An assessment of the CO_2 storage potential of the Indian subcontinent

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Abstract

Current annual CO_2 emissions from large industrial point sources in India, Pakistan, Bangladesh and Sri Lanka are estimated to be 721, 45, 17 and 3 million tonnes (Mt) CO_2 respectively. Rapid growth in annual CO_2 emissions is likely: in India, the nine planned ultramega power plants alone could add some 257 Mt CO_2 to annual emissions. The main potential CO_2 storage sites in India are located in the saline aquifers and oil and gas fields around the margins of the peninsula, especially offshore, but also onshore in the states of Gujarat and Rajasthan. There is also thought to be considerable saline aquifer CO_2 storage potential in NE India, but this is distant from the main emission sources. CO_2 sources in the centre of the peninsula appear to be poorly placed with respect to potential CO_2 storage sites. There is estimated to be about 5Gt CO_2 storage potential in India's major coalfields and oil and gas fields. It is important that India's saline aquifer storage capacity is quantified, as this will determine whether there is significant potential for the application of CCS. Pakistan will have significant CO_2 storage potential (c. 1.6 Gt CO_2) in its gas fields when they become depleted. It is also thought to have good potential for saline aquifer CO_2 storage in the Lower Indus and Potwar Basins and there is a good match between the locations of sources and potential storage sites. Bangladesh's annual CO_2 emissions from large point sources are approximately 17 Mt CO_2. It is thought to have significant CO_2 storage potential in its gas fields (c. 1.1 Gt CO_2) which will become available gradually as the individual fields are depleted. Bangladesh also probably has significant CO_2 storage potential in saline aquifers in most of the eastern half of the country, both onshore and offshore. Sri Lanka's total annual emissions of CO_2 from large point sources are estimated to be approximately 3 Mt. These will be increased by the operation of new coal-fired power plant. There may be some saline aquifer CO_2 storage capacity offshore to the north of the island, in Palk Bay and the Gulf of Mannar, but at present this requires further investigation.

Keywords: CO2 storage; India; Pakistan; Bangladesh; Sri Lanka

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1. Introduction

This study comprises an overview of the potential for CO_2 storage in four countries in the Indian subcontinent: India, Pakistan, Bangladesh and Sri Lanka.

Inventories of estimated CO_2 emissions from large point sources in the Indian subcontinent were compiled and used to update the IEAGHG R&D Programme's Global CO_2 Emissions Database, and then entered into a GIS, which was used to map the locations of emission sources. Potential geological CO_2 storage sites in coal fields, oil and gas fields and saline water-bearing reservoir rocks (saline aquifers) were then identified and where possible quantified. Sources and potential storage sites were then overlain in the GIS to visually match the CO_2 sources and potential storage sites and draw conclusions about the potential for the application of carbon dioxide capture and storage to reduce national emissions.

It was not possible to quantify the saline aquifer CO_2 storage potential of any of the four countries due to a lack of suitable geological information (e.g. seismic and well data). Instead, the sedimentary basins of the four countries were divided into categories of good, fair and limited saline aquifer CO_2 storage potential on the basis of published geological data. Basins with good potential contain hydrocarbon fields (proving at least local containment of buoyant fluids over geological timescales) and there is expectation of good reservoir and seal quality at depths below 800 m over at least a significant part of the basin. Basins with fair potential contain one or more potential regional seals, underlying reservoirs at depths >800 m, and potential structural closures, but containment of buoyant fluids over geological timescales is not yet proven by the discovery of hydrocarbon fields. In basins with perceived limited potential, porous and permeable reservoir are absent or not sealed, or the basins lack structural closures, or are in structurally complex fold belts, or they face major potential conflicts of use.

2. India

2.1. Industrial point sources of CO_2 in India

Total annual CO_2 emissions in India are estimated to have been 1343 million tonnes (Mt) in 2004 – the latest year for which information is available from the United Nations Statistics Division [1]. During this study, which took place in 2006, annual CO_2 emissions from large point sources in India are estimated to have been 721 Mt CO_2, i.e. about half total emissions.

Marland et al. [2] indicate that India's CO_2 emissions are rising rapidly and they look set to continue to rise at increasing rates. For example, annual emissions from operational power plants in India are estimated to be 467 Mt whereas predicted annual emissions from planned power plants and plants under construction are estimated to be 653 Mt.

