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RESOLUTION BASED EVALUATION STUDY OF COMMONLY USED SATELLITE IMAGES FOR THE IDENTIFICATION OF WATER RESOURCE FEATURES

Dr. R. S. Suja Rose
Department of Environmental Remote Sensing and Cartography
Madurai Kamaraj University
Madurai – 625 021.
E-Mail: rssujarose@yahoo.co.in

Abstract

A detailed analysis on the capability of various satellite image data products and their processing techniques are analysed systematically in this paper. From this piece of study, it is clear that the satellite image digital data products and the spectral bands along with the processing techniques are very important in identifying the water resource details. Hence a detailed evaluation study was attempted for the selected most commonly used digital data products viz. Landsat-5 TM, IRS-1B LISS II, IRS-1C PAN, IRS-1D WIFS and IRS-1D LISS III. They have been rated based on the interpretation capability as very clear, clearly seen, moderately clear and poorly seen. When the single bands of the data products was considered, most of the water resource features remain unidentified; some differences within water bodies was seen in the green band and the delineation was easier in the near infrared band. So in order to get a good clarity, false colour composites, a band combination of three spectral bands was attempted. Accordingly, the mid infrared, near infrared and green band when projected through red, green, and blue guns produced results in which water resource features were very clearly seen. The false colour composites were subjected to various digital enhancement techniques namely geometric, radiometric and multispectral transformation. The edge enhancement and linearly stretched false colour composites gave a better idea in deciphering the linear water resource details like the streams and canals. The radiometrically enhanced images with histogram equalization also revealed certain details relating to the surface water storage features. Level sliced images were used to differentiate or separate the water resource features from other land uses, whereby further analysis within the features was made easier. The multi-spectral transformation of images gave better results in discriminating water bodies. Principal component images were very much used in the water resource identification and delineation. The merged data products of IRS-1C PAN and IRS-1D LISS III gave a very good result and revealed almost all the water resource features under study. The merged data product showed a higher spatial and spectral property. Hence, the water resource features were easily identifiable and delineation within features was facilitated. It is concluded that remote sensing plays a vital role in the easy identification, mapping and delineating of water resources, which may also occur in inaccessible areas. Moreover, these techniques can be

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used for easy updating and formulating models, which can be used for proper water resource planning.

1. Introduction

The challenge of a remote sensing scientist and water resource specialist is the interpretation of the remotely sensed data products in a way that could be used for the effective management and monitoring of earth resources including water. In fact, modern remote sensing is based on interpreting measurable variations in spatial, spectral, temporal, and radiometric characteristics of earth observing sensors. Today, several nations operate various satellite missions of remote sensing systems to observe the earth resources. So the interpretation of remotely sensed data products of different satellite sensors poses difficulties to the scientists for selecting the appropriate data products with desired resolution characteristics that is suitable for their own field of investigation. In fact, the evaluation of remotely sensed data products for the applicability of these products to a particular field of investigation becomes essential and inevitable.

2. Methods of derivation

Digital images acquired by earth observing satellite sensors can be used in several ways in order to nourish the basic data needed for the theme under study. The basic data needs are of various geomorphic characters, geologic features, land use/land cover, and other subtle information that are visible on the image in a varied manner. Even for the basic usage, it is necessary to carry out preliminary visual interpretation or image processing to obtain a readily understandable document. Thus, the processes of image preprocessing, image enhancement and image manipulation becomes essential in this regard. Notable scholars who made such similar studies were Chari, K.N., et.al. (1980), Drayton, R.S. (1986), France, M.J., et.al. (1986), Subudhi, A.P., et.al. (1989), Krishnamurthy, J.,et.al.(1992, 1996), Kachhwaha, T.S., et.al. (1992) and Patel, A.N., et.al. (1999). These studies pointed out the usage of remote sensing data products and their processing techniques mostly suitable for water and

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other land resource studies. The present study aims at the interpretative capability of the selected satellite data products and its processed images for the analyses of water resources in the present study area.

3 Results and Discussions

The primary database for the geospatial analysis of water resources in the present study is the varied remotely sensed satellite digital data products. It is pertinent to note that the digital images of the present study area comprises Kanyakumari and Nambiyar basins, which spans over eleven Survey of India (SOI) toposheets on 1:50,000 scale. Both the images and the toposheets covering the whole study area have to be brought into ERDAS Imagine, version 8.4 software (Earth Resource Data Analysis System, 1999), for further processing and analysis of water resources. The use of satellite images through visual interpretation requires a minimum amount of processing such as preprocessing of the signal and processing abutting in colour composites. In the present attempt of evaluation, selected types of commonly used and readily available visible range based sensor data products viz. Landsat-5 TM, IRS-1B LISS II, IRS-1C PAN, IRS-1D WIFS and IRS-1D LISS III are chosen.

The processing of digital image data

At the outset, six test sites (vide Figure 1) representing the various water resource features like streams and canals, lakes and ponds, reservoirs, bays and estuaries that are located within the study area are suitably selected for the present study. The comparative interpretation ability range of the water resource features seen in the image is grouped into four categories viz. very clear (VC), clear (C), moderately clear (MC) and poorly seen (PS). The interpretative ability of the same is rated as 'very clear' when the water resource features can be discriminated directly. It is rated as 'clear' when the features can be discriminated by analyzing the associated features. It is rated as 'moderately clear' if it could be discriminated with the help of collateral data (toposheet) and it will be rated as 'poorly seen' when the feature cannot be recognized neither with the help of associated features nor with the collateral data. This rating is carried out for the purpose of evaluation of both the raw image as well as digitally enhanced data products.

