Soil and plant nutrient loss during the recent floods in North Karnataka: Implications and ameliorative measures

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Climate change has resulted in several kinds of aberrations in the weather phenomenon all over the globe. The recent unprecedented rainfall leading to floods in 13 districts of North Karnataka was said to be one such event. Very high rainfall received over a short period of time in a region dominated by black soils, resulted in severe loss of crops, soils, soil organic matter and soil nutrients besides destruction of humans, livestock and farming infrastructure. The shallow depth and heavy texture of the soil made the situation worse. An estimate made after the calamity revealed that nearly 287 million tonnes (mt) of top soil, 8 lakh tonnes of soil nutrients and 39 lakh tonnes of soil organic matter were washed away. In monetary terms, about 853 crores rupees worth of soil organic matter and 1625 crores rupees worth of plant nutrients, and nearly 57.5 mt of soil microbial biomass were lost from the region during this short period. In addition, nearly 2 lakh ha of cultivated fields in the flood-affected area were deposited with sand along the river courses. These losses have severe long-term implications on crop productivity and rural economy of the region. The present study points out the damages caused to the soil and other natural endowments of the area, and the amelioration measures needed to bring back the area to cultivation for the future.

Keywords: Climate change, floods, soil nutrient loss, organic matter loss.

In Karnataka, as in other Indian states, livelihood of the majority is intertwined with farming pursuits. Challenges in agriculture would seriously threaten the livelihood of a large number of farmers as they have been practising farming against adverse factors beyond their control. Climatic factors have become more significant in recent times due to rapid climate changes induced by intensive anthropogenic activities affecting our ecosystem in multiple ways. Climate change has become a reality; it is happening and has become inevitable. The rising temperatures and unpredictable rainfall patterns would seriously hamper the day-to-day decisions to be taken by the farmer.

It is generally recognized that impacts of climate change will not be uniform across the globe. It is said that impact is more severe in South Asia. Based on the analysis of meteorological and ancillary data, it is predicted that in India, there will be an upward surge in mean temperature, and a downward trend in relative humidity, annual rainfall and the number of wet days in a year[1]. Also, in general, phenomena like erratic monsoon, shifting of agricultural zones, spread of tropical diseases, rise in sea levels, changes in availability of freshwater, frequent floods, droughts, heat waves, storms and hurricanes have been predicted. Each one of these adverse situations is already being experienced in various parts of the globe and more so in India. Decline in agricultural productivity with small and marginal farmers becoming more vulnerable has already been witnessed in many states of the country[2,3].

During October 2009, 13 districts of North Karnataka witnessed the effect of climate change phenomenon. A cyclonic depression built up along the eastern coast of India during the last week of September 2009, moved rapidly across the Deccan and then to the north by the first week of October 2009. This caused a very deep depression in the region[4]. The total quantity of rainfall received during the short period from 29 September to 3 October 2009 (less than a week's time) has no parallel in the recent past. In just about five days, this region received about 70% of its total annual rainfall (Figure 1).

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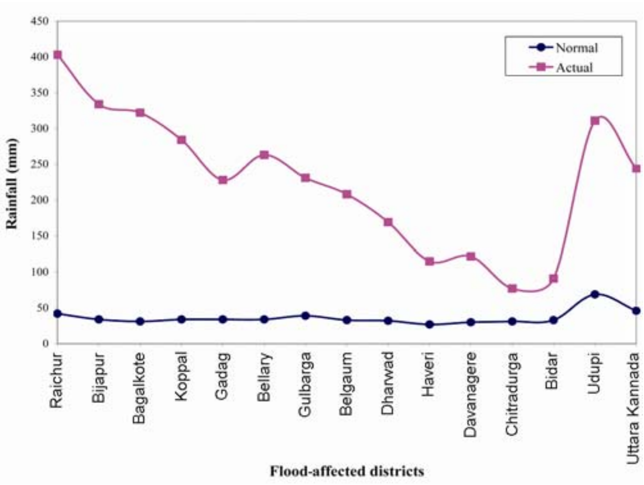

Figure 1. Rainfall received during 29 September to 30 October 2009 in the flood-affected areas.

The excess rainfall was about 177–924% in the affected districts. For example, in Bellary, the total rainfall received during the year (up to the middle of November 2009) had already exceeded the 100-year return period value. In October alone, the total rainfall received (314 mm) was above the 50-year return period. This sudden heavy downpour had caused severe damage to the soils, crops and infrastructure facilities in the catchment and command areas of the Krishna and Tungabhadra rivers, the two major river systems of the state, and their tributaries.