Coal-based power plants are the backbone of the Indian power sector and will continue to be the major source of electricity generation in the country for the foreseeable future. A major upcoming development in the Indian power sector is the Indian Ministry of Power's initiative for the development of coal-based Ultra-Mega Power Projects (UMPPs), each with a capacity of 4,000 MW or above. In the first phase, nine sites have been identified by the Central Electricity Authority for UMPPs. These include four pithead sites and five coastal sites (Figure 1). These UMPPs will add some 257 Mt CO_2 emissions and 36,000 MWe installed capacity at nine locations within 7-8 years.

2.2. Potential CO_2 storage sites in India

The CO_2 storage potential of saline water-bearing reservoir rocks, oil and gas fields and coal fields were considered in the analysis. The area of India north of the Himalayan mountain front was not analysed because it is geologically complex and was considered to have little practical CO_2 storage potential. Figure 1 indicates that much of Peninsula India is unsuitable for CO_2 storage because basalt or crystalline basement rocks occur at the surface. It is possible that sedimentary rocks may occur beneath the basalt in some areas but imaging problems would probably prevent effective site characterisation and monitoring.

India has the fourth largest recoverable coal reserves in the world. However, much of this coal is easily mined and will be used as fuel. This means that the potential for CO_2 storage on coal at depths above 1200 m could be severely constrained. An indicative calculation for IEAGHG [3] suggests that the potential could be of the order of 345 Mt CO_2 nationally in the major coalfields, and none of the coalfields are estimated to have the capacity to store >100 Mt CO_2. If CO_2 storage on coal proves practical at depths >1200 m the very large resource present at depth, e.g. in the Cambay Basin and down dip to the east of the Rajmahal coalfields, could be brought into play. This is an area that requires further investigation.

Oil and gas fields occur in three areas: Assam and the Assam-Arakan Fold Belt, the Krishna-Godavari and Cauvery Basins, and the Mumbai/Cambay/Barmer/Jaisalmer basin area. The total storage capacity in oil and gas fields is estimated to be between 3.7 and 4.6 x 109 t CO_2. Many Indian oil and gas fields are relatively small in CO_2 storage terms. Only a few fields, e.g. the Bombay High field, offshore Mumbai, are thought to have ample storage capacity for the lifetime emissions of a medium sized coal-fired power plant. However, some of the recent offshore gas discoveries may have potential as CO_2 storage sites in the future. It is also clear from Kumar et al. [4] that there are opportunities for enhanced oil recovery using CO_2.

It is thought likely that there is significant CO_2 potential in the saline water-bearing sedimentary rocks in the oil- and gas-bearing sedimentary basins around the margins of the peninsula, especially in the offshore basins, but also onshore in the states of Gujarat and Rajasthan. However, CO_2 sources in the centre of the peninsula are poorly placed with respect to potential CO_2 storage sites unless the Gondwana basins in which the coalfields, and thus many of the pithead power plants, are found can be demonstrated to have good potential, as indicated by Mondal [5]. There may also be saline aquifer CO_2 storage potential in Assam and possibly in Cachar, Tripura and Mizoram, although this is distant from most of the main emission sources in India, especially if any pipelines from the major CO_2 sources did not cross Bangladesh. In this study, the Ganga Basin, which lies beneath the Ganges plain, was considered to have limited CO_2 storage potential because of the potential conflict of interest with the use of (relatively shallow) groundwater for potable water supply and agriculture. This classification might be considered contentious but it is a factor that needs to be considered in assessing CO_2 storage capacity in the water-bearing reservoir rocks of onshore India in general.

Singh et al. [6] indicate that basalt formations might have good storage potential in India in the future, but because the storage of CO_2 in basalt formations, by reaction of basic aluminosilicate minerals with injected CO_2, is considered to be an immature technology at present, it is not considered further here. Nevertheless, development of this concept into a mature technology would potentially be beneficial to India: large areas of the country are covered by basalt (Figure 1).

2.3. Matching CO_2 sources and potential CO_2 storage sites in India

Figure 1 shows the geographical relationship between the major existing and planned sources of CO_2 in India and areas containing the sedimentary basins considered on the basis of this first-pass assessment to have good, fair and limited storage potential. The basins rated as good are the hydrocarbon-bearing basins, so they also contain all the potential in oil and gas fields.

