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The Effect of Radiometric Resolution on Information Sharing Between Landsat8 Bands

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Abstract: The technological revolution that the world is witnessing also included the development of the characteristics of remote sensing devices, which had a direct impact on increasing the accuracy of the data obtained through these devices. For example; the radiometric resolution of Landsat satellite sensors increased from 7 bits in the first Landsat sensors to 16 bits in Landsat-8. In this study, the effect of this improvement in radiometric resolution was measured to find the amount of change in the mutual information at several dynamic ranges. The study area was the state of Khartoum, and the study was conducted on four different types of land cover (agricultural, urban, water, and desert) to determine the amount of shared information between several dynamic ranges based on the land cover unit. The image obtained from the Landsat-8 satellite for the study area had a 16-bit dynamic range. However, it was down sampled to 8bits, 9 bits, 10 bits, 11 bits, 12 bits, 13 bits and 14 bits, and the amount of information shared between these dynamic ranges and the original image was calculated for the first seven bands of Landsat-8. The results showed that the amount of shared information varies based on the type of land cover, however, this amount reaches its lowest value on the water cover between the 8-bit image and the 16-bit image which is 80%. The study ended with a recommendation that the effect of change in radiometric resolution should be examined in the stage classification of images.

Keywords: *Liquid desiccant dehumidification, Desiccant cooling, Hybrid desiccant cooling system, Air conditioning.*

1. INTRODUCTION

1.1. Overview

In recent years, there was a huge improvement in spatial, spectral, radiometric, and temporal resolutions. As a result, extensive studies have been carried out for various kinds of spatial and spectral resolutions to various categories of applications. However, little attention has been paid to the impacts of radiometric resolution even though it is directly related to the design and the operation of the sensor system. Radiometric resolution denotes the sensitivity of the sensor, and its capacity to discriminate between small motivations.

New sensors provide data with a very high radiometric resolution. However, such data require a massive storage capacity which raises the question about the feasibility of developing such an expensive technology, and whether it is possible to achieve approaching results with sensors that have relatively lower radiometric resolutions and are more affordable to execute for countries like Sudan. Also, it is important to empirically examine the effect of this change in radiometric resolution on image classification.

1.2 Objective

1. Studying the effect of radiometric Resolution on information sharing between Landsat-8 bands.
2. Quantifying the amount of change in the shared information at different radiometric resolutions comparing the original 16 bits.

2. Literature Review

2.1 Previous Studies

Different studies have been made on radiometric resolution

1. An assessment of Radiometric Resolution impact on classification accuracy was made in 2018, to test the classification accuracy on vegetation, using fine and low scale radiometric resolution Ikonos-2 images classified through a bagging classification tree. In certain cases, higher radiometric resolution has led to up to 8% higher classification accuracies compared to lower resolution radiometric data, other results indicate that higher radiometric resolution does not necessarily imply improved classification accuracy. [1]
2. Entropy techniques were first used 1984 to compare the amount of information for 8-bit and 6-bit images from the TM and MSS Landsat-4 sensors. The study resulted in that unless these techniques are used, stripping will result even with perfect calibration parameters.[2]
3. An article emphasizing the role of Entropy in neuroscience, an unbiased and computationally efficient tool for estimating the level of entropy and mutual information, were suggested [3] in order to overcome “sampling disaster” using non mathematical method by expanding entropy-encoding compression algorithms.
4. Radiometric calibration necessity assessment was tested in 2019, using Entropy in an Aerial multispectral image. The results showed that the radiometric calibration has a negligible result on image classification. [4].
5. Entropy and mutual information were also analytical tools in another study [5] where a comparison between Landsat4-Thematic Mapper and Multi-Spectral Scanner for the agriculture dataset was made.