In addition to the excess rainfall received in the catchment areas of Krishna and Tungabhadra rivers and their tributaries, the other factors responsible for the large-scale devastation are:

1. Nature of the soil, being predominantly fine-textured, erosion-prone black soils.
2. Poor infiltration (in black soils) and consequent high surface run-off.
3. Longer slopes, which accelerate the rate of erosion, particularly in black soils.
4. Ineffectiveness of the soil and water conservation measures followed/adopted in the catchment and command areas.
5. Cultivation in river beds and stream courses.
6. Encroachment of the waterways and stream courses.
7. Thick growth of *Prosophis* sp. (Bellary jali) in the stream courses/riverbeds and on the stream/river banks and consequent blockage of the stream flow.
8. Lack of drainage facilities in the command areas, particularly in the Tungabhadra command areas, and consequent waterlogging.

All the above factors together have led to very high flows in hundreds of small streams and seasonal rivers, leading to overflow of their banks which has caused damage to the standing crops and siltation of fields along their water courses (Figure 2). Standing crops in nearly 22 lakh ha of area were affected by the heavy downpour and floods. Crop damage was mainly due to waterlogging, lodging and high incidence of disease. But, more than the damage caused by the floods in the downstream areas, maximum damage in the form of severe loss of soil (Figure 3 *a–d*), soil organic matter and soil nutrients was caused by the heavy downpour in the catchment areas of all the 13 districts in the state.

These events have a long-term negative effect on the agricultural productivity and rural livelihood security in the region. Hence, the present study was undertaken to make a scientific quantification of the loss of soil, soil organic matter, total nutrients and financial implications of these losses. Such a study was essential to make recommendations on the ameliorative measures needed and modifications to be made while undertaking soil and water conservation projects in the future. The study would enlighten the concerned authorities about the enormity of the problem and its impact on farm production in the region during the coming years. The study also provides a scientific basis for undertaking relief measures by the Government departments dealing with the restoration of soil health and agricultural productivity in these areas.

Methodology of estimation

During November 2009, an extensive traversing of the flood-affected districts to quantify the extent of soil loss in selected representative spots was undertaken. Detailed discussions were held with officials of various departments and farmers in the region to make these estimations. Taking into account the normal soil loss during normal rainfall years, conservative estimation of soil loss during the current abnormally high rainfall situation was carried out. The standard soil loss estimation procedure is available in the literature[5]. It was estimated that the abnormal weather phenomenon has resulted in a soil loss of 30 tonnes/ha in black soils and 20 tonnes/ha in red soils in the affected districts. The average nutrient content of the black soils and red soils was taken into consideration for estimating nutrient loss[6]. During the floods, as entire soil mass was removed from the agricultural fields, total nutrients loss was estimated instead of available nutrients. The prevailing market prices of nutrients were used for calculating the financial implications of soil nutrient and organic matter loss[7].

Results and discussion

Soil loss

An area of about 10.75 m ha, almost equal to half the total geographical area (TGA) of Karnataka, was affected

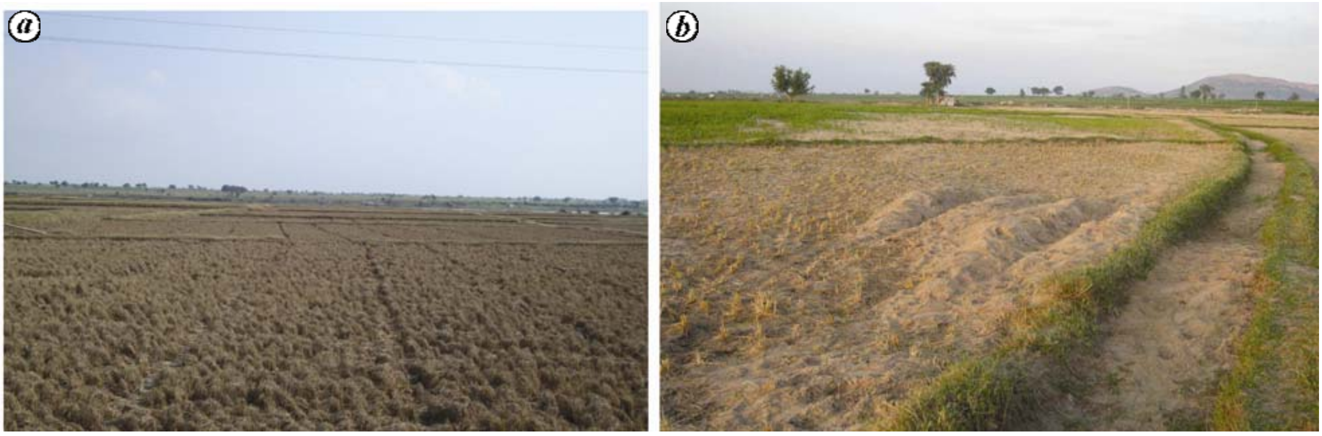

Figure 2. ***a***, Damaged paddy crop due to waterlogging near Albanur village, Sindhanur taluk, Raichur District. ***b***, Sand deposition in cultivated fields after the breach of bunds along the Hagari river, Bellary District.

