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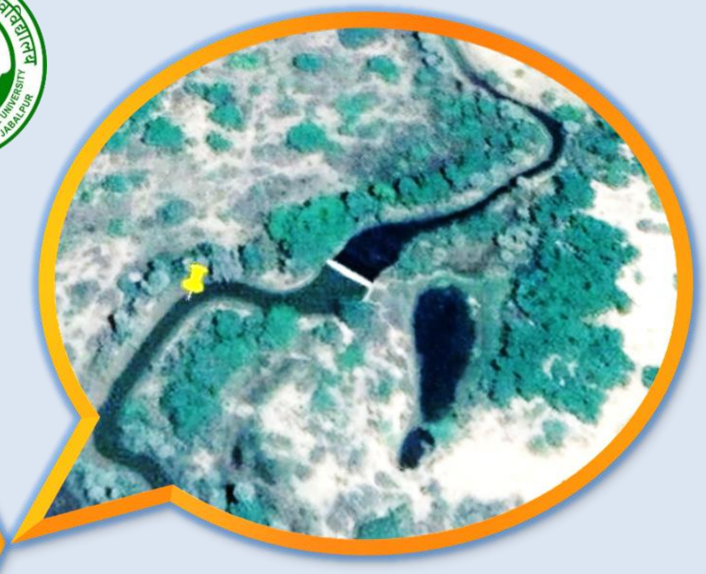
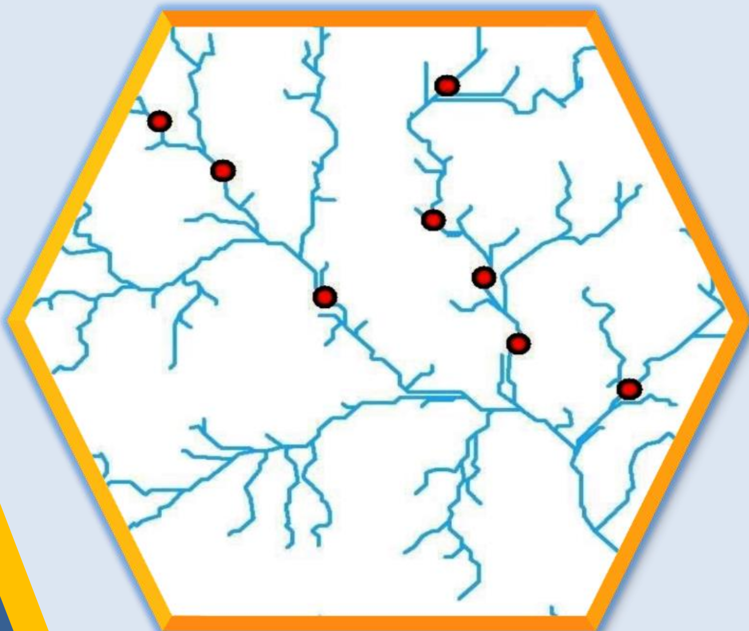
Atlas of Suitable Sites for Groundwater Recharge Structures in River Basins of MP





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M.K. Awasthi

2024

AICRP on Irrigation Water Management
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PROLOGUE

Water is indispensable for life and economic growth. In Madhya Pradesh, groundwater plays a pivotal role in agriculture, industry, and daily life. Ensuring sustainable groundwater management is vital for long-term water security and balanced regional development.

The "Atlas of Suitable Sites for Groundwater Recharge Structures in River Basins of MP" provides invaluable information for sustainable groundwater management, pinpointing ideal locations for recharge structures. This comprehensive resource, meticulously crafted through rigorous scientific analysis and expert consultation, provides invaluable insights into the groundwater recharge hydrogeological characteristics of the state's river basins.

By identifying optimal locations for groundwater recharge structures, the Atlas empowers decision-makers, planners, and communities to take proactive steps towards conserving and replenishing this vital resource. It is a testament to the commitment of the dedicated team of researchers who have worked tirelessly to bring this valuable tool to fruition.