6. The number of radiometric quantizing levels required for satellite monitoring of vegetation resources was evaluated by Compton J. Tucker [6] using Thematic Mapper-3 (TM3) and Thematic Mapper-4 (TM4) sensor data, which studied the data at 6 bits and 8 bits. The study concluded that the overall improvement was 2-3% in the TM data.
7. Effects of Sensor Resolution on Mapping Instream Habitats were examined in 2002 [7] and it showed that the spectral resolution is more important than spatial and radiometric resolution for image classification.
8. Another study [8] found that AVIRIS holds modest, but real, advantages over Landsat for the classification of heterogeneous and vegetated land uses.
9. A comparative study [9] to determine whether current generation high radiometric resolution remote sensing data could be used accurately for land use and land cover classification was conducted. It was used to evaluate the utility of the simulated 12-bit LISS-III sensor compared with that of the original 7-bit LISS-III sensor. A 4-6% improvement was in the classification results.
10. Also, in 2006 Rao N.[10] performed another study on the effect of radiometric resolution on the retrieval of leaf area index from agriculture crops. The study evaluated the performance of simulated 12 LISS-III sensor data with the original 7 bit of LISS-III sensor data. The results revealed that no significant improvement in the correlation coefficient was encountered when high radiometric resolution data were used.
11. Entropy analysis was performed [11] to compare Landsat7-ETM+ and Landsat5-TM information content to study the saturation phenomena.
12. Multiracial analysis and Entropy were used to examine the effect of radiometric resolution on vegetation indices using four-band images taken by satellites Ikonos-2 and Landsat-7 [12]. The result showed that radiometric resolution influences blue and green bands greater than red and near-infrared bands.

2.2 Theoretical Approach

The basic idea of this paper is to sample the radiometric resolution of the Landsat-8 image at different bits and compute mutual information between the first seven bands. The given image will have a resolution of 16 bits afterwards the image will be down-sampled to 14 bits, 13bits, 12 bits, 11 bits, 9 bits, 8 bits and compute mutual information for each bit dynamic range.

Mutual information between two variables is formulated as follows:

$$I(X,Y) = H(X) + H(Y) - H(X,Y) \qquad (\mathbf{1})$$

I (X, Y) = Mutual Information.

H(X) = Entropy of X.

H(Y) = Entropy of Y.

H (X, Y) = Joint Entropy of X & Y.

Entropy for variable X is formulated as follows:

$$H(X) = -\sum_{i=1}^{i=n} p_i(X) \log 2\big(p_i(X)\big) \qquad (\mathbf{2})$$

Where p(x) represents the probability of occurrence for variable X.

Joint Entropy measures the uncertainty of two variables and its formulated as follows

$$H(X,Y) = -\sum_{i=1}^{i=n} p_i(X,Y) \log 2\big(p_i(X,Y)\big) \qquad (\mathbf{3})$$

2.3 Data

The Landsat-8 16-bit images in Geotiff format are used in this study to measure the amount of shared information between bands properties are:

WRS Path = 173, WRS Row= 49, Date Acquired = 2020-12-23 and with Cloud Coverage = 0.00, the first seven bands were the only bands used in the study.

2.4 Study Area

The area of interest for this study is a sample area located in Khartoum, Sudan to represent each of the four Land units' categories and a single 2K X 2K image with path and raw: 173,49. Date:23-Dec-2020 has been used for each category.

2.5 Work Flow

Firstly, images will be geo-referenced and then mutual information was computed using python 3.9 for each image at 16 bits.

Also, by using the python libraries NumPy, Rasterio, Skimage, and matplotlib images were down sampled to 15 bits, 14 bits, 13bits, 12 bits, 11bits, 10 bits, 9bits, and 8 bits. Mutual information will be compared at these different dynamic ranges.

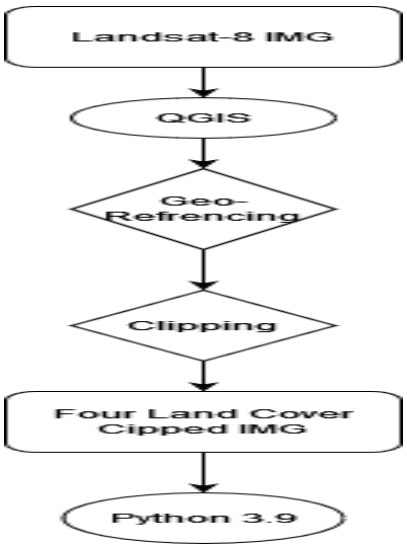

Fig 1.1. Work Flow

Table 1. Study Area Coordinates.