Figure 3. ***a***, Sunflower plot affected with rill erosion in black soils near Kalmali village, Raichur District. ***b***, Deep gullies in black soils in Kalmali village. ***c***, Depth of severe gullying (60 cm) in cultivated fields in Kalmali village. ***d***, Erosion in red soils near Somnal village, Talikotta taluk, Bijapur District.

by the floods. The area affected comprised of catchment and command areas of two major river systems, namely Krishna and Tungabhadra, and their tributaries. Out of the 13 affected districts, the severity of damage was more in Raichur, Bijapur, Bellary, Gulbarga, Bagalkot, Koppal, Gadag and Belgaum. The area of flood inundation varied from 20 to 50 m all along the river courses and in a few areas to even 500 m on either side of the rivers.

The nature of the terrain was nearly level to very gently sloping in most of the affected districts (Figure 4)[6]. The slope was nearly level to very gentle in black-soil areas (1–2%), very gently to gently sloping in red-soil areas (2–8%) and gently to moderately steeply sloping (8–30%) in hilly and lateritic areas. More than the nature of the slope, it was the length of the slope which was responsible for the severity of erosion, observed particularly in black-soil regions.

Shallow to deep black soils (Vertisols) and shallow to moderately deep red soils are the major soils of this region. The black soils occur extensively on nearly level to very gently sloping lands. The clay content in the black soil is high to very high and after initial soaking and dispersion, they are prone to erosion if they are not protected by effective conservation measures. Maximum soil loss was noticed in Gulbarga, followed by Belgaum and Bijapur due to the dominance of black soils in these districts (Figure 5). Nearly 287 mt of soil was washed away during the flood period (Table 1). The loss of black soil was almost three times more than that of red soil due to its poor infiltration rate. It is estimated that the soil-forming process needs hundreds of years for the formation of a few inches of agriculturally productive soils. The floods have resulted in disrupting the entire soil ecosystem in this region, which will affect crop production negatively for many more years to come, unless urgent corrective steps are initiated.

Under natural condition, undisturbed by man, equilibrium is established between the climate of a place and the vegetation cover that protects the soil layer. A certain amount of erosion does take place even under this natural cover, but it is slow and limited in nature, which is balanced by the soil that is formed by continuous weathering and the soil-forming process. When this balance is upset because of the cultural practices followed or any other reason, removal of soil takes place at a faster rate than its renewal. Due to this imbalance, soil erosion has already become a serious problem in the affected districts (Figure 6). Severe sheet erosion, and formation of rills and gullies

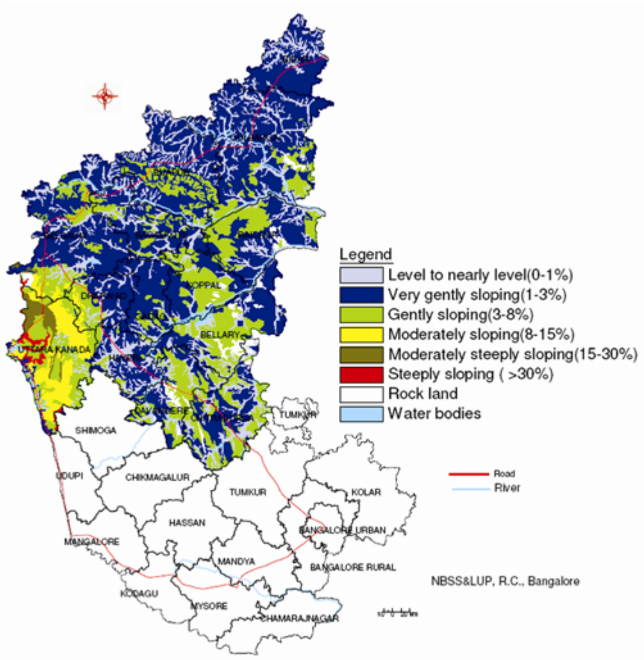

Figure 4. Slope map of flood-affected areas.