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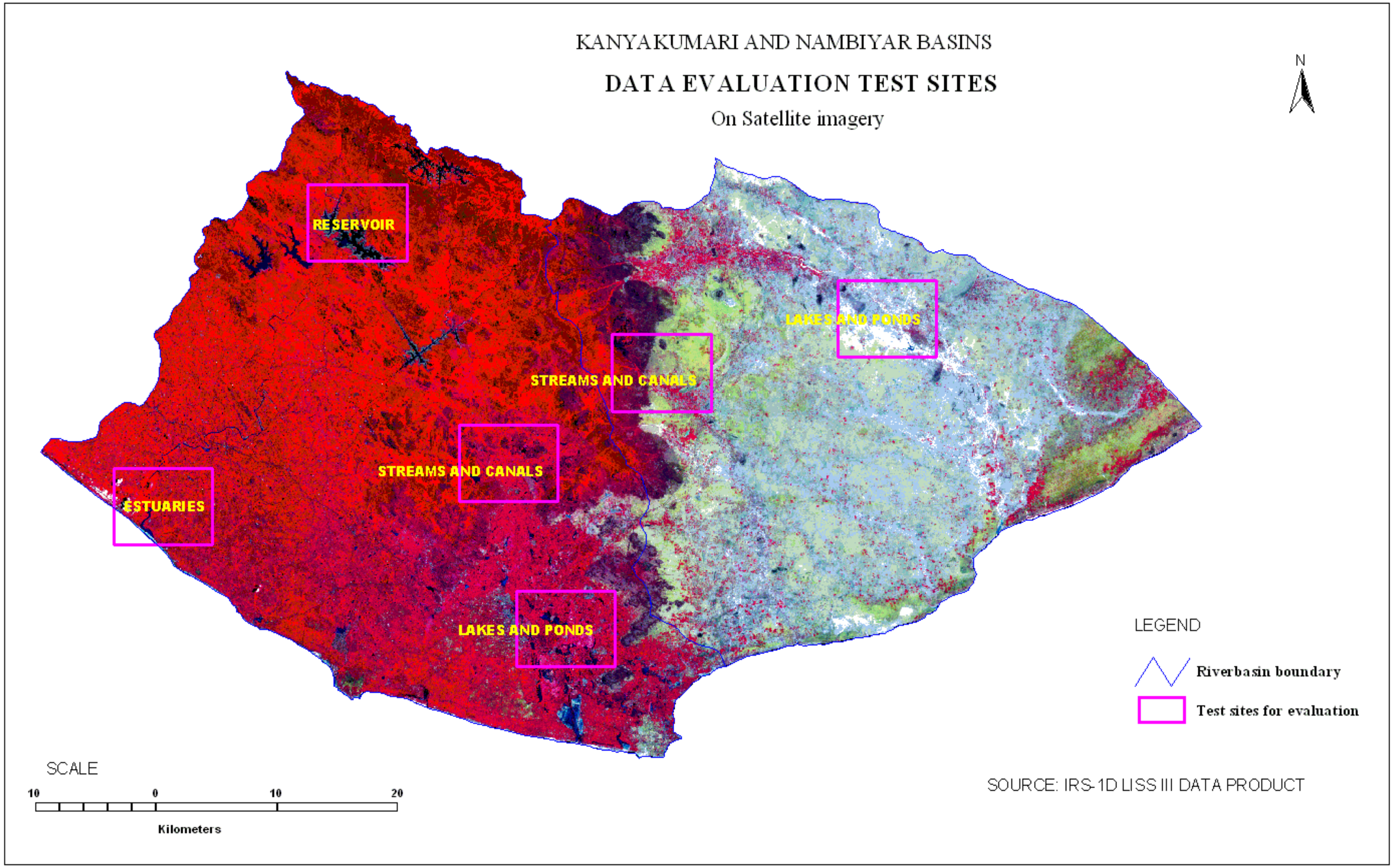

Figure 1

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Remote sensing satellite image data products - An evaluation

The water resource details as per the four different levels in USGS classification scheme, have been considered for qualitative evaluation. Accordingly, the level I water bodies is classified in level II into four categories namely, natural streams and canals, lakes and ponds, reservoirs and bays and estuaries. Again these four water resource features are further grouped into various categories under level III and level IV and all of them are shown in Table 1. Various image processing techniques are also used and evaluated for water resource feature interpretation and identification.

Table 1 Water resource level IV categories with their codes

Level I	Level II	Level III	Level IV
Water body	1.1 Streams and Canals	1.1.1 Natural Streams	1.1.1.1 1st order 1.1.1.2 2nd order 1.1.1.3 3rd order 1.1.1.4 4th order 1.1.1.5 5th order 1.1.1.6 6th order
		1.1.2 Man made canals	
	1.2 Lakes and Ponds	1.2.1 Minor Tanks	
		1.2.2 Intermediate Tanks	1.2.2.1 Water Surface 1.2.2.2 Depth 1.2.2.3 Dry Tank Bed 1.2.2.4 Tank Bed Vegetation
		1.2.3 Major Tanks	1.2.3.1 Water Surface 1.2.3.2 Depth 1.2.3.3 Turbidity 1.2.3.4 Dry Tank Bed 1.2.3.5 Tank Bed Vegetation
	1.3 Reservoirs	1.3.1 Depth 1.3.2 Turbidity	
	1.4 Bays and Estuaries	1.4.1 Depth 1.4.2 Turbidity	

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Comparative interpretation ability range

The interpretation ability range has been brought under four categories with respect to the recognition ability of water resource details as given in Table 2 such as very clear, clear, moderately clear and poorly seen.

Table 2 Water resource features – A comparative Visual interpretation ability range of various satellite data products

Code	Water Resource Details	Comparative Interpretation Ability Range				
		LANDSAT - 5 TM	IRS - 1B LISS II	IRS – 1C PAN	IRS – 1D WIFS	IRS – 1D LISS III
1.1	**Streams and Canals**					
1.1.1	Natural Streams	C	MC	C	PS	VC
1.1.2	Man made canals	C	MC	VC	PS	VC
1.2	**Lakes and Ponds**					
1.2.1	Minor Tanks	C	MC	C	PS	C
1.2.2	Intermediate Tanks	VC	C	C	PS	VC
1.2.3	Major Tanks	VC	VC	C	PS	VC
1.3	**Reservoirs**	VC	VC	VC	MC	VC
1.4	**Bays and Estuaries**	VC	VC	VC	MC	VC

Note: Multi-spectral images are of standard FCCs.

