Investigating changes in land cover patterns in the Richards Bay area

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Land can be described as one of the most basic and undervalued resources available to humans [1]. It provides the means for the production of nutrition, living space, and energy. With over 7-billion humans on earth it becomes clear why it is important to study land cover change and all of its uses [2]. More than half of the human population lives in cities around the world. This places pressure on any city in terms of growth rate. Moreover, urban expansion changes the land cover surrounding the city into urban areas or agricultural land for the production of more nutrition.

South African coastlines have undergone a vast amount of development over the past decade [3]. This is partly because the coast offers many ecosystem goods and services that attract human activity. Subsequently, this leads to the development of the coastal areas and this rapid development puts pressure on the coastal ecosystems. Most of the northern coast of KwaZulu-Natal is prime for sugar cane and pine forest plantations. Consequently, agriculture and urbanisation are changing the land cover of coastal areas and increasing the strain on land resources [3]. In Richards Bay, agricultural activity, plantation forestry, surface mining, tourism industry and high living desirability aid in changing the land cover of the area. In addition, Richards Bay is located next to several dune forests and wetlands that are highly sensitive to change. Therefore, it is imperative to study the rate of land cover change and stresses of land resources in the Richards Bay area.

Remote sensing and change detection
Remote sensing is built around the premise that every object on the Earth's surface or in the Earth's atmosphere reflects, absorbs, emits or transmits electromagnetic energy in different proportions [4]. It is these different proportions of electromagnetic energy that are detected by the on-board satellite sensors and allows for the object to be identified.

Remote sensing techniques are indispensable when dealing with a phenomenon that is highly dynamic through time and space [5]. Within the past 20 years, there has been a growing body of knowledge revolving around change detection using remotely sensed data [6]. Techniques have been developed and refined to effectively analyse change through satellite imagery. This is mostly due to the fact that human activity changes the natural land cover of an area that directly effects on its biophysical and environmental state [7]. However, human activity is not the only factor that contributes to land cover change. Factors such as climate change and animal activity also affect the land cover of an area but these effects are usually over a longer period of time whereas human impacts are more direct and immediate. Urban expansion is one of the leading factors of land cover change and as more people move to cities a greater pressure is placed on a city's growth [8].

Drivers of land cover change
Land cover classification is possibly
the most extensively used application in remote sensing [9]. Examining land cover and land use (LCLU) changes is considered to be a crucial tool in monitoring the impact of change on the environment whether the changes are naturally or unnaturally induced [10]. Biggs and Scholes [7] suggest that human activity is the most important factor in rapid land cover change over time. Whereas, Veldkamp and Lambin [11] propose, that land cover change is not solely affected by human activity but also from biophysical factors. It is predicted that by 2100 LCLU changes will have more of an effect on ecological systems than that of climate change [12].

**Human factors**

Human intervention on the environment, particularly on coastal environments, has had a massive impact on the ecology and the rate of land cover change [3]. In the 20th century, urban sprawl and urbanisation have been a major dilemma in the practice of urban development [1]. Urban population growth is one of the major characteristics and determinates of urban expansion [13]. With an increasing population comes an increased need for urban expansion, resource demands grow and infrastructure requirements increase. If a city’s growth cannot keep up with the population growth and influx of people, it could lead to the formation of informal settlements which in turn has a negative effect on the land cover. In addition, the coastline offers many ecosystem goods and services that attract human activity [3]. This leads to the development of the coastal areas and the tourism industry. Other than tourism development, the South African middle- and high-income classes are buying second homes (holiday homes) or permanently moving to the more desirous coastline thereby substantially increasing the development of houses on the urban periphery [14].

South Africa has a rich mining history and has depended on natural resources for many decades. On the KwaZulu-Natal coastline near Richards Bay, the sand dunes are dredged for titanium, pig iron, zircon and rutile minerals [15]. These surface-mining activities change the LCLU activities in the area over a period of time, often causing harm to the natural dune forests in the area [16]. In addition, mining activities create jobs which attract job seekers and inadvertently lead to more urban expansion and land cover change [17]. One of the most common land cover transformations that occurs worldwide is the transformation of grassland or forest areas for agricultural land [18]. The KwaZulu-Natal area has a booming fruit and sugarcane industry that has had a substantial effect on the LCLU of the area. Sappi and Mondi, paper companies, use the climate of KwaZulu-Natal for their tree plantations.