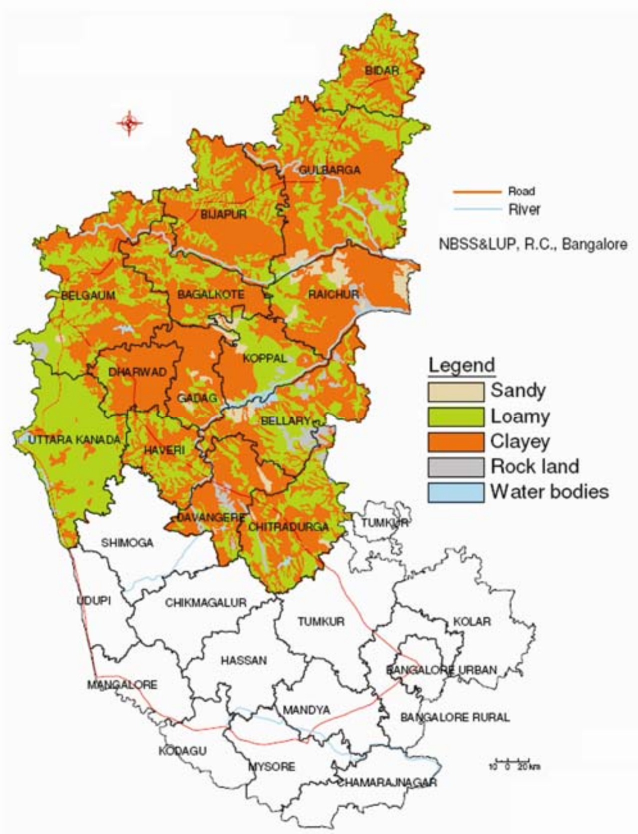

Figure 5. Soil texture of flood-affected areas.

Table 1. Soil loss from flood-affected areas in North Karnataka (mt)†

District	Red soil	Black soil	Total
Bagalkot	5.0	12.1	17.11
Belgaum	7.8	27.87	35.68
Bellary	7.5	11.27	18.84
Bidar	2.2	13.0	15.25
Bijapur	0.93	30.34	31.28
Chitradurga	9.1	10.4	19.63
Davangere	7.09	5.8	12.96
Dharwad	3.5	7.46	11.01
Gadag	2.4	10.15	12.62
Gulbarga	5.4	40.33	45.79
Haveri	4.5	7.62	12.15
Karwar	19.4	1.05	20.50
Koppal	5.5	7.44	12.96
Raichur	5.39	16.09	21.48
Total	86.21	201.10	287.32

†Average loss of red soil during the flood = 20 tonnes/ha.
Average loss of black soils during the flood = 30 tonnes/ha.
Average mass of 15 cm soil depth of bulk density 1.4 = 2100 tonnes/ha.

are common features in this area, particularly in black soils occurring dominantly in this region.

During sheet erosion, the movement of run-off water and eroded soil occurs in thin sheets continuously. When this moving sheet assumes sufficient velocity, its cutting action on the soil increases and results in the formation of rills, trenches or gullies. If the velocity of the run-off water is doubled, its energy increases fourfold; its erosive action on the soil increases correspondingly and its capacity to carry soil particles increases by 64 times[9]. The gullies tend to get deeper and wider with every succeeding rain and eventually cut up the agricultural lands into fragments, making them unfit for cultivation. Gully erosion is more evident and spectacular at the surface, but sheet erosion is more dangerous as it is insidious and seldom noticed before it is too late to remedy its destructive effects on heavy soils, i.e. black that are dominant in the North Karnataka region. These are highly susceptible to erosion as they are slow to absorb rainwater on account of their high clay fraction content[7]. Widespread damage due to sheet, rill and gully erosion many times exceeding the rate during normal seasons was noticed in the flood-affected areas depending upon the topography.

Another important reason for the severity of soil loss was due to the texture of the soils. The dominant black soils contain high amounts of clay (Figure 5). In the absence of sufficient organic matter in the black soils, the clay tends to become deflocculated and becomes hard when dry and sticky when wet. This impedes the further absorption of rainwater. With more rainfall all the fine particles are broken down from the crumb structure and get washed-off from the surface and carried away with the run-off water. The amount of run-off depends on the intensity of rainfall, a heavy storm lasting for a few hours can cause as much or even more damage than the rains during the rest of the year[8]. This is because gentle rain does not pulverize and break down the crumb structure of the soil, and the soil is able to absorb the water and accumulate it in the deeper layers for use by subsequent crops. Therefore during normal years, rabi crops are raised on stored/residual soil moisture in all the black-soil areas.