Interpretation Ability Range:
VC – Very Clear
C – Clear
MC – Moderately Clear
PS - Poorly Seen

Accordingly, it is found that the natural streams are very clear in IRS-1D LISS III data product, whereas man made canals are very clearly seen in IRS-1C PAN and IRS-1D LISS III. In the case of lakes and ponds category, minor tanks are clearly seen in IRS-1C PAN, while intermediate and major tanks are seen very clearly in Landsat-5 TM and as well as in IRS-1D LISS III. The reservoirs, bays and estuaries are clearly seen in all the data products except IRS-1D WIFS.

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Image enhancement and ability of interpretation - an evaluation of digital data products

An evaluation of individual spectral bands of raw digital data of the selected five products is attempted on the basis of the spectral reflectance property of water resources.

Raw digital data products: Individual spectral bands for water resource features - An evaluation

For the qualitative evaluation of the data products, each and every band of the raw digital data products has been analysed separately for the identification of water resource features, and the results are shown in Table 3 wherein the interpretation ability ratings have also been given. The sample image output of individual bands showing the water resource features of the selected five digital data products have been given in Figure 2. It is to be noted that in these figures, the spectral bands are represented by their appropriate band numbers.

Out of the seven bands of Landsat-5 TM, the near infrared and mid infrared bands (see Figure 2a & 2b) give fruitful results in the identification of natural streams and man-made canals. In these bands, the 4th order streams are moderately clear and 5th and 6th order are clearly seen, but these features are poorly seen in the image data products like IRS-1B LISS II (see Figure 2c) and IRS-1D WIFS due to their coarser resolution property. However, it is to be noted that the 6th order stream alone, is clearly seen and could be identified from IRS-1C PAN data (see Figure 2d). At the same time in IRS-1D LISS III red band (see Figure 2e) and near infrared band, both give better results whereby the 5th and 6th order streams could be identified.

In the case of lakes and ponds, the minor tanks are easily identified from the near infrared band of Landsat-5 TM and IRS-1D LISS III (see Figure 2f, 2g & 2j) due to their specific spectral band and spatial resolution. These features as shown in the Figure 2i are moderately seen in IRS-1C PAN data in spite of its higher spatial resolution owing to its wide spectral band. The intermediate tanks however, are clear in near infrared band and mid infrared of Landsat-5 TM data. The water surface in the intermediate tanks is clearly seen in these bands. But in IRS-1D LISS III near infrared band, it is moderately seen, while the other categories are poorly seen there. The water surface in IRS-1C PAN data product is also clear and can be used for the delineation of intermediate tanks. The water surface of the same is moderately clear in the blue band of IRS-1B LISS II data (see Figure 2h). However, the major tanks are clear in near infrared and mid infrared bands of Landsat-5 TM data. The water surface of the major tanks is clearly seen in IRS-1C PAN and IRS-1D LISS III data as its green band is aptly used for the delineation of the same in the present study area.

The reservoirs are very clearly seen in near infrared and mid infrared band of IRS-1D LISS III data product (see Figure 2k and 2m), while it is poorly seen in IRS-1B LISS II bands (see Figure 2l). But notably bays and estuaries are very clearly seen in IRS-1C PAN band (Figure 2o) wherein the depth and turbidity values are also moderately seen. Similarly it is clear in near infrared bands of both Landsat-5 TM (see Figure 2n) and IRS-1D LISS III while it is poorly seen in IRS-1B LISS II and other bands.

In brief, on analyzing the individual bands of the selected five sensors three of them viz. Landsat-5 TM, IRS-1C PAN, and IRS-1D LISS III data products are found suitable for the identification and delineation of water resource features of the present study area. These three products are found to hold good owing to their spatial and spectral resolution properties. However, as the images of Landsat-5 TM and IRS-1D LISS III are multi-spectral in nature, false colour composites of these data products can be further generated for evaluation with their easy identification of water resource features in the present study area.

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Table 3 Spectral band wise Qualitative evaluation of raw digital data for water resource feature identification

Code	Water Resource Details	LANDSAT - 5 TM							IRS - 1B LISS II				IRS – 1C PAN	IRS – 1D WIFS		IRS – 1D LISS III			
		1	2	3	4	5	6	7	1	2	3	4	1	1	2	1	2	3	4
1.1	**Streams and Canals**																		
1.1.1	Natural Streams																		
1.1.1.1	1st order	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS
1.1.1.2	2nd order	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS
1.1.1.3	3rd order	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS
1.1.1.4	4th order	PS	PS	PS	MC	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS
1.1.1.5	5th order	PS	PS	PS	C	PS	PS	MC	PS	PS	PS	PS	PS	PS	PS	PS	MC	MC	PS
1.1.1.6	6th order	PS	PS	PS	C	MC	PS	MC	PS	PS	PS	PS	MC	PS	PS	PS	MC	MC	PS
1.1.2	Man made canals	PS	PS	PS	MC	PS	PS	PS	MC	PS	PS	PS	PS	PS	PS	PS	PS	MC	PS
1.2	**Lakes and Ponds**																		
1.2.1	Minor Tanks	PS	PS	PS	MC	PS	PS	PS	PS	PS	PS	PS	MC	PS	PS	PS	PS	PS	PS
1.2.2	Intermediate Tanks	PS	PS	PS	MC	MC	PS	C	PS	PS	PS	PS	C	PS	PS	PS	PS	PS	PS
1.2.2.1	Water Surface	PS	PS	PS	C	C	PS	C	MC	PS	PS	PS	C	PS	PS	PS	PS	MC	PS
1.2.2.2	Depth	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS
1.2.2.3	Dry Tank Bed	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS
1.2.2.4	Tank Bed Vegetation	PS	PS	PS	PS	PS	PS	PS	PC	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS
1.2.3	Major Tanks	PS	PS	PS	C	MC	PS	C	MC	PS	PS	PS	C	PS	PS	PS	PS	MC	PS
1.2.3.1	Water Surface	PS	PS	PS	C	C	PS	C	PS	PS	PS	PS	C	PS	PS	PS	PS	C	MC
1.2.3.2	Depth	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS
1.2.3.3	Turbidity	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS
1.2.3.4	Dry Tank Bed	PS	PS	PS	PS	PS	PS	PS	MC	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS
1.2.3.5	Tank Bed Vegetation	PS	PS	PS	PS	PS	PS	PS	MC	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS
1.3	**Reservoirs**	MC	PS	PS	VC	VC	PS	C	MC	MC	MC	MC	C	PS	PS	MC	C	VC	MC
1.3.1	Depth	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	MC	PS	PS	PS	MC	MC	PS
1.3.2	Turbidity	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	MC	PS	PS	PS	MC	MC	PS
1.4	**Bays and Estuaries**	PS	PS	PS	C	MC	PS	PS	PS	PS	PS	MC	VC	PS	PS	PS	PS	C	PS
1.4.1	Depth	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	MC	PS	PS	PS	PS	PS	PS
1.4.2	Turbidity	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	PS	MC	PS	PS	PS	PS	PS	PS