It may be seen that sources in the NW of peninsula India and along the SE coast have good nearby storage potential, whereas those in SE, Central and, in this analysis northern India, do not. The good potential in NE India, in Assam and the Assam-Arakan Fold Belt, appears to be stranded relative to most of the major sources.

The calculations in the IEAGHG CO_2 sources inventory indicate that each individual UMPP may have annual emissions of between 28 and 29 Mt CO_2. If they have a 35 year lifetime they are each likely to emit approximately 1 Gt CO_2, and send significantly more CO_2 for storage if fitted for CO_2 capture. We estimate that the total storage capacity of India's major coal fields and oil and gas fields is <5 Gt CO_2, and none of the fields have the capacity to store the lifetime emissions of a single UMPP. As there is insufficient storage capacity in oil and gas fields and coal fields to make significant inroads into India's current and future emissions, it is clear that there is a need to quantify the realistic saline aquifer CO_2 storage capacity of India's sedimentary basins. This would require the use of oil and gas exploration data and might best be approached on a basin-by-basin basis, starting with the most strategically placed basins, as it is a time-consuming and resource-intensive process. If the saline aquifers are found wanting, export of CO_2 by ship, perhaps to the Middle East, would be the only remaining alternative for CCS in India, unless the basalt storage concept can be advanced into a mature technological option.

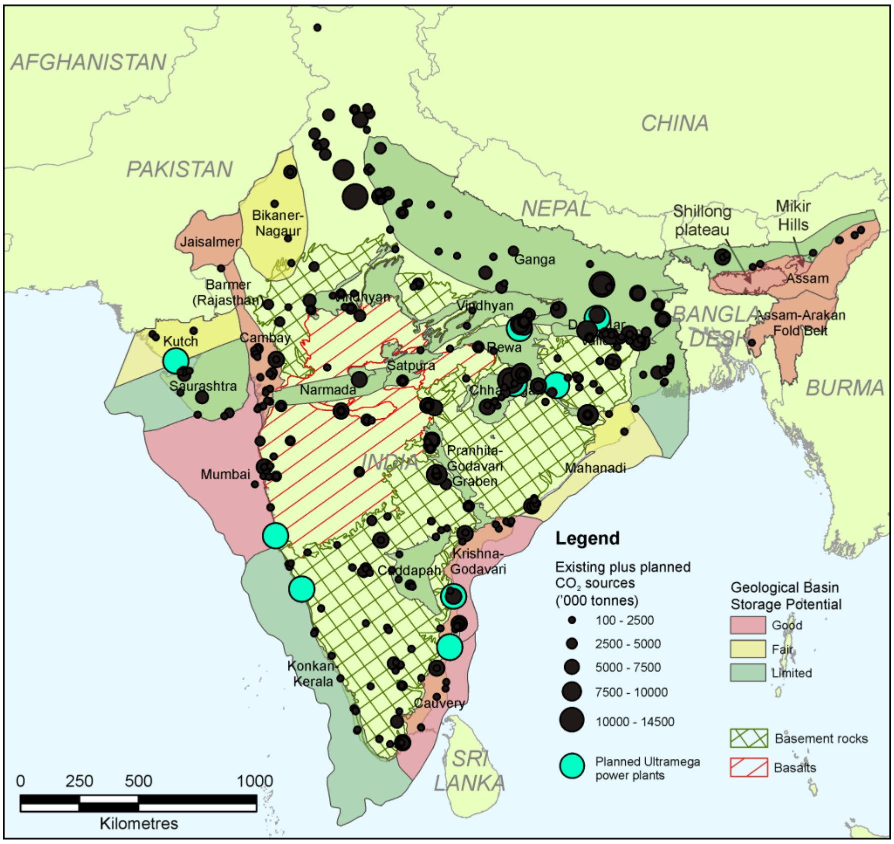

Figure 1 Geographical relationship between existing and planned CO_2 sources and sedimentary basins in India

3. Pakistan

3.1. Industrial point sources of CO_2 in Pakistan

Pakistan's total annual CO_2 emissions are estimated to have been 126 Mt in 2004 [1]. Annual CO_2 emissions from large point sources were estimated in this study to have been approximately 45 Mt CO_2, just over half of which comes from the power sector.