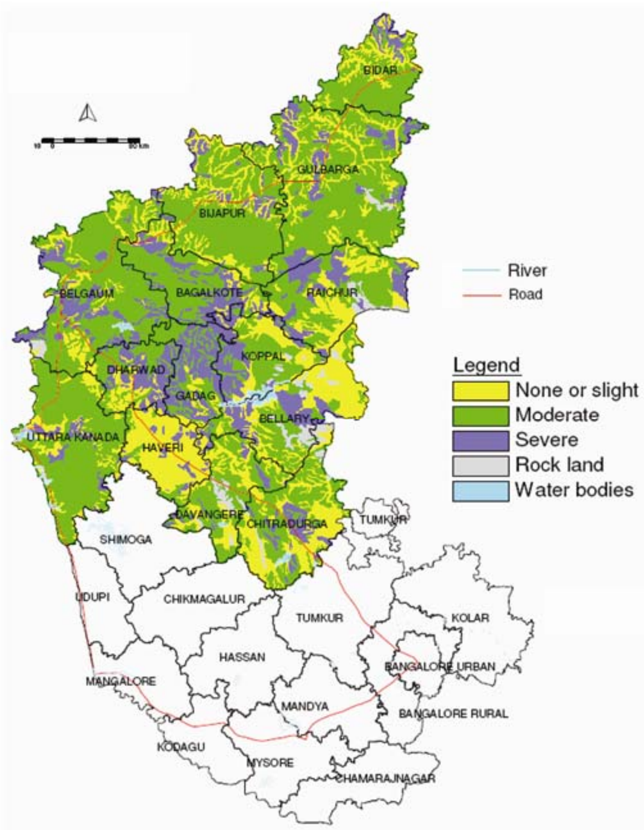

Figure 6. Soil erosion status of flood-affected areas before flood damage.

Due to the extreme events of rainfall, length of slope and nature of soils, the magnitude of the damage varied widely in the affected districts. Besides black-soil areas, it was noticed that soil loss was severe in the catchment areas adjoining seasonal streams, rivulets and agricultural fields that had been prepared and levelled on the natural drainage network. The thick growth of *Prosopsis* sp. in the streams blocked the natural flow of water. Areas cultivated with lift irrigation along the banks of rivers that usually carry very little flow or are dry for a major part of the year also suffered. Due to the large variation in rainfall from the long-term average, absence of adequate soil-conservation measures in the contributing area and release of water from the dams, the severity of crop damage was more in the lower reaches of the affected districts, but the soil loss was severe in the upper catchment areas of all the river systems. The calamity turned alarming because the soil depth in major parts of the flood-affected areas was already shallow to very shallow (Figure 7). Even a small soil loss reduced the crop productivity significantly in such shallow soils.

Soil nutrient loss

During the flood period nearly Rs 1625 crores worth of total soil nutrients were lost (Tables 2 and 3, and Figure 3 *a–c*). The losses were maximum in Gulbarga, Belgaum and Bijapur districts. Nearly Rs 888 crores worth of phosphorus, Rs 464 crores of micronutrients, Rs 161 crores of nitrogen and Rs 110 crores of potassium were lost during the flood period. The extent of loss of phosphorus was high as these soils are very rich in this nutrient element. Totally 8.17 lakh tonnes of soil nutrients were washed away. For restoring reasonable levels of crop yields, additional application of plant nutrients than the normal recommendation is now required. The essential role of these nutrients in maintaining crop productivity, particularly in rainfed areas needs no emphasis. In a short period of five days, the amount of nutrients equivalent to that normally applied over a period of one and half decades was washed from the region. In spite of best efforts, it shall take a considerable period of time to restore the status of nutrients to the original level.

Loss of soil organic matter and soil microbial biomass

Nearly 8 lakh tonnes of organic matter from red soils and 30 lakh tonnes from black soils were lost during the flood period. At the present purchase prices of organic manure, it will cost around Rs 853 crores to restore the same to its original status (Table 4). This was mainly because of the severe loss of topsoil due to the floods. Agriculturally essential surface soils have certain unique characters, which make them indispensable for crop production. The soil provides food and home to millions of beneficial microorganisms. As such fertile surface soils are the combined result of efforts of farmers and natural forces over a long period of time. When surface soils are removed due to such calamities, the first negative effect is on soil organic matter and soil microorganisms. Both of these are important to the functioning of soil and crop production system by affecting infiltration, water-holding capacity, erosion resistance, run-off, soil crusting, porosity, ease for tillage, nutrient transformation and release. Soil organic matter accounts for 50–90% of cation exchange capacity of surface soils. Tropical soils contain on an average 200 mg of soil microbial biomass in every kilogram of the soil[8]. During floods, nearly 57.5 mt of soil microbial biomass was lost and it will take many years to restore to original level.

