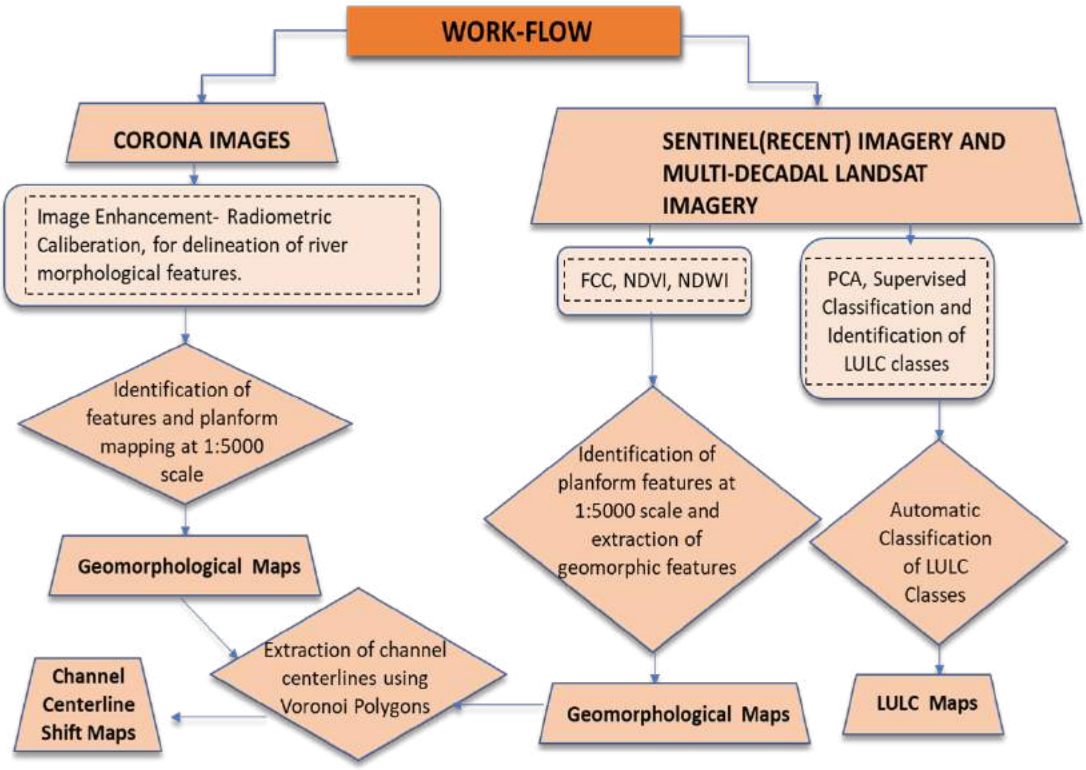


Figure 17 Methodology involving post processing of the Corona and recent imagery to study the planform dynamics and land use land cover changes of the selected windows.

For planform change detection the respective images were set at a similar scale of 1:5000, and visual identification of the instream and floodplain features was done, and the features were delineated in a vector format. Geomorphic maps were created along with the change in channel centerline maps to assess the magnitude of change in the last 60 years. For land use land cover changes we used a supervised maximum likelihood classification for the extraction of the LULC classes.

For this work, we have selected 10 major windows along the Ganga river and have carried out detailed geomorphic mapping of the Corona images (1965-66) and the Landsat images (2019) to map the major changes. Corona images were found to be unsuitable for reliable LULC mapping and therefore, we have used the Landsat data of 1976-77 for this purpose and have compared this with the LULC maps from 2019 images. Systematic description of each of these windows are presented in the Atlas.

6.0 Policy on desirable land use:

A comparison of LULC changes in different windows in the Ganga basin brings out some interesting points which are critical to understand before formulating any policy in this region. We have analysed two dominant LULC classes in detail, agriculture and built-up areas, to understand their temporal trends. The Ganga basin is primarily agriculture dominated and a comparison of the area covered by agriculture in different windows that there is no major change between 1976 and 2018 in several windows. However, we note a sizable decrease in agriculture areas in major urban windows such as Kanpur, Prayagraj, Varanasi and Patna (Fig. 18). Interestingly, all these windows also show a very sharp rise in urban areas (Fig. 19).

Figure 18 Window wise change in Agricultural land area in the last 60 years.

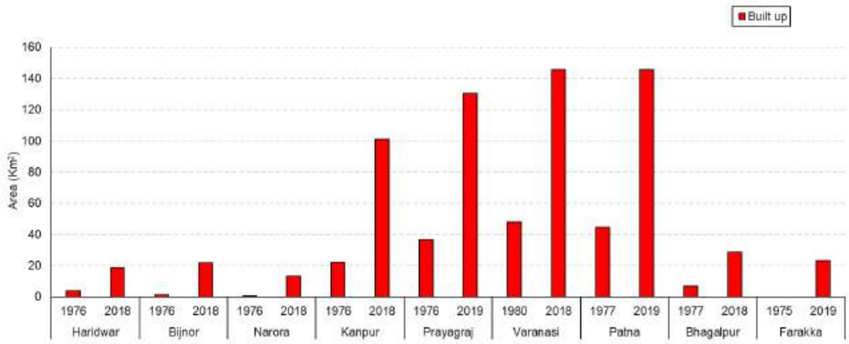


Figure 19 Window wise change in Built up area in the last 60 years.

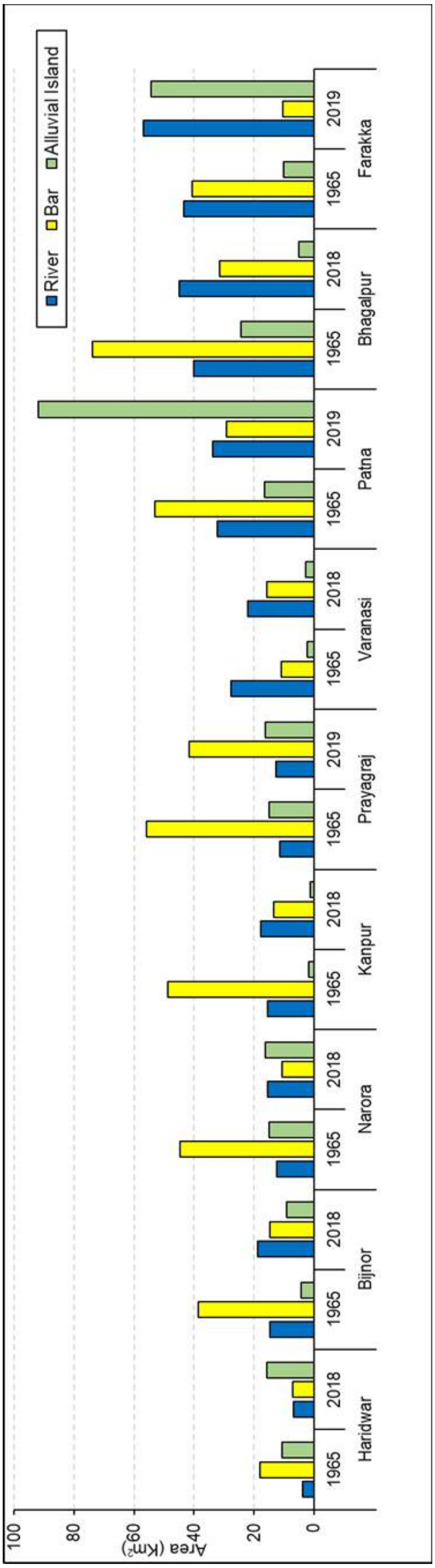


Figure 20 Window wise geomorphic change in area of river, bars and alluvial island in the last 60 years.

Further, geomorphic changes in different windows shown in Figure 20 also shows that several reaches of the Ganga river are silting as reflected in significant increase in bar areas and alluvial islands. With time, these areas which were once a part of the channel belt, tend to merge with the floodplain which are then occupied for human settlements. This data suggests that a major part of the river floodplains is being converted to built-up areas due to population pressure and this calls for a sustainable policy for landuse in river floodplains. It is important to highlight that rivers and their floodplains are natural geomorphic entities, and the understanding of process-form relationship is extremely critical to develop a sustainable management plan. Some of the major drivers and challenges in river management may include ecological restoration, urbanization and other land use changes, silt management, water allocation, water quality, control of invasive species, climatic variability, and even in some regions, removal of dams/barrages and relicensing of river infrastructure facilities. Human disturbances of different types at different scales in river systems are a consequence of the perceived needs of human populations; however, these needs have to be in consonance with the needs of the river itself. As per the NGT directive, several states a. re now trying to 'notify' the river floodplains but before doing this it important to first delineate the floodplain accurately and assess the current landuse. This brings the concept of 'River space'.

From a geomorphic perspective, 'River Space' can be represented by the channel belt plus active floodplain of the river. Active floodplain is defined as an area on either side of a stream/river which is regularly flooded. Also, a floodplain is a morpho-sedimentary unit built through time by the rivers. Thus, a floodplain is a clearly delimited and mappable physical unit that has developed through time. It is therefore critical that the active floodplain of the river is mapped accurately as this will have an important bearing on the restoration of the naturalness of the river. The floodplain creation involves a time scale that extends beyond the short instrumental hydrological records in the tropical countries. A river with a complete floodplain is not just considered as the one holding a mosaic of fluvially-conditioned environmental units but also in good health. Floodplains support a wide variety of rich life forms ranging from riparian vegetation and aquatic ecosystems to a variety of environmental and socio-economic services for ecosystems and humans. Thus, these areas are good for agriculture due to its high nutrient content, and that is why, they are frequently occupied by local population at the cost of other ecosystems. Preserving the active floodplain of the river also reduces the risk to life and property because of annual flooding but also provide the necessary hydro-sedimentological connectivity to sustain the floodplain functionality and ecosystems.

Some recent efforts in this direction have delineated the floodplain reasonably well based on the flood recurrence interval and then transferring the resulting inundation areas on the satellite images. It has then been classified the floodplain into no development or regulatory zone. While such work presented is important and significant, we would like to propose a few additional steps to before notifying the floodplain zone:

1. While the hydrologic approach provides a good assessment of the modern-day floodplain extent, it does not quite furnish any information of the historical scale changes in channel position and the floodplain. In alluvial reaches of the Ganga river, the channels are fairly dynamic and channel migration of several kilometers have been reported in some reaches in the last few decades, as shown by our work presented in this report. This means that there must have been significant changes in the position of channels and therefore the extent of floodplains at historical time scales. The actual extent of the channel/floodplain dynamics is generally spatially variable and depends upon the local channel cross morphology (e.g. incised vs flat bank, symmetrical vs asymmetrical etc.) but it is generally possible to map this on planform using satellite images.
2. The above-mentioned issue can be resolved by creating temporal maps of channel and floodplain dynamics and then demarcating historical extent of channels and floodplain based on geomorphic features extracted from specific image processing techniques. This will not only provide a much stronger basis for delineating the floodplains based on channel/floodplain relationship but will also relate the historical extent of floodplain with specific recurrence interval of floods.
3. The classification of floodplain into two zones (no development or regulatory) as suggested by some workers is perhaps too simplistic. In large river systems, we generally identify, three distinct zones: channel belt, active floodplain and inactive floodplain which can be delineated on the basis of

geomorphic features and landuse etc. These zones are defined as 'River Space' or River Corridors' and they should have a prescribed landuse for maintaining 'River health'. They are often related to flooding extent corresponding to different recurrence intervals, so they can also be used for flood hazard mitigation. Therefore, it may be necessary to design a few more categories of floodplains based on the geomorphic characteristics and current landuse.

4. Further, for each of these zones, it is important to map not only the current landuse but also the landuse dynamics in the last 4-5 decades so that we can identify the 'hotspots' of change and then classify the floodplains in terms of priority for action. There may be additional information such as ecological hotspots that can be added to the GIS database, so that an appropriate notification strategy can be planned.
5. Once the floodplain delineation work and classification are complete, we can then overlay the revenue records on these maps to ascertain the ownership of land falling in different zones. This will give provide further information about the floodplain degradation/occupation in the 'river space' and would help in prioritizing the action plan.

7. Major Achievements of the project

The desired Ganga river length is now covered by the archival imagery with +/-20m positional accuracy. In total we processed a total of 79 Corona images as a part of this project and these corrected images are planned to be put on the Bhuvan portal for the use of the scientific community. Figure 21 show the areas covered and Annexure I lists the images processed as a part of this project. This image data is valuable reference for the current and future research work related to the Ganga river projects. Previously many attempts were made to rectify these images, but this project has generated a wider data volume which covers a more than 1600 km long Ganga river stretch which is different for the conventional piecemeal application of the resource.