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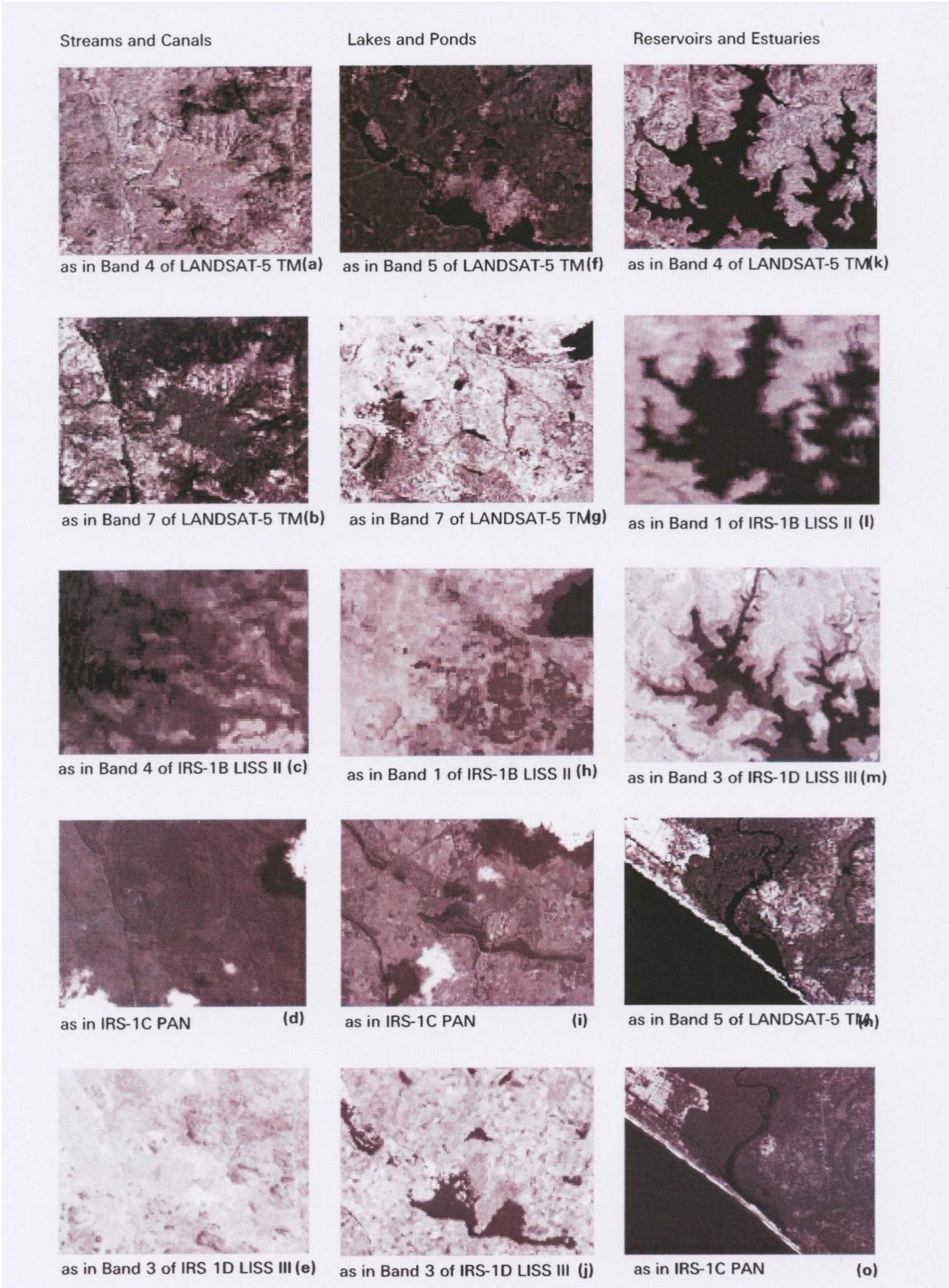

Figure 2

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Digital false colour composites: Landsat-5 TM and IRS-1D LISS III for water resource features- An evaluation

Multi-spectral analysis with FCC band combinations has been attempted to bring out the subtle details of water resources, and the results are given in Table 4. The sample pictures as shown in Figure 3a to 3o clearly depict the false color composites that are generated using red, green and blue gun of the CRT computer display. It is to be noted that in these figures, the spectral bands are represented by their appropriate band numbers.