We express our sincere gratitude to all contributors whose dedication and expertise made this Atlas possible. We hope that it will not only guide effective groundwater management in Madhya Pradesh but also inspire similar efforts nationwide and globally.

(G.K. Koutu)

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PREFACE

This Atlas represents a significant milestone in the field of groundwater management in Madhya Pradesh. The increasing demand for water resources, coupled with the challenges posed by climate change and unsustainable land use practices, has necessitated innovative approaches to ensure the long-term sustainability of groundwater supplies.

Atlas provides a comprehensive and accessible resource for planners, researchers, and policymakers to identify suitable locations for groundwater recharge structures within the various river basins of Madhya Pradesh. By leveraging advanced technologies and extensive data analysis, this Atlas offers valuable insights into the hydrogeological characteristics of the region, enabling informed decision-making and effective implementation of groundwater recharge initiatives.

I congratulate all the scientists and workers involved in this task and bringing out river basin wise unique Atlas of Suitable Sites for Groundwater Recharge Structures in River Basins of MP. I am glad to know that the digital maps of prepared Atlas are of fine resolution of 10 m making it more useful. I hope that this Atlas will be a catalyst for further research, development, and implementation of groundwater recharge strategies, contributing to the overall well-being of the state and its people.

(R.K. Nema)

FOREWORD

The extensive research has been conducted to enhance the groundwater recharge through assessing current groundwater levels and identifying the suitable sites for recharge structures. The maps included in this atlas, specifically developed for the river basins of Madhya Pradesh, provide valuable insights for planners, researchers, and students, facilitating more informed decision-making.

The Suitable Sites for Groundwater Recharge Structures map is an output obtained after integration of various thematic layers (such as slope, soil permeability, stream order, lineaments etc.) developed on GIS environment using ArcGIS 10.8. The development of each layer involved a large dataset and time-consuming processes. Different government agencies and their official portals provided basic data. The product provided the pin point locations (latitude longitude) of suitable groundwater recharge structures like check dam, nala bund, percolation tanks and staggered contour trenches.

The authors and contributors express their gratitude to the Indian Council of Agricultural Research for providing invaluable guidance, encouragement, and financial support. Authors are indebted to Dr. P.K. Mishra, Honourable Vice Chancellors for providing opportunity, all necessary facilities and blessings during the work. The guidance provided by Dr. A.K. Sarangi, Director, IIWM and constant encouragement by Dr S.K. Mohanty, Principal Scientist, Project Coordinating unit, Bhubneshwar makes this task possible. Thanks are due for Dr. G.K. Koutu, Director Research Services, Dr A.K. Shrivastava, Dean Faculty of Agricultural Engineering and Dr. R.K. Nema, Head of the Department, Soil and Water Engineering.

Deepak Patle, M.K. Awasthi

Content

Introduction

The increasing population in India, driven by urbanization, industrialization, and agricultural expansion, has led to a significant rise in water demand. This demand has far exceeded the natural recharge of groundwater in many parts of the country, resulting in severe water stress, including scarcity, pollution, and over-extraction. To address this crisis, the central and state governments have implemented various water conservation schemes, such as rainwater harvesting, afforestation, and water treatment plants. This comprehensive atlas will provide invaluable insights for identifying optimal locations for groundwater recharge structures, facilitating sustainable water management practices.

The application of remote sensing and GIS techniques in groundwater studies has been used for more than two decades. GIS may effectively be used for selecting recharge structure site locations in order of their priorities. The spatial data may be stored as different thematic layers and manipulated to derive new usable information using the existing ones in GIS. In general, GIS is designed to accept large volumes of spatial data derived from different sources and to efficiently store, retrieve, manipulate, analyse them. Various fields including remote sensing, cadastral mapping, cartography, civil engineering, geography, soil science, surveying and photogrammetry can be used as an input to GIS. Apart from dealing with a number of given basic spatial entities and measures of their location in the earth space, RS & GIS also deals with a host of non-spatial attributes of these entities. Thus, a GIS represents a computer based information system for handling both spatial data as well as non-spatial data derived from a variety of sources. Further, GIS permits not only the automated mapping or display of locations of features but also provide a relational database capability for recording and analysing descriptive characteristic about features. Data from the GIS may be retrieved by specifying either location or attribute retrieval criteria. Thus, RS & GIS technique can serve as a test bed for studying, planning, environmental processes, analysing the results of trends' anticipating the possible results of planning decisions and management of resources.