Category	Lat (deg)	Long (deg)
Urban	15.562899 N 15.580835 N	32.561237 E 32.579667 E
Agriculture	15.304585 N 15.327217 N	32.982628 E 32.997031 E
Desert	16.639700 N 16.657360 N	32.624970 E 32.643505 E
Water	15.570819 N 15.585807 N	32.499300 E 32.476700 E

3. Results& Discussion

Radiometric Resolution is directly related to the sensitivity of the satellite sensor and its ability to differentiate between small variations in the reflected waves. However, this improvement in the radiometric resolution has a very high cost in designing. and implementing the satellite sensor. Therefore, the amount of shared information at different radiometric resolution has been measured as a way for evaluation and questioning the feasibility of the study.

3.1 Full Image

From table 3-2 it is clear that the amount of shared information jumped by more than 4% when the dynamic range have changed from 8 to 9 bits. However, the amount has changed by almost 2% rising from 9 to 10 and from 10 to 11 bits, and it remained within 1% or less in all the other improvements.

Table 2. Full Image MI, Between 7 bands.

	8 BITS	9 BITS	10 BITS	11 BITS	12 BITS	13 BITS	14 BITS	16 BITS
Band 1	1.731 904	1.782 374	1.867 502	1.940 299	1.923 808	1.979 176	1.991 076	2
Band 2	1.720 037	1.861 666	1.859 632	1.941 874	1.938 176	1.980 359	1.983 661	2
Band 3	1.744 324	1.857 827	1.901 488	1.931 448	1.976 452	1.978 639	1.986 922	2
Band 4	1.789 128	1.860 077	1.907 455	1.940 099	1.973 81	1.981 433	1.989 065	2
Band 5	1.776 461	1.851 753	1.906 076	1.937 866	1.966 516	1.978 9	1.989 114	2
Band 6	1.789 102	1.854 977	1.909 273	1.940 99	1.970 233	1.978 511	1.990 792	2
Band 7	1.797 168	1.861 578	1.910 881	1.945 406	1.974 315	1.980 389	1.990 346	2

Table 3. Percentage of Shared Information

	Bit 8	Bit 9	Bit 10	Bit 11	Bit 12	Bit 13	Bit 14
Band 1	86.60 %	89.12 %	93.38 %	97.01 %	96.19 %	98.96 %	99.55 %
Band 2	86.00 %	93.08 %	92.98 %	97.09 %	96.91 %	99.02 %	99.18 %
Band 3	87.22 %	92.89 %	95.07 %	96.57 %	98.82 %	98.93 %	99.35 %
Band 4	89.46 %	93.00 %	95.37 %	97.00 %	98.69 %	99.07 %	99.45 %
Band 5	88.82 %	92.59 %	95.30 %	96.89 %	98.33 %	98.94 %	99.46 %
Band 6	89.46 %	92.75 %	95.46 %	97.05 %	98.51 %	98.93 %	99.54 %
Band 7	89.86 %	93.08 %	95.54 %	97.27 %	98.72 %	99.02 %	99.52 %
Average	**88.20 %**	**92.36 %**	**94.73 %**	**96.99 %**	**98.02 %**	**98.98 %**	**99.44 %**

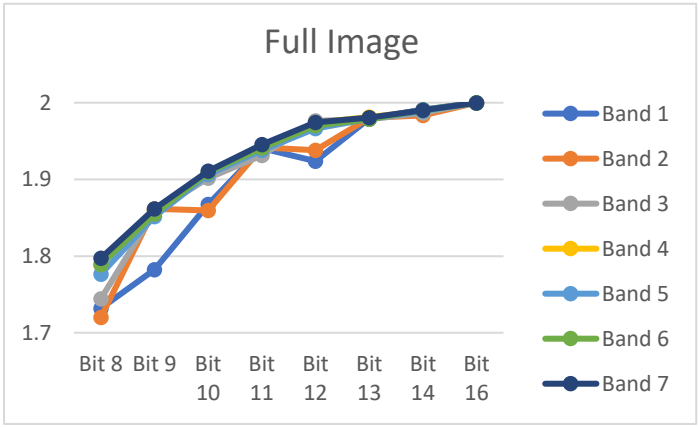

Fig. 2. Line Graph of MI between 7 bands.