Table 4 Digital FCCs and Qualitative evaluation of IRS - 1D LISS III and LANDSAT -5 TM data for water resource feature identification

Code	Water Resource Details	Raw FCCs					Linearly Stretched FCCs					
		LANDSAT - 5 TM (432)	IRS – 1D LISS III (321)	LANDSAT - 5 TM (542)	IRS – 1D LISS III (431)	IRS – 1D LISS III (123)	LANDSAT - 5 TM (432)	IRS – 1D LISS III (321)	LANDSAT - 5 TM (742)	LANDSAT - 5 TM (542)	IRS – 1D LISS III (431)	IRS – 1D LISS III (123)
1.1	**Streams and Canals**											
1.1.1	Natural Streams											
1.1.1.1	1st order	PS	PS	PS	PS	PS	PS	PS	MC	PS	PS	PS
1.1.1.2	2nd order	PS	PS	MC	PS	PS	MC	MC	C	MC	MC	PS
1.1.1.3	3rd order	PS	PS	MC	PS	PS	MC	MC	C	C	MC	PS
1.1.1.4	4th order	MC	MC	MC	MC	PS	C	C	VC	C	C	PS
1.1.1.5	5th order	C	C	C	C	PS	C	VC	VC	VC	VC	MC
1.1.1.6	6th order	C	C	VC	C	MC	VC	VC	VC	VC	VC	C
1.1.2	Man made canals	MC	MC	C	C	PS	MC	C	C	VC	C	PS
1.2	**Lakes and Ponds**											
1.2.1	Minor Tanks	MC	C	MC	C	PS	MC	C	VC	VC	VC	PS
1.2.2	Intermediate Tanks	MC	C	C	C	MC	C	C	VC	VC	VC	MC
1.2.2.1	Water Surface	C	C	VC	VC	MC	C	C	VC	VC	VC	MC
1.2.2.2	Depth	PS	PS	C	MC	PS	MC	MC	VC	VC	C	PS
1.2.2.3	Dry Tank Bed	MC	C	C	MC	PS	VC	VC	VC	VC	MC	MC
1.2.2.4	Tank Bed Vegetation	C	C	C	MC	PS	VC	VC	VC	C	MC	C
1.2.3	Major Tanks	VC	VC	VC	VC	C	VC	VC	VC	VC	VC	MC
1.2.3.1	Water Surface	VC	VC	VC	VC	C	VC	VC	VC	VC	VC	C

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1.2.3.2	Depth	PS	C	C	MC	PS	C	C	VC	VC	VC	PS
1.2.3.3	Turbidity	C	C	MC	MC	PS	MC	C	C	C	VC	PS
1.2.3.4	Dry Tank Bed	MC	C	MC	MC	PS	VC	VC	VC	C	MC	MC
1.2.3.5	Tank Bed Vegetation	VC	C	C	MC	PS	VC	VC	VC	C	MC	C
1.3	**Reservoirs**	VC	VC	VC	VC	MC	VC	VC	VC	VC	VC	MC
1.3.1	Depth	PS	VC	MC	MC	PS	PS	VC	VC	C	VC	PS
1.3.2	Turbidity	PS	VC	MC	MC	PS	PS	VC	VC	C	C	PS
1.4	**Bays and Estuaries**	C	VC	C	VC	MC	VC	VC	VC	VC	VC	MC
1.4.1	Depth	PS	MC	PS	MC	PS	MC	VC	VC	C	C	PS
1.4.2	Turbidity	PS	C	PS	MC	PS	MC	VC	VC	C	C	PS

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MC – Moderately Clear
PS – Poorly Seen

Note: Colour combination assigned to FCCs is in the order of RGB.

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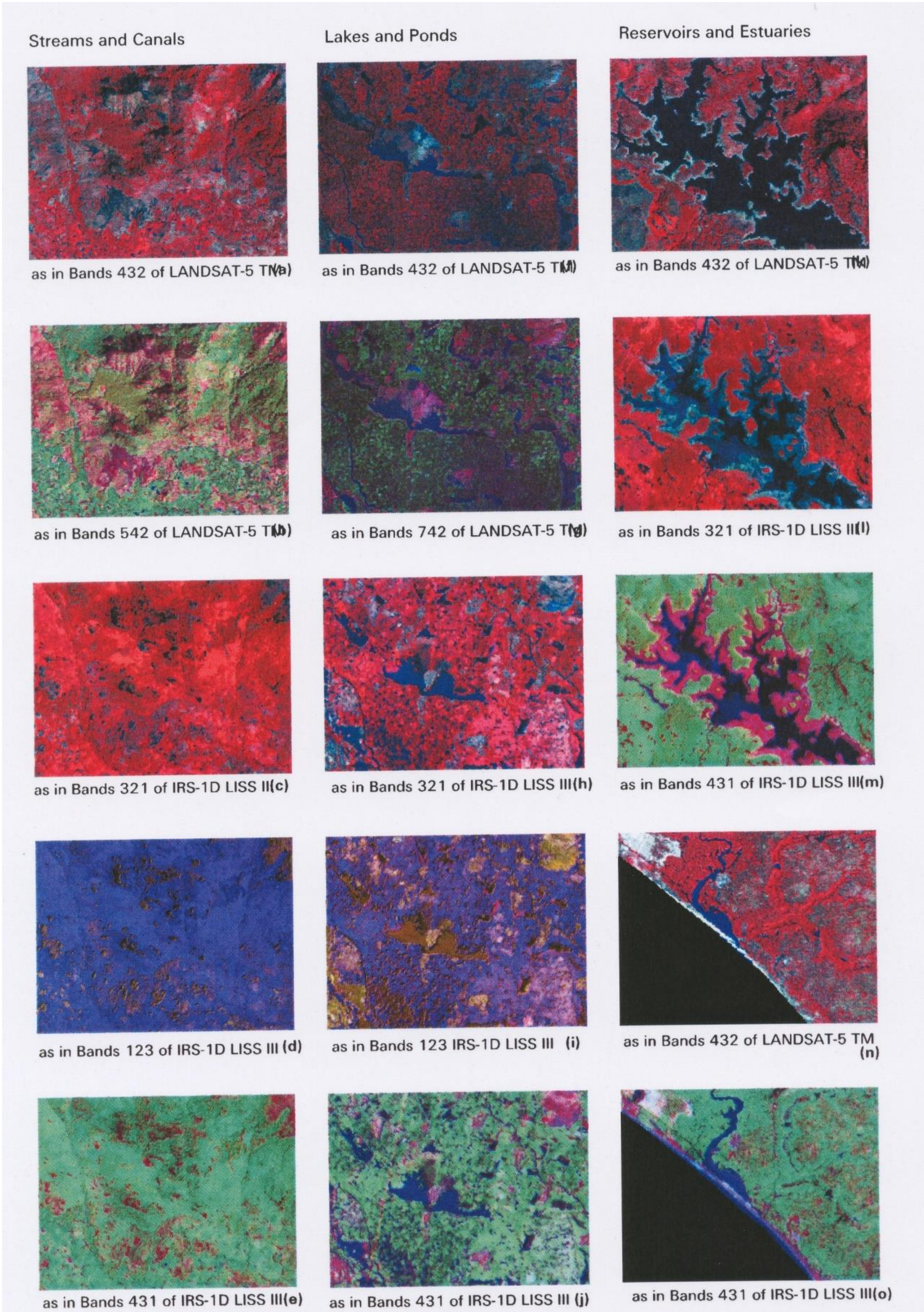