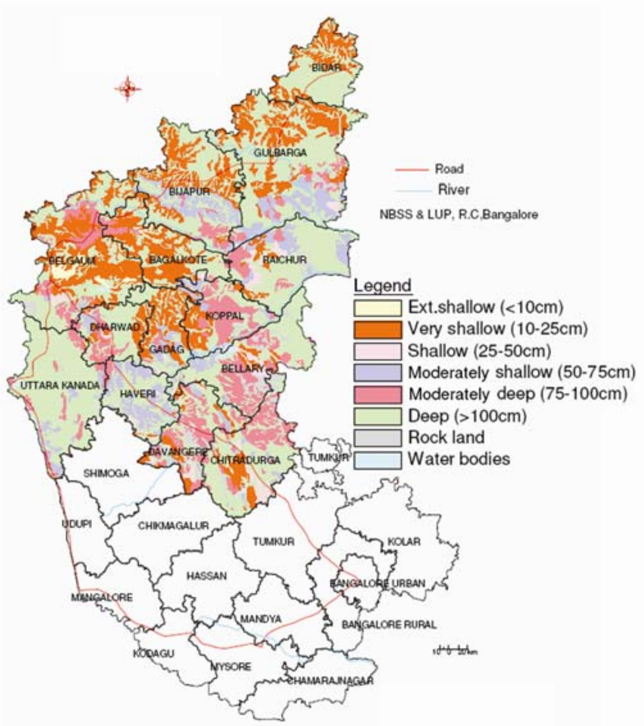

Figure 7. Soil depth of flood-affected areas.

Sub-surface soils show reduced biological activity. Organic amendments and fertilization of sub-surface soils are necessary to ensure rapid build-up of microbial populations and initiate nutrient cycling. Once surface soils are eroded or washed away by such unprecedented rains, bulk density of the remaining soil increases and hydraulic conductivity decreases. Due to this, plant establishment and growth are adversely affected leading to crop loss[10].

Table 2. Total nutrient loss from flood-affected areas of North Karnataka (tonnes)†

District	N	P_2O_5	K_2O	Fe, Mn, Zn, Cu	Total
Bagalkot	9183	32,700	4758	1935	48,577
Belgaum	18,820	65,991	10,119	3953	98,885
Bellary	10,367	37,711	5085	2194	55,359
Bidar	7911	27,310	4408	1656	41,287
Bijapur	15,757	52,915	9314	3282	81,269
Chitradurga	10,965	40,377	5202	2326	58,872
Davangere	7369	27,520	3357	1568	39,815
Dharwad	5949	21,307	3037	1255	31,549
Gadag	6619	23,095	3601	1389	34,706
Gulbarga	23,578	80,868	13,328	4931	122,706
Haveri	6641	24,024	3305	1404	35,375
Karwar	12,685	50,389	4693	2735	70,504
Koppal	7171	26,201	3475	1519	38,367
Raichur	11,416	40,302	6040	2401	60,162
Total	154,438	550,716	79,730	32,554	817,439

†Average total nutrient content of red soils – N: 750, P_2O_5: 800, K_2O: 750 kg/ha, Fe: 10, Mn: 2, Cu: 0.5 and Zn: 1 ppm.
Average total nutrient content of black soils – N: 1000, P_2O_5: 3000, K_2O: 750 kg/ha, Fe: 4, Mn: 4, Cu: 0.4 and Zn: 0.2 ppm.

Table 3. Total value of nutrient loss from flood-affected areas of North Karnataka†

District	N	P_2O_5	K_2O	Fe, Mn, Zn, Cu	Total
Bagalkot	9.6	52.7	6.6	27.7	96.7
Belgaum	19.7	106.6	13.4	58.8	198.6
Bellary	10.8	60.7	7.6	29.7	109.0
Bidar	8.2	44.1	5.5	25.5	83.6
Bijapur	16.5	85.7	10.7	53.8	166.9
Chitradurga	11.4	64.9	8.2	30.5	115.1
Davangere	7.6	44.2	5.6	19.7	77.3
Dharwad	6.2	34.3	4.3	17.7	62.6
Gadag	6.9	37.3	4.7	20.9	69.9
Gulbarga	24.7	130.7	16.4	77.2	249.3
Haveri	6.9	38.7	4.9	19.3	69.8
Karwar	13.1	80.6	10.2	28.0	132.2
Koppal	7.4	42.1	5.3	20.3	75.3
Raichur	11.9	65.0	6.3	35.1	118.5
Total	161.6	888.5	110.4	464.9	1625.6

†Cost of nutrients (Rs/kg nutrient; 2009 prices) – N: 10.50, P_2O_5: 16.22, K_2O: 7.43, Cu: 458, Zn: 97, Fe: 36 and Mn: 326.