Keeping this in view, the work of suitable site selection for artificial groundwater recharge structures has been done in all the 12 major river basins of Madhya Pradesh. Suitable sites for artificial groundwater recharge structures such as Check Dams (CD), Nala Bunds (NB), Percolation Tanks (PT), and Staggered Contour Trenches (SCT) were identified using RS & GIS technique in the Betwa, Chambal, Dhasan, Ken, Mahanadi, Mahi, Narmada, Sindh, Sone, Tapi, Tons and Wainganga River basin.

Thematic Map Preparation

In this study, four major different thematic layers slope, soil permeability, stream order, and lineaments were used for site selection. A map of Madhya Pradesh showing different river basins was collected from the MPWRD website (http://mpwrd.gov.in/wp-content/uploads/2018/03/image_gallery-2.png) and clipped basin wise than digitized manually on a scale of 1: 50,0000. The datasets were gathered from the different geo portals of government of India for development of thematic layers. Digital Elevation Model (DEM) datasets of SRTM (30-m spatial resolution) were downloaded from the USGS Earth Explorer data portal (https://earthexplorer.usgs.gov/). Slope map and Stream Order map for the river basins were developed through SRTM DEM in Arc GIS software ®10.8. The Lineament data on a scale of 1:50,000 was manually digitized from WMS link obtained from Bhuvan geoportal (https://bhuvan.nrsc.gov.in/) of ISRO using QGIS 3.16 software. Previously, the many researchers have used lineament map on a scale of 1:250,000 for mapping of groundwater potential and other natural resources. Previously, several studies have been done with the FAO soil maps on a scale of 1:50,00,000 which contains very coarse information. but in this study, the Soil map collected from National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), Nagpur on a scale of 1:250,000 was manually digitized. These soil map sheets contain finer information than the FAO soil map. Soil Permeability map was derived based on Soil Texture Map. All the thematic maps were reclassified and exported in the same cell size which is 10 m spatial resolution.

Methodology

It is necessary to provide the scientifically suitable location for construction of artificial recharge structures in critical area to enrich recharge potential for any user. In this study, different guidelines were analysed for suitable site selection of various groundwater recharge, which are given as below:

i. Integrated Mission for Sustainable Development. National Remote Sensing agency. 1995.

ii. Manual on Artificial Recharge of Ground Water. Central Ground Water Board. 2007.

iii. Concept of Ground Water Prospects Map Preparation. Rajiv Gandhi National Drinking Water Mission Project. 2011.

iv. Natural Resources Management through Integrated Watershed Development under Mahatma Gandhi National Rural Employment Guarantee Scheme. Saksham. 2017.

After the analysis of above given guidelines, criteria for suitable site selection for different groundwater recharge structures were provided in following Table 1.

Table 1. Criteria for site selection of groundwater recharge structures

SN.	Groundwater Recharge Structures	Slope	Stream Order	Soil Permeability	Lineament
1.	Check Dam	3-5%	1-2 @	Low $	Fractures does not exist
2.	Nala Bund	Less than 1% *	3-4 #	High *	Fractures does not exist
3.	Percolation Tank	Less than 2% *	Drainage does not exist	High #	Fractures @
4.	Staggered Contour Trenches	8-25%	Drainage does not exist	Low $	Fractures does not exist

* IMSD (1995)

CGWB (2007)

@ NRSA (2011)

$ SAKSHAM (2017)

Slope, stream order, soil permeability, and lineament were considered as main criteria for the suitable site selection of artificial groundwater recharge in the study area. In addition to, all the groundwater recharge structures are suitable for hard rock as well as alluvial region.