Figure 3

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Digital enhancement techniques: Enhanced IRS-1D LISS III for water resource features- An evaluation

The foregoing discussion clearly reveals that the mid infrared, near infrared and green band combinations show very good results when compared to that of other bands with regard to the interpretations. It is mainly due to the availability of higher spatial and the required spectral resolution characteristics of the IRS-1D LISS III data product and so it has been selected for further enhancement. The enhancement techniques of three major types viz. radiometric, geometric and multi-spectral transformation along with their related enhancement tools and procedures are used appropriately. The first type of enhancement namely, radiometric enhancement includes tools like linear contrast stretch, histogram equalisation and level slice. At this stage linear contrast enhancement is applied to the histogram of the FCC with raw digital data with skewed digital number, for an easier interpretation of water resource features. Linear contrast enhancement is achieved by the method of *linear* seen in the *general contrast* sub-menu of the *raster* menu. Accordingly, the first combination of IRS 1D LISS III FCC bands namely near infrared, red and green shows good results by which certain range of poorly seen features are enhanced to moderately clear; moderately clear to clear category and clear to very clear category. In addition the 2nd and 3rd order streams including the depth of intermediate tanks, are enhanced from their range of poorly seen to moderately clear range; and that of the 4th order streams including man made canals and depth of estuaries are also enhanced from moderately clear to clear range. So also the interpretation range of 5th and 6th order streams including dry tank bed, tank bed with vegetation, as well as turbidity of bays and estuaries are enhanced from clear to very clear range. Thus, the radiometric tools of this enhancement technique have further improved the interpretation ability of water resources in the present study. Likewise, using the combination of IRS 1D LISS III FCC bands of near infrared, red, green (321) few stream features and bays and estuaries are enhanced

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from the moderately clear to very clear category; and also few poorly seen to moderately clear category. However, the only category still poorly seen is the 1st order streams, if the bands of mid infrared, near infrared and green of IRS-1D LISS III digital products get stretched linearly (see Table 5) then the outcome of a good combination from which almost all the resource features can be clearly interpreted. In contrast, the combination of green, red and near infrared bands of IRS 1D LISS III with linear contrast stretch reveal only certain details with due clarity for interpretation.

The histogram equalized image is derived by using the *histogram equalization* tool of *general contrast* sub-menu in the *viewer* module. The histogram equalized image of IRS-1D LISS III data product reveals certain water resource features. The 5th and 6th order streams are very clearly identified from the image. Most of the features like 4th and 3rd order streams, minor tanks, intermediate tanks and water surface, major tanks and their turbidity and depth classes, reservoirs and their depth characters as well as the bays and estuaries and their classes are clearly discernible whereas the 1st and 2nd order streams, depth and dry tank bed are moderately clear. The level sliced images as discussed earlier is used to differentiate land and water pixels so that they can be further studied in detail as given in Figure. The figures show the water bodies in blue tone and the other land features in two tones namely red and magenta. These blue toned pixels can be further analysed and processed for the differences in water resource features. The geometric enhancement of images includes the filtering as well as edge enhancement techniques. The filtering tool can be with either low pass or high pass filters. The high pass filters are used to identify

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Table 5 Qualitative evaluation of digitally enhanced IRS - 1D LISS III data product for water resource feature identification

Code	Water resource details	Radiometric enhancement			Geometric enhancement		Multi-spectral transformation		
		Linearly stretched	Histogram equalised	Level sliced	Low pass filtered	Edge enhanced	PC image	Band ratio	PAN + LISS III merged
1.1	**Streams and Canals**								
1.1.1	Natural Streams								
1.1.1.1	1st order	PS	MC	PS	MC	MC	C	PS	MC
1.1.1.2	2nd order	MC	MC	PS	MC	C	C	PS	C
1.1.1.3	3rd order	MC	C	PS	C	C	VC	MC	C
1.1.1.4	4th order	C	C	PS	C	VC	VC	MC	VC
1.1.1.5	5th order	VC	VC	PS	C	VC	VC	MC	VC
1.1.1.6	6th order	VC	VC	PS	C	VC	VC	MC	VC
1.1.2	Man made canals	C	MC	PS	C	VC	VC	MC	VC
1.2	**Lakes and Ponds**								
1.2.1	Minor Tanks	C	C	C	C	PS	VC	C	VC
1.2.2	Intermediate Tanks	C	C	C	VC	C	VC	VC	VC
1.2.2.1	Water Surface	C	C	PS	PS	MC	MC	VC	VC
1.2.2.2	Depth	MC	MC	PS	PS	MC	PS	C	VC
1.2.2.3	Dry Tank Bed	MC	MC	PS	PS	MC	PS	C	VC
1.2.2.4	Tank Bed Vegetation	C	C	PS	PS	MC	PS	C	VC
1.2.3	Major Tanks	C	C	C	VC	C	VC	VC	VC
1.2.3.1	Water Surface	C	C	PS	C	MC	MC	VC	VC
1.2.3.2	Depth	C	C	PS	PS	MC	PS	C	VC
1.2.3.3	Turbidity	C	C	PS	PS	MC	PS	C	VC
1.2.3.4	Dry Tank Bed	MC	MC	PS	PS	MC	C	C	VC
1.2.3.5	Tank Bed Vegetation	C	C	PS	PS	MC	C	C	VC
1.3	**Reservoirs**								
1.3.1	Depth	VC	C	PS	PS	MC	PS	C	VC
1.3.2	Turbidity	VC	C	PS	PS	MC	PS	C	VC
1.4	**Bays and Estuaries**								
1.4.1	Depth	VC	MC	PS	PS	MC	PS	C	VC
1.4.2	Turbidity	VC	MC	PS	PS	MC	PS	C	VC