3.2. Potential geological CO_2 storage sites in Pakistan

Based on reserve estimates provided by Kazmi and Jan [7], the total storage capacity in oil and gas fields in Pakistan is estimated to be approximately 1.7 Gt CO_2. Four of the gas fields (Sui, Mari, Qadirpur and Uch) are estimated to have the potential to store >200 Mt CO_2, but none of the oil fields are thought to have significant storage capacity (10 Mt or more). None of Pakistan's coal fields are thought to have potential as CO_2 storage sites as, with the exception of Thar, they are all shallow and actively mined. The saline aquifers in the Kohat-Potwar Basin and Indus Basin are considered likely to have good CO_2 storage potential, and there may also be potential in the Balochistan Basin.

3.3. Matching CO_2 sources and potential geological CO_2 storage sites in Pakistan

Figure 2 shows the location of oil and gas fields, coalfields, sedimentary basins with good and fair aquifer storage potential and sources of CO_2 in Pakistan. There is a very good match between sedimentary basins with perceived good saline aquifer storage capacity and CO_2 sources.

Given that the estimated gas field CO_2 storage capacity alone is of the order of 35 times larger than the current annual emissions of CO_2 from large point sources, it appears that Pakistan is well placed to deploy carbon dioxide capture and storage technology.

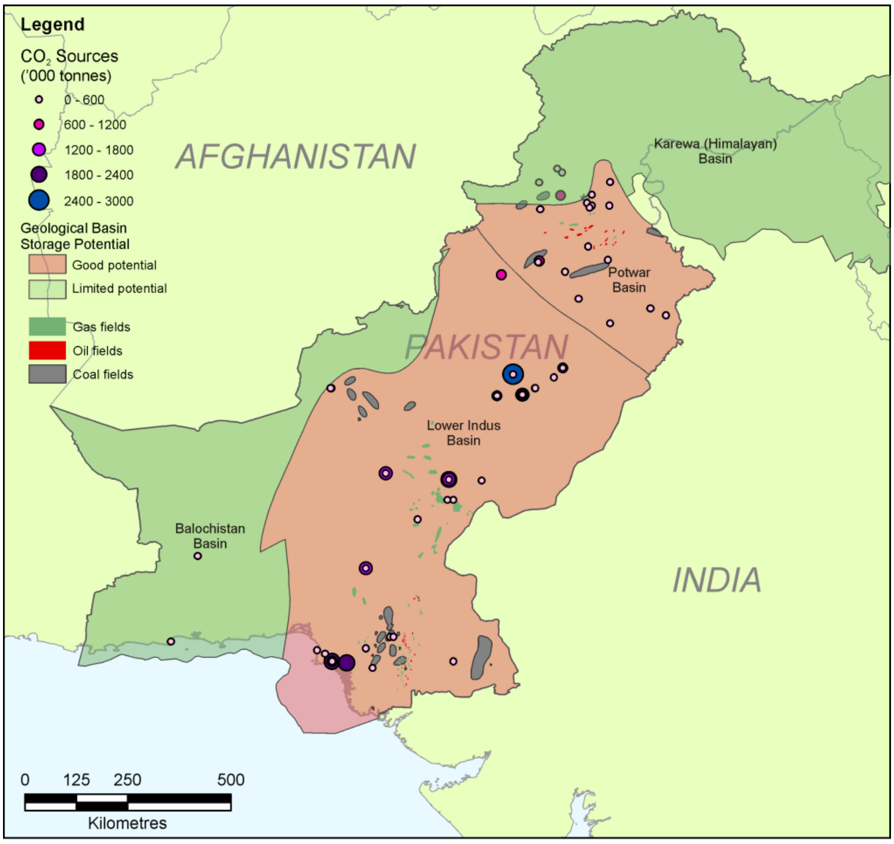

Figure 2 Storage potential and CO_2 sources in Pakistan

4. Bangladesh

4.1. Industrial point sources of CO_2 emissions in Bangladesh

Bangladesh's total annual CO_2 emissions are estimated to have been 37 Mt in 2004 [1]. Total CO_2 emissions from large point sources are estimated to amount to some 17 Mt CO_2, of which over 15 Mt are produced by the electrical power generation sector