Total catchment of the stream/nala should normally be 40 to 100 ha for check dam, nala bund and percolation tank. The distance between two structures sites were considered about 250 m for check dams and percolation tanks. For the nala bunds, distance between two structures sites were considered about 1 km. In case of staggered contour trenches, the distance between two structures sites were considered about 500 m. Above given criteria will be supportive to suggestion of suitable sites for artificial groundwater recharge structures.

Suitable sites were identified using a GIS-based site suitability model, created with the Model Builder in ArcGIS 10.8. The workflow of Model Builder to identify appropriate sites for various groundwater recharge structures are presented in Fig 1.

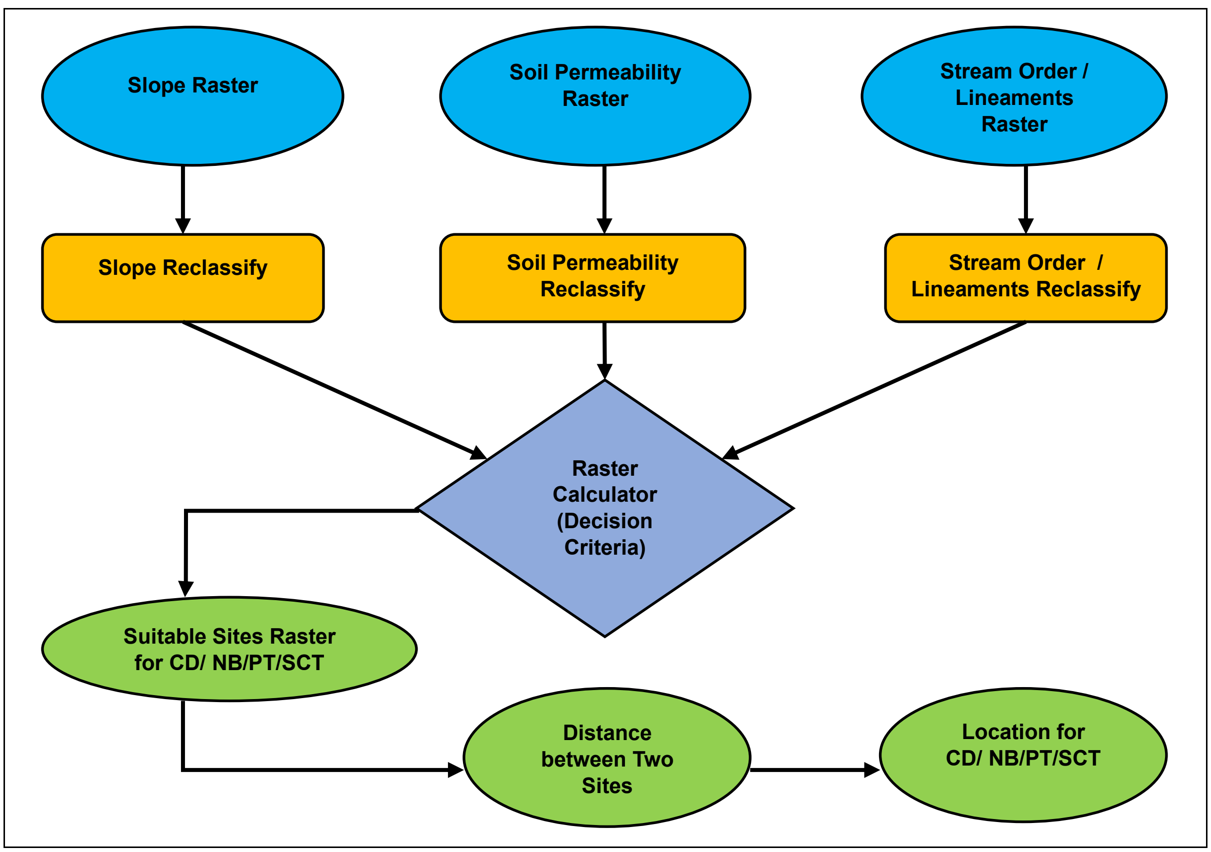

Fig 1. Work Flow of Model Builder for identification of suitable sites for Check Dams (CD)/ Nala Bunds (NB)/ Percolation Tanks (PT/)/ Staggered Contour Trenches (SCT)

Details of site specific groundwater recharge structures

Check Dam

Check Dams are constructed across the lower order streams having gentle slope and are feasible both in hard rock terrain as well as alluvial region. It should be preferably in catchment area having less than 1000 mm/ annum. A typical DSS was applied for suitable site selection for check dams using raster calculator in ArcGIS 10.8 software. Suitable locations were identified for check dams (CD) to augment the groundwater recharge for different River Basin.