3.2 Water

Figure 3-3 illustrates the water cover curve, for the study area shown in figure 3-2. It shows the most dramatic increase in the amount of shared information between different dynamic ranges. As depicted in table 3-4 the percentage of MI has risen with more than 4% when the dynamic range was improved from 8 bits to 9 bits. The MI increased 3.77% when the dynamic range was increased from 9 to 10 bits. The percentage improvement dropped between 10 bits and 11 bits. However it reached a peak between 11 bits and 12 bits.

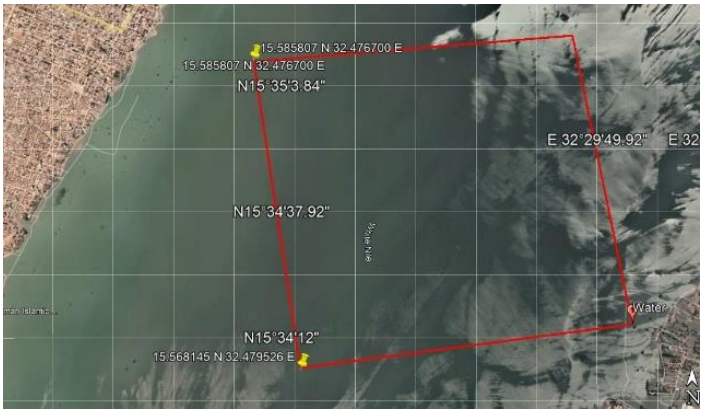

Fig .3. Water, Study Area

Table .4 MI between 7 bands in Water.

	8 BITS	9 BITS	10 BITS	11 BITS	12 BITS	13 BITS	14 BITS	16 BITS
Band 1	1.55 473 3	1.6769 10306	1.7507 11178	1.782 027	1.876 139	1.960 517	1.917 553	2
Band 2	1.64 668 6	1.7394 43508	1.7566 47466	1.796 324	1.883 37	1.961 362	1.977 539	2
Band 3	1.70 980 2	1.7345 73975	1.8244 31195	1.922 292	1.937 753	1.973 155	1.988 46	2
Band 4	1.75 050 6	1.7465 27949	1.8106 40488	1.881 36	1.926 489	1.951 973	1.978 934	2
Band 5	1.61 223 4	1.7356 58282	1.9294 00817	1.912 179	1.943 359	1.967 856	1.969 453	2
Band 6	1.51 231 1	1.7864 07304	1.5892 47264	1.852 879	1.994 417	1.866 916	1.993 536	2
Band 7	1.48 295 7	1.4916 97303	1.7773 44392	1.626 469	1.850 377	1.853 259	1.999 18	2

Table 5. Percentage of Shared Information.

	Bit 8	Bit 9	Bit 10	Bit 11	Bit 12	Bit 13	Bit 14
Band 1	77.74 %	83.85 %	87.54 %	89.10 %	93.81 %	98.03 %	95.88 %
Band 2	82.33 %	86.97 %	87.83 %	89.82 %	94.17 %	98.07 %	98.88 %
Band 3	85.49 %	86.73 %	91.22 %	96.11 %	96.89 %	98.66 %	99.42 %
Band 4	87.53 %	87.33 %	90.53 %	94.07 %	96.32 %	97.60 %	98.95 %
Band 5	80.61 %	86.78 %	96.47 %	95.61 %	97.17 %	98.39 %	98.47 %
Band 6	75.62 %	89.32 %	79.46 %	92.64 %	99.72 %	93.35 %	99.68 %
Band 7	74.15 %	74.58 %	88.87 %	81.32 %	92.52 %	92.66 %	99.96 %
Average	**80.49 %**	**85.08 %**	**88.85 %**	**91.24 %**	**95.80 %**	**96.68 %**	**98.75 %**

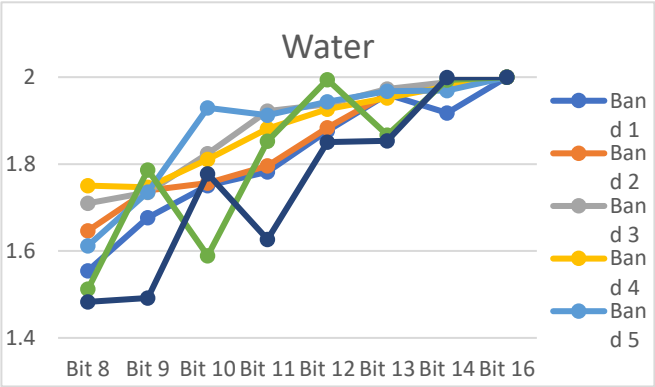

Fig . 4. Line Graph for MI in Water.