4.2. Potential geological CO_2 storage sites in Bangladesh

There are no oil fields in Bangladesh although there is minor production of condensate and light oil from some of the gas fields. Fourteen of the gas fields have estimated CO_2 storage capacities >10 Mt. Two have estimated CO_2 storage capacities >200 Mt. Norman [8] and Holloway and Baily [9] discuss Bangladesh's three concealed coalfields: Jamalganj, Khalaspir and Barapukuria. All are in the NW of the country, west of the Jamuna river. The only field that has been exploited to date is Barapukuria, which is being mined at present. Additionally, coal has been discovered in a borehole at Dighipara, at a depth of about 328 m. None of these fields are sufficiently large to be of interest for CO_2 storage. The greater part of Bangladesh lies in the eastern part of the Bengal Basin (Figure 10). The Bengal Basin becomes progressively more folded to the east and eventually merges into the Assam-Arakan fold belt, which occurs in the Chittagong Hill tracts of eastern Bangladesh. The eastern, folded, half of the Bengal basin in eastern Bangladesh has excellent CO_2 storage potential in the many anticlines that are found there. There is also likely to be potential in the Chittagong Hill Tracts, although this region is remote from many large point sources and may suffer from overpressure, at least locally. The western half of Bangladesh, west of the Jamuna river, suffers from a lack of large structural closures suitable for containing geologically stored CO_2, and so may have less storage potential.

4.3. Matching CO_2 sources and potential CO_2 storage sites in Bangladesh

Given that the estimated gas field CO_2 storage capacity alone is of the order of 65 times larger than the current annual emissions of CO_2 from large point sources, it can be stated with certainty that Bangladesh is well placed to take advantage of carbon dioxide capture and storage technology should it be required in the future.

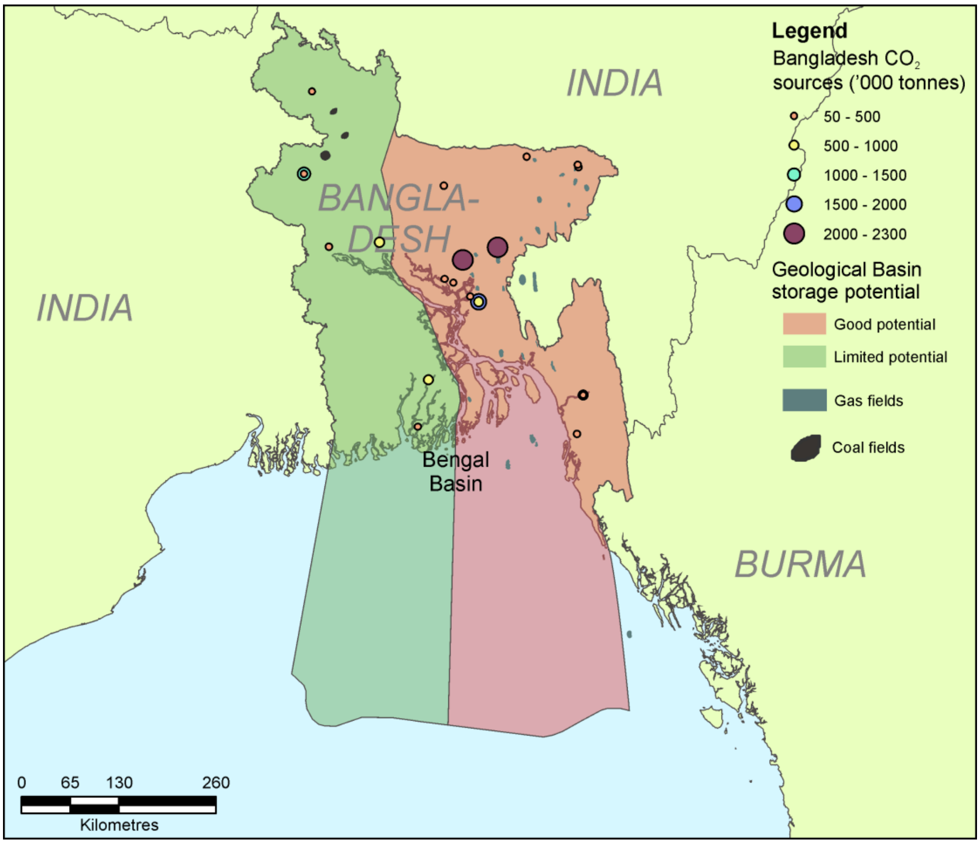

Figure 3 CO_2 sources and potential storage sites in Bangladesh

5. Sri Lanka

5.1. Industrial point sources of CO_2 emissions in Sri Lanka

Sri Lanka's total annual CO_2 emissions are estimated to have been 11.53 Mt in 2004. The total annual emissions of CO_2 from large point sources in Sri Lanka are very small, and estimated to be approximately 2.6 Mt. They derive mainly from 6 oil-fired power plants, a refinery and a cement plant. They will be increased by the operation of new coal-fired power plant, but national emissions will still be very small in global terms.