**Natural factors**

Climatic condition of an area has an immense influence in determining the land use or human activity for a particular region [19]. Climatic conditions can favour the growing of a particular crop and therefore it can be the chief driving force that encourages land cover change. The KwaZulu-Natal

<table>
<thead>
<tr>
<th>Area (%)</th>
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<th>Area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake</td>
<td>6.17</td>
<td>4.60</td>
<td>3.84</td>
<td>5.32</td>
<td>4.06</td>
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<tr>
<td>Stagnant lake</td>
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<td>0.00</td>
<td>0.12</td>
<td>0.57</td>
<td>0.34</td>
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<tr>
<td>Saline water</td>
<td>28.66</td>
<td>30.26</td>
<td>29.40</td>
<td>28.07</td>
<td>28.20</td>
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<tr>
<td>Sand</td>
<td>0.57</td>
<td>0.69</td>
<td>5.08</td>
<td>2.30</td>
<td>1.15</td>
</tr>
<tr>
<td>Sugar cane</td>
<td>7.71</td>
<td>9.34</td>
<td>11.27</td>
<td>8.34</td>
<td>4.90</td>
</tr>
<tr>
<td>Cultivated cleared land</td>
<td>7.36</td>
<td>5.67</td>
<td>1.53</td>
<td>7.12</td>
<td>9.81</td>
</tr>
<tr>
<td>Forest</td>
<td>9.94</td>
<td>6.97</td>
<td>9.21</td>
<td>14.84</td>
<td>18.63</td>
</tr>
<tr>
<td>Surface mine</td>
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<td>0.00</td>
<td>1.04</td>
<td>2.51</td>
<td>1.51</td>
</tr>
<tr>
<td>Urban residential</td>
<td>6.15</td>
<td>12.04</td>
<td>7.20</td>
<td>9.98</td>
<td>7.89</td>
</tr>
<tr>
<td>Urban industrial</td>
<td>1.13</td>
<td>3.65</td>
<td>2.99</td>
<td>2.56</td>
<td>3.13</td>
</tr>
<tr>
<td>Grass land</td>
<td>34.00</td>
<td>21.93</td>
<td>25.25</td>
<td>17.54</td>
<td>16.79</td>
</tr>
<tr>
<td>Coal terminal</td>
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<td>0.00</td>
<td>0.21</td>
<td>0.27</td>
<td>0.30</td>
</tr>
<tr>
<td>Roads</td>
<td>0.76</td>
<td>4.86</td>
<td>3.66</td>
<td>3.34</td>
<td>1.77</td>
</tr>
<tr>
<td>Wood chip piles</td>
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<td>0.00</td>
<td>0.15</td>
<td>0.29</td>
<td>0.34</td>
</tr>
<tr>
<td>Unclassified pixels</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.00</strong></td>
<td><strong>100.00</strong></td>
<td><strong>100.00</strong></td>
<td><strong>100.00</strong></td>
<td><strong>100.00</strong></td>
</tr>
</tbody>
</table>

Table 1: Summary table of the percentage area for land cover classes (1973 - 2011).

![Fig. 2](image_url) Fig. 2: Percentage area changed of land cover classes from 1973 – 2011.
area’s climatic conditions are perfect for sugar cane and pine forest plantations. The ocean plays a role in determining the growth of an urban settlement [3]. It acts as a natural barrier that forces development into a different direction. In the South African context development is naturally forced alongside the coastline because of its attractiveness to tourism and favourable desirability for living.

Materials and methods
Landsat imagery was obtained for a 39 year period. All the imagery collected was from Landsat 1 MSS (images 1973 and 1976), Landsat 5-TM (images 1987 and 1999) and Landsat 7 ETM+ (images 2006 and 2011). Geo-referencing or geocoding was performed on the images to ensure that they have the same spatial reference and extent. Geo-referencing was done in ERDAS 2011 with the help of ground control points. The results indicated a ground control error of 0.1965, which is considered extremely good. After all images had been re-projected over each other, pixel-by-pixel, the study area could be clipped.

Classification stage
Image classification has been used in multiple studies for monitoring land cover changes. The objective of the image classification process is to group individual pixels into land cover classes or themes [20]. The digital number (DN) of the individual pixels is used as the main determinant for classification. The DN of the pixel represents the spectral reflectance value and remittance properties of the object. Thus, each pixel with the same DN value or each pixel that has a DN value that falls within certain parameters will be classified together.

A supervised classification technique alongside the maximum likelihood decision rule algorithm was used during the classification stage. Supervised classifications depend on the user’s ability and knowledge in recognising homogenous areas and creating training sites [4, 20]. These training sites are then stored in the signature file and are used as a baseline for grouping other pixels with the same DNs together. Training sites can be merged together to give a wider range of DNs that will be grouped together in one class. After the training sites and the signature file have been set up one can classify the image. The flow chart (Fig. 1) graphically illustrates the process of a supervised classification.

The classes selected were done so in accordance to the guidelines set out by Thompson [21]. There were a total of 15 classes selected which included; urban industrial, urban residential, woodchip pile, surface mine, stagnant lake, sugar cane, sand, saline water, roads, lakes, grassland, forest, cultivated cleared land, coal terminal, and unclassified pixels.

Post classification change detection
Land cover change post classification comparison (PCC) is deemed to be the most accurate and widely used [22]. Two images from different dates are classified independently and change is determined through direct comparison of the classified data [3]. The change detection process uses the classified pixel of the images to do the change detection. This is done by opening the attribute tables of the images and looking at how many pixels of a specific land cover section changed.
from time \((t)\) to time \((t + 1)\). The total percentage of land cover is determined as well as the change from time \((t)\) to time \((t + 1)\). This was done for each image and then tabulated in a systematic way using Microsoft Excel 2010 as shown in Table 1.

