**Valuation of the ecosystem services provided by the Kailadevi Wildlife Sanctuary, Rajasthan, India**

**Supplementary details of methods and results**

This Supplementary Information document details methods and results for assessment of seven groups of ecosystem services produced by KWLS:

* S1 Fodder-related ecosystem services;
* S2 Timber and fuelwood-related ecosystem services;
* S3 Economic value of carbon stock and sequestration;
* S4 Economic value of soil- and water-related ecosystem services;
* S5 Economic value of tourism;
* S6 Qualitatively described ecosystem services; and
* S7 Miscellaneous ecosystem services.

**S1. Fodder-related ecosystem services of KWLS**

Livestock plays an important role in India’s economy, 90 per cent of dry fodder derived from forest and pastureland (Garnett *et al*., 2017). Assessment of fodder-related ecosystem services comprised three methods: a socioeconomic survey of communities in the forest to determine fodder demand from livestock numbers; fodder availability assessment through fieldwork; and economic valuation.

*S1.1 Socioeconomic survey of fodder demands*

The socioeconomic survey (also used for assessment of other ecosystem services) aimed to understand the livelihood and socioeconomic structure of communities in the forest and their dependencies on marginal agriculture and livestock. An initial round of stakeholder discussions derived preliminary information about livestock types and numbers in villages in KWLS, the local landscape, fodder availability, grazing patterns, fodder extraction from the forest, and fodder availability from farms. This initial survey helped shape a subsequent detailed survey methodology deriving quantitative data. Every household in all 66 villages in KWLS was visited to conduct a demographic livestock census. In every forest Range, 20 livestock keepers were surveyed to analyze grazing pattern of livestock, percentage of farm residue and other market inputs to livestock feed, with rapid, closed-question surveys querying number and type of livestock, duration and extent of the camp, water sources, means of commuting, community structure, predation by wild animals, and milk production.

In addition to grazing of the KWLS forest and grassland, many villagers with sizable land holdings on plateaus build ‘gher’, using stone fencing to protect the grass from cattle and other wild herbivores during the monsoon season, harvesting fodder from the gher to enable livestock to be retained in the Village during winter. Crop residues from crops such as Bajara and Paddy are also fed to the livestock, and oilcake derived from sesame is also used as supplementary feed.

Data on livestock numbers were converted into Adult Cattle Units (ACUs) following guidance from Ranjhan (1977), Singh *et al.* (1993) and FAO (1975) using an average weight of 250 kg per tropical livestock unit. The daily consumption of an ACU would normally be 6.2 kg of Dry Matter calculated from an estimate of 2.5 kg of dry matter per 100 kg stock body mass, which can form the basis for calculating an ACU-based stocking rate to be established. Adjustment for other types of livestock included horses and camel being equivalent to cattle, whereas calves were assessed as 0.7 ACU, and sheep and goats comprised 0.10 ACU.

The socioeconomic survey across the 66 villages revealed a total resident population of 19,179 people and a grazing head of 50,288.4 ACU, averaging 2.62 ACU per person. Survey data also indicated that the size of an average family (a unit composed of a married couple and their unmarried children) was 3.83, with a consequent average of 9.96 ACU per family. Although the livestock population inside KWLS (cattle, buffalo, sheep, goats, camel and horses) is not constant, highest in monsoon months when grass is abundant and lowest in summer due to lack of water on the plateaus, about 80% of cattle population spend 10 months of the year inside the Sanctuary. In addition to these resident livestock numbers, feral (unclaimed and abandoned for various reasons) cattle tend to spend daytime grazing in the forest moving into villages by night, typically spending 8 months of the years in the KWLS. Additional domestic cattle from nearby villages are brought into the KWLS on a seasonal basis by Kirkadis (cattle camps) during the months of July to October.

Total ACU grazing in KWLS is calculated as 50,288.4. At a fodder requirement of 6.5 kg per day per ACU, this amounts to a fodder requirement from the KWLS of 76,993.72 tonnes year-1. Livestock density amounts to 0.74 ACU ha-1 of the total KWLS area. Fodder requirements of the total livestock numbers/ACUs calculated from surveys are summarized in Table S1.1.

### *Table S1.1: Fodder requirement of the total ACU population KWLS*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Type of ACU population** | **ACU** | **Grazing days** | **Fodder requirement @ 6.5 kg dry matter day-1** | **Fodder requirement tonne yr-1** |
| Resident Villagers ACU for 12 months | 58,79.58 | 365 | 13,949,303.6 | 13,949.3 |
| ACU for 10 months | 23,518.32 | 300 | 45,860,724 | 45,860.72 |
| Feral cowsACU for 8 months | 5,090 | 240 | 7,940,400 | 7,940.4 |
| Khirkari ACU for 3 months | 15,800.5 | 90 | 9,243,292.5 | 9,243.293 |
| **Total** | **50,288.4****ACU** |  | **76,993,720.1** | **76,993.72** |

*S1.2 Assessment of fodder availability in the KWLS*

Fodder availability assessments included: three major sources (leaves of dhonk trees; seasonal grasslands; and crop residues) and three minor sources (fodder crops; oil cake; weeds in fields; and forage cultivation).

* The leaves of Dhonk (*Anogeissus pendula*) trees. Dhonk leaves have excellent fodder potential with high protein content of 11.60% (Ganguli *et al.* 1964, Sen and Ray 1971, Rai *et al*. 2001). The tender young leaves of A. pendula are heavily harvested by grazers, and the extent of this practice has transformed this medium-sized tree into a stunted pillow form (Bonsai type) in many places within KWLS, and with a contraction in forest range to only 14,828 hectares. A study by Vyas *et al.* (1978) in semi-arid regions near Udaipur (IBPJPT Programme - IndiajPT/7) found a positive correlation of leaf biomass (LB) of *Anogeissus pendula* with CBH (Circumference at breast height), deriving relationship between these attributes. In this study, 40 sampling plots each with an area 0. 1 hectare were established to study leaf biomass of *A. pendula* based on CBH measurements. Total biomass was calculated using the regression equation:

Leaf Biomass (LB) = 0.192 + 0.057 X CBH

Leaf biomass production in KWLS is estimated at 9619.81 tonnes, with average biomass highest on the plateaus at 431.80 kg ha-1 and Biomass lower in the khoh due to higher biodiversity and inaccessibility to large livestock (Table S1.2). The economic value of the harvestable leaf biomass of *A. pendula* produced in KWLS was estimated at 19.23 million Rupees year-1. However, there is need to control overharvesting in order to protect the value of other ecosystem services flowing from forested plateaus.

### *Table S1.2: Economic value of harvestable dhonk leaf biomass in different habitats of KWLS*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Habitat type** | **Live biomass****(kg ha-1)** | **Economic Value****(INR ha-1)** | **Area (ha)** | **Live biomass total****(tonnes)** | **Economic Value****(million Rupees)** |
| Dhonk Forest | 431.806 | 863.612 | 14,828 | 6,402.819368 | 12.80564 |
| Khoh | 249.978 | 499.956 | 9,883 | 2,470.532574 | 4.941065 |
| Ravine Habitat | 200.661 | 401.322 | 3,720 | 746.45892 | 1.492918 |
|  |  |  | **Total** | **9,619.810862** | **19.2396** |

* Seasonal grassland on the plateaus of KWLS, of the Sehima-Dichanthium type. Productivity of the seasonal grassland, locally known as *Dang*, was calculated by a harvest method following the method developed by Silori and Mishra (2001). ‘Net aerial primary production” (Golley 1965, Naik and Misra 1977, Siingh and Yadava 1972) was calculated on the basis of there being only a single growth period (the monsoon). Three gher sites in the villages of Dangada, Sankada and Ghanteshwar, protected from stock grazing by stone barriers, were used as experimental areas for sampling the productivity of the grasses following the methods of Silori and Mishra (2001). In each gher site, three 1m2 plots were established. Grass was harvested from all the plots at level of 5 cm from the ground during the period of optimum growth. Grass was harvested again after 7 days in one plot, in 14 days in a second plot, and in 21 days in the third plot, to estimate the impact of repeated grazing. Harvested grass was oven-dried at 60◦C until a constant weight was achieved, from which unit biomass production was calculated.

Total average standing biomass of the grassland was found to be 1.94 tonnes ha-1 (dry above ground biomass), the relatively low grassland productivity attributed to heavy grazing and subsequent loss of the soil and nutrients from the plateaus, semi-arid areas being highly susceptible to erosion and the adverse effects of overgrazing substantially due to their scarce vegetative cover (Cornelis, 2006). From experimental data summarized in Table S1.3, maximum harvestable biomass of edible forage produced in the grassland of the KWLS throughout the year was estimated using the equation:

kg dry matter biomass ha-1 year-1 = (k1 + k2 +... + kn)

Where, k1 = kg biomass @ 30 days;

k2 = k1 + 21 days, and

k3 = k2 + 21 days.

Dry matter biomass = (1.94+1.06+0.98+0.95)

= 4.96 tonnes ha-1 year-1

= 4,960 kg ha-1 year-1

Not all the biomass produced in the grassland is edible for the livestock. Species composition of the grassland is made up of edible and inedible plants. Quantity of the edible biomass in given grassland is expressed as edibility of the particular grassland. The edibility of tropical grassland has been recorded as 50% by Suttie *et al*. (2005).