5.2. Potential geological CO_2 storage sites in Sri Lanka

Geologically, most of onshore Sri Lanka is made up of Precambrian crystalline rocks with no CO_2 storage potential. The only significant development of sedimentary rocks onshore is along the NW coast, where Miocene limestones overlie the Precambrian basement.

There are no significant coal deposits known in Sri Lanka. No oil fields or gas fields have been discovered to date, but there is oil and gas potential in the Sri Lankan side of the Cauvery Basin, offshore to the north of the island, in Palk Bay and the Gulf of Mannar. There may be some saline aquifer CO_2 storage capacity in this area as well, but it cannot be quantified at present.

5.3. Matching CO_2 sources and potential geological CO_2 storage sites in Sri Lanka

The only potential geological CO_2 storage sites are offshore to the N and W of the island. The storage capacity in this area cannot be quantified at present, so no estimate of the storage potential relative to national emissions from large point sources can be made. However, the new coal-fired power plant under construction at Norochcholai is relatively well placed with respect to the inferred CO_2 storage potential in the Cauvery Basin.

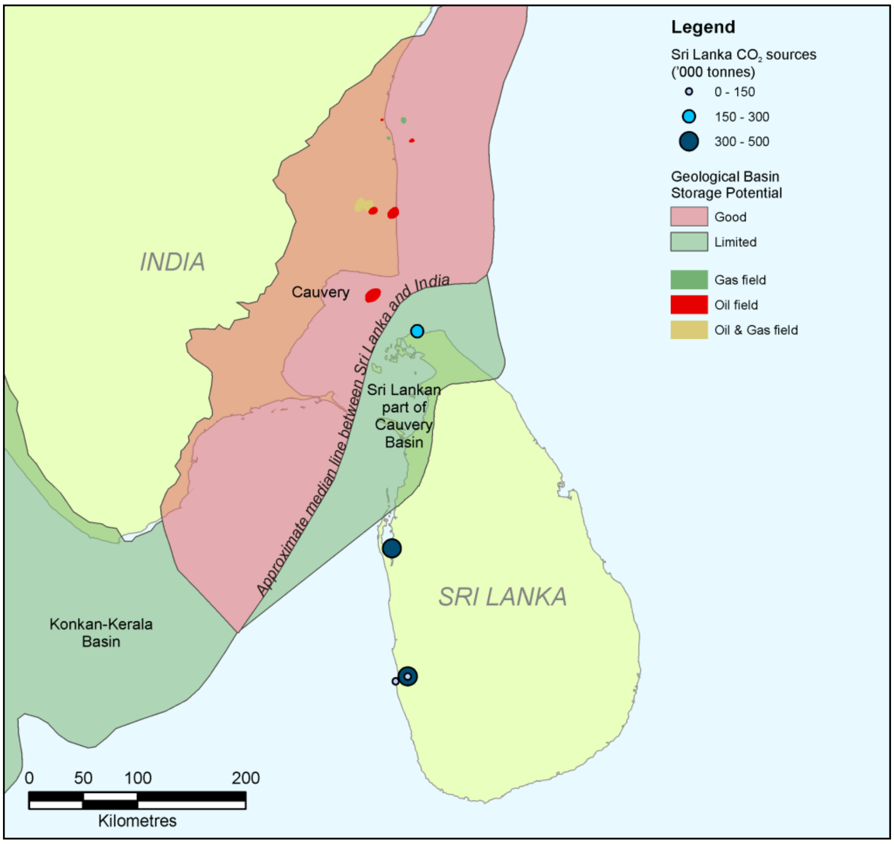

Figure 4 CO_2 sources and potential storage sites in Sri Lanka

6. Conclusions

It is concluded that the CO_2 storage potential of saline water-bearing reservoir rocks in India should be investigated as a matter of urgency in order to determine whether there is realistic potential for the technology in India. It is clear from the outline analysis presented above that Pakistan and Bangladesh are well placed to exploit CCS technology in the future.

7. Acknowledgements and disclaimer

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The maps in this report are intended to provide a graphical example for accompanying textual material. International boundaries of different countries are shown only for information and display purposes. These boundaries are neither authentic nor correct.

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