Table 4. Loss of organic matter (tonnes) and its value (Rs crores; cost of nutrients according to 2009 prices) in the flood-affected areas of North Karnataka[†]

District	Loss in red soils	Loss in black soils	Total loss of organic matter	Value of organic matter at current prices[#]
Bagalkot	50,130	181,513	231,643	509,616,250
Belgaum	78,165	418,052	496,218	1091,680,700
Bellary	75,652	169,184	244,836	538,639,750
Bidar	22,527	195,104	217,632	478,791,060
Bijapur	9357	455,183	464,540	1,021,988,220
Chitradurga	91,790	156,867	248,657	547,047,380
Davangere	70,938	88,074	159,012	349,826,400
Dharwad	35,436	112,033	147,469	324,432,570
Gadag	24,700	152,285	176,986	389,369,750
Gulbarga	54,568	605,035	659,604	1,451,130,120
Haveri	45,271	114,355	159,627	351,180,280
Karwar	194,523	15,832	210,355	462,781,770
Koppal	55,160	111,705	166,865	367,105,090
Raichur	53,935	241,370	295,305	649,673,090
Total	862,156	3,016,598	3878,755	8,533,262,430

[†]Average organic matter content of red soils is 0.2% and black soils is 0.45%.
[#]Value of organic matter (compost form): Rs 2200/t; Karnataka Compost Corporation, Government of Karnataka, 2009.

Ameliorative measures

Measures for areas affected by siltation

Sand (fine and coarse) has been deposited in agricultural fields adjoining the river banks only in a few locations, particularly along the Hagari River, Garchi Vanka stream in Bellary District, Sindhnur Nadi and Maski Nadi in Raichur district, Dhoni River in Bijapur District and Malaprapha River in Bagalkot District (Figure 3 *b* and *c*). The depth of sand deposition varied from place to place. In many places, deposition was limited to a depth of 10–15 cm. Only in a few places the deposition was up to more than 1–2 m high. The distance of siltation varied from 50 to 200 m from the river course. Only in a few locations, like in Dhoni River near Belvad village, was siltation spread over more area along the river course. Sedimentation was observed mostly in those locations where the river course is meandering and has breached the banks.

The deposition, comprising mostly of sand and some amount of silt, has caused damage to the standing crops like paddy. In the long run it is beneficial to crop growth. This is because of the heavy clayey texture of the soil present in the area, particularly along the river course. Actually mixing of some amount of sand in this type of clayey-textured soil improves permeability, aeration, aggregation and nutrient availability[11]. These soils already suffer from severe salinity, particularly in the Tungabhadra command areas. Addition of sand to a clayey soil will result in a dilution effect, which not only improves the drainage but also helps in leaching some amount of excess salts present in the soil, thereby reducing the ill-effects of salinity in the affected areas. There is every possibility that considerable amounts of salts were washed away in the flood water. This needs to be estimated and compared with the pre-flood content of salts in the region.

Measures required to be undertaken in flood-affected areas

1. Construction of field bunds wherever it has been breached with adequate provision for free drainage.
2. Repair of breached field bunds.
3. Removal of excess sand (if > 10 cm depth) and spreading it out in the field evenly.
4. Deep ploughing to mix the sand and silt with the clayey soil.

Measures for areas affected by river-bank erosion

To prevent further stream-bank erosion, stream bank cutting and collapse of river banks, a series of measures, both short and long term, are needed for the area.

- Identification of critical areas along major tributaries.
- Construction of wired guided banks and gabions along critical lengths.
- Construction of retaining walls along the weak points and turns of streams and rivulets.
- Establishment of erosion-resistant species like bamboos, *Vetivar* grass, etc. along the banks of small rivers, especially where the streams/rivers take a turn or meander[12].
- Removal of *Prosopis juliflora* thickets and encroachments which obstruct the natural flow of water in the streams, rivulets and seasonal rivers.
- Restoration of the original riverbeds, especially in the low-lying areas.