### *Table S1.3: Biomass productivity of seasonal grassland in KWLS*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Sampling Site** | **Total average biomass gm m-2** | **Growth of biomass in 7 days average biomass****gm m-2** | **Growth of biomass in 14 days average biomass gm m-2** | **Growth of biomass in 21 days average biomass gm m-2** |
| Wet Wt | Dry Wt | Wet Wt | Dry Wt | Wet Wt | Dry Wt | Wet Wt | Dry Wt |
| Dangada  | 561.67 | 198.33 | 194.5 | 70.5 | 210 | 90 | 265 | 109.5 |
| Sankada | 930 | 184.16 | 217 | 65 | 205 | 70.5 | 245 | 110 |
| Ghanteshwar | 765 | 202 | 235.5 | 50.5 | 357.5 | 75 | 237.5 | 100 |
| AVG | 752.22 | 194.83 | 215.66 | 62 | 257.5 | 78.5 | 249.16 | 106.5 |

Therefore, available fodder dry weight = 2.480 ha-1 year-1 based on data recorded from serial harvesting thro9ughout the growing season. From this dry weight value, the economic value of fodder grass produced in KWLS @ INR 4 kg-1 is calculated as INR 9920 ha-1 year-1. Annual fodder production in KWLS is consequently estimated at 85,798.08 tonnes with economic value, worth INR 343.19 million (Table S1.4).

*Table S1.4: Economic value of fodder grass produced in seasonal grassland of KWLS.*

|  |  |  |  |
| --- | --- | --- | --- |
| Dry matter biomass tonnes ha-1 year-1 | Total grassland area in KWLS (ha) | Total fodder produced in the grasslands of KWLS (tonnes) | Value of fodder produced @ INR 4000 tonnes-1 (INR million) |
| 2.48 | 34,596 | 85,798.08 | **343.19** |

The calculated productivity of KWLS grassland of 2.48 tonnes ha-1 could support a theoretical maximum of 1.58 ACU ha-1. However, this value is 50% higher than the recommended stocking limit of 1 ACU per hectare in semi-arid areas for sustainable grazing (Planning Commission, 2011). Consequently, our livestock census and harvesting experiment concluded that the seasonal grassland is overstocked. Overstocking of grasslands poses a serious threat to the ecosystem functioning and flows of goods and services (Eldridge *et al.,* 2016), some significantly affected services include conservation of soil and water, carbon storage and sequestration with impacts on gene pool and habitat protection. There is a pressing need to reduce the numbers of livestock to avoid these negative impacts of overgrazing, not only to reduce pressure on the grassland but to enhance linked ecosystem services benefitting local communities and wider nature conservation goals.

* Crop residues and fodder crops. The ratio of grain and leaf biomass of crops was calculated following the methods of Singh *et al*. (1995) and Pandya and Prem (2008). The local unit of measure for land area is the bigha, equivalent to 2529 m2 (3.95 ha). Data deduced for crop residues used for animal fodder in this study are summarised in Table S1.5. The principal crops grown in the KWLS are paddy and bajara in kharif season, and wheat in rabi season. The area sown under each crop revealed through socioeconomic survey is converted to straw production using straw-to-grain ratios provided by Singh *et al*. (1995) and Pandya and Prem (2008). An estimated 11,219.09 tonnes year-1 straw is produced in KWLS, broken down between wheat, paddy and bajara with associated economic values totaling 44.87 million Rupees in Table S1.5. Assuming that all the agricultural crop residue is utilized for meeting the requirements of dry fodder in the area, it provides 9.4% of the total fodder requirement of 1,19,309.23 tonnes year-1 consumed by the 50,288.4 ACU livestock population of KWLS.

### *Table S1.5: Production and estimated economic value of agricultural residue in KWLS*

|  |  |  |  |
| --- | --- | --- | --- |
| **Crop** | **Area sown****(ha year-1)** | **Total straw Production (tonnes year-1)** | **Economic value (INR million****@ INR 4000 tonne-1)** |
| Wheat | 1,395.74 | 6,280.83 | 25.12332 |
| Paddy | 1,038.86 | 1,582.29 | 6.32916 |
| Bajara | 1,398.32 | 3,355.97 | 13.42388 |
| **Total** | **44.87** |

* Oil cake, a highly nutritious cattle feed, with a high content of protein, minerals and fats, is also derived from sesame in the kharif season and mustard in the rabi season by farmers in KWLS grow. Production of oil cake calculated as per DOR (2006) and summarised in Table S1.6.

### *Table S1.6: Production of agricultural crop residue as per Singh et al. (1995), Paddy-Pandya and Prem (2007-08)*

|  |  |  |  |
| --- | --- | --- | --- |
| **Crop** | **Grain-Yield (Kgs/ha)** | **Straw/Grain Ratio** | **Straw yield (kg ha-1)** |
| Wheat | 3000 | 1.5 | 4500 |
| Paddy | 2031 | 0.33 | 1523.1 |
| Bajara | 1200 | 2.0 | 2400 |

*Table S1.7: Production of oil cake as per DOR (2006)*

|  |  |  |
| --- | --- | --- |
| Crop | Oil seed yield (kg ha-1) | Seed/Oil Ratio |
| Mustard | 1056 | 2.5 |
| Sesame | 326 | 2.5 |
| Mustard @ 40 Rupees/kg; Sesame @ 25 Rupees/kg (Local Market Price). |

* Use of weeds in fields as fodder in KWLS. Weeds and grasses from cultivated fields and field bunds also constitute a source of green fodder, particularly in the monsoon season. However, in irrigated areas, these weeds may be available throughout the year. On the basis that an average, 0.1 tonnes of green weeds can be collected from on hectare of land annually in India (Singh *et al.,* 1995), total green weeds available in the KWLS area = 2,849.42 ha X 0.1 tonnes = 284.94 tonnes year-1. Multiplying this biomass by the price of green fodder in local market (INR 2000 tonne-1) yields a total economic value of weeds produced in KWLS fields is INR 0.56 million.
* Forage cultivation of a kasani (chicory: *Cichorium intybus*) crop was recorded in socioeconomic surveys during the rabi season in 8 villages: Nidhar, Bhojpur, Sakada, Daulatpura, Nainiyaki, Pahadpura, Pulan and Kalyanpura. An average of 2 hectares of land under cultivation in these villages implies a total of 16 ha of land under cultivation. On the basis of a value of 9 x 103 kg ha-2 (Yang; 2008; Wang and Cui, 2010), the total annual production of kasani is 108 tonnes with and estimated economic value 0.26 million Rupees year-1 based on a local market price of 2,400 Rupees tonne-1.

Integration of the three major and three minor sources of fodder supply produced in KWLS provides an aggregate annual economic value of 415.02 million Rupees per year (Table S1.7). KWLS currently supports 50,288.4 ACU with grassland fodder worth INR 9,920 ha-1 year-1, comprising 0.338.35 tonnes ha-1 year-1 *A. pendula* leaf biomass and an estimated 11,219.09 tonnes year-1 straw produced on croplands valued at 44.87 million Rupees year-1. There is need to reduce the number of livestock for the optimum growth of fodder species in the sanctuary, which will also improve the flow of other linked ecosystem services such as water conservation, bring prosperity and security to the local community as well as improving the conditions for wild herbivores.

### *Table S1.7: Economic value of grazing-related ecosystem services of KWLS*

|  |  |
| --- | --- |
| **Source of fodder-related ecosystem service** | **Economic Value** **(INR million year-1)** |
| **Major Sources of fodder** |
| Grassland fodder | 343.19 |
| Leaf biomass | 19.23 |
| Crop residues | 44.87 |
| **Minor Sources of fodder** |
| Oil cake | 6.91 |
| Weed as fodder | 0.56 |
| Cultivated forage | 0.26 |
| **Total** | **415.02** |

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**S2. Timber and fuelwood-related ecosystem services of the KWLS**

Wood resources are economically and socially important for India. The forests of the KWLS had formerly been heavily exploited for timber and charcoal leading to severe forest depletion by the end of the 1980s. Timber extraction is now technically banned in KWLS, yet the degraded forests of the Sanctuary still represent a significant resource base for communities living in and around the Sanctuary. Values to those exploiting wood resources are therefore assessed.

*S2.1 Timber stock value*

Reflecting the banning of timber extraction, annual recurring revenue from the timber is not assessed. Instead, a value of the timber stock is calculated to illustrate the scale of its potential value.

Field sampling was carried out in four forest Ranges of KWLS using a stratified random sampling technique to established 88 sampling quadrats of 31.6 m × 31.6 m (0.1 ha) size across the study area, encompassing three principal habitat types: (1) Tropical Dry Deciduous Forests dominated by *Anogeissus pendula* (Dhonk Forest); (2) Mixed deciduous forests of Khoh (gorge); and (3) scrubland forests of ravines. The objective of the stratification was to categorize these differing forest types into homogeneous groups.

Metrics used to calculate tree density is document in Table S2.1, and data regarding timber density converted to economic value (following Verma *et al.* (2015) with inflation adjustment) is summarised in Table S2.1. Average price of timber was taken from with a considered INR 28,359.68 m-3 and accounting for maintenance and transportation costs at 20% of the market price. The area under tree cover in KWLS was recorded as 28,431 ha with standing timber volume 1.2 million m3 worth 34,160.42 million Rupees.