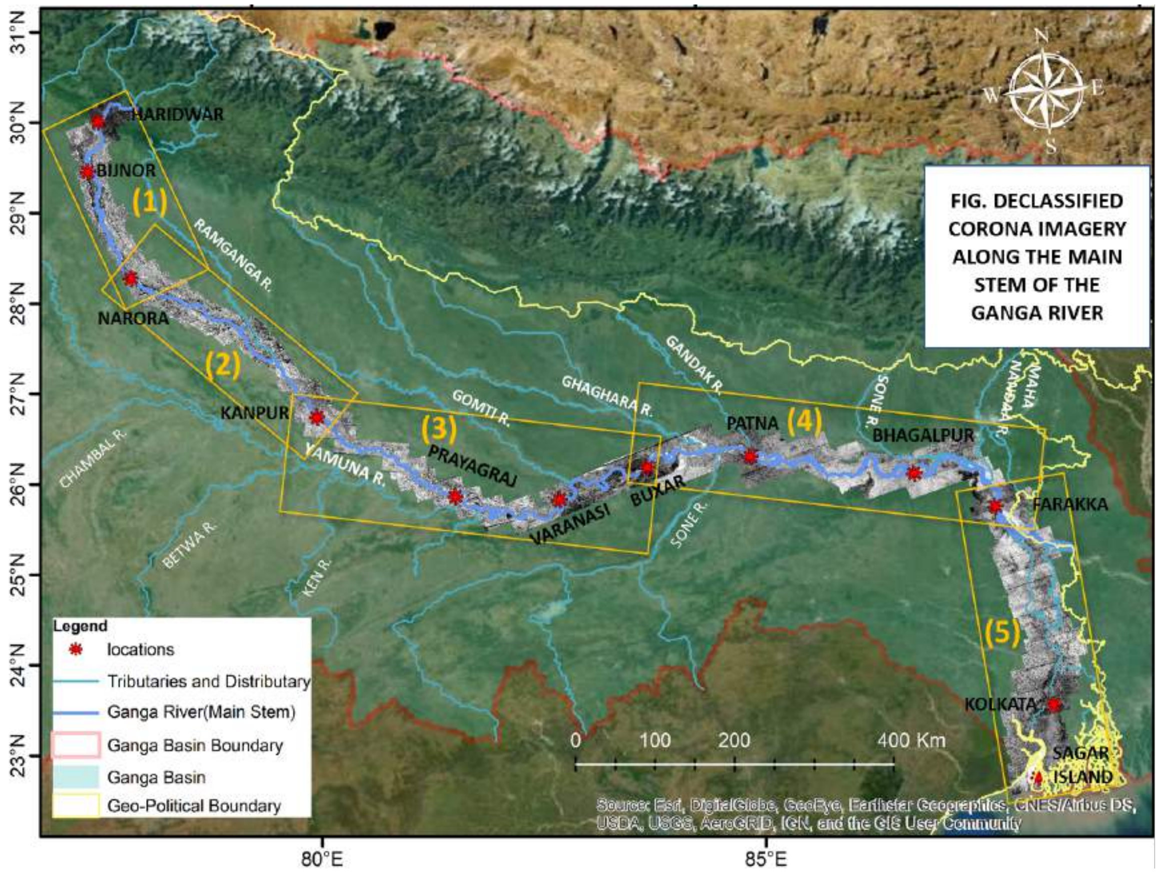


Figure 21. Final result of the defined project objectives. The locations also correspond to the sites selected for preparation of the Ganga Atlas.

Further, we have interpreted and compared the corona images with the recent Landsat images to derive information about the geomorphological changes to assess the anthropogenic impact on the river Ganga. Since the LULC mapping of the Corona images were problematic, we have used the Landsat images of 1976 to derive the LULC changes and have presented all these data set in an Atlas called the "Ganga of the Past". This Atlas may be published as a coffee table booklet and will also be available online.

8.0 Capacity Building & Workshop

A full time PhD student, Smruti Ranjan Patra, was trained as a part of this project and he has contributed significantly to the completion of this project. Most of the results generated from this project will form a part of his PhD thesis.

A virtual training workshop on "*Protocols for processing the declassified satellite imageries using modern tools and their applications*" was conducted from 14-18

December, 2020. A total of 16 participants in the workshop are from various organizations:

1. Regional Remote Sensing Centre-South, ISRO, Bengaluru
2. Regional Remote Sensing Centre-East, NRSC, ISRO, Kolkata
3. Indian Institute of Remote Sensing (IIRS), ISRO
4. National Institute of Hydrology, Western Himalayan Regional Centre, Jammu
5. National Institute of Hydrology, Jalvigyan Bhawan, Roorkee
6. Wadia Institute of Himalayan Geology, Dehradun
7. Department of Earth and Environmental Sciences (EES), IISER Bhopal
8. Department of Geology, University of Delhi
9. Department of Earth Sciences, IIT Kanpur
10. GIS Division, NMCG, Ministry of Jal Shakti, New Delhi

The workshop was done in online mode for 5 days and mostly consisted on hands-on exercises by the participants under our guidance. In terms of technical content, this consisted of the following modules: (a) data format and downloads, (b) Stitching of tiles, (c) georectification and accuracy assessment, (d) Object based classification, and (e) applications and case studies. The participants were very enthusiastic, and they hope to utilise this valuable resource for their projects.

A working manual was prepared as a part of this effort (Annexure - II).

8.0 Future perspectives

The Corona images have to be georeferenced laboriously with a minimum of 200 points to accurately project the data and extract necessary information. But these set of images come in a stereopair with a 60% overlap. The basic photogrammetry question is whether these images can be orthorectified or not. While lot of workers outside India have already undertaken a photogrammetric approach, none has yet been performed in India, owing to the following limitations:

Misrepresentation of the cataloguing data footprint in the USGS website.

- Low quality imagery. Few best quality KH-4B images are available for sections of the Ganga basin.

- Inconsistent image series on a uniform time period or non-availability of high resolution stereopairs.
- Existence of cloud covering rendering most of the stereopairs useless in the North Gangetic region.

While the objectives envisaged in this project have been completed, we are continuing this research to refine the methodology. For example, we are trying to implement the new structure from motion (SfM) approach developed and followed up by (Nita et al., 2018; Rendenieks et al., 2020), respectively, that orthorectifies the corona stereo pairs to generate an orthomosaic of these images. We have modified the methodology and have created the dense point clouds in the low quality stereopairs that are available in the Indian region. Our new methodology has created a seamless stitch of the panorama and we use a licensed photogrammetric software to establish the external orientation parameters of the camera configuration.

We manually selected control point pairs between pixels on the historical image and known ground locations. After the points are identified, the orientation of the satellite can be estimated via the collinearity condition. Compared to the conventional approach we have optimised the time required for rectifying a single stereopair to less than 3 hours with only 60 ground control points.

Post creation of a dense point cloud and GCP placement, we could rectify the whole stereopair, compared to the previous approach of only being confined to our region of interest which was the Gangetic valley margin extent. This method is reproducible and renders a very high quality orthomosaic with no information loss. This way the whole orthomosaic can be used for a plethora of applications ranging from river science, agriculture, urban development, forestry, etc. We are also developing an OBIA approach for segmentation of riverine features USING eCognition software such as water area extent and sand bodies, which is an automatic approach to planform mapping compared to standard manual digitisation of those features. These methods have been used in forest cover classification by (Rendenieks et al., 2020; Song et al., 2015), respectively. We hope that these new approaches would improve the accuracy of georectification of the Corona images and will also reduce the processing time. We will be reporting these findings through scientific publications in near future.

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Annexure – I: List of Corona images processed in this project

Image ID	SENSOR	SPATIAL RESOLUTION	ACQUISITION DATE	COORDINATES
Rishikesh to Narora				
DS1017-1023DF108	KH-4A	9 feet	27-Feb-65	30.16 , 78.325
DS1017-1023DF109	KH-4A	9 feet	27-Feb-65	30.01 , 78.362
DS1017-1023DF110	KH-4A	9 feet	27-Feb-65	29.87 , 78.404
DS1025-1039DF029	KH-4A	9 feet	08-Oct-65	29.9 , 77.419
DS1025-1039DF030	KH-4A	9 feet	08-Oct-65	29.75 , 77.47
DS1025-1039DF031	KH-4A	9 feet	08-Oct-65	29.58 , 77.515
DS1025-1039DF032	KH-4A	9 feet	08-Oct-65	29.41 , 77.561
DS1025-1039DF033	KH-4A	9 feet	08-Oct-65	29.25 , 77.603
DS1025-1039DF034	KH-4A	9 feet	08-Oct-65	29.1 , 77.653
DS1025-1039DF035	KH-4A	9 feet	08-Oct-65	28.93 , 77.707
DS1025-1039DF036	KH-4A	9 feet	08-Oct-65	28.76 , 77.745
DS1025-1039DF037	KH-4A	9 feet	08-Oct-65	28.6 , 77.795
DS1025-1039DF038	KH-4A	9 feet	08-Oct-65	28.45 , 77.837
DS1025-1039DF039	KH-4A	9 feet	08-Oct-65	28.27 , 77.887
Narora to Kanpur				
DS1025-1023DA054	KH-4A	9 feet	07-Oct-65	27.88 , 80.195
DS1025-1023DA055	KH-4A	9 feet	07-Oct-65	27.72 , 80.237
DS1025-1023DA056	KH-4A	9 feet	07-Oct-65	27.55 , 80.283
DS1025-1023DA057	KH-4A	9 feet	07-Oct-65	27.39 , 80.328
DS1025-1023DA058	KH-4A	9 feet	07-Oct-65	27.23 , 80.374
DS1025-1039DA049	KH-4A	9 feet	08-Oct-65	27.74 , 77.974
DS1025-1039DA050	KH-4A	9 feet	08-Oct-65	27.57 , 78.02
DS1025-1039DA051	KH-4A	9 feet	08-Oct-65	27.41 , 78.062
DS1025-1039DF040	KH-4A	9 feet	08-Oct-65	28.11 , 77.932
DS1025-1039DF041	KH-4A	9 feet	08-Oct-65	27.95 , 77.978
DS1025-1039DF042	KH-4A	9 feet	08-Oct-65	27.79 , 78.028
DS1037-1007DA099	KH-4A	9 feet	09-Nov-66	26.94 , 80.553
DS1037-1007DA100	KH-4A	9 feet	09-Nov-66	26.8 , 80.508
Kanpur to Buxar				
DS1025-1007DF023	KH-4A	9 feet	06-Oct-65	25.46 , 83.225
DS1025-1007DF024	KH-4A	9 feet	06-Oct-65	25.29 , 83.262
DS1037-1007DF100	KH-4A	9 feet	09-Nov-66	26.89 , 80.612
DS1037-1007DF101	KH-4A	9 feet	09-Nov-66	26.75 , 80.566
DS1037-1007DF102	KH-4A	9 feet	09-Nov-66	26.6 , 80.52