Rehabilitation measures for catchment areas

The catchment areas of the two major river systems and their tributaries in the flood-affected districts consist of very gently to gently sloping lands covered with thin to shallow veneer of soil (red and black) and a dense network of ephemeral streams that carry small quantities of water during the rainy season.

Black soils occurring extensively in this area are highly prone to erosion. Because their permeability is slow and once the rain soaks them, they disperse easily and get removed by any subsequent rain, if they are not protected. The widespread soil loss observed in the affected districts only indicates the inadequacy or lack of proper soil and water conservation measures adopted in this region in the past. The deep and wide gullies seen in many fields, caused by the recent floods need to be plugged and whatever soil is left needs to be conserved before the start of the next kharif season. If this is not done, then cultivating the fields will become difficult in the subsequent season. Further, this will expose the ploughed soil to more severe erosion during summer and monsoon rains.

The situation is almost similar in red-soil areas of the affected districts. Already red soils have lost most of their finer fractions like silt and clay due to neglect; the recent floods have aggravated the situation further in these soils. These along with several other practices, like cultivation in the stream courses and nallas, have resulted in the obstruction of the natural drainage systems of the area. As a consequence, serious sheet, rill and gully erosion problems have aggravated further. The downstream reaches are the worst affected and need urgent corrective measures. In all land forms (arable, non-arable and marginal) proper drainage systems, water-storage measures and *in situ* soil moisture conservation practices have to be implemented, for which technologies are already available[12].

Conclusion

The unprecedented natural calamity has seriously threatened the crop production ability of the land resources. Large-scale efforts and investments on the farming infrastructure are needed to restore the health of the natural resource base and hence the livelihood security of the rural mass in the region. The present study provides the basis for undertaking the required ameliorative measures. The available database for planning and conserving the land resources is general in nature. Under the present circumstance, this can be made use of to the extent possible. However for undertaking, managing and monitoring of all land-based developmental projects on a scientific basis in the future, generation of a farm-level detailed database is essential. Lack of a location-specific database on soil and other resources appears to be mainly responsible for the inadequacy of natural resource conservation measures followed in the affected areas of the state. Availability of such a database would have been of immense utility in undertaking timely restoration and conservation measures in these areas. It is essential that a predominantly rainfed state like Karnataka undertake the generation of a location-specific farm-level database on priority basis.

1. Prasad, K. V. S. and Radha, T. M., Dealing with climate change. *Leisa India*, 2008, **10**(4), 4–5.
2. Agarwal, K. P., Climate change and its impact on agriculture and food security. *Leisa India*, 2008, **10**(4), 6–7.
3. Mukharjee, R., Agarwal, R. and Prasad, B., Global warming victims not heard in Copenhagen. *Civil Soc.*, 2010, **7**(3), 6–8.
4. Karnataka State Natural Disaster Monitoring Cell, GoK, Weekly report on rainfall, agricultural situation, crop condition, and reservoir levels for standard week 46, 2009, p. 36.
5. Sehgal, J. and Abrol, I. P., *Soil Degradation in India: Status and Impact*, Oxford & IBH Publishing Co. Pvt Ltd, New Delhi, 1994, p. 80.
6. Shivaprasad, C. R., Reddy, R. S., Sehgal, J. L. and Velayutham, M., *Soils of Karnataka for Optimizing Land Use*, NBSS Publ. No. 47b, NBSSLUP (ICAR), Nagpur, 1998, p. 111 + 4 maps.
7. Fertilizer Association of India. Annual review of fertilizer production and consumption 2008–2009. *Indian J. Fert.*, 2009, **5**(9), 108–155.
8. Chander, K., Goyal, S., Mundra, M. C. and Kapur, K. K., Organic matter, microbial biomass and enzyme activity of soils under different crop rotations in the tropics. *Biol. Fertil. Soils*, 1997, **24**(3), 306–310.
9. Memoirs of the Department of Agriculture, Government of Madras, 1954, pp. 689–720.
10. Grewal, M. S. and Kuhad, M. S., Soil desurfacing – impact on productivity and its management. In Proceedings of 12th ISCO Conference, Beijing, 2002, pp. 133–137.
11. Suganya, S. and Sivasamy, R., Moisture retention and cation exchange capacity of sandy soils as influences by soil additives. *J. Appl. Sci. Res*., 2006. **11**, 949–951.
12. Hegde, N. G. and Daniel, J. N., Multipurpose tree species for agroforestry in India. BAIF Development Research Foundation, Pune, 1994, p. 137.

Received 1 February 2010; revised accepted 14 October 2010