*Table S.2.1: Data of Vegetation matrices gathered for this study*

|  |  |
| --- | --- |
| **Metric** | **Data collection method(s) used** |
| **Basal area** | Basal area of each tree was calculated by using following standard formulae:* DBH(cm) = GBH(cm)/ π
* DBH(m) = DBH(cm)/100
* Radius(r) = DBH (m)/2
* Basal area (m2 ha-1) = π r2x10
 |
| **Volume estimation** | Bole Volume (m3) = Tree Basal area (m2) x Height of the tree (m) |
|  | DBH- Diameter at Breast HeightGBH- Girth at Breast Height |

### *Table S2.2: Estimated Timber stock present in different habitat type of KWLS and its economic value*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Habitat Type** | **Timber density m3 km-2** | **Area****(ha)** | **Total volume (m3)** | **Economic Value in INR (million)** |
| Ravine | 38.37 | 3,720 | 142,736 | 4,047.95 |
| Khoh | 75.18 | 9,883 | 743,004 | 21,071.35 |
| Dhonk Forest | 21.5 | 14,828 | 318,802 | 9,041.12 |
|  |  | **Total** | **1,204,542** | **34,160.42** |

*S2.2 Wood consumption by village communities*

Although technically illegal and contributing to forest degradation leading to erosion, loss of biodiversity and increasing climate change (Williams and Shackleton 2002, Pandey 2002), wood remains a primary fuel source for people living in adjacent to the KWLS. The quantify fuel wood consumption by villages and other biomass (dung cake, agriculture residues, etc.) consumed by villages inside KWLS, socioeconomic surveys included questions concerning the general trend in fuelwood consumption. Major findings related to villagers’ fuelwood consumption were that this dependence was in part related to many villages lacking electricity and other modern amenities, and also that as milk is the main economic produce along with farm produce, a lack of marketing and preservation facilities means that people opt for energy-intensive preservation techniques such as mava (condensed milk) and ghee making consuming substantial quantity of wood.

15% villages (9 out of 66) villages inside KWLS were randomly selected to investigate fuelwood and other biomass consumption patterns, this number decided by a sample size required to obtain a 5% margin of error and 95% confidence using the Rosoft sample size calculator. An open-ended questionnaire survey was designed and translated into Hindi to determine family size, occupation, dependence on fuelwood and other biomass, use of LPG cylinder, distance travelled for wood collection, preferred species and seasonal variation in fuelwood consumption.

Small timber in form of small poles is regularly extracted by villagers for construction of houses, barn and cattle sheds, fencing agricultural fields, and for making agricultural implements and other household instruments and furniture. Dhonk is the preferred, all-purpose and durable wood for these purposes. The household surveys revealed that the average family of 5-8 persons (average family size 7.2) uses 10-12 wooden poles every year, with poles typically 6 feet in length and 10 cm of diameter. The wood volume of 10 poles is 0.159 m3. There are 2,663.75 families inside the sanctuary, extracting approximately 423.53 m3 of small timber worth 12.01 million Rupees annually for household purposes.

This was backed up by field assessment of the quantity of fuelwood consumed was measured over a period of 24 hours using a weight survey method (Mijitaba and Jing, 2013), considered the most accurate means to estimate the fuelwood consumption (Fox, 1984; Maikhuri,1991). This weight survey method comprised:

* + - A surveyor visited each sampled household and requested the family to set aside an amount of fuelwood that would be required for the next 24 hours;
		- The wood was weighed using a calibrated digital balance and then left in the kitchen. Wood to be used for different purposes was weighted separately (cooking, milk processing, heating, etc.)
		- The family was asked to use firewood from the same bundle.
		- Residual wood was weighted after 24 hours and its weight was deducted from the previous weight to calculate consumption per day.
		- A similar method was followed to calculate dung cake consumption.

Dhonk (Anogeissus pendula) and Dichrostachys cinerea were the preferred species for burning by the community, both high-density species with a specific gravity of 0.619 and 0.680 respectively (FRI 1996; FAOSTAT, 2013). Both also has high sapwood calorific value: 4.83 K cal for A. pendula and 5.02 K cal for D.cinerea (Rai, 2001). Average per capita consumption of fuelwood was calculated at 1.08 kg day-1 or 397.176 kg year-1 (calculated at a 5 Rupees kg-1 fuelwood costs observed in local markets). For the KWLS village population as a whole, this amounts fuelwood consumption of 7,617.44 tonnes yr-1 worth INR 38.08 million (Table S2.3). 55% of wood consumption was found to be for mava-making, 12% for heating, and 33% for cooking.

### *Table S2.3: Economic value of annual fuelwood used in KWLS*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Wood consumption in KWLS** | **Per person (kg/day)** | **Yearly per****person (kg /yr)** | **Yearly per person (tonne/yr)****by people in KWLS** | **Economic value of wood burned in****INR million @ INR 5** |
| wood consumption monsoon summer (245days) | 0.364 | 89.18 | 4250 | 21.25 |
| wood consumption winter(127 days) | 0.72 | 86.4 | 1710.383 | 8.551915 |
| Wood burned for Mavamaking | 0.6 | 221.596 | 1657.066 | 8.28533 |
| **Total** | **7617.449** | **38.08725** |

Communities are heavily dependent on cattle for secure income, with most of the fuelwood used for milk processing such as mava (condensed milk) and ghee making. One kiligramme of Mava is made from 4 kg milk, which requires 10 kg wood. On average, 2 kg Mava is produced by every family, mava production across KWLS as a whole estimated at 1710 kg day-1 (allowing for 250 days macva production annually to address seasonal variability). Despite its substantial demand for fuelwood, mava is sold at the same price INR 30 l-1 as milk from the local dairy. Considering the additional inputs of human labour and fuelwood, mava is both a loss-making enterprises whilst also exerting devastating effects on the wood resources of KWLS. Potential means for limiting this impact include: (1) subsidies dairy collection of milk from remote villages; (2) establishing milk collection centres; or (3) some form of payment for ecosystem service to protect wood resources.

Other forms of fuel used in KWLS include agricultural residues (considered negligible inside KWLS), cow dung cake (only a m small level of consumption was found by survey at 0.65 kg day-1 or 237.25kg year-1), and LPG cylinders (also very low uptake due to lack of refilling stations in villages and also cultural beliefs including impacts on the taste of food).

*S2.3 Summary of timber and fuelwood-related ecosystem services of the KWLS*

In summary, economic values for the principal timber and fuelwood-related ecosystem services derived from KWLS include a stock value of 34,160.42 million Rupees, and an annual consumption of 38.087 million Rupees year-1.

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**S3. Assessment of carbon stock and sequestration of the KWLS**

Carbon stock assessment included:

 S3.1 Carbon stock of forests

 S3.2 Carbon sequestration by seasonal grassland in open forest

*S3.1 Carbon stock of forests*

Forest ecosystem processes perform many regulating ecosystem services, ranging from regulation of pest and disease to air quality, erosion, storm buffering, and including the significant regulating service of climate regulation. Forest flora and soil absorb atmospheric CO2, as well as releasing some of it through respiration, as key elements driving the global carbon cycle. Forests consequently constitute major global reservoirs of carbon, holding more than double the amount of carbon as that found in the atmosphere.

The biomass of terrestrial ecosystems comprises four carbon pools: above-ground biomass (AGB); below-ground biomass (BGB); dead biomass (necromass) of wood and litter; and soil organic matter (SOM). Although proportions vary with forest type, Tanabe (2006) and Gibbs *et al*. (2007) observed that 74% of C is stored as AGB; 16% as BGB; and 10% as dead matter and soil in an undisturbed forest. Carbon sequestration rates by any forest type depend on multiple factors, such as vegetation type and diversity, habitat, climate, soil, nutrients and biotic pressure, so it is essential to conduct rigorous primary field study to estimate carbon stocks and sequestration rates in any specific forest, as generalisations can prove misleading (Gorte 2009, Everard *et al*. 2018).

Considering these factors, a detailed site study was conducted in different habitat types in KWLS across four forest Ranges of KWLS: Karanpur; Madrail; Nainiyak; and Kailadevi. A stratified random sampling technique was used to established 88 sampling quadrats of 31.6 m × 31.6 m (≅ 0.1 ha) size across the study area spanning these differing forest ranges, encompassing three principal habitat types: Tropical Dry Deciduous Forests dominated by *Anogeissus pendula* (dhonk forest); khoh (gorge); and ravines. Stratification ensured coverage of all these three principal forest habitat types, accounting for variation encountering in KWLS. Field data were collected following the methodology developed under the National Carbon Project by the Indian Institute of Remote Sensing (IIRS) (Singh and Dadhwal, 2008), with the sequence of metrics used to assess forest carbon stocks summarised in Table S3.1.