3.3 Agriculture:

In the agriculture category the study area appears in figure 3-4. Table 3-6 and figure 3-5 have shown that the amount of shared information has only dramatic change when the resolution was improved from 8 bits to 9 bits. However, all the change was below 3% in all the other improvements.

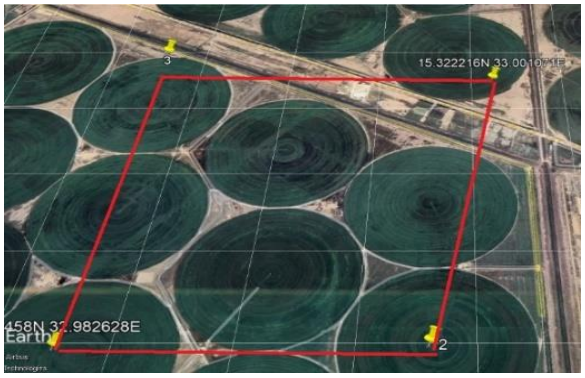

Fig .5. Line Graph of MI in Agriculture.

Table 6. MI of Seven bands in Agriculture.

	8 BITS	9 BITS	10 BITS	11 BITS	12 BITS	13 BITS	14 BITS	16 BITS
Band 1	1.688818	1.762406	1.844329	1.862964	1.936485	1.970839	1.998278	2
Band 2	1.710615	1.797122	1.853495	1.913006	1.943437	1.955063	1.980203	2
Band 3	1.733827	1.781 14	1.887765	1.919533	1.967942	1.976899	1.987879	2
Band 4	1.720046	1.915 7	1.899 54	1.944 33	1.971121	1.980501	1.984505	2
Band 5	1.787086	1.884403	1.932101	1.961325	1.959602	1.985098	1.991581	2
Band 6	1.793293	1.847128	1.894284	1.957365	1.952936	1.982807	1.994501	2
Band 7	1.792024	1.810672	1.905957	1.944342	1.957905	1.981648	1.986242	2

Table 7. Percentage of Shared Information.

	Bit 8	Bit 9	Bit 10	Bit 11	Bit 12	Bit 13	Bit 14
Band 1	84.44 %	88.12 %	92.22 %	93.15 %	96.82 %	98.54 %	99.91 %
Band 2	85.53 %	89.86 %	92.67 %	95.65 %	97.17 %	97.75 %	99.01 %
Band 3	86.69 %	89.06 %	94.39 %	95.98 %	98.40 %	98.84 %	99.39 %
Band 4	86.00 %	95.78 %	94.98 %	97.22 %	98.56 %	99.03 %	99.23 %
Band 5	89.35 %	94.22 %	96.61 %	98.07 %	97.98 %	99.25 %	99.58 %
Band 6	89.66 %	92.36 %	94.71 %	97.87 %	97.65 %	99.14 %	99.73 %
Band 7	89.60 %	90.53 %	95.30 %	97.22 %	97.90 %	99.08 %	99.31 %
Average	**87.33 %**	**91.42 %**	**94.41 %**	**96.45 %**	**97.78 %**	**98.81 %**	**99.45 %**

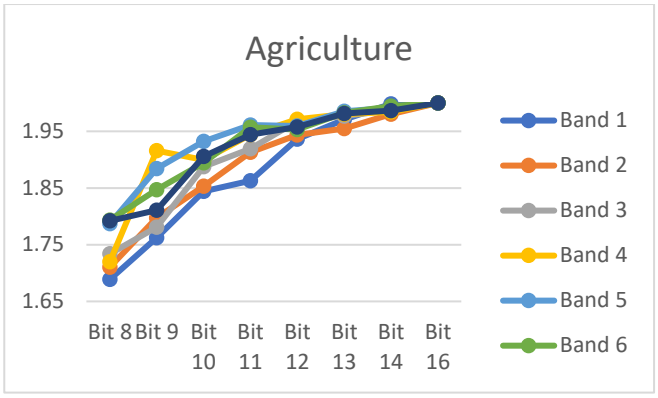

Fig .6. Line Graph of MI in Agriculture.