**Results and discussion**

In 1972 the government approved of the development of the harbour at Richards Bay. The decision was based upon the premise that Richards Bay was the closest possible location to South Africa’s mining heartland. In addition to the large lagoon, easy dredging conditions, an already established rail road network, ample labour availability and fresh water helped in the decision making process [23]. In 1976 the first phase of the harbour was officially opened. This development of the harbour can clearly be seen in the two images from 1973 and 1976. Moreover, the results show that the percentage of urban industrial areas has increased from 1,13% to 3,65% for that time period. Richards Bay’s port is South Africa’s largest export gateway of coal and wood chips; therefore these resources are being stockpiled in the area. The port exports 92-million tons of coal annually and the coal terminal can stockpile 6,7-million tons of coal [23]. Wood chips are being exported at a rate of 4,6-million tons per annum. The coal terminal class and wood chip pile class remains relatively constant over the study period reaching a total percentage area of land cover of 0,31% and 0,34%, respectively.

Heavy metals were discovered in the dunes surrounding Richards Bay in the 1920s however; detailed investigations were not done until 1971 [15]. In 1976 RBM (Richards Bay Minerals) was formed and had the rights to mine the dunes north of Richards Bay. In 1985, RMB acquired additional mining rights for more sites. Thus, the 1999 image shows the first signs of surface mining activity near Richards Bay. In 2006, a new surface mining site is seen just west of Lake Cubhu. In addition, the first mining site had not been fully rehabilitated and still shows up on the 2006 image. In the 2011 image the first mining site is fully rehabilitated but the second site is still active. This explains why there was a fluctuation in percentage for this class with 2006 being the highest (2,51%) because of the still rehabilitating first site.

Sugar cane and forest production go hand in hand with the cultivated cleared land class. After the sugar cane or plantation forests have been harvested it naturally leaves bare soil exposed. Therefore, after harvesting, the cultivated cleared land class should naturally be higher than that of the sugar cane class and vice versa. This can clearly be seen when one examines Fig. 2. In the 1987 image, the sugar cane class is 11,27% and the cultivated cleared land class is 1,53%. The pattern repeats itself in 2006 and 2011 with sugar cane being 9,9% in 2006 and 2,94% in 2011. The forestry class takes a big leap in total percentage area cover in 1999 with a total increase of 5,63% from 1987 to 1999 (Table 1). Thereafter, the industry grew substantially reaching its highest percentage land cover in 2006 with 18,63%.

Saline water and the lake classes remain relatively stable throughout the study period when comparing percentage area covered. The stagnant lake class emerges in 1987 and it can be argued that the development of the harbour caused this. The sand class is moderately stable apart from the jump in the 1987 image where it reaches a high of 5,08%. This jump can only be explained by inadequate training site for that class in that image.

Urban industrial and urban residential have been rising since the development of the harbour in 1976. The urban residential class was 6,15% in 1973 and 14,63% in 2011. This equates to an overall increase in urban residential areas of 8,48% over the 38-year period and can clearly be seen when examining Fig. 2. Urban industrial areas have not had such a substantial amount of development over the 38-year period with the most development happening between 1973 and 1976. The road network development (road class) also increased during this period and remains relatively stable for the remainder of the study.

Most notably, the grassland class has decreased substantially over the 38-year study period with 34,00% of grassland in 1973 and 10,91% of grassland in 2011. The 23,09% decrease in grassland is due to the substantial amount of development in and around Richard Bay during the study period. Urban residential areas and plantation forests can be seen as the main driver of grassland reduction. This is because the forestry industry had grown from 9,94% to 17,21% and urban residential areas have grown from 6,15% to 14,48% during the study period. Even though agricultural development is one of the major drivers of land cover change [18] it is not the case in this study regarding sugarcane. The sugar cane fields surrounding Richards Bay have maintained their relative spatial extent during the study period. The total expansion of sugar cane fields could not be quantified during this study because of the fluctuation of sugarcane during the seasons. The forestry industry, as mentioned before, has grown but the extent of that growth could also not be quantified for the same reasons as that of the sugar cane.
Accuracy assessment

Accuracy assessment was only done for the 2011 classified image because of availability of reference data. A simple random sampling method was used to established points for ground truthing. The 2011 image was overlain on top of the ground truth reference data and ground truthing was done on a pixel-to-pixel basis for 100 points. The total accuracy for the land cover image of 2011 was established to be 64%. Thereafter, a Kappa statistic was further employed and a Kappa result of 0.8127 was achieved.

Conclusion

When examining the percentage land cover change from one period to another over the entire study period, one can observe a significant amount of change in the land covers. Reasons for this are that Richards Bay is becoming an extremely popular tourist destination and expansion in this area has been increasing. General expansion of the urban areas for economic growth and population growth does occur in the area. These trends do not just occur at Richards Bay but along most of KwaZulu-Natal's coastline [3]. Ecosystem, good and desirable climate and soils for agriculture are some of the core reasons for urban and agricultural growth. It becomes clear that policy developments need to take into consideration land resources and its importance to human activity. Sensitive areas such as wetlands, dune forests and beaches need to be protected and the conversion of these areas to urban or agricultural areas must be prohibited, or strictly governed through future planning and policed permits.

References


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