### *Table S3.1: Metrics used to derive forest carbon stocks*

|  |  |
| --- | --- |
| **Metric** | **Data collection method(s) used** |
| **Survey of above- ground biomass (AGB)** | Girth of all enumerated trees was measured at breast height (GBH at 1.37m) using a measuring tape, with height measured using a digital laser range finder. On slopes, the observations have been taken from elevated side of the tree. GBH supports estimates ofcarbon sequestration |
| **Basal area** | Basal area of each tree was calculated by using following standard formulae:* DBH(cm) = GBH(cm)/ π [where DBH is diameter at breast height]
* DBH(m) = DBH(cm)/100
* Radius(r) = DBH (m)/2
* Basal area (m2 ha-1) = π r2x10
 |
| **Bole volume estimation** | Bole volume (m3) = Tree basal area (m2) x Height of the tree (m) |
| **Calculation of AGB** | The estimated bole volume was converted into biomass by multiplying by species specific gravity (Rajput *et al.* 1996, Limaye and Sen 1956).Bole Biomass (Tonne) = Volume (m3) x Specific gravity |
| **Calculation of below-ground biomass (BGB)** | Assuming that root biomass is 26% that of the above-ground biomass (Houghtonsnes *et al.* 2001, Ramankutty *et al*. 2007) then:* BGB (Tonne) = 0.26 x Above-ground Biomass
 |
| **Calculation of total biomass (TB)** | TB = AGB + BGB |
| **Estimation of forest carbon** | Estimation of carbon stocks was achieved by multiplying total biomass (TB) by the default 0.475 carbon fraction used by the IPCC (McGroddy et al. 2004) as follows:Carbon (tonnes) = Biomass (tonnes) x 0.475* Average carbon stock per hectare of habitat x Area of Habitat
 |

Three types of forest in the KWLS were assessed: dhonk forest on the plateaus; scrub forest in river valley ravines; and khoh. Economic valuation of the carbon mitigation service provided by tree cover in KWLS based on a social cost of carbon (estimated monetary damage per unit annula increase in greenhouse gas emissions: Gayer 2017) of carbon used of $US 11 tonne-1 at 4% discount rate for 2015 (EPA, 2016), with the value of 1$ equated to INR 71.29.

* The estimated range of total carbon in deciduous dhonk forest determined in this study ranged from 4.29 t C ha-1 to 83.10 t C ha-1, with a mean value of 19.99 t C ha-1. Litter and soil in the total area of dhonk forest holds 5,486.36 tonnes and 377,995.36 tonnes carbon, respectively valued at 0.30 and 257.21 million Rupees. In total, 14,828 hectares of dhonk forest stores 0.62 million tonnes of carbon, valued at 493.93 million Rupees (Table S3.2).

*Table S3.2: Estimated carbon stock in different compartments of dhonk forest in the KWLS*

|  |  |  |  |
| --- | --- | --- | --- |
| **Stock** | **Carbon** | **Carbon (tonnes)** | **Estimated value (INR million)** |
| **(t C ha-1)** |
| Litter | 0.37 | 5,486.36 | 0.308 |
| Soil | 22.12 | 327,995.36 | 257.21 |
| Forest | 19.99 | 296,411.72 | 232.44 |
| Total | 42.48 | 629,893.44 | 493.95 |

To estimate carbon sequestration rate values of carbon sequestration in RTR (Verma et al., 2015) were used after adjusting with difference in biomass of the corresponding forest. Table S3.3 tabulates the carbon sequestration potential of dry deciduous open forest is KWLS of 8,748.52 tonnes of carbon year-1 with an estimated value of INR 6.86 million year-1.

*Table S3.3: Potential carbon sequestration in dry deciduous open forest of KWLS*

|  |  |  |  |
| --- | --- | --- | --- |
| **Sequestration (potential)** | **Carbon (t C ha-1)** | **Carbon (tonnes)** | **Estimated Price (INR million)** |
| **dry deciduous open forest** | 0.59 | 8,748.52 | 6.860501 |

The carbon stock of the dhonk forest of the KWLS is very low (42.48 tC ha-1) compared to similar dry deciduous forest elsewhere, such as Tropical Rainforest in the Western Ghats of India as between 92 tC ha-1 to 268.49 tC ha-1 (Bhat *et al.,* 2003), an estimated average carbon density of India’s forests as of 35 tC ha-1 (FAO, 2007) and an estimated carbon stock range from 15.6 tC ha-1 to 151 tC ha-1 in India’s Tropical Dry Forest (Chaturvedi *et al*., 2011). Verma *et. al.* (2015) recorded 113.61 tC ha-1 carbon in the Ranthambhore division of the RTR. Annual carbon sequestration potential of the KWLS was found to be 4,748.52 tonnes (@ 0.59 tC ha-1), potentially attributed to biotic pressure from the villages dependent for grazing and fuelwood.

### The carbon stock of scrub forest in the complex habitat in mounds and gullies in the river valley ravines of KWLS ranged from 20.96 t C ha-1 to 30.46 t C ha-1 with a mean value of 26.22 t C ha-1, an average carbon stock 31.16% higher than that of dhonk forest. Soil and litter of ravine scrubland holds 156,984 tonnes and 1,488 tonnes respectively of carbon, valued at 123.1 and 1.16 million Rupees. Tree biomass in the ravines held an estimated 97,538.4 tonnes of carbon, valued at 76.48 million Rupees. In total, 3,700 ha of ravine scrubland retain 0.25 million tonnes of carbon, valued at 200.76 million Rupees (Table S3.4).

### *Table S3.4: Estimated carbon stock in different compartments of ravine areas of KWLS*

|  |  |  |  |
| --- | --- | --- | --- |
| **Stock** | **Carbon** | **Carbon (tonnes)** | **Estimated value (INR million)** |
| **(t C ha-1)** |
| Litter | 0.4 | 1,488 | 1.16687472 |
| Soil | 42.2 | 156,984 | 123.105283 |
| Forest | 26.22 | 97,538.4 | 76.4886379 |
| Total | 68.82 | 256,010.4 | 200.7607956 |

Sequestration to potential of is 4,612.8 tonnes of carbon year-1 with an estimated value of 3.617311632 INR million year-1 is summarised in Table S3.5.

*Table S3.5: Potential carbon sequestration of scrublands in ravines*

|  |  |  |  |
| --- | --- | --- | --- |
| **Sequestration (potential)** | **Carbon (t C ha-1)** | **Carbon (tonnes)** | **Estimated value (INR million)** |
| **scrublands in ravines** | 1.24 | 4612.8 | 3.617311632 |

Generally, ravines are considered by land use planners as ‘wastelands’, and many are consequently being flattened for alternative uses, particularly for agriculture. However, ravines provide suitable habitat for a diversity of wildlife as well as serving as wildlife corridors, especially outside protected area (Khandal and Khandal 2013). Our study has highlighted that their productivity, in terms of carbon storage, is higher than that of Dry Deciduous Forest. Furthermore, shading by the steep ravine topography provides respite from high temperatures, which in summer can reach 48 °C. Another factor contributing to a high rate of productivity in ravines is the deep alluvial soils that form within them, retaining elevated soil moisture, and the higher surface area due to the undulating topography supports more vegetation (Everard *et al.* 2017, Thorat and Gurjjer 2010).

* Carbon stock and sequestration in mixed deciduous forest in the khoh (deep gorges) hosts dense forest. The estimated range of total carbon calculated in khoh varies from 49.26 tC ha-1 to 108.03 tC ha-1, with a mean value of 78.19 t C ha-1. Carbon stock in khoh exceeds that per unit area in both dhonk forest and ravines. It also contains rich soil with high moisture retention, and a cooler temperature throughout the year (Das *et al.* 2011), both contributory factors to the observed high carbon stock. Litter and soil of khoh forest retain 3,953.2 tonnes and 417,062.6 tonnes respectively, valued at 3.10 and 327.05 million Rupees. Tree biomass retains an estimated 772,751.77 tonnes of carbon, valued at 605.98 million Rupees. In total, 9883 ha of Khoh forest in the KWLS stores 1.19 million tonnes carbon, valued at 936.14 million Rupees (Table S3.6).

### *Table S3.6: Estimated carbon stock in different compartments of khoh forest in the KWLS*

|  |  |  |  |
| --- | --- | --- | --- |
| **Stock** | **Carbon** | **Carbon (tonnes)** | **Estimated Price (INR million)** |
| **(t C ha-1)** |
| Litter | 0.4 | 3,953.2 | 3.100059908 |
| Soil | 42.2 | 417,062.6 | 327.0563203 |
| Forest | 78.19 | 772,751.77 | 605.9842105 |
|  | 120.79 | 1.19 million | 936.1405907 |

Sequestration potential of the khoh of the KWLS is 16,899.93 tonnes of carbon year-1 with an estimated value of 13.25275611 INR million year-1 is summarised in Table S3.7.

*Table S3.7: Potential carbon sequestration of mixed deciduous forest in khoh*

|  |  |  |  |
| --- | --- | --- | --- |
| **Sequestration (potential)** | **Carbon (t C ha-1)** | **Carbon (tonnes)** | **Estimated Price (INR million)** |
| **mixed deciduous forest in khoh** | 1.71 | 16,899.93 | 13.25275611 |

*S3.2 Carbon sequestration by seasonal grassland in open forest*

The quantity of carbon sequestered annually in the grasslands of KWLS was estimated using data generated by the harvest experiment in patches of protected grass in gher within the KWLS (Section S1). Total carbon stored in grassland was assessed using the following equation:

Dry matter biomass (tonne ha-1)

= (Above-ground biomass ha-1) + (Below-ground biomass ha-1)

= (2.04) + (5.71)\*

\* Root: Shoot biomass ratio in dry semi-arid grassland is taken as 2.8 (Penman et al 2003)

= 7.75 t biomass ha-1

C (carbon content) = 0.475\* x oven-dry biomass.

\* The default 0.475 carbon fraction used by the IPCC (McGroddy et al. 2004)

Therefore, total carbon stock of carbon in grassland = 3.68 t C ha-1 year-1.

To estimate growth of biomass, grass was harvested at level of 5 cm from the ground to mimic the heavy grazing on the plateau at intervals of three weeks (21 days). Calculation of grassland biomass used the following calculation:

kg dry matter biomass ha-1 year-1 = (k1 + k2 +... + kn)

Where, k1 = biomass @ 1st harvest of grass, K2 = 2nd harvest of grass (K1 + 21st day) and K3= 3rd harvest of the grass (K2 +21st days).