DS1037-1007DF103	KH-4A	9 feet	09-Nov-66	26.45 , 80.487
DS1037-1007DF104	KH-4A	9 feet	09-Nov-66	26.31 , 80.441
DS1037-1007DF105	KH-4A	9 feet	09-Nov-66	26.17 , 80.403
DS1038-1007DF086	KH-4A	9 feet	15-Jan-67	25.89 , 82.068
DS1038-1007DF087	KH-4A	9 feet	15-Jan-67	25.74 , 82.093
DS1038-1007DF088	KH-4A	9 feet	15-Jan-67	25.6 , 82.114
DS1038-1007DF089	KH-4A	9 feet	15-Jan-67	25.46 , 82.131
DS1038-1007DF090	KH-4A	9 feet	15-Jan-67	25.31 , 82.164
DS1038-1007DF091	KH-4A	9 feet	15-Jan-67	25.16 , 82.189
Buxar to Farakka				
DS1021-2134DF027	KH-4A	9 feet	27-May-65	25.79 , 86.912
DS1021-2134DF028	KH-4A	9 feet	27-May-65	25.64 , 86.946
DS1021-2134DF029	KH-4A	9 feet	27-May-65	25.49 , 86.983
DS1021-2134DF030	KH-4A	9 feet	27-May-65	25.34 , 87.029
DS1021-2134DF031	KH-4A	9 feet	27-May-65	25.19 , 87.067
DS1021-2134DF032	KH-4A	9 feet	27-May-65	25.04 , 87.104
DS1021-2134DF033	KH-4A	9 feet	27-May-65	24.89 , 87.138
DS1021-2134DF034	KH-4A	9 feet	27-May-65	24.74 , 87.184
DS1021-2134DF035	KH-4A	9 feet	27-May-65	24.59 , 87.221
DS1021-2150DF020	KH-4A	9 feet	28-May-65	25.71 , 84.854
DS1021-2150DF021	KH-4A	9 feet	28-May-65	25.56 , 84.896
DS1021-2150DF022	KH-4A	9 feet	28-May-65	25.41 , 84.938
DS1021-2150DF023	KH-4A	9 feet	28-May-65	25.26 , 84.979
DS1021-2150DF024	KH-4A	9 feet	28-May-65	25.1 , 85.012
Farakka to Gangasagar				
DS1021-2134DF034	KH-4A	9 feet	27-May-65	24.74 , 87.184
DS1021-2134DF035	KH-4A	9 feet	27-May-65	24.59 , 87.221
DS1021-2134DF036	KH-4A	9 feet	27-May-65	24.43 , 87.263
DS1021-2134DF037	KH-4A	9 feet	27-May-65	24.28 , 87.3
DS1021-2134DF038	KH-4A	9 feet	27-May-65	24.13 , 87.346
DS1021-2134DF039	KH-4A	9 feet	27-May-65	23.99 , 87.379
DS1021-2134DF040	KH-4A	9 feet	27-May-65	23.83 , 87.413
DS1021-2134DF041	KH-4A	9 feet	27-May-65	23.68 , 87.455
DS1021-2134DF042	KH-4A	9 feet	27-May-65	23.53 , 87.496
DS1021-2134DF043	KH-4A	9 feet	27-May-65	23.37 , 87.538
DS1021-2134DF044	KH-4A	9 feet	27-May-65	23.23 , 87.571
DS1038-2102DF181	KH-4A	9 feet	21-Jan-67	23.2 , 88.898
DS1038-2102DF182	KH-4A	9 feet	21-Jan-67	23.05 , 88.915
DS1038-2102DF183	KH-4A	9 feet	21-Jan-67	22.91 , 88.936
DS1038-2102DF184	KH-4A	9 feet	21-Jan-67	22.77 , 88.96

DS1038-2102DF185	KH-4A	9 feet	21-Jan-67	22.62 , 88.981
DS1038-2102DA179	KH-4A	9 feet	21-Jan-67	23.28 , 88.856
DS1038-2102DF186	KH-4A	9 feet	21-Jan-67	22.48 , 89.002
DS1038-2102DA180	KH-4A	9 feet	21-Jan-67	23.14 , 88.885
DS1038-2102DF187	KH-4A	9 feet	21-Jan-67	22.33 , 89.023
DS1038-2102DA181	KH-4A	9 feet	21-Jan-67	22.99 , 88.902
DS1038-2102DF188	KH-4A	9 feet	21-Jan-67	22.19 , 89.044
DS1038-2102DF189	KH-4A	9 feet	21-Jan-67	22.04 , 89.06
DS1038-2102DF190	KH-4A	9 feet	21-Jan-67	21.9 , 89.082

Annexure - II : Manual for Processing the Corona Declassified Imagery

1.0 Corona image acquisition

In between 1960 and 1972, satellite missions named Corona, Argon and Lanyard has been achieved which becomes the first constellations of reconnaissance spy satellite missions. 860000+ film images were physically retrieved over the regions in Eastern and Southeastern Europe, Asia, and South America. This historic Earth observation satellite archive becomes declassified and available to scientific community in 1995, when it is recognized to be not critical to the national security. However, lack of the historic concurrent ground truth data imposes several challenges in exploring the feature and information extraction from the Corona imagery.

The intelligence community used Keyhole (KH) designators to describe system characteristics and accomplishments. The CORONA systems were designated KH-1, KH-2, KH-3, KH-4, KH-4A, and KH-4B. The ARGON systems used the designator KH-5 and the LANYARD systems used KH-6. Mission numbers were a means for indexing the imagery and associated collateral data. KH-1, KH-2, KH-3, and KH-6 carried a single panoramic camera or a single frame camera whereas the ARGON system was embedded with a single frame camera. KH-4, KH-4A, and KH-4B carried two panoramic cameras with a separation angle of 30° with one camera looking forward and the other looking aft. The image coordinates were based on the camera operation and satellite paths. More information on the imagery and the mission parameters are show in Table 1.

This training workshop, currently funded by National Mission for Clean Ganga (NMCG), Ministry of Jal Shakti utilize this archive to develop protocols for processing the declassified imagery with a unique view of producing the historic landscape. Despite of the limitations of extreme distortions, orientation and unavailability of the exact locations, the Corona imagery can be helpful to wide user interface when overlaid through the geo-correction process.

The digital image from USGS is provided to the user in the form of a film. A glimpse of the Corona images is shown below:

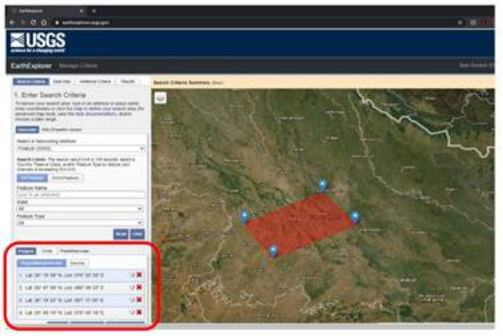
The flowchart of the process of working on the declassified Corona imagery and the major section of this manual are as follows:

1. Downloading the Corona satellite imagery archive
2. Stitching the image tiles using
   1. Microsoft ICE
   2. Adobe Photoshop (Commercial tool)
   3. Hugin
3. Georeferencing the stitched image using Web map service in QGIS

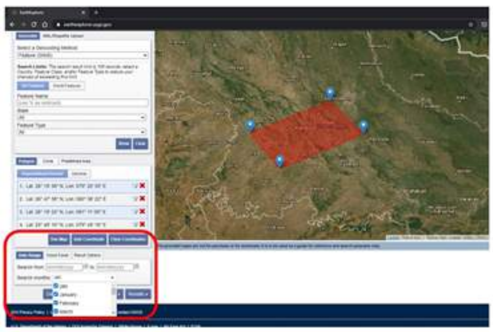
1. Downloading the Corona imagery (with illustrations)

i. Create an account in the https://earthexplorer.usgs.gov/

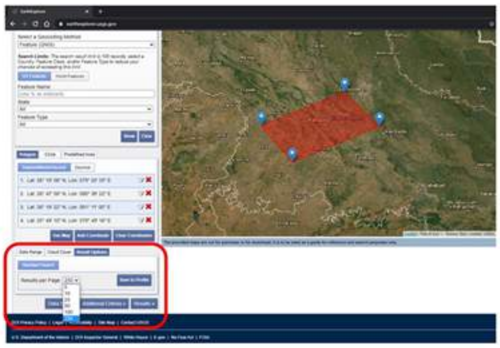
ii. Now, after signing into the webpage, select the ROI (Region of Interest), either using a set of manually placed points or by uploading a shapefile.



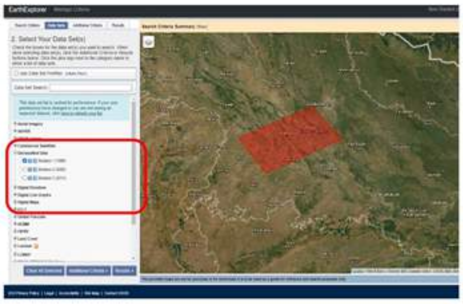
iii. After selecting the ROI, proceed with filtering the data using the time range for the purpose of study.



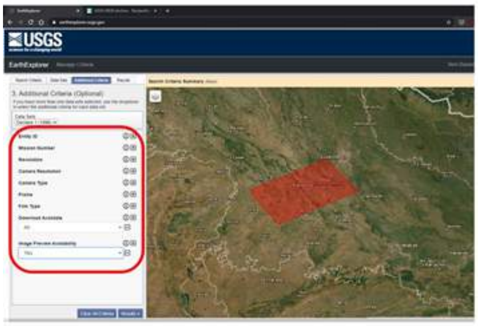
iv. Set the number of results as maximum available, so that the user could have option of filtering the suitable image.



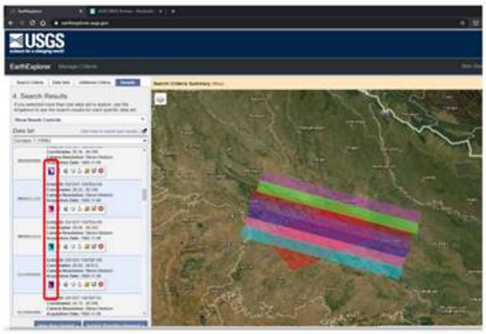
v. Select the Declass 1 (1996)



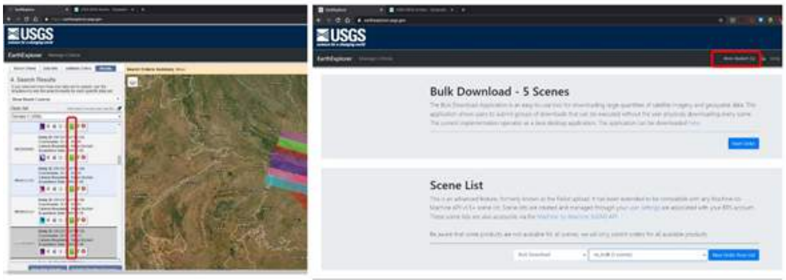
vi. Select the additional details of the datasets if known priorly such as the Entity ID, Mission Number, Revolution, Camera Resolution, etc. Also, select the Image Preview Availability to 'Yes'.



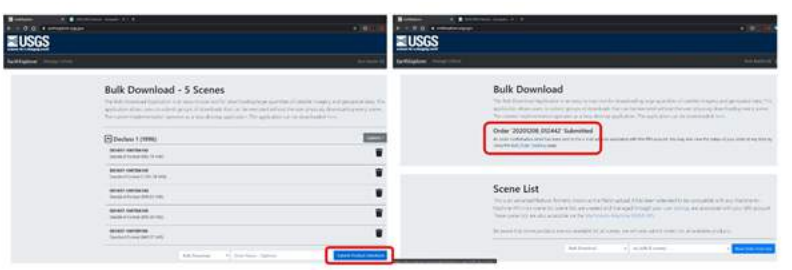
vii. Now select the footprint that corresponds to the ROI for further download.



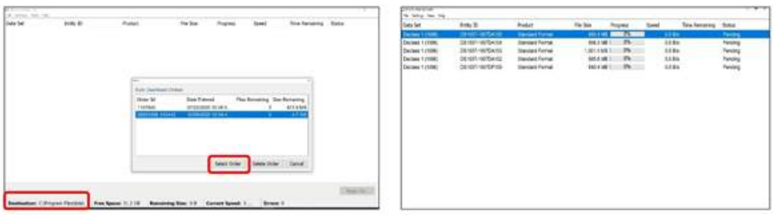
viii. Based on the visual view of the datasets, select the required tiles to add to the cart/item basket option and proceed to the item basket option appear at the right-hand corner of the page.



ix. Now, proceed with the "Submit product selection" once the list displayed. Further, open the "Bulk download option" app for downloading the data.



x. After signing in your USGS earth explorer User credentials, a pop up will appear. Click on the "Select order" option and it would start downloading the data in the hard drive.