Nala Bund

The Nala Bund are built on the streams having 3rd to 4th order which flowing through plain and valleys with sufficient weathering strata. Nala bund is utilized for water harvesting as well as groundwater recharging both the purpose. This structure is feasible both in hard rock terrain as well as alluvial region. A typical DSS was applied for suitable site selection for nala bund using raster calculator in ArcGIS 10.8 software. Specific sites were identified for nala bunds (NB) to augment the groundwater recharge for the study area.

Percolation Tank

Percolation Tank is the most efficient groundwater recharge structure to enrich the groundwater reservoir which mostly depends on the strata of bed. It is also feasible in hard rock terrain as well as alluvial region. The feasible geomorphology are the plains, valley, and piedmont zones for the percolation tanks. A typical DSS was applied for suitable site selection for the percolation tanks using raster calculator in ArcGIS 10.8 software. The pin point suitable locations were identified for the percolation tanks (PT) to augment the groundwater recharge for different River Basin.

Staggered Contour Trenches

Staggered Contour Trenches are the water harvesting structures, which are constructed on the hill slope as well as degraded land, waste lands having low rainfall areas. The staggered contour trenches are the best practice for enriching the groundwater recharge in hilly areas to augment the groundwater recharge as well as the control soil erosion and reduce the velocity of runoff. A typical DSS was applied for suitable site selection for staggered contour trenches using raster calculator in ArcGIS 10.8 software. Site specific suitable locations were identified for staggered contour trenches (SCT) to augment the groundwater recharge in different river basins.

Above suggested suitable sites for different groundwater recharge structures will be helpful to development of numerous watersheds in the various River Basin. After the implementation of artificial recharge structures, the ground water status of the basin will be positively improved. The Remote Sensing and GIS technique (combinedly called geoinformatics) is a very powerful and precise approach in natural resources planning and management works.

Suitable Sites Identified for Artificial Groundwater Recharge Structures

The pin pointing suitable sites for different artificial groundwater recharge structures were identified for the different river basins are given as below:

Betwa River Basin

The Betwa River Basin has a basin area 21847 sq. km in Madhya Pradesh. The Betwa or Betravati is a river in Northern India, and a tributary of the Yamuna. Also known as the Vetravati, the Betwa originates at an elevation of 470 m in the Bhopal District in Madhya Pradesh. Its basin extends from longitude 77° to 81° E and latitude 23°8' to 26°0' N. In Betwa River Basin, suitable sites were identified as 14505 for check dams, 932 for nala bunds, 1184 for percolation tanks, and 9653 for staggered contour trenches. In this Basin, different maps showing locations of suitable sites for check dams, nala bunds, percolation tanks, and staggered contour trenches are depicted in Fig 2 to Fig 5.

Chambal River Basin

The total basin area of Chambal River basin in Madhya Pradesh is 57256 sq. km. which is second largest river basin after Narmada River. Before joining the Yamuna River, the Chambal River flows through the states of Madhya Pradesh, Rajasthan, and Uttar Pradesh. The length of Chambal River is 960 km. The river has its source near the Singar Chouri crest in the northern sides of the Vindhyan cliffs, 15 km west to southwest of Mhow in Indore District, Madhya Pradesh. In Chambal River Basin, suitable sites were identified as 55674 for check dams, 1776 for nala bunds, 600 for percolation tanks, and 25690 for staggered contour trenches. In this Basin, different maps showing locations of suitable sites for check dams, nala bunds, percolation tanks, and staggered contour trenches are depicted in Fig 6 to Fig 9.