Dry matter biomass = (1.94+1.06+0.98+0.95)

= 4.96 t C ha-1 yr-1

Annual sequestration of carbon in grassland = 2.33 t C ha-1 year-1

Carbon stock in soil was 31 t C ha-1, based on the ration provided by Penman *et al.* (2003)

The estimated carbon stock in seasonal grassland was calculated as 1.19 million tonnes, valued at 939.77 million Rupees (Table S3.8). Seasonal grasslands of the KLWS were calculated as sequestering 80,608.68 tonnes of carbon, worth 63.21 million Rupees annually (Table S3.9).

### *Table S3.8: Estimated carbon stock and sequestration in different components of seasonal grassland in the KWLS*

|  |  |  |  |
| --- | --- | --- | --- |
| **Carbon stock** | **Carbon (t C ha-1)** | **Carbon (tonnes)** | **Estimated Price (INR million)** |
| Soil | 31 | 1,072,476 | 841.02 |
| Biomass | 3.64 | 125,929.44 | 98.752 |
| Total | 34.64 | 1,198,405.44 | 939.777562 |

*Table S3.9: Estimated carbon sequestration in seasonal grasslands of the KWLS*

|  |  |  |  |
| --- | --- | --- | --- |
| **Sequestration (potential)** | **Carbon (t C ha-1)** | **Carbon (tonnes)** | **Estimated Price (INR million)** |
| Sequestration | 2.33 | 80608.68 | 63.21 |

This seasonal grassland is not in a natural state, but is the result of intensive and extended tree cutting and subsequent grazing in the original dry deciduous forest on the plateaus of KWLS. Consequently, if this habitat is given protection from anthropogenic pressures, along with soil and water conservation measures, there is a high potential for the progressive regeneration of original forest habitat, which would increase carbon sequestration and other ES flows from the KWLS.

*S3.3 Summary of carbon stock and sequestration in KWLS*

The total estimated carbon stock in the KWLS was found to be 2.08 million tonnes. The estimated economic value of the carbon stock was found to be 2,570.629 million Rupees (Table S3.10). Total estimated annual carbon sequestration in the KWLS was found to be 0.11 million tonnes, with an estimated economic value of 86.94 million Rupees (Table S3.11).

### *Table S3.10: Estimated economic value of carbon stock in different habitat units of the KWLS*

|  |  |  |  |
| --- | --- | --- | --- |
| **Stock** | **Carbon (t C ha-1)** | **Carbon (tonnes)** | **Estimated value (INR million)** |
| Dhonk Forest | 42.48 | 629,893 | 493.95 |
| Ravine | 68.82 | 256,010 | 200.761 |
| Khoh | 120.79 | 1.19 | 936.141 |
| Grassland | 34.64 | 1,198,405 | 939.778 |
|  | **Total** | **2,084,310** | **2,570.629** |

*Table S3.11: Estimated economic value of carbon sequestration in different habitat units of the KWLS*

|  |  |  |  |
| --- | --- | --- | --- |
| **Stock** | **Carbon (t C ha-1)** | **Carbon (tonnes)** | **Estimated value (INR million)** |
| Dhonk forest | 0.59 | 8,748.52 | 6.860501 |
| Ravine | 1.24 | 4,612.8 | 3.617311632 |
| Khoh | 1.71 | 16,899.9 | 13.25275611 |
| Grassland | 2.33 | 80,608.7 | 63.21277 |
| **Total** | **110,869.9** | **86.94333874** |

The results of this study found that, overall, carbon stock and sequestration rates in the KWLS are low compared with studies from similar forest types elsewhere. This indicates heavy biological pressure from grazing and wood extraction, though also taking account of harsh natural conditions.

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**S4. Economic value of soil- and water-related ecosystem services of the KWLS**

Many ecosystem services that are not directly consumed yet are vital for ecosystem functioning and resilience are largely ignored by policy-makers, including many produced by soil and water. Water flows are also the vector of many linked ecosystem services, water-related ecosystem services providing a diversity of benefits extending for substantial distances downstream of catchment sources. The availability and quality of water are strongly influenced by forests, forested catchments acting as sources and supplying a high proportion of the water for domestic, agricultural, industrial and ecological needs of humanity (Calder et al. 2007).

Agro-pastoral communities formerly inhabiting the KWLS have increased the carrying capacity of some of these services, for example in the construction of *Pagaraa*: check-dams comprising a low wall of stones erected across seasonal streams to intercept and conserve soil and water carried down streams from surrounding plateaus and hills during heavy rainfall, enabling people to grow crops once the monsoon recedes. Some significant water-related ecosystem services provided by forests groundwater recharge, flood regulation including reducing run-off peaks, and maintaining water quality.

Soil-related ecosystem services assessed in this study, many often overlooked by policy-makers, include:

 S4.1 Soil retention;

 S4.2 Sedimentation avoidance; and

 S4.3 nutrient retention.

Water-related ecosystem services assessed in this study include:

 S4.4 Water volume within the KWLS

 S4.5 Water volume in reservoirs outside KWLS dependent on the Sanctuary

 S4.6 Groundwater recharge increased by KWLS

 S4.7 Fish productivity

*S4.1 Soil retention*

Tree canopy cover, grasses, leaf litter and humus all contribute to arresting soil erosion and improving soil quality. The roots of forest trees also stabilize and provide mechanical support to soils, a particularly important consideration in dry climates such as those of the KWLS in helping prevent mass movements of shallow soils.

In the scientific literature, estimates of soil-related ecosystem services tend to use replacement cost methods. These take the form, for example, of assigning a price for nutrient loss by calculating the cost of fertilizer required to replace it, or assigning an economic value to sedimentation of water bodies by estimating the cost of dredging reservoirs. The economic value of soil conservation in this study has been estimated using the avoided off-site costs from sedimentation and nutrient loss, as the study area is prone to soil erosion by water but with negligible wind erosion. Soil erosion by water is a complex natural process. Detachment, transport and deposition of soil particles by falling raindrops and flowing run-off is affected by many soil attributes, including the physico-chemical properties of soil, topography, local weather and climate, and land use. The Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978) predicts long-term average losses from a specified land type and management system, and has been widely used to assess soil erosion.

India’s National Remote Sensing Agency (NRSA) uses the USLE equation formula below for estimating sediment yield from watersheds, informing the prioritization of management responses. Use of this model has also been recommended by Soil and Water Conservation Wing, Department of Agriculture, Government of India.

A=RxKxLxSxCxP

Where:

A = the mean annual soil loss;

R = rainfall erosivity factor;

K = soil erodibility factor;

L = slope length factor;

S = slope steepness factor;

C = crop management factor; and

P = erosion control practice or land.

The value of Erosivity factor (R) for KWLS is 300. Value was derived from Iso-erodent map of India by Babu *et al.* (1978). Soil erodibility factor (K) depends upon texture, structure, particle size, permeability and organic matter of the soil. Singh *et al.* (1981), developed ‘K’ values for Indian conditions. The soil series of the study area ‘sandy clay loam’ with a K value of 0.11. Slope length and slope steepness (LS) factors derived by Mongkolsawat *et al.* (2004) are used for this study. Slope (%) LS factor 0-2\*degree - 0.255. The crop management (C) factor: The crop management factor represents change in soil erosion due to different land use. A land use/land cover map of KWLS was used to analyze the ‘C’ factor. ‘C’ values estimated by Gupta *et al.* (2005) were used for this study (see Table S4.1). Erosion Control Practice (P) factor: ‘P’ value is change in soil erosion rate by means of different mechanical structures such as bunds, terrace farming etc. In absence of any such structures it is taken as 1, following Arnoldus (1980).

### *Table S4.1: Crop management ‘C’ factor for different land uses in the KWLS*

|  |  |
| --- | --- |
| **Land use category** | **C factor** |
| Built-up Land | 0.01 |
| Water bodies | 0.6 |
| Exposed areas | 1.0 |
| Scrubland | 0.001 |
| Forests | 0.001 |
| Agriculture land | 0.3 |
| Rocky | 0.8 |
| Grassland | 0.1 |

As noted above, soil retention services are not directly valued, but inform economic valuation of avoided off-site costs from sedimentation (S4.2) and nutrient loss (S4.3).

*S4.2 Assessing sedimentation avoidance*

Eroded soils result in sedimentation, reducing the water-holding capacity of rivers and reservoirs. Desilting of reservoirs a very costly, and often an impossible process, accentuating the importance of maintaining forest health in the catchment areas of reservoirs and so extending the utility and longevity of impoundments. Estimation of the economic value of avoidance of sedimentation by the KWLS was based on the cost of alternative technological interventions (in this case dredging). Cost estimates of INR 58.31 m-3 of sediment removed were derived from the Central Water Commission (Verma *et al*. 2015).

Weight of soil was considered as 1.2 tonnes m-3 as per Verma *et al*. (2015). This study estimated that 0.48 million tonnes of soil loss is avoided by the vegetative cover of the KWLS Dry deciduous Dhonk forest and mixed deciduous forest in khoh avoid maximum soil loss estimated avoidance cost benefit of sedimentation avoided in KWLS was estimated at 4.7 million per year considering 20% sedimentation rate. Quantification of soil loss avoidance by land cover type is outlined in Table S4.2, and translated into sedimentation avoided (80,621.7 m3) with a total economic value of INR 4.701 million as summarised in Table S4.3.