3.4 Desert

For the study area shown in figure 3-6, although the desert curve of the amount of mutual information between the seven bands rises regularly as illustrated in figure 3-7. Table 3-9 shows that the change in the shared information rises dramatically between almost every resolution improvement. It starts with 5.08% to reach accumulatively to 17.47%.

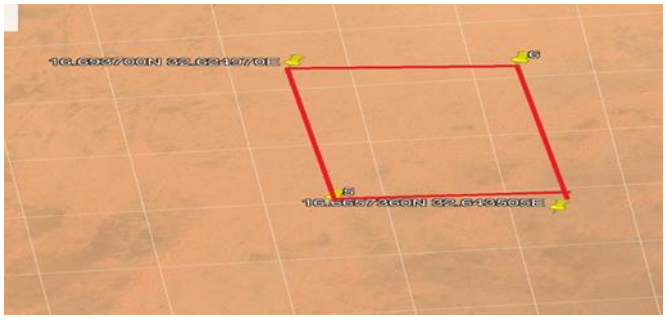

Fig .7. Desert, Study Area.

Table 8. MI of seven bands in Desert.

	8 BITS	9 BITS	10 BITS	11 BITS	12 BITS	13 BITS	14 BITS	16 BITS
Band 1	1.514118	1.647835	1.727647	1.833168	1.872468	1.932875	1.977078	2
Band 2	1.579964	1.658512	1.816753	1.880915	1.916945	1.966849	1.966849	2
Band 3	1.645761	1.726537	1.845361	1.897121	1.936821	1.975313	1.983 11	2
Band 4	1.670834	1.847944	1.884398	1.952534	1.963874	1.986247	1.992659	2
Band 5	1.724083	1.792496	1.871393	1.919711	1.953624	1.973107	1.982489	2
Band 6	1.688819	1.790635	1.852778	1.926704	1.959685	1.986984	1.982056	2
Band 7	1.730 27	1.801893	1.875872	1.932836	1.962778	1.972622	1.984368	2

Table 9. Percentage of shared information in Desert

	8 BITS	9 BITS	10 BITS	11 BITS	12 BITS	13 BITS	14 BITS
Band 1	75.71 %	82.39 %	86.38 %	91.66 %	93.62 %	96.64 %	98.85 %
Band 2	79.00 %	82.93 %	90.84 %	94.05 %	95.85 %	98.34 %	98.34 %
Band 3	82.29 %	86.33 %	92.27 %	94.86 %	96.84 %	98.77 %	99.16 %
Band 4	83.54 %	92.40 %	94.22 %	97.63 %	98.19 %	99.31 %	99.63 %
Band 5	86.20 %	89.62 %	93.57 %	95.99 %	97.68 %	98.66 %	99.12 %
Band 6	84.44 %	89.53 %	92.64 %	96.34 %	97.98 %	99.35 %	99.10 %
Band 7	86.51 %	90.09 %	93.79 %	96.64 %	98.14 %	98.63 %	99.22 %
Average	**82.53 %**	**87.61 %**	**91.96 %**	**95.31 %**	**96.90 %**	**98.53 %**	**99.06 %**

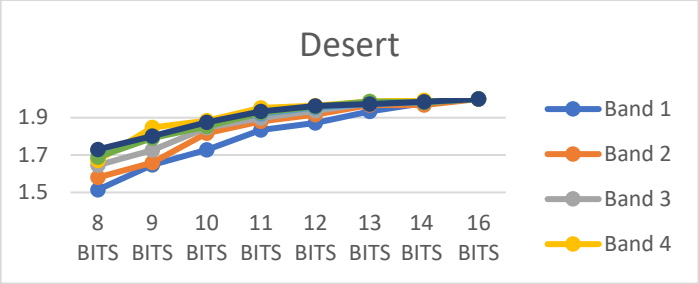

Fig .8. Line Graph for MI in Desert.

Urban:

In Urban areas shown in figure 3-8, table 3-11 and figure 3-9 illustrate the amount of shared information rises regularly with less than 4% between different radiometric resolutions.

Fig .9. Urban, Study Area.

Table 10. MI of Seven bands in Urban Area.