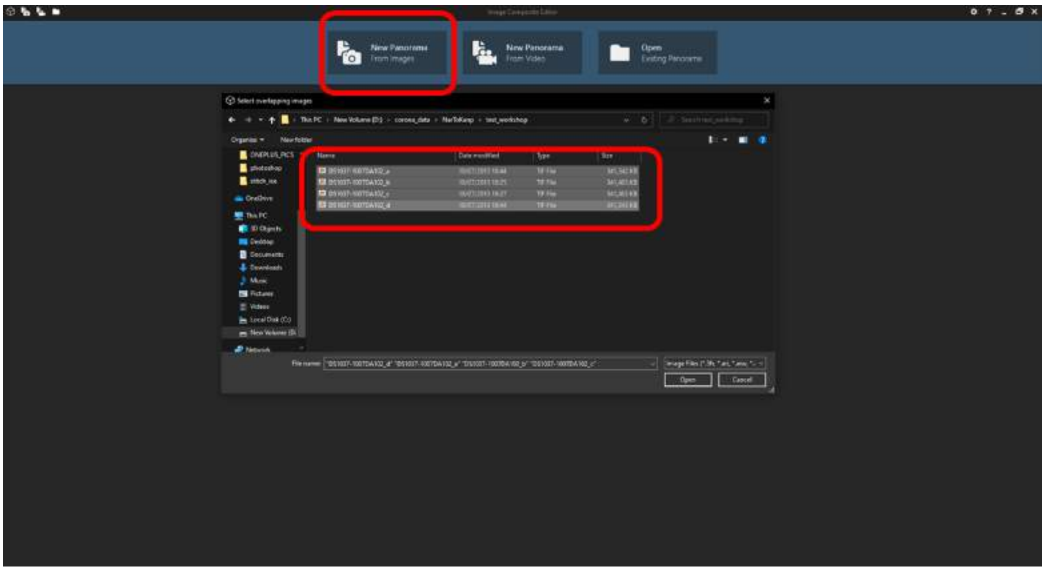
Since, the scanned images are separated with tiles, stitching was needed to make the complete panorama. There are numerous tools to stitch the images based on the overlapping areas. Some of them are commercial based applications (ex- Adobe Photoshop) where one can use the open tools such as Microsoft Image Composite Editor (ICE), Hugin, etc.
Stitching of the Corona imagery can be done through various open-source software are described next.

2. Stitching using Microsoft Image Composite Editor (ICE)

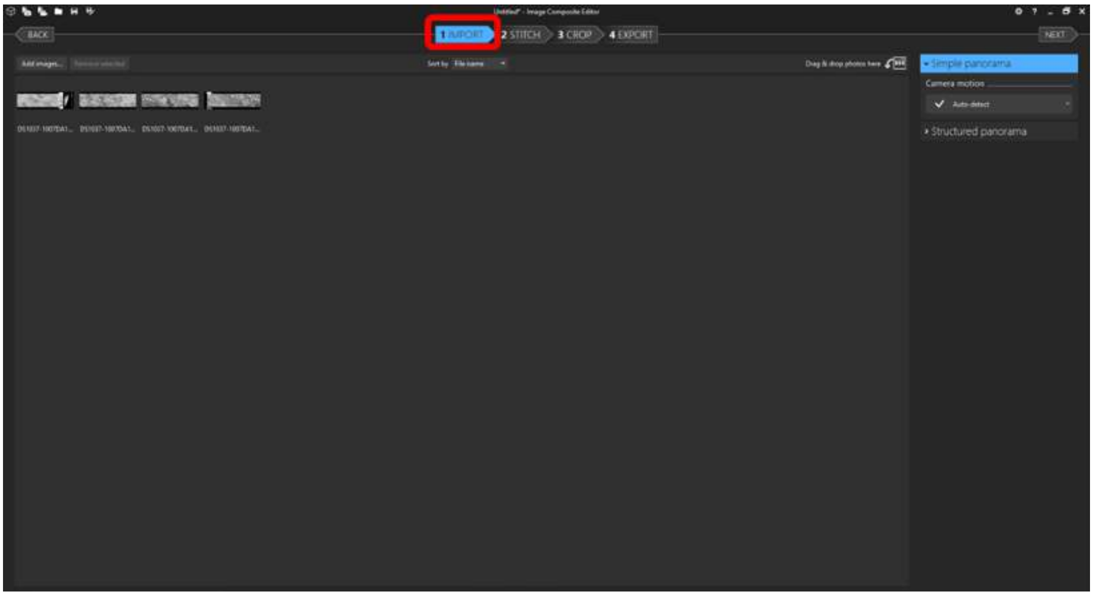
Microsoft ICE: https://www.microsoft.com/en-us/research/product/computational-photography-applications/image-composite-editor/

Each Corona image is delivered as 4 individual scans with 10% overlapping. Stitching is needed to reconstruct the whole image. Also, Corona images are devoid of any projection information, stitching will be based on key-point content in overlapping area using ASIFT algorithm. The generic workflow in producing an image composite out of the multiple Corona imagery tiles are described as follows:

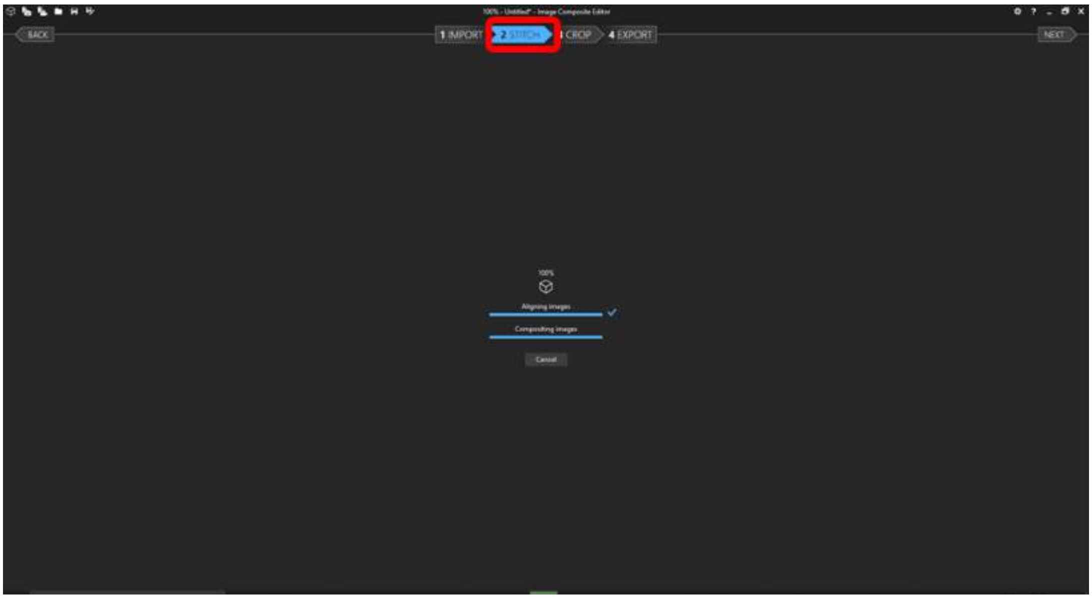
i. Open a 'New Panorama' in the Microsoft ICE and select the images to be create the composite.



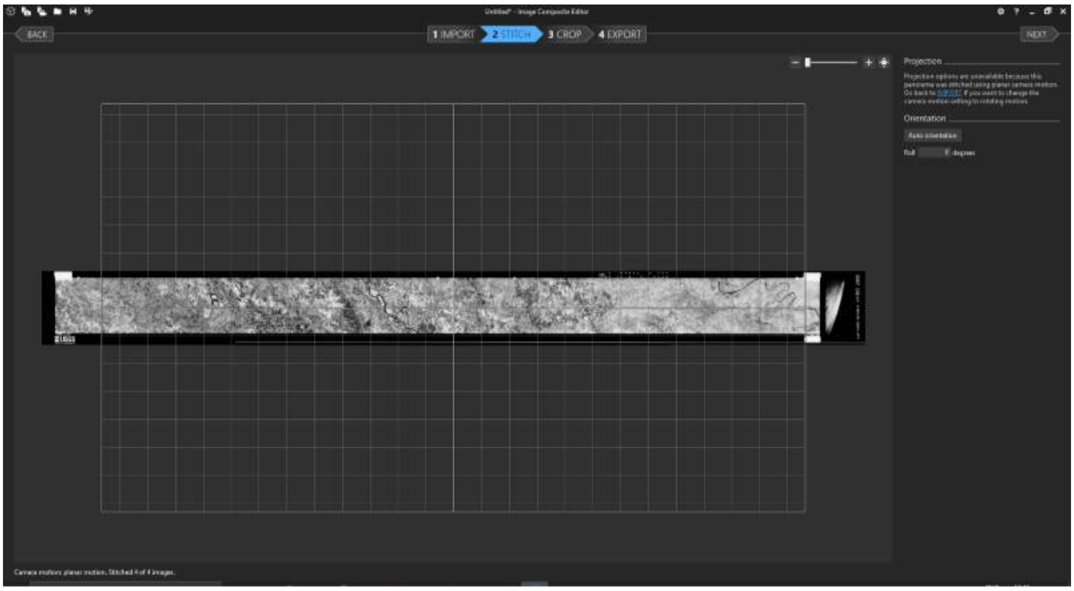
ii. The added scenes are now be the part of the display window in the ICE



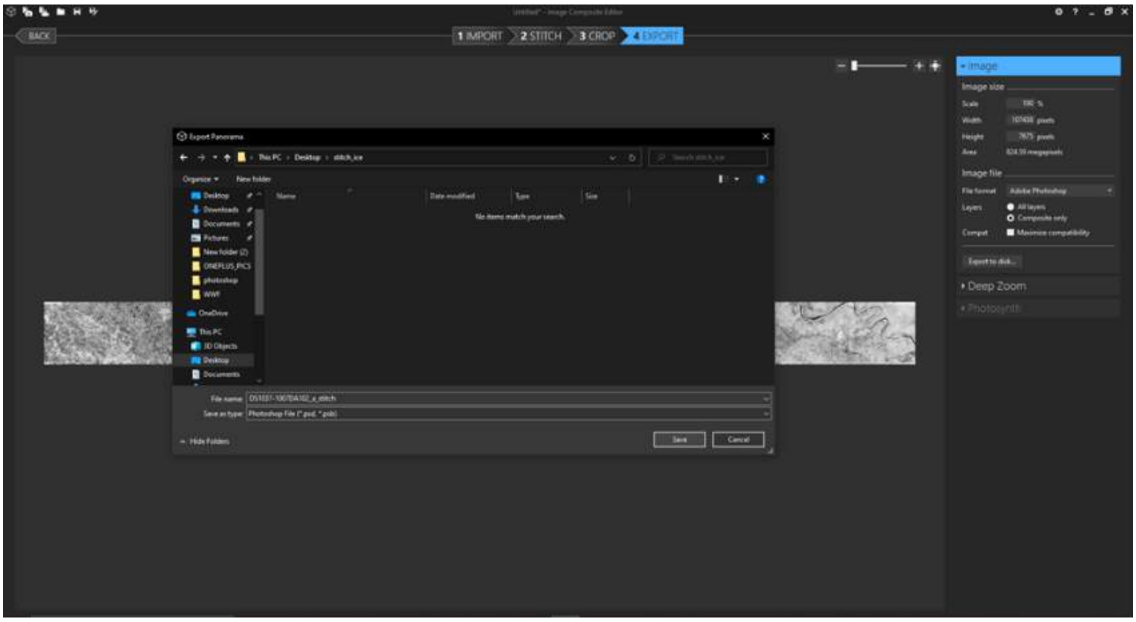
iii.Now, go to the stitch option which might takes few minutes depending upon the hardware configuration of the system.



iv.The stitched image will now appear in the screen, where the user can crop it to remove the redundant part at the edges of the composite.