*Table S4.2: Soil erosion avoided by different land use class in KWLS*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Land use class** | **Area (ha)** | **Soil loss (tonnes ha-1)** | **Soil loss avoided (tonnes ha-1)** | **Total soil loss avoided (tonnes ha-1)** |
| **Waterbody** | 536 | 4.95 | 3.3 | 1,768.8 |
| **Ravines/Barren** | 3,720 | 8.25 | 0 | 0 |
| **Seasonal grassland** | 34,596 | 0.825 | 7.425 | 256875.3 |
| **Dhonk forest** | 14,828 | 0.02475 | 8.22525 | 121,964.01 |
| **Dense forest** | 9,883 | 0.0165 | 8.2335 | 81,371.681 |
| **Farmland** | 3,424 | 2.475 | 5.775 | 19,773.6 |
| **Human habitation** | 242 | 0.0825 | 8.1675 | 1,976.535 |
| **Total** | **67,229** | **Total** | **483,729.92** |

*Table S4.3: Economic value of avoided sedimentation from different land use class in KWLS*

|  |  |  |  |
| --- | --- | --- | --- |
| **Land use class** | **Sedimentation avoided (\*tonnes)** | **Sedimentation avoided (m3)** | **Economic value (INR)** |
| **Waterbody** | 353.76 | 294.8 | 17189.8 |
| **Ravines/Barren** | 0 | 0 | 0 |
| **Seasonal grassland** | 51375.1 | 42812.6 | 2496400 |
| **Dhonk forest** | 24392.8 | 20327.3 | 1185287 |
| **Dense Forest** | 16274.3 | 13562 | 790797 |
| **Farmland** | 3954.72 | 3295.6 | 192166 |
| **Human habitation** | 395.307 | 329.423 | 19208.6 |
| **Total** | **96,746** | **80,621.7** | **4.701 million Rupees** |

*S4.3 Assessing soil nutrient retention*

Nutrients are also lost in eroded soil. Consequently, reducing soil erosion from forests retains soil nutrients and their beneficial slow release into the surrounding environment, also resulting in eutrophication of water bodies with potentially serious impacts on the health of aquatic ecosystems (Koskiaho *et al.* 2003, Pinard and Putz 1996, Unger and Vigil 1998). Economic evaluation of nutrient retention was calculated based on the replacement cost of commercial fertilizers. The study estimated a nutrient retention value of KWLS at 85.92 INR million per year based on calcuations in Table S4.4.

*Table S4.4: Economic value of soil nutrient loss avoided by KWLS forest*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Soil Nutrient Concentration (kg tonne-1)** | **Nutrient loss avoided by forest (kg)** | **Fertilizer used for evaluation** | **Economic value (INR millions)** |
| Nitrogen | 2.32 | 1,122.25 | Urea | 5.95 |
| Phosphorus | 0.044 | 21.28 | DAP | 0.43 |
| Potassium | 8.25 | 3,990.77184 | Muriate of Potash | 79.54 |
| **Total** | **85.92** |

Assessment of water-related ecosystem services reflects that, when precipitation falls on a forested landscape, it is intercepted by the dense canopy cover reducing the intensity of impact with the soil surface and consequent run-off. This process can be represented by a simple water balance equation (P) (Kumar *et al.* 2005):

P = E + R + F+GW

Where

‘P’ is precipitation;

‘E’ is evapo-transpiration; ‘R’ is run-off;

‘F’ is Field capacity (It is the amount of soil moisture or water content held in the soil after excess water has drained away and the rate of downward flow); and

‘GW’ is groundwater recharge.

*S4.4 Water volume within the KWLS*

Water volume within the KWLS was estimated by multiplying water body area in impoundments with the average depth of water, considered to be 2m for small check-dams and 7m for masonry dams. This is a stock value, with calculations of economic value were based on a price of 158.08 INR ha-1 representing an average of canal irrigation water rates in Rajasthan (Central Water Commission 2017).

A total human population of 19,179 and a population of 73,032 livestock units was found to be living within the KWLS at the time the surveys were carried out. Farmland inside the KWLS provides food to this population, and are sustained by the surface water resources of the KWLS. These water bodies are also used for small-scale fishing as well as for growing Singada (*Trapa natans*) during the monsoon season. In KWLS, there are many check dams known as P*angara* and one small masonry reservoir at Kalyanpura. Water remains in check dams until the end of February, whereas Kalyanpura reservoir is drained in September to utilized exposed fertile land for winter cropping. Cumulative surface area of Pangara was measured as 3.26 km2 (calculated from satellite image dated January 2015), storing a theoretical 6,520 m3 water valued at 0.13 million Rupees. A small masonry reservoir located at Kalyanpura occupies a surface area of 2.1 km2, storing 14,700 m3 of water valued at 0.3 million Rupees.

The total stock value of water stored inside KWLS was estimated at 0.16 million Rupees.

*S4.5 Water volume in reservoirs outside KWLS dependent on the Sanctuary*

The KWLS forest forms an important source of streams draining to plains adjoining to the area of reserve. Around the KWLS, a number of reservoirs have been constructed to harness surface flows from the sanctuary, maintaining the water table and directly used for irrigation. Four small reservoirs located outside the KWLS receive water from KWLS watershed. Needhar dam is completely dependent on KWLS for its water, forming the eastern border of the sanctuary with a catchment area lying exclusively within the KWLS and irrigating 1,088 haof farmland in 12 villages. KWLS also forms a significant part of the catchment areas for the other three dams (Kalisil Reservoir, Mamchari Dam and Atewa) receiving an estimated 50% of their water from KWLS and collectively irrigating 6,658 ha of farmland in 41 villages. The value of water within these four reservoirs was calculated on the same basis as that for water bodies within the KWLS, yielding a total estimated economic value of irrigation water of 0.61 million Rupees per year (Table S4.5).

*Table S4.5: Small and medium dams peripheral to and reliant upon the KWLS watershed*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Reservoir** | **Surface area (ha)** | **Land under irrigation area (ha)** | **No. of villages irrigated** | **Gross Capacity (Mcft)** | **Economic value of water (Rupees)** |
| Kalisil Reservoir | 235 | 4,700 | 14 | 1,471.56 | 371,488 |
| Mamchari Dam | 130 | 587 | 5 | 174.45 | 46,396.48 |
| Nidar Dam | 210 | 1,088 | 12 | 346.08 | 171,991 |
| Atewa | 11 | 283 | 10 | 833.426 | 22,368.32 |
| **Total** | **586** | **6,658** | **41** | **2,825.516** | **612,243.8** |

*S4.6 Groundwater recharge increased by KWLS*

Groundwater resources in Karauli district are overexploited (CGWB 2017) emphasizing the importance of conservation of the KWLS. Groundwater recharge is highly dependent on the geology and topography with additional significant influences from land use and land cover. The roots of vegetation facilitate the downward percolation of water, and permeable soils reduce the quantity, pace and concentrations of suspended matter running off landscapes. Forest land notably reduces sediment load as well as forming an important source of water entering river catchments (Sanford 2002, Nolan *et al*. 2007, Kumar *et al*. 2006). The KWLS is of substantial value for recharging groundwater, acting as a lifeline for the survival of local people surrounding the KWLS.

Table S4.6 provides a breakdown of the effects of different land cover categories within the KWLS on groundwater recharge and run off. The estimated quantity of additional groundwater recharge and run-off facilitated by vegetation in the KWLS is shown in Table S4.7, totaling 40.17 million m3 year-1 valued at 823.16 million Rupees.

*Table S4.6: Effect of land use pattern on groundwater recharge and run-off in the KWLS*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Habitat** | **Field capacity (F)** | **Root constant (mm)** | **Run-off (mm)** | **Groundwater Recharge (mm)** |
| Khoh forest | 100 | 300 | 14.28 | 83 |
| Dhonk forest | 100 | 200 | 14.28 | 80 |
| Agricultural fields | 100 | 100 | 16.32 | 53 |
| Grassland | 100 | 100 | 16.32 | 53 |

*Table S4.7: Quantity and economic value of groundwater recharge in the KWLS*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Habitat type** | **Run-off (m3 ha-1)** | **Groundwater****Recharge (m3 ha-1)** | **Additional Groundwater recharge (m3)** | **Value of groundwater (INR millions)** |
| Khoh Forest | 142.8 | 0.830 | 8,161,390 | 167.22 |
| Dhonk Forest | 142.8 | 0.830 | 11,862,400 | 243.06 |
| Agricultural field | 163.2 | 0.530 | 1,814,720 | 37.18 |
| Grassland | 163.2 | 0.530 | 18,335,880 | 375.7 |
| **Total** | **612** | **2,690** | **40,174,390** | **823.16** |

*S4.7 Fish productivity*

Fish productivity data were also collected fromreservoirs in and around KWLS were also obtained from the Department of Fisheries, Karauli District, with fish productivity data for Sawai Madhopur district obtained from the FAO (2009) database. The price of table fish was determined to be 100 INR kg-1 based on the average fish price in local markets.Nidhar dam is completely dependent on the KWLS watershed, whereas Kalisil, Atewa and Mamchari dams were considered to be 50% dependent on the KWLS. Fish productivity of the dams is calculated from average fish production, yielding a total of 34,960 kg, worth 0.34 million Rupees year-1.

*S4.8 Cumulative totals for soil-and water-related ecosystem services*

Summary values for soil- and water-water related ecosystem services provided by KWLS are provided in Table S4.8.