Interpretation Ability range: VC – Very Clear
C – Clear
MC – Moderately Clear
PS – Poorly Seen

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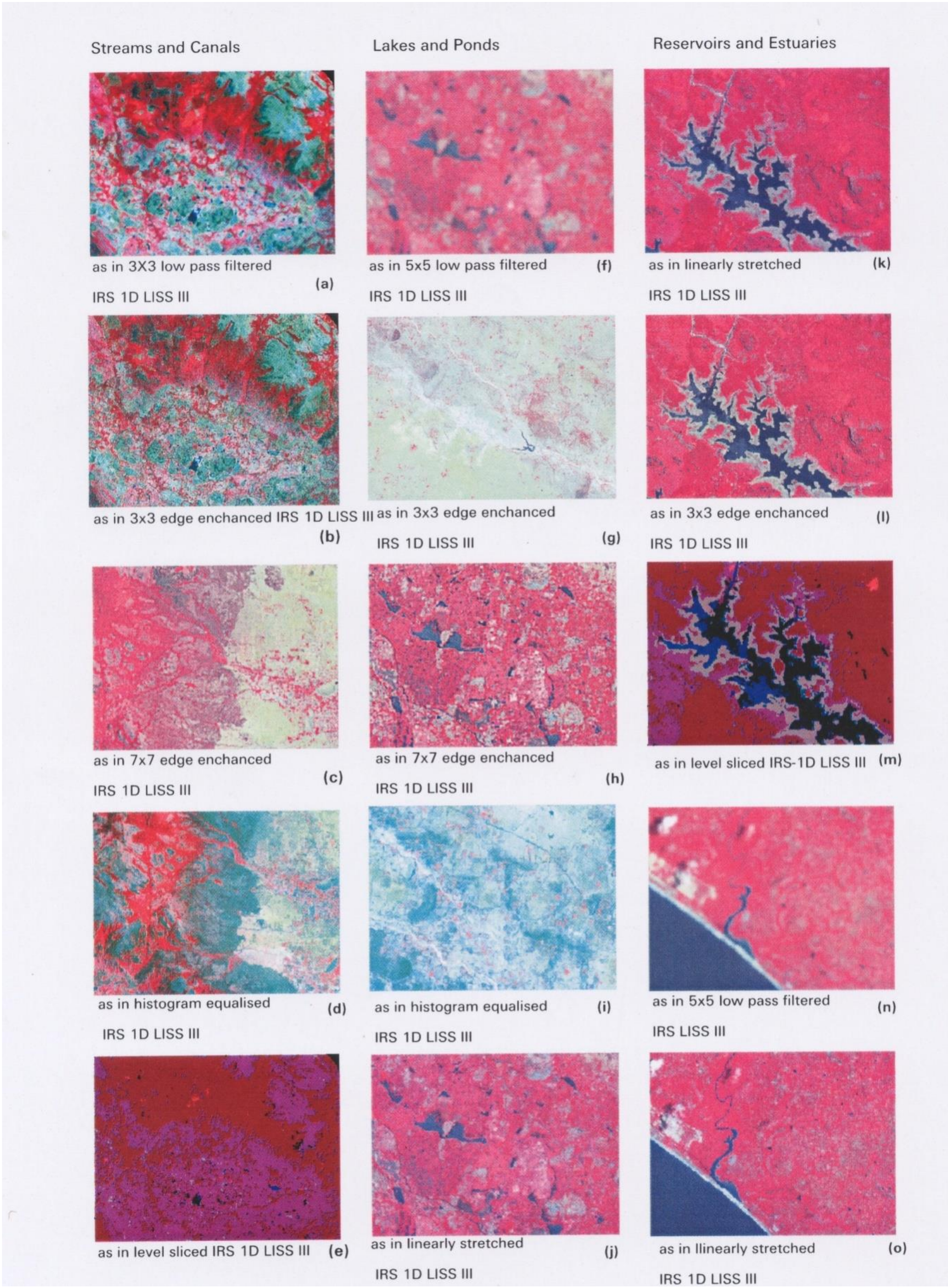

Figure 4

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clearly and study only the linear features, like the water features of drainage lines. This layer when overlaid with a false colour composite highlights the linear features clearly. The image looks rough after enhancement. The low pass filter gives a smoother appearance to the images and so delineation becomes slightly difficult but the differentiation of features within can be done easily. The edge enhanced FCC can be used for the interpretation of water resource details. The edge enhancement of images is derived by using the *convolution-filtering* tool of sub-menu in the *viewer* module The linear drainage features of even the 1^{st} order are clearly seen in comparison with the features produced by other image processing techniques. The stream features are seen in the order ranging from moderately clear to very clear. The sub-classes of other water resource features are also moderately clear. Thirdly, regarding the multi-spectral transformation of images, band ratioing, principle component, and data merging are the notable enhancement tools. The output sample images are given in Figure and the interpretation ability range is presented in Table 5. The sample images generated as a result of band ratio of green, near infrared and mid infrared band of IRS-1D LISS III is given in the Figure. The lowest order of streams namely 1^{st} and 2^{nd} are the only poorly seen water resource category; the other categories of natural streams and man-made canals are moderately clear; and the rest of the categories of water resources range from clear to very clear. The principle component image of IRS-1D LISS III data is quite useful in the delineation of water resource details. In the present study, the components are derived in single and 3 band combinations to produce the FCC in order to reveal the water resource features. It is evident that except the first and second order streams, the streams and man made canals are seen very clear as