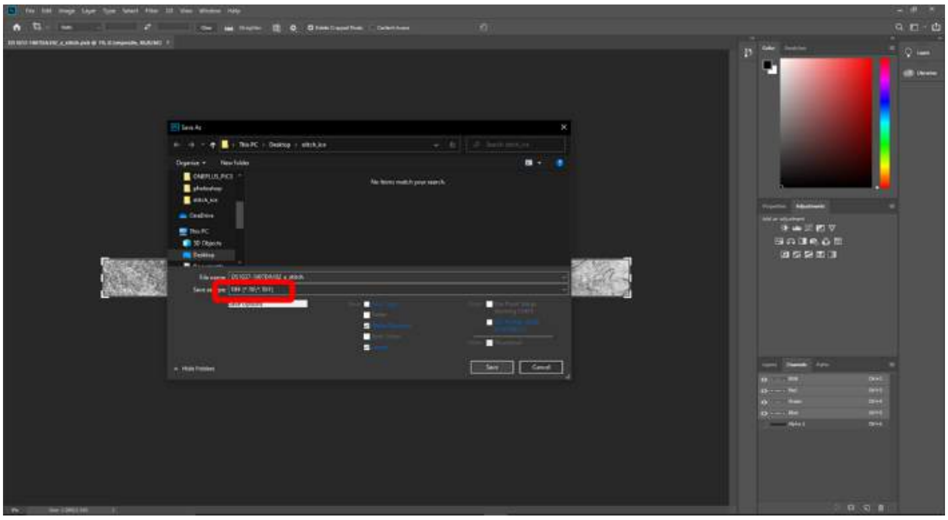


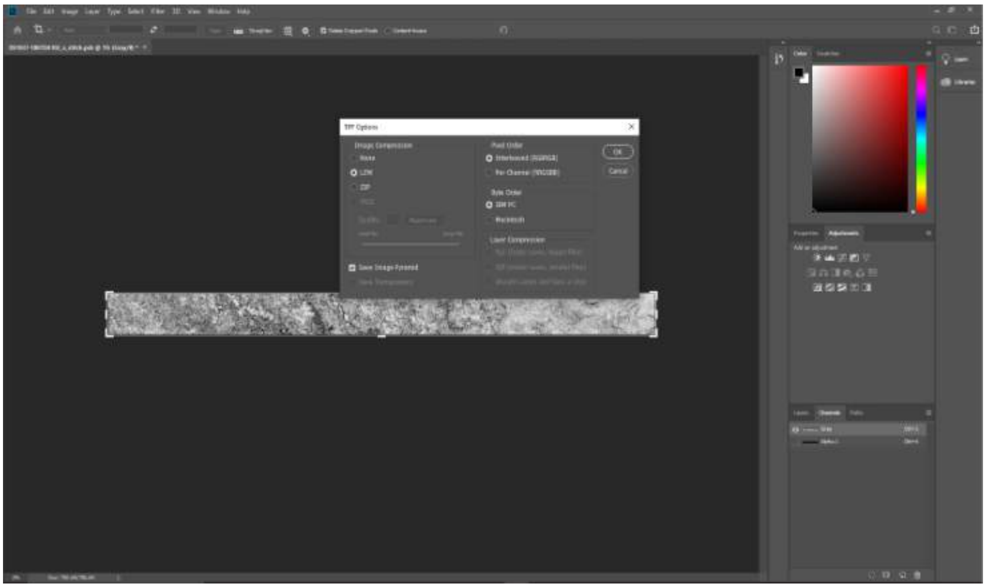
v. After making the composite, it is time to export the image for the further use. However, the export image size will be around 4 to 8 GB which becomes limited for its use afterward. So, it will be efficient to export the stitched image to an Adobe Photoshop extension (.psb), which keeps the internal details of the imagery.



vi. Now, run the Adobe Photoshop to make the stitched imagery visible on it and to export it to suitable format with a convenient file size (~ 1GB).

vii. Open the image in the Photoshop. Choose the "Flatten image" option from the Layer menu and the "mode as grayscale" to reduce the file size. Proceed with saving the image as .TIFF file for georeferencing further.

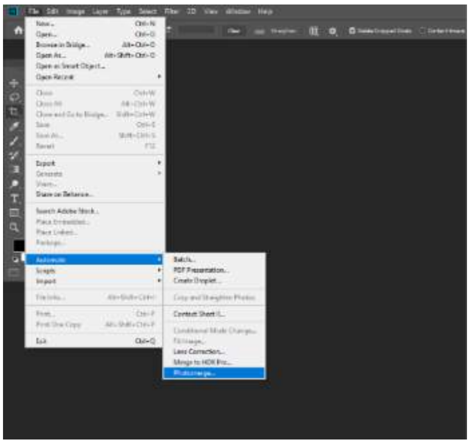


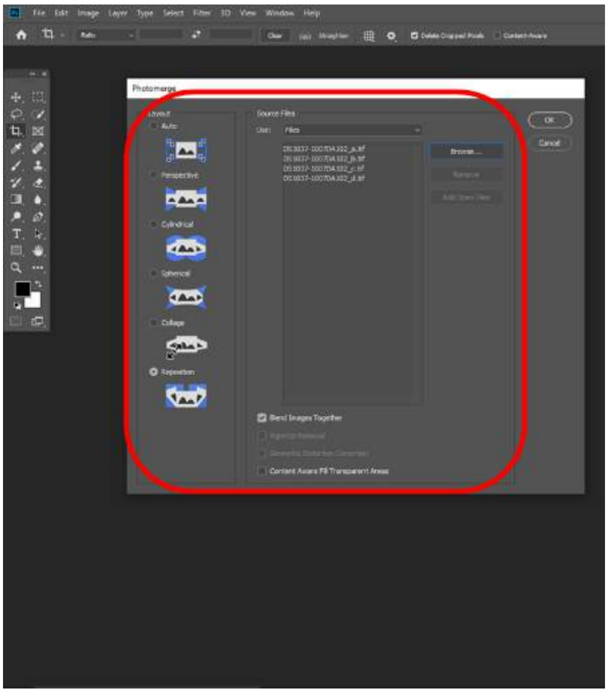


3. Stitching using Adobe Photoshop (Not mandatory)

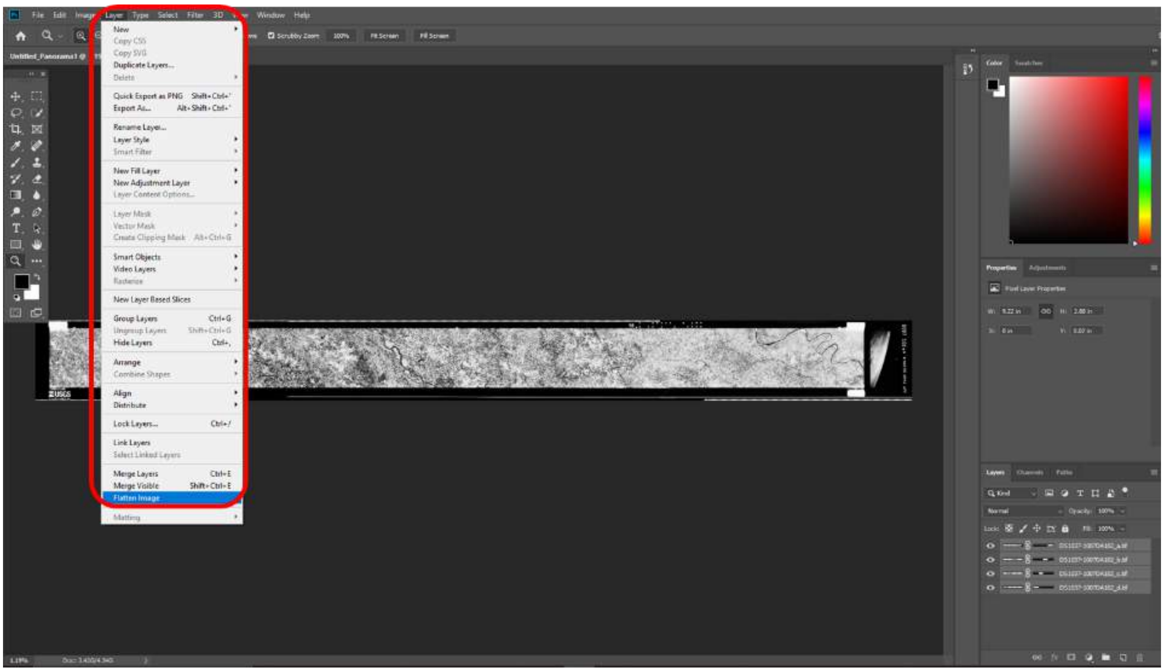
Adobe Photoshop: https://www.adobe.com/in/products/photoshop.html
Although, Adobe photoshop is a commercial tool to work with, it produces a greater quality stitched images with detail on the pixel information. The various procedure involves in creating stitching of Corona imagery in the Adobe Photoshop is described below:

i. Run the Adobe Photoshop. Go to File > Automate > Photomerge. Add the Corona declassified subset imagery tiles after extracting the zip file after downloading it. Select "Reposition" when adding it to the Adobe window as illustrated below.

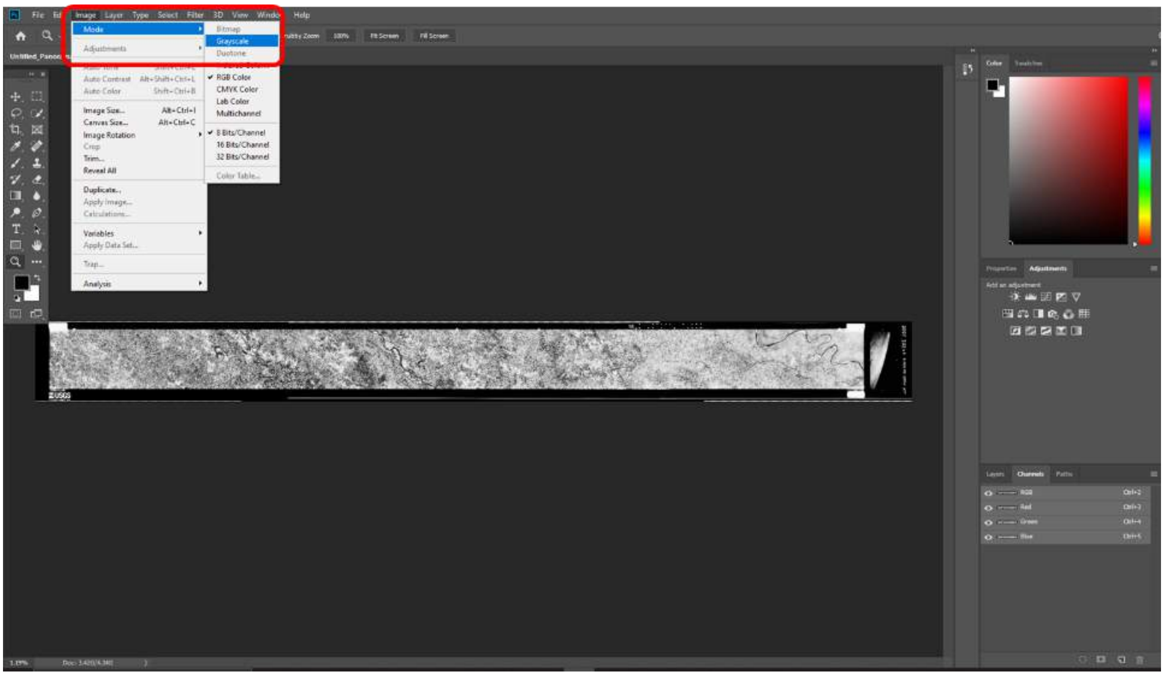




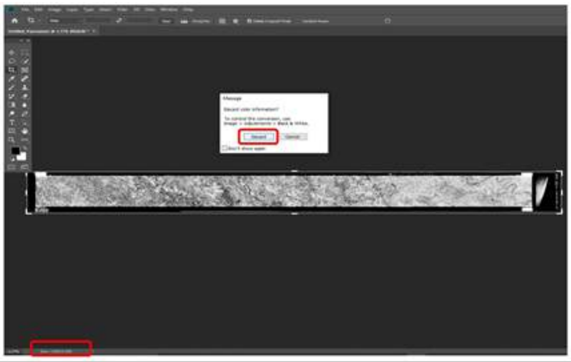
ii.Choose the "Flatten image" option from the Layer option in the Menu bar after getting the image in the working window.