*Table S4.8: The combined economic value of soil and water-related ecosystem services of the KWLS*

|  |  |
| --- | --- |
| **Ecosystem service** | **Economic value (millions Rupees year-1)** |
| Soil loss avoidance | 4.7 |
| Nutrient retention | 85.92 |
| Groundwater recharge | 823.16 |
| Water supply to dams | 0.61 |
| Water stored within the KWLS | 0.13 |
| Fish production | 0.34 |
| **Total** | **914.86** |

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**S5. Economic value of tourism of the KWLS**

Tourism is one of the fastest growing industries in the world, creating millions of jobs and, in India, contributing 14.1 trillion Rupees to the economy (USD208.9 billion) in 2016 (Economic Times, 2017). India’s rich biodiversity, including charismatic wildlife species such as the depiction of India as a land of Tigers (India is home to 70% of the global tiger population), supports local economies and generates support for conservation (Sekhar 2003, Soto *et al.* 2001, Wallace and Pierce 1996, King and Stewart, 1996). The rich and varied topography, vibrant culture and festivities of Rajasthan state makes it a particularly attractive tourism destination despite the extreme climate Rajasthan.

Tiger Reserves constitute the highest revenue-generating wildlife destinations in India, Ranthambhore National Park (RNP) constituting one of the most popular wildlife tourism destinations in the world and the largest generator of revenue amongst all of India’s Tiger Reserves (Buckley and Pabla 2012, Sinha *et al.* 2012). In financial year 2016-17, the revenue generated by the Forest Department through entry fees and surcharges was 19.57 crore Rupees. (An estimate of 30 crore Rupees was made for 2018- 19). Total management budget of the park was 13.89 crore Rupees during the same 2016- 17 period. This makes RNP not only self-sufficient financially, but also generates surplus funds by 140.89%. This revenue is utilized entirely for management of the park and for tiger conservation. The economy of Sawai Madhopur, the nearest town of Ranthambhore, is almost entirely dependent on tourism. According to one estimate, 15,000-20,000 persons in the area are directly employed in tourism-related activities (Upamanyu *et al*. 2018). Overspill from the overpopulated RNP tiger population includesanimals crossing into the KWLS, which has a fundamentally similar landscape. The KWLS also sustains a large population of the Indian grey wolf, offering scope for developing wolf-centred ecotourism in addition to the attraction of strong populations of golden jackal, Bengal fox, white-footed fox, Indian striped hyena, leopard, caracal, jungle cat and sloth bear. There is therefore significant scope for promoting wildlife tourism in KWLS, beneficial for nature conservation but also increasing revenue for the forest department and local communities, and potentially reducing pressure on the RNP.

The travel-cost method (TCM), a behavioural method representing the ‘use value’ of a particular ecosystem service (Clawson and Knetsch 1966), was used for estimating the potential economic value of tourism in the KWLS. Travel cost information was collected by surveying visitors to the site to determine the number of visits made over a defined period (usually during the last 12 months), distance travelled from the visitor’s home to the site, mode of travel (car, plane, bus, train, etc.), and time spent travelling to the site.

The researcher then uses this information about distance and mode of travel to calculate travel costs. Alternatively, visitors can be asked directly in a survey to state their travel costs, although this information tends to be somewhat less reliable (Ward and Beal 2000, Zhang *et al.* 2015, Zandi *et al.* 2015).

Several small religious sites belonging to different religions are present inside the KWLS. Due to the remoteness of these places, and the consequent hardships entailed in traversing difficult forest paths, most of the sites receive very few visitors. Some of the sites though are relatively better-connected by transport facilities, and hence visited by larger numbers of visitors. Assess of use of the most active religious sites used key informant interviews with people who have detailed knowledge to produce results that can be generalized across the population (Scott and Garner 2013, Marshall 1996, Slater *et al.* 2005), and also focus group discussions (FGDs) (Morgan 1996). Key informants were selected from the local villages by Forest Department staff. A list religious sites receiving a good number of visitors were prepared after discussion with the key informants. Five religious sites (Ghanteshwar, Kudaka Math, Maheshra Kho, Kailadevi cave, and Kedar-Baba Khoh) were shortlisted as the most visited places in the KWLS following key informant interviews, and FGD meetings were conducted in each on a predetermined date near the religious sites involving the priest, local villagers and forest staff (Liswanti and Basuki 2009) and all key informants. FGDs included open-ended questions addressing: the number of pilgrims visiting the temple on a normal day and on holidays; variation in number of pilgrims in different seasons and during festivals; distance travelled by visitors and the common modes of transport that they use; and duration of the visit and other expenditure.

From there assessments, it was determined that approximately 52,980 tourist visits the five selected temples in the KWLS per year (Table S5.1), most tourists coming from nearby villages and small towns (including Sapotara, Kailadevi, Hadoti and Malana) but the Kedar Baba temple is visited by pilgrims coming from further afield including as far away as Jaipur and bordering districts of Madhya Pradesh. Money spent on travelling, determined using evidence gathered at the FGDs, derived a total economic value of INR 6,894,000 year-1.

Tourist also brings with it pressures. Large quantities of plastic waste were found to have accumulated near temples. Also, as all religious sites are situated in khoh, the importance of these habitats for soil quality, moisture retention, cool microclimate and biodiversity can be compromised with irresponsible behaviour. It is therefore recommended that: an inventory of the number of tourists should be maintained; arrangements should be made for proper disposal of waste and banning of persistent drink and food containers should be banned; cooking should be located away from water sources; and temporary sanitation facilities should be erected in the forest on festival days to prevent contamination of the ecosystem.

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**S6 Qualitatively described ecosystem services of the KWLS**

Although ecosystem service valuation is progressively becoming part of major international agreements and supported by an evolving tool set, not all of ecosystem service values can be expressed in monetary terms. Some services relate to the status of the ecosystem and may be expressed in terms of biophysical metrics, others relate to changes affecting communities and can be expressed in surrogate terms of monetary values or employment creation (Turner *et al.* 2016, Goulder *et al. 1997,* Kelemen *et al.* 2014), whilst other (particularly cultural) service can be highly culturally subjective and may require representation in other ways. This study used an in-depth literature review, discussions with local and international experts and consultations with communities in and around the KWLS to identify relevant ecosystem services to be assessed but, where data were unavailable or a robust methodology was lacking, the service is qualitatively described to demonstrate its relative significance. These qualitatively described ecosystem services include: pollination services;

### *S6.1 Pollination ecosystem services*

Pollination services are a key regulating ecosystem service for agriculture and food security, enhancing agricultural production of a broad range of crops including fruits, oilseeds, vegetables, fibre crops and nuts (e.g. Levin 1984, Costanza et al. 1997, Gordon and Davis 2003). As many as one-third of crop species in the world require animal pollinators. There are two main methods to assess the economic value of pollination based on: the total value of crops dependent on pollinators; and pollinator dependency rates (% fruit or seed set by insect pollinators) of the crop. Both these methods are routinely used to estimate the value of pollination at local, national and global scales (Brittain and Potts 2011, Lautenbach *et al.* 2012).

In the KWLS, the main cropping season is in thekharif (post-monsoon), during which time 2,551.07 ha are under cultivation, with 1,749 ha cropped in the rabi (dry season). Cereal grains are the most important crops in both the cropping seasons but, as all grain crops belong to the *Poaceae* (grass) family, they are mostly depend on wind pollination with little or no contributions from insect pollinators. Crops benefitting from insect and other pollinators in the KWLS, as revealed by household surveys, include sesame, pulses and sweet potato during the kharif season, and chickpeas and mustard in the rabi season. Forests provide a niche for habitat, hibernation and food for a variety of pollinator species, so a decline in forest area whether due to conversion to farmland or other reasons will have a negative impact on pollinator abundance. Most studies of the economic value of pollination provided by insects use benefit-transfer methods based on payments by farmers and orchardists in the US for hiring in bee hives. However, these systems have no match in the ecosystems and farming pattern in the KWLS. There is an absence of any relevant prior study for estimating the role and economic value of forest-dwelling pollinators in similar semi-arid ecosystems to the KWLS. There is a consequent need to conduct a field experiment to analyze the role of pollinators. However, as this type of experimental study would requires eight months and some significant investment, it is beyond the scope of this time-limited study. Therefore, the pollination-related ecosystem services provided by the KWLS are described in qualitative terms.

### *S6.2 Genetic resources ecosystem services*

Biodiversity itself is not an ecosystem service, but rather it is the essential foundation along with geodiversity of many processes producing a diversity of provisioning, regulating, cultural and supporting ecosystem services. Prior studies of the value of biodiversity have employed a range of valuation methods, including addressing it as a marketable commodity, a proxy for eco-tourism, through contingent evaluation (CV) of non-marketable commodities, or potential exploitation of genetic diversity. Most of these methods are hypothetical in nature and susceptible to considerable biases since no actual monetary payment is transferred (Freeman 1993, Mitchell and Carson 1989). Furthermore, the idea of economic valuation of biodiversity is justifiably criticized for commodifying nature, and it is beyond human capabilities to replace the ecosystem services provided by biodiversity (Mainwaring 2001).

Nevertheless, the genetic diversity (gene pool) present in all species within an ecosystem represents a rich and co-evolved resource. However, as devising a measure, monetary or otherwise, for the value of biodiversity is impossible, this study does not attempt to assign a monetary value to the flora and fauna of the KWLS beyond supporting documentation of the biodiversity of the KWLS through rapid biodiversity surveys.