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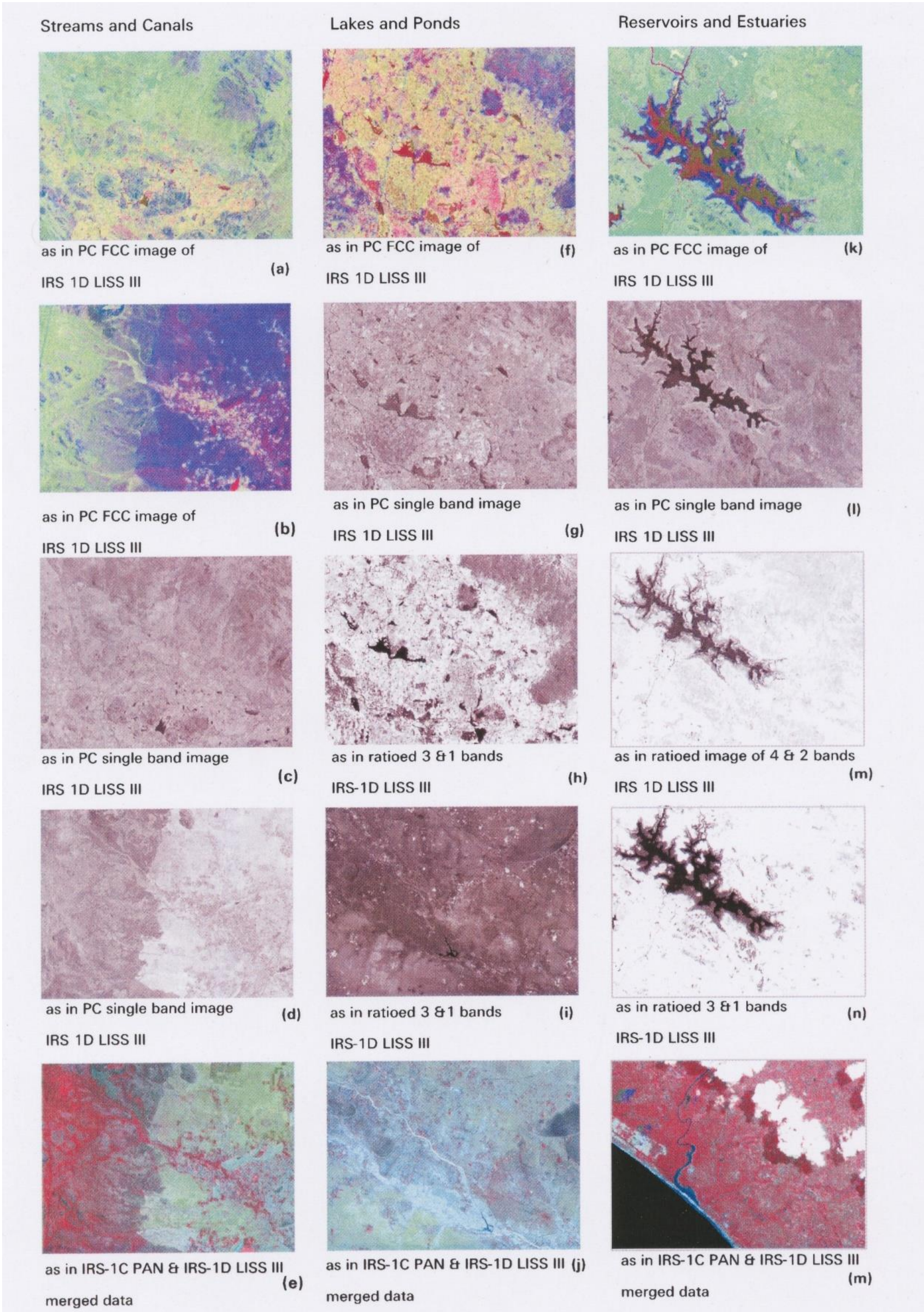

Figure 5

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It is evident from the study that the PC images reveal the linear water resource details clearly and also the other level III details are seen ranging moderately clear to poorly seen. Data merging is mostly performed to improve the resolution property of the same data with the previous analysis. The spatial resolution in IRS-1C PAN is higher and the spectral resolution of IRS 1D LISS III data product is quite good. So these two data products are selected for data merging. In the present study, the *principal component* method and *nearest neighbor* resampling technique were used to generate the *unsigned 8 bit* output image file. The merged data product is apt for water resource studies as all the water resource details are discerned very clearly from the merged image. The 2nd and 3rd order streams are rated under clear category and the first order streams under moderately clear category based on merged image. Thus data merging becomes a very good image processing tool in which the highest spatial as well as the spectral resolution property are obtained. The linear features are clearly seen and the differences if any within the water bodies are also clearly seen. It is to be noted that the image enhancement techniques and tools are more powerful while they are employed with multi-spectral data. The resultant transformed images thus support the derivation of very clear geo-spatial database useful for water resource analysis.

Conclusion

A detailed analysis on the capability of various satellite image data products, their processing techniques, in the present study of water resources was attempted. When the single bands of the data products was considered, most of the water resource features remain unidentified; some differences within water bodies was seen in the green band and the delineation was easier in the near infrared band. So in order to get a good clarity, false colour composites, a band combination of three spectral bands was attempted. Accordingly, the mid infrared, near infrared and green band when projected through red, green, and blue guns produced results in which water resource features were very clearly seen. The false colour composites

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were subjected to various digital enhancement techniques namely geometric, radiometric and multispectral transformation. The edge enhancement and linearly stretched false colour composites gave a better idea in deciphering the linear water resource details like the streams and canals. The radiometrically enhanced images with histogram equalization also revealed certain details relating to the surface water storage features. Level sliced images were used to differentiate or separate the water resource features from other land uses, whereby further analysis within the features was made easier. The multi-spectral transformation of images gave better results in discriminating water bodies. Principal component images were very much used in the water resource identification and delineation. The merged data products of IRS-1C PAN and IRS-1D LISS III gave very good results and revealed almost all the water resource features under study. The merged data product showed a higher spatial and spectral property. Hence, the water resource features were easily identifiable and delineation within features was facilitated.