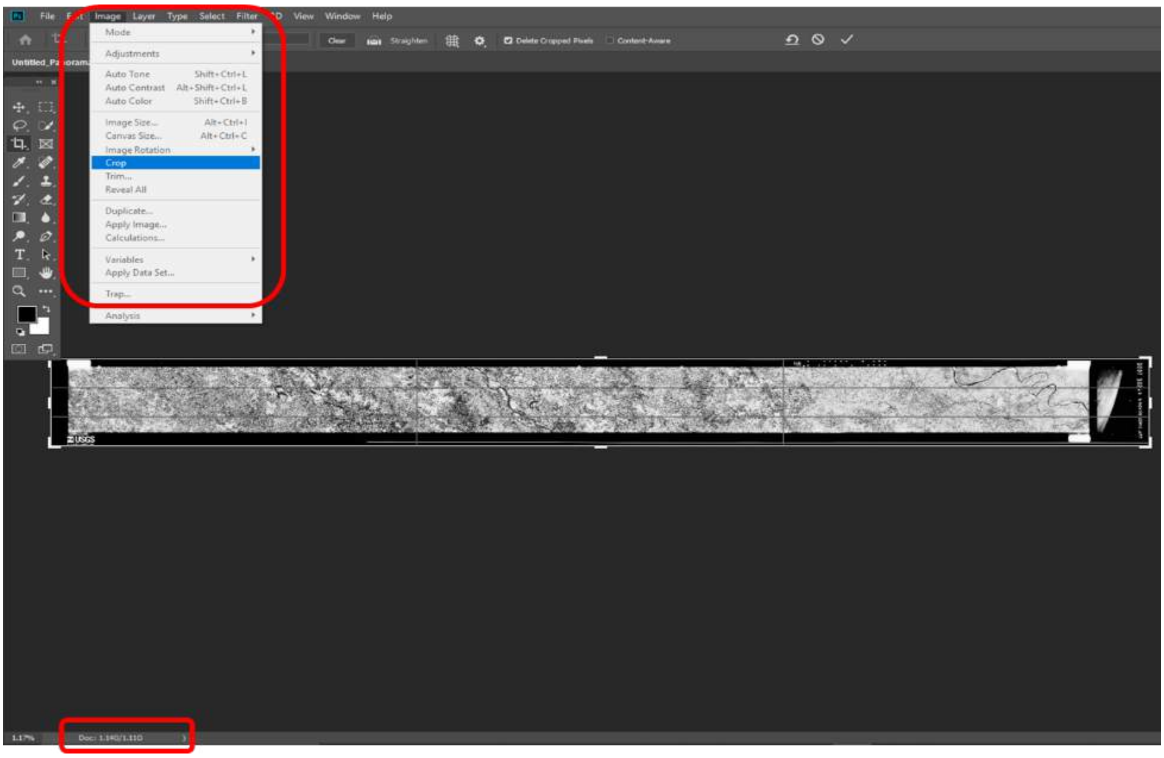
iii.Now, select the mode as "Grayscale" available in the Image option in the Menu bar.



iv.Confirm ‘Discard’ Color Information. (Notice the file size in the lower left corner)



v.After the file size is reduced, crop the image removing the redundant portion in the edges. Save the cropped image as a TIFF File. (Go to: File > Save as > Save)



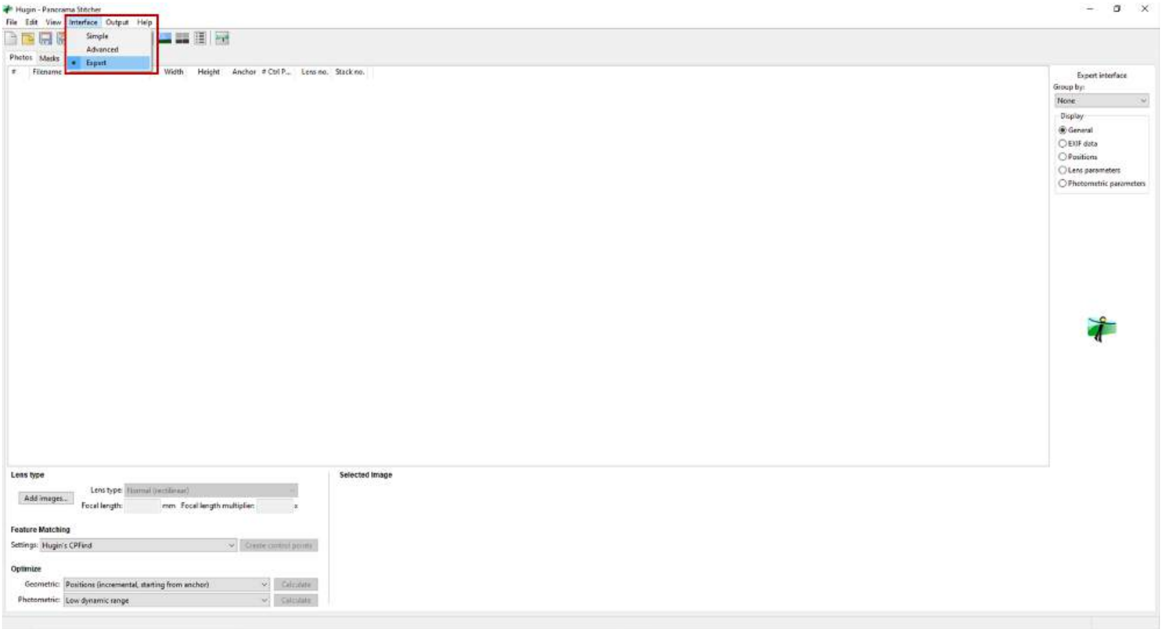
4. Stitching using Hugin

Hugin: http://hugin.sourceforge.net/download/

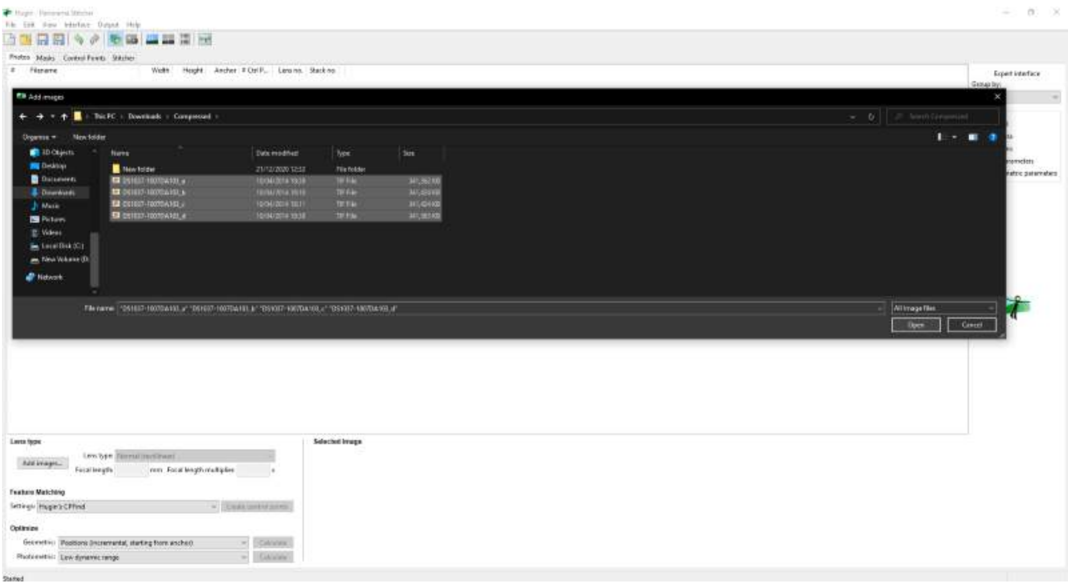
Hugin is an open-source platform for assembling the mosaic of the images into a complete panorama.

Below are the steps to create the panorama from the Corona image tiles using Hugin:

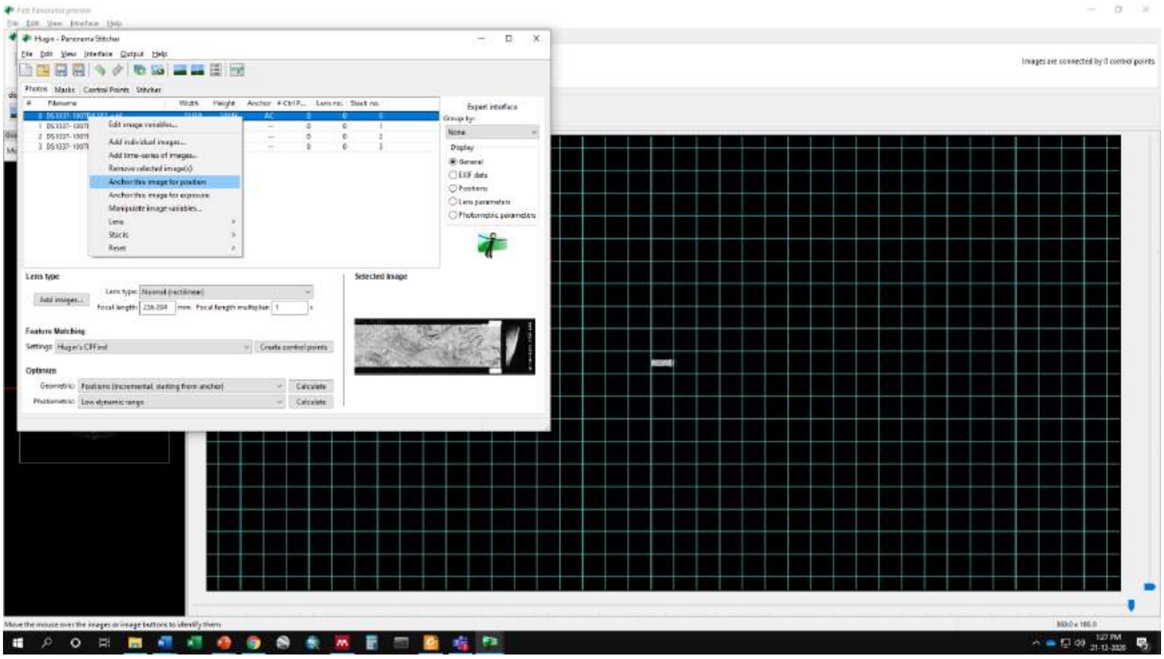
i.Run the Hugin tool. Go to Interface > Expert

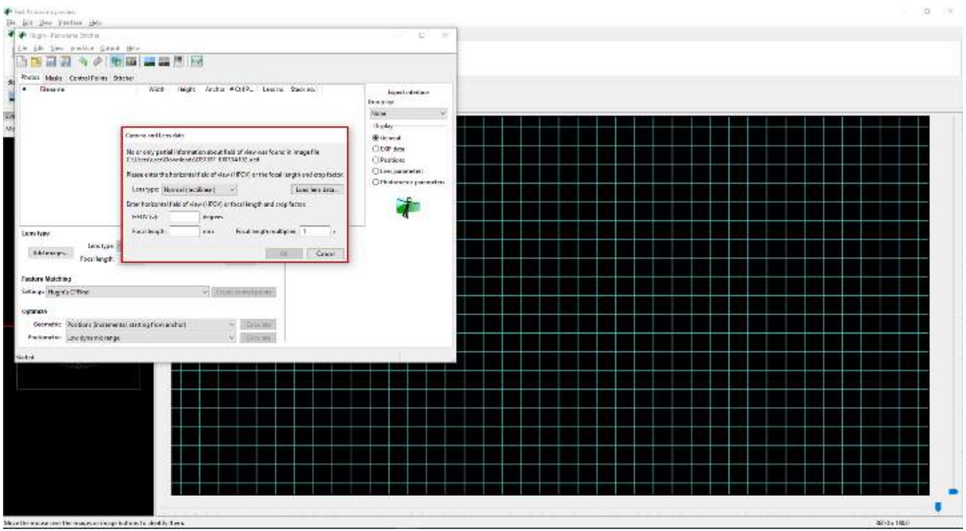


ii. Using the Images tab select "Add individual images" button to select the four individual image tiles of the Corona imagery



iii. Select image #0 then click on Anchor this image for position and Anchor this image for exposure. If selected image files do not have complete EXIF data, the Camera and Lens data dialogue box will open asking for the user to enter the details. For a standard pocket camera, it is usually safe to enter 50 deg for the HFOV (Horizontal Field of View). For scanned image put HOV as 10.





iv. Now, switch to the control point tab where the input of the control points must be done to aligning of the images.

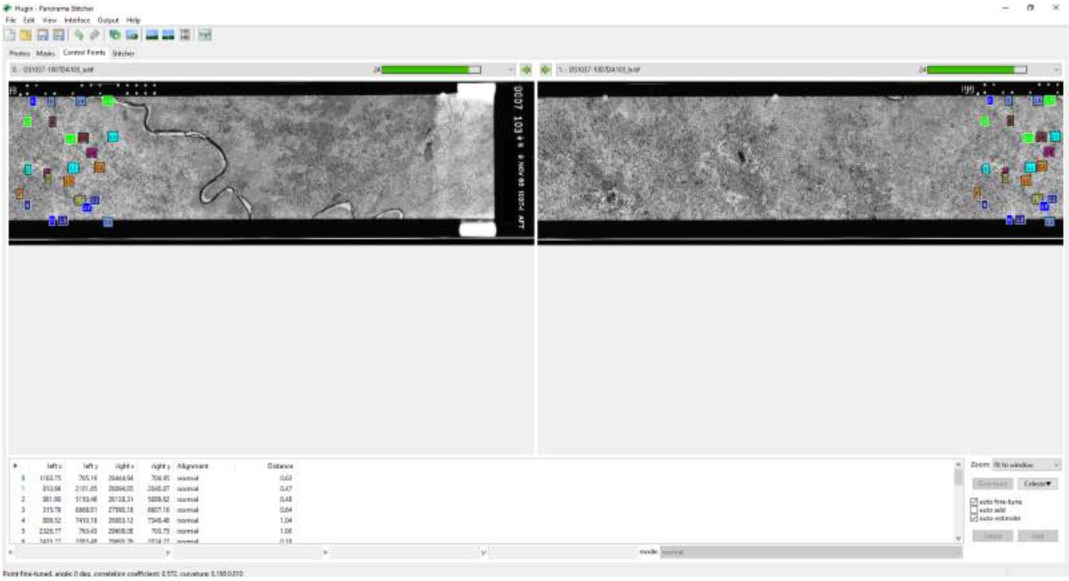
a. Click on the title bar above each image to select image 0 on the left-hand side and image 1 on the right-hand side.

b. Make sure that Zoom is set to fit to window and that both Auto fine-tune and Auto-add are set.