### *S6.3 Non-timber forest products (NTFPs) ecosystem services*

Non-timber forest products (NTFPs) broadly encompass any biological resources collected from the wild by the local community for direct consumption or income generation generally on a small scale (Shackleton and Shackleton 2004), an important set of provisioning ecosystem services. NTFPs derive from both plants (e.g. herbs, fuel, fodder and fruits) and animals (e.g. animal hides or bushmeat). The comprise food, medicines, tools and materials for crafts and other uses (Cordell *et al.* 2012, Robbins *et al.* 2008, McLain and Jones 2005, Perez and Arnold 1997). The benefits that people derive from NTFPs are generally tangible, and some are traded though other may serve subsistence or cultural needs. Valuation of ecosystem services is incomplete without taking account of these diverse tangible items, including products derived from them. A range of prior studies have sought to attribute economic values to NTFPs, comprising the sum of consumer and producer surpluses (Dash *et al.* 2016).

Villages and small settlements in the KWLS are very remote and isolated, the human population with a consequent high dependency on forests including various NTFPs. Fodder and timber are the most extensively harvested NTFPs of the KWLS, though these have already been accounted for. A list of the other more important NTFPs from the KWLS, derived from the large-scale villager socioecological survey, includes: wild fruits (Ber, *Grewia*, Carandas, etc.); asparagus roots; *Grewia tenax* sticks; *Ocimum basilicum* seeds; gum; medicinal plants; and fibres from plants. However, there is extensive illegal extraction (poaching) of *Asparagus* roots, sticks from the *Grewia tenex* shrub and seeds from the herb *Ocimum basilicum*. Villager surveys in this study found that there was little or no commercial utilization of NTFPs by local communities. However, illegal extraction was being carried out at substantial scale by people from Seharia and Mogya communities inhabiting the neighbouring state of Madhya Pradesh, groups of poachers crossing the Chambal river and camping for a number of days to collect these NTFP materials. The attributes of these three principal types of illegally extracted materials are described in Table 8.6 below.

### *Table 6.2: List of important illegally extracted NTFPs from the KWLS*

|  |
| --- |
| **Roots from the herb *Asparagus racemosus* (Shatavari)**Shatavari is a perennial, prickly climbing herb with extensively branched prickly stems. It occurs throughout the tropical and subtropical regions of India up to an altitude of 1200 metres. The roots of the shatavari are tuberous, 15-40 cm long, and greyish in colour. These *Asparagus* roots are one of the most important plants in traditional indian medicines, believed to increase vigour and vitality and particularly for women’s reproductive health. Thse roots consequently have a high market value, and are therefore heavily poached from the forest. Every winter, a few hundred poachers from the neghbouring state of Madhya Pradesh illegally remove hundreds of tonnes of Shatavari, selling the roots in local markets in Sheopur and adjacent towns for 150-200 Rupees per kg. As this the plant is a critical food source for porcupines and many other small mammals, its extensive removal can have significant ecological consequences. |
| **Sticks cut from the shrub *Grewia tenex****Grewia tenax* is a large shrub, growing up to 2 metres tall. The bush is usually rounded in shape, but is more commonly encountered battered and untidy due to browsing by animals. The bark is smooth, grey and very fibrous, so the twigs are hard to break. The fruits of *Grewia tenax* are consumed by humans and animals, and contain a large amount of iron. Fruit storage can be extended by drying. The young leaves are consumed by livestock, with reasonable palatability at the end of dry season and good feed value. The wood is sturdy, and is used in making durable products such as the handles of weapons, agricultural equipment and other general purposes. *Grewia tenax* is one of the most common shrubs in the KWLS, and a large quantity of twigs is illegally harvested. A single twig of 4-5 feet in length can be sold for 5-10 Rupees in local markets. |
| **Seeds from the herb *Ocimum basilicum****Ocimum basilicum* is an aromatic, perennial herb growing up to 0.5 metres tall. The stem is erect, rounded or slightly square in cross-section, much branched and glabrous or pubescent. The whole plant and the essential oil extracted form it have many applications in traditional medicine, especially in Africa and India. Preparations from the whole plant are used as a stomachic and for treating sunstroke, headache and influenza. The seeds have laxative properties and are also used as flavouring agents in food. The essential oil is used to treat fever, inflammations of the throat, ears or eyes, stomach pain, diarrhoea and skin diseases. *Ocimum basilicum grows* commonly in the ravine areas of the KWLS. Large quantities of seeds from the herb are harvested and taken for use and sale in Madhya Pradesh. |

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**S7 Miscellaneous ecosystem services of the KWLS**

Remaining ecosystem services not thus far addressed that are recognised in this study include:

 S7.1 Assessment of gene pool protection ecosystem service in the KWLS

 S7.2 Estimation of pollination ecosystem services in the KWLS

 S7.3 Provision of habitat for wildlife and refugia as a supporting ecosystem service

S7.4 Biological control as a regulating ecosystem service

S7.5 Gas regulation

S7.6 Waste assimilation

**S7.1 Assessment of gene pool protection ecosystem service in the KWLS**

The gene pools of different species of plants, animals and microbes contribute to commercial products in industries such as pharmaceuticals, medicines, crop protection, cosmetics, horticulture, manufacturing and construction sectors, as well as in agriculture providing the basis for further development of commercial crops and livestock (Busch *et al*. 2005, Brock and Xepapadeas 2003, Verma *et al*. 2017). Verma *et al* (2015) calculated an economic value of gene pool protection for Ranthambhore division RTR at INR 91,020 ha-1 yr-1. This study transfers that value due to the close proximity and similarity of the RTR to KWLS. Correcting for area differences, gene-pool protection for KWLS forest is assigned an indicative value of INR 6124 million yr-1.

**S7.2 Estimation of pollination ecosystem services in the KWLS**

Verma *et al* (2015) calculated an economic value for pollination-related ecosystem services of Ranthambhore division RTR of INR 1,800 ha-1 yr-1. This study transfers this value due to the close proximity and similarity of the RTR to KWLS. Correcting for area differences, pollination services in the KWLS are assigned an economic value of INR 121.10 million Rupees.

### S7.3 Provision of habitat for wildlife and refugia as a supporting ecosystem service

Verma *et al* (2015) calculated an economic value for habitat protection-related ecosystem services of Ranthambhore division RTR of 2,340 INR ha-1 yr-1. This study transfer this value due to the close proximity and similarity of the RTR to KWLS. Correcting for area differences, habitat for wildlife services in the KWLS are assigned an economic value of INR 157.44 million Rupees.

**S7.4 Biological control as a regulating ecosystem service**

Forest ecosystems are more resilient than agriculture ecosystems against the diseases and pests affecting plants and animals due to complex food webs and populations of predators that are often absent or diminished in habitats altered by human activities. Birds, bats, ﬂies, wasps, frogs and fungi all act as natural controls and help to reduce the incidence of various infectious diseases (Verma *et al.* 2017, Lele *et al.* 2013). Verma *et al* (2015) calculated an economic value for biological control-related ecosystem services of Ranthambhore division RTR of INR 660 ha-1 yr-1. This study transfers this value due to the close proximity and similarity of the RTR to KWLS. Correcting for area differences, the regulating services of biological control of pests and diseases in the KWLS are assigned an aggregate economic value of INR 44.4 million Rupees.

### S7.5 Gas regulation

### Forest ecosystems regulate the chemical composition of atmospheric gases like oxygen, ozone and CO2, regulating ambient environmental concentrations. This occurs through the complex interactions and processes that occur between organisms (mainly plants and microbes) with the wider environment. Verma *et al* (2015) calculated an aggregated economic value for gas regulation-related ecosystem services of Ranthambhore division of RTR of INR 720 ha-1 yr-1. This study transfers this value due to the close proximity and similarity of the RTR to KWLS. Correcting for area differences, the aggregated gas regulation-related ecosystem services in the KWLS are assigned a cumulative economic value of INR 48.44 million Rupees.

**S7.6 Waste assimilation**

Similar to gas regulation, ecosystem also breaks down various manmade chemical and other waste products though complex food and energy webs. This aggregated set of services, including the regulating service of physico-chemical purification of water and other purification processes related to natural cycles, are very important in detoxifying the environment without producing secondary pollutants (Rees and Wackernagel 2008, Kautsky *et al*. 2000). Verma *et al* (2015) calculated an aggregate economic value for waste assimilation-related ecosystem services in the Ranthambhore division of RTR at INR 7200 ha-1 yr-1. This study transfers this value due to the close proximity and similarity of the RTR to KWLS. Correcting for area differences, the aggregated waste assimilation-related ecosystem services in the KWLS are assigned a cumulative economic value of INR 484.43 million Rupees.

**S7.7 Summary of miscellaneous ecosystem services of the KWLS**

Table S7.1 summarises the above categories of miscellaneous ecosystem services provided by the KWLS.

*Table S7.1: Summary of miscellaneous ecosystem services provided by the KWLS*

|  |  |
| --- | --- |
| **Miscellaneous ecosystem services** | **Indicative economic value****(INR million year-1)** |
| S7.1 Gene pool protection | 6,124 |
| S7.2 Pollination | 121.10 |
| S7.3 Provision of habitat for wildlife and refugia | 157.44 |
| S7.4 Biological control | 44.4 |
| S7.5 Gas regulation | 48.44 |
| S7.6 Waste assimilation | 484.43 |
| **Total** | **6,979.82** |

**References for S7**

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**End of Supplementary Material**