	8 BITS	9 BITS	10 BITS	11 BITS	12 BITS	13 BITS	14 BITS	16BITS
Band 1	1.703 09	1.800 236	1.843 664	1.928 662	1.951 839	1.967 876	1.994 736	2
Band 2	1.756 027	1.854 866	1.905 895	1.946 602	1.964 993	1.969 82	1.991 073	2
Band 3	1.764 839	1.827 955	1.850 234	1.942 791	1.957 996	1.979 741	1.991 293	2
Band 4	1.794 364	1.847 944	1.884 398	1.952 534	1.963 874	1.986 247	1.992 659	2
Band 5	1.738 385	1.862 234	1.903 265	1.946 616	1.966 859	1.977 181	1.988 495	2
Band 6	1.798 757	1.844 76	1.916 022	1.924 313	1.971 026	1.979 771	1.993 045	2
Band 7	1.813 24	1.872 131	1.921 016	1.938 637	1.979 132	1.984 515	1.992 502	2

Table 11. Percentage of shared information in Urban Area.

	8 BITS	9 BITS	10 BITS	11 BITS	12 BITS	13 BITS	14 BITS
Band 1	85.15 %	90.01 %	92.18 %	96.43 %	97.59 %	98.39 %	99.74 %
Band 2	87.80 %	92.74 %	95.29 %	97.33 %	98.25 %	98.49 %	99.55 %
Band 3	88.24 %	91.40 %	92.51 %	97.14 %	97.90 %	98.99 %	99.56 %
Band 4	89.72 %	92.40 %	94.22 %	97.63 %	98.19 %	99.31 %	99.63 %
Band 5	86.92 %	93.11 %	95.16 %	97.33 %	98.34 %	98.86 %	99.42 %
Band 6	89.94 %	92.24 %	95.80 %	96.22 %	98.55 %	98.99 %	99.65 %
Band 7	90.66 %	93.61 %	96.05 %	96.93 %	98.96 %	99.23 %	99.63 %
Average	**88.35 %**	**92.22 %**	**94.46 %**	**97.00 %**	**98.26 %**	**98.89 %**	**99.60 %**

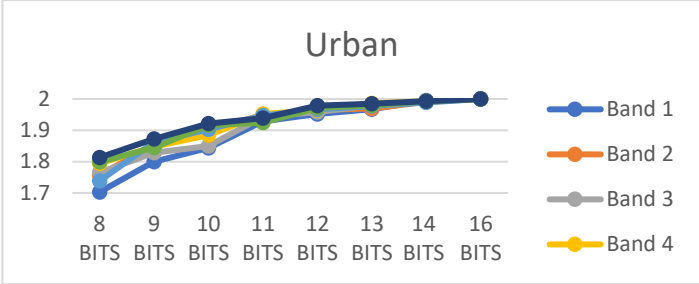

Fig .10. Line graph for change of MI in Urban Area.

3.5 Discussion

This study has undertaken the theoretical approach of measuring the change in mutual information at Landsat-8 seven bands in four different categories. The study revealed that the amount of shared information differs based on the land category. However, this amount of information reaches its lowest at 8 bits in water and the highest 8 bits of image shared information is in urban areas. By considering a full image, the amount of shared information reaches its lower value at 8 bits with 88%. At 10 bits image it has been found that the amount of shared information is relatively high in all categories.

The absorption of IR shows up clearly, the dramatic change in all MI in band 5, band 6 and band 7. As for band 2 the amount of shared information is 82.33% between images at 8 bits and 16 bits images and it reached 98.88% at 14 bits image as illustrated in table 5.

In the agricultural cover, it was notice that the amount of shared information is 87% between 8bits image and 16bits image, the value rises to reach the almost full value of MI at 14 bits image.

4 Conclusions and Recommendations:

4.1 Conclusions:

- Mutual information changes based on the change in dynamic range but this change depends on the reflecting/emitting land category.
- Mutual Information changes are based on the change of radiometric resolution but this change accumulatively reaches 18% from 8- bits to 16- bits dynamic range.
- Mutual information can be used for quality assessment and distortion measurement between a referenced image (in our case 16 bits Landsat-8 image) and any other image.

4.2 Recommendations:

- Apply image classification and compare the effect of change in radiometric resolution on image classification.
- Expand the study area to include different types of soils to examine the effect of radiometric resolution on other land cover types and its application in the minerals field.

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