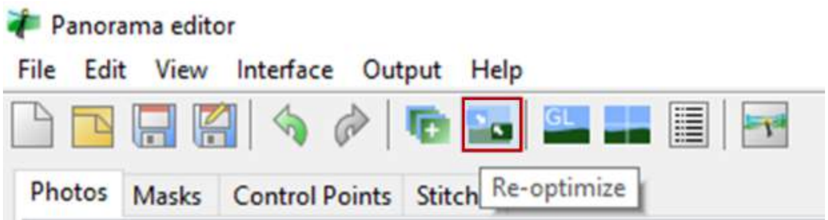
c. Now you can use the mouse to select control points; pick well-defined features that you can see in both the left and right-hand window.

d. First click will put a new point – Hold Left mouse for moving the point to the desired location, do the same for other images.

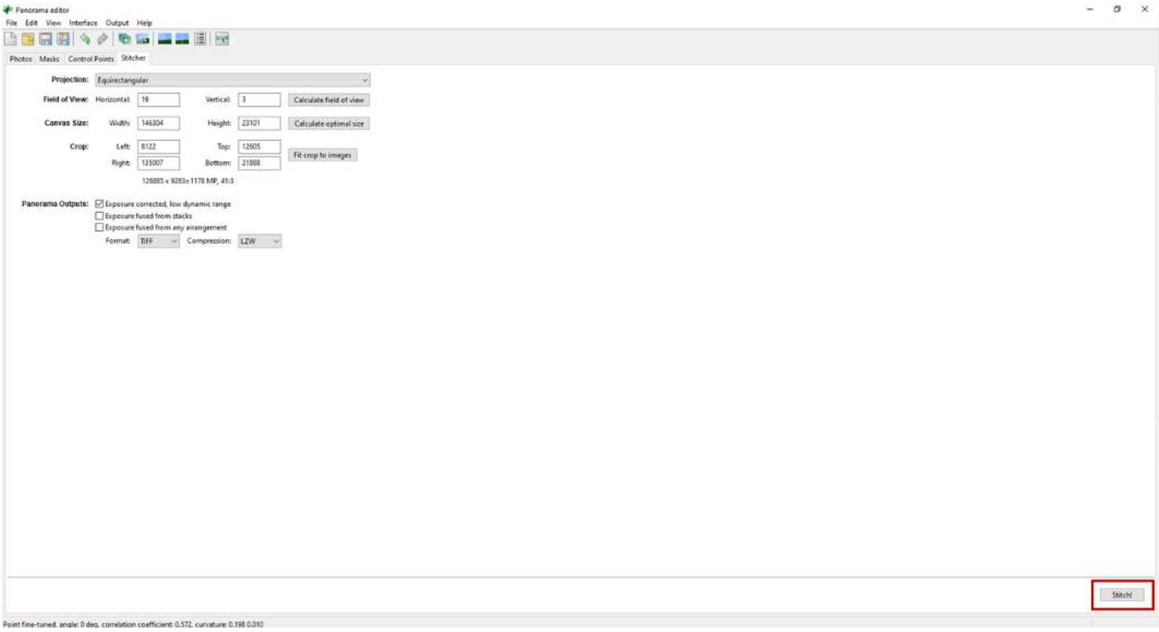
e. After pointing the same position on both images, press right-click to sync the points (They will be denoted by the same number) Repeat until you have about 5 or 6 pairs of control points.



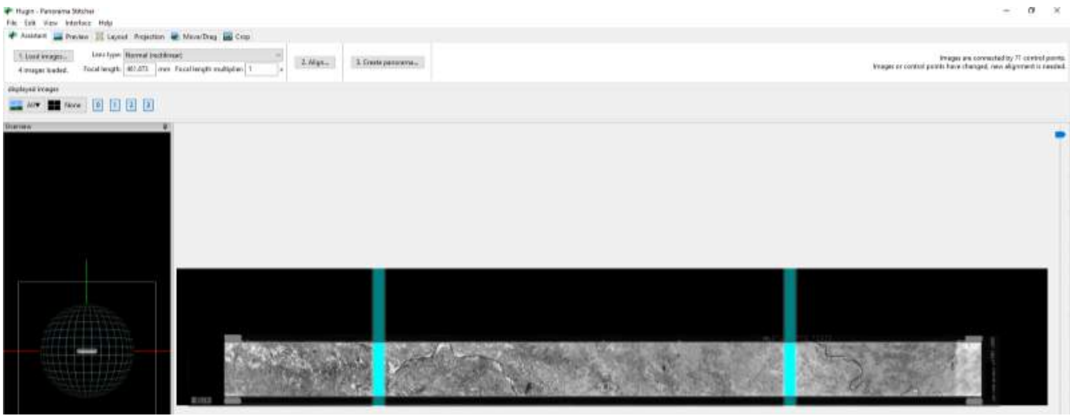
v.Now, go to re-optimize option and apply the changes



vi.Finally, move into the “Stitch” tab and press Stitch button at lower right corner to stitch the individual images. Save the project.



vii. Open the stitched image and check for further consistency. Now, crop the stitched image appropriately and export as the .TIFF extension image file.

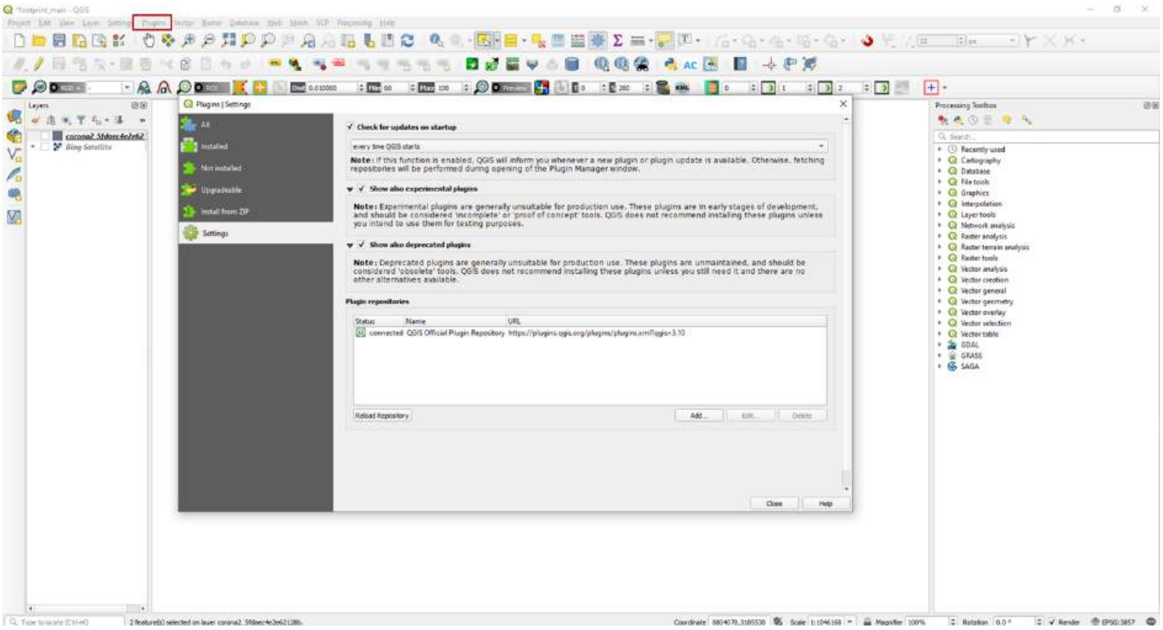


5. Georeferencing of Corona Imagery

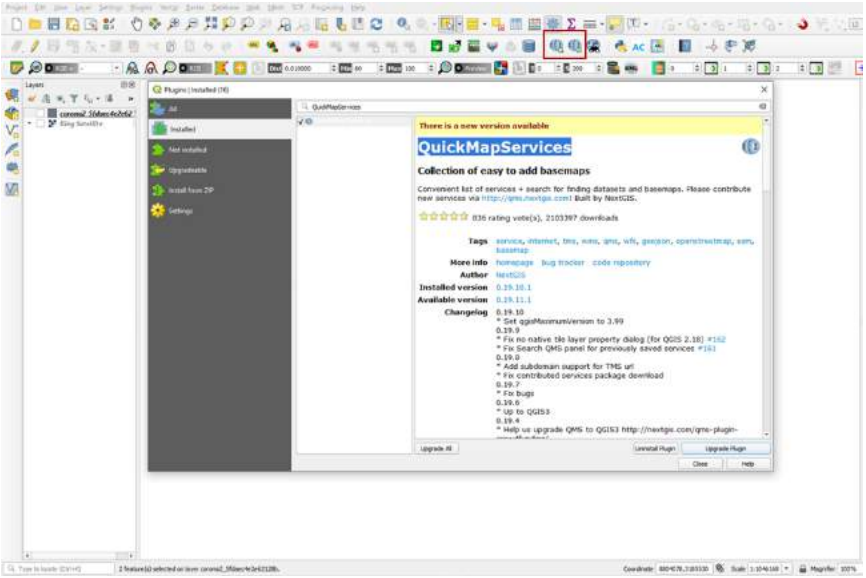
The stitched image is now be georeferenced to with the Ground Control Points (GCPs) in the QGIS using Web Map Service plugin and subsequently projected to a coordinate system for the further feature extraction.

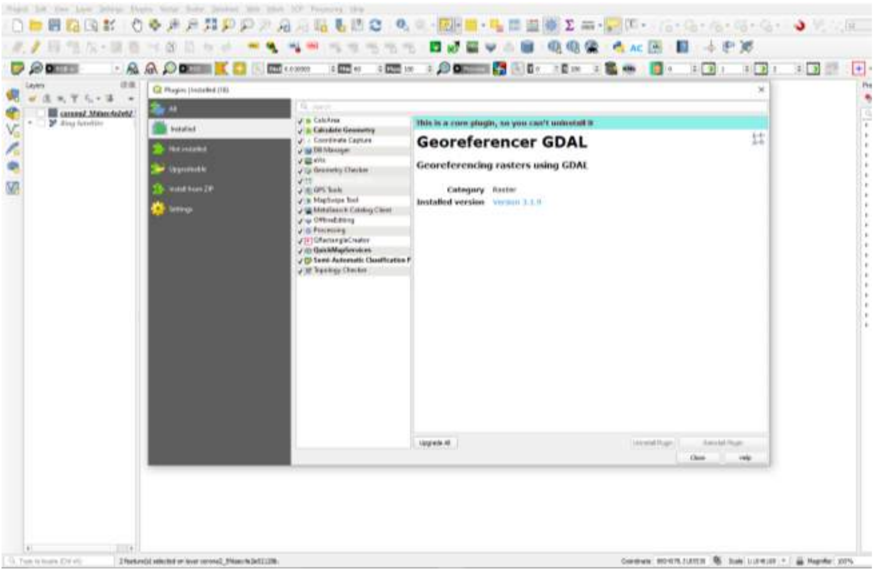
The process of georectification is described as below:

i. Open the QGIS > Go to Plugins in the Menu bar and Check (make active) all boxes for installing Plug-Ins

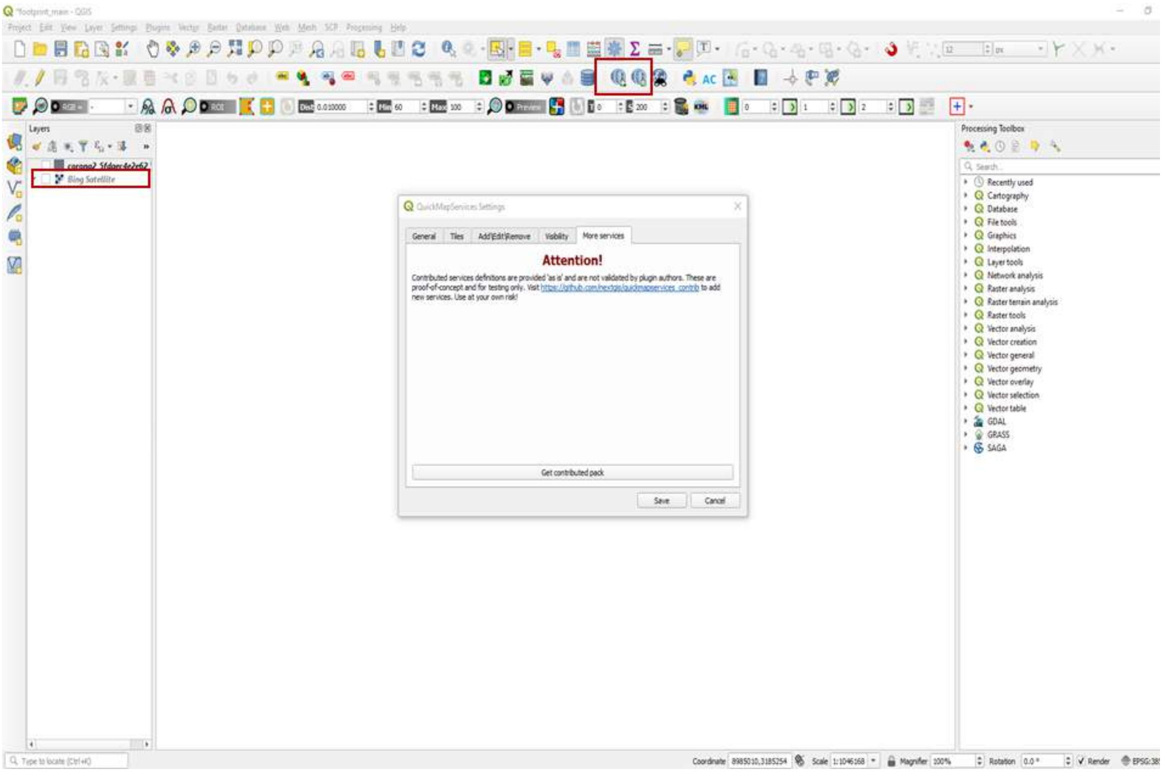


ii.Now, go to the installed tab and search for “QuickMapService” and install it if previously not installed. As soon as the plugin get installed, two icons start showing in the working window as illustrated below. Also, install the “Georeferencer GDAL” and the “MapSwipe Tool” plugin by searching it again in the installed tab.

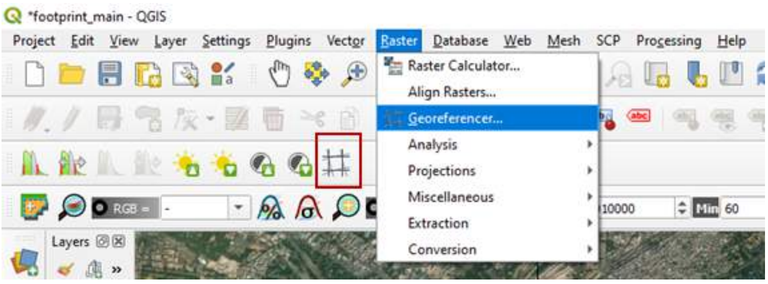




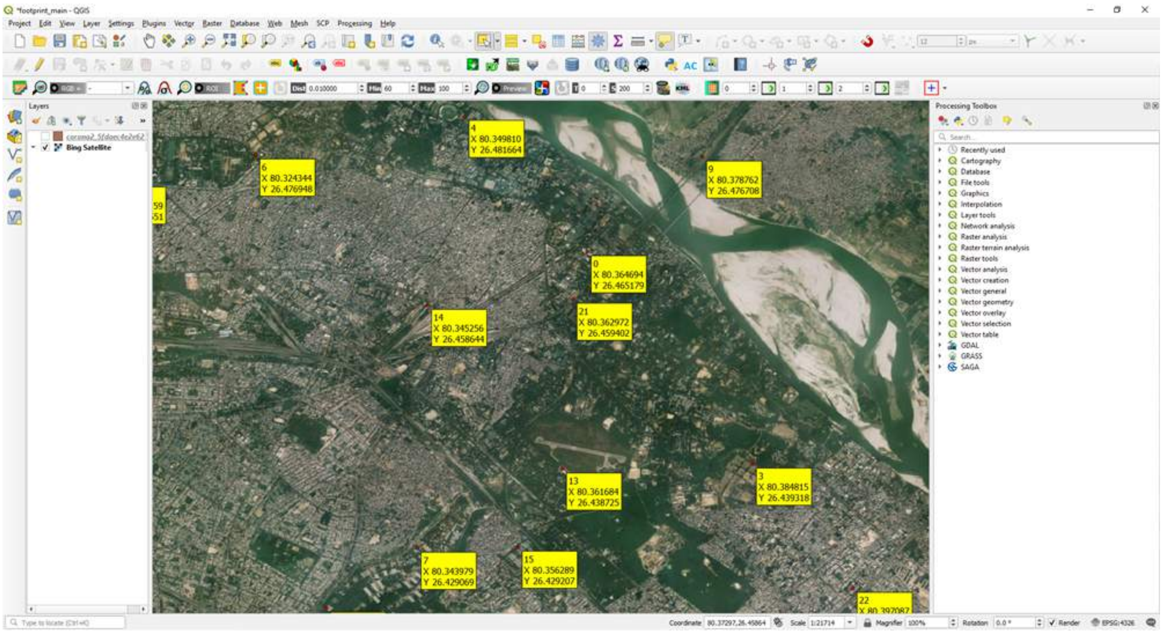
iii. Left click on QuickMapService (QMS) > Settings > click on “get contributed pack”. Select Bing or Google layers, which will appear at the layer menu in the left side of the working window.



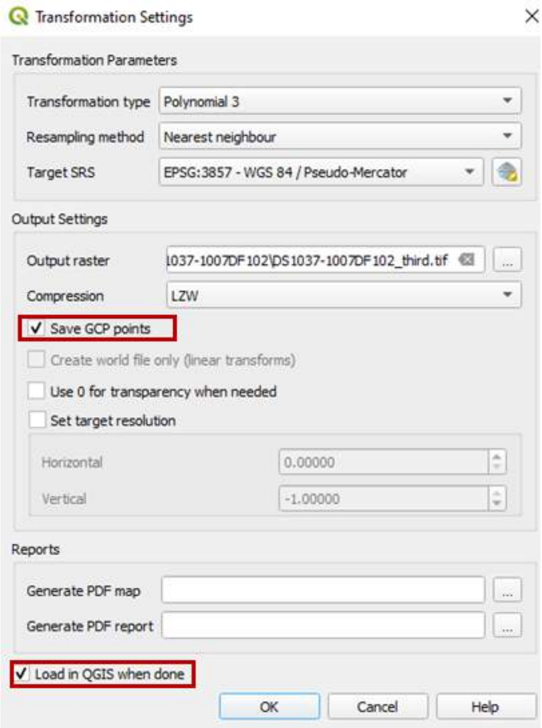
iv.Go to Raster tab in the Menu bar > Select Georeferencer if the icon (as shown below) not previously appeared.



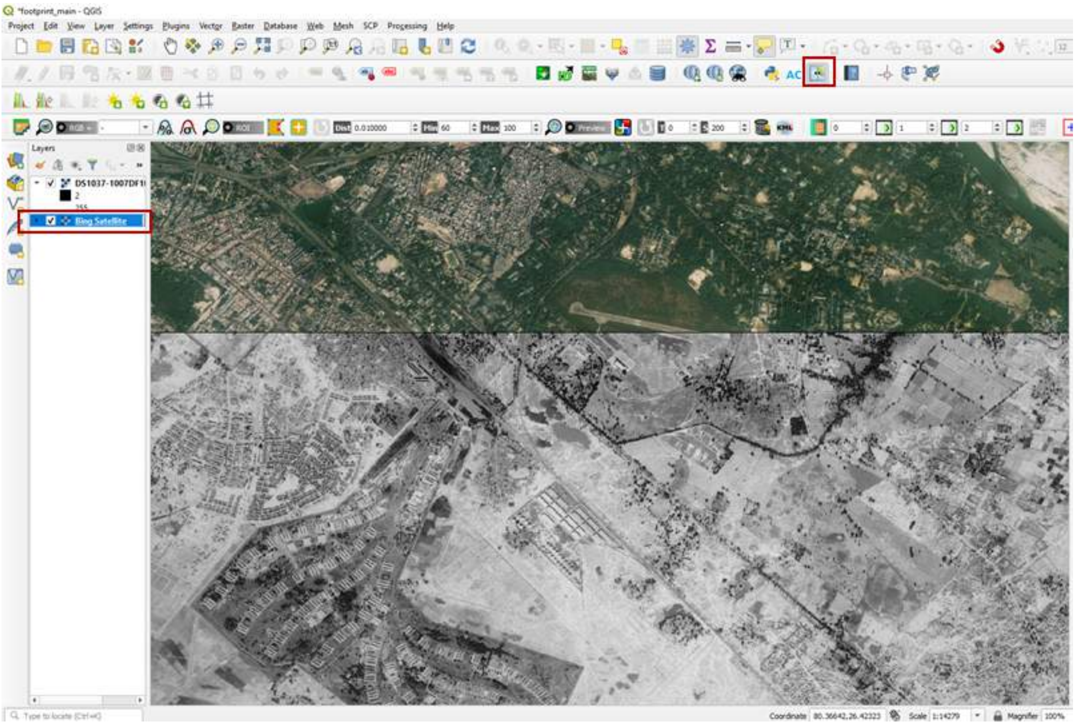
v.Find suitable locations for placing the point in the Corona image and the Bing layer simultaneously. Selection of more than 100 locations distributed evenly throughout the Corona satellite image are needed for georeferencing it accurately.



vi.At the end of georeferencing, go to Settings appear at the menu bar of Georeferencer window (illustrated above). So the Transformation Settings window will appear and let you to choose to check the “Save GCP points” and the “Load QGIS when done”.



vii.The MapSwipe Tool plugin (appear as an icon in the toolbar) can help in visualizing the alignment of the georeferenced image with the base (Bing) image. This will help in placing more suitable points to increase the accuracy further.



viii.Finally, the accuracy of the georeferenced image can be assessed by determining the root mean square error (RMSE) from the actual location with corresponding georeferenced locations in the Corona image. Now, the image can be used for the further feature extraction.

Table 1: **Mission parameters** ***(Source: USGS)***

Satellite System	Mission Designator	Successful Missions	Film Acquisition
CORONA	KH-1	9009	8/1960
CORONA	KH-2	9009 9017 9019	12/1960-7/1961
CORONA	KH-3	9022 9023 9025 9028 9029	8/1961-12/1961
CORONA	KH-4	9031-9032 9035 9037-9041 9043-9045 9047-9048 9050-9051 9053-9054 9056-9057 9062	2/1962-12/1963
CORONA	KH-4A	1001-1002 1004 1006-1031 1033-1052	8/1963-9/1969
CORONA	KH-4B	1101-1112 1114-1117	9/1967-5/1972
ARGON	KH-5	9034A 9046A 9058A 9059A 9065A 9066A	5/1962-8/1964
LANYARD	KH-6	8003	7/1963-8/1963

Table 2: Digital products

CORONA			
Mission Designators	Film Size	Micron Size	File Size
KH-1 KH-2 KH-3 KH-4 KH-4A KH-4B	70 mm x 29.8 inch	14 Micron (1800 dpi)	80 MB (× 4 files)
		7 Micron (3600 dpi)	319 MB (× 4 files)
ARGON			
KH-5	5 x 5 in	14 Micron (1800 dpi)	80 MB
		7 Micron (3600 dpi)	335 MB
LANYARD			
KH-6	5 x 25 in	14 Micron (1800 dpi)	80 MB (× 3 files)
		7 Micron (3600 dpi)	325 MB (× 3 files)