Dhasan River Basin

The total basin area of Dhasan river in Madhya Pradesh is 8664 sq. km. The Dhasan River is a right bank tributary of the Betwa River in central India. It originates from Begumganj tehsil of Raisen district in Madhya Pradesh. The river forms the southeastern boundary of the Lalitpur District of Uttar Pradesh state. Its total length of the river is 365 km, out of which 240 km lies in Madhya Pradesh, 54 km common boundary between Madhya Pradesh and Uttar Pradesh, and 71 km in Uttar Pradesh. In Dhasan River Basin, suitable sites were identified as 3139 for check dams, 2496 for nala bunds, 189 for percolation tanks, and 3127 for staggered contour trenches. In this Basin, different maps showing locations of suitable sites for check dams, nala bunds, percolation tanks, and staggered contour trenches are depicted in Fig 10 to Fig 13.

Ken River Basin

The total basin area of Ken river in Madhya Pradesh is 24556 sq. km. The Ken River is one of the major rivers of the Bundelkhand region of central India, which originates from the village Ahirgawan on the northern-western slopes of Barner Range in Katni district (MP) and confluence with the Yamuna River at Chilla village, Banda district (UP). Ken River travels a total distance of 427 km, out of which 292 km lies in Madhya Pradesh, 84 km in Uttar Pradesh and 51 km forms the common boundary between both the states. Ken River Basin lies between 23°07' – 25°51' N latitudes and 78°30' – 80°38' E longitudes. In Ken River Basin, suitable sites were identified as 10783 for check dams, 1864 for nala bunds, 4289 for percolation tanks, and 9211 for staggered contour trenches. In this Basin, different maps showing locations of suitable sites for check dams, nala bunds, percolation tanks, and staggered contour trenches are depicted in Fig 14 to Fig 17.

Mahanadi River Basin

The total area of Mahanadi River Basin in Madhya Pradesh is very small which is approximately 166 square kilometres. The Mahanadi basin extends over states of Chhattisgarh and Odisha and comparatively smaller portions of Jharkhand, Maharashtra and Madhya Pradesh, draining nearly 4.3% of the total geographical area of the country. The geographical extent of the basin lies between 80°28' and 86°43' east longitudes and 19°8' and 23°32' north latitudes. The basin has maximum length and width of 587 km and 400 km in India. In Mahanadi River Basin, suitable sites were identified as 12 for check dams, 18 for nala bunds, 52 for percolation tanks, and 04 for staggered contour trenches. In this Basin, different maps showing locations of suitable sites for check dams, nala bunds, percolation tanks, and staggered contour trenches are depicted in Fig 18 to Fig 21.

Mahi River Basin

Mahi basin has a total area of 7034 sq. km in Madhya Pradesh. The Mahi basin extends over states of Madhya Pradesh, Rajasthan and Gujarat having a maximum length and width of about 330 km and 250 km. It lies between 72°21' to 75°19' east longitudes and 21°46' to 24°30' north latitudes. It is bounded by Aravalli hills on the north and the north-west, by Malwa Plateau on the east, by the Vindhyas on the south and by the Gulf of Khambhat on the west. In Mahi River Basin, suitable sites were identified as 5337 for check dams, 177 for nala bunds, 324 for percolation tanks, and 8242 for staggered contour trenches. In this Basin, different maps showing locations of suitable sites for check dams, nala bunds, percolation tanks, and staggered contour trenches are depicted in Fig 22 to Fig 25.

Narmada River Basin

The Narmada River Basin is a large river basin located in central India, covering parts of the states of Madhya Pradesh, Gujarat, and Maharashtra. In Madhya Pradesh, the basin covers an area of around 85083 square kilometers. The Narmada River is approximately 1,312 kilometres long, with approximately 1,077 kilometres flowing through Madhya Pradesh. The river begins in the Amarkantak highlands of Madhya Pradesh, travels through the state, then continues through Maharashtra and Gujarat before emptying into the Arabian Sea. In Narmada River Basin, suitable sites were identified as 110970 for check dams, 5774 for nala bunds, 13256 for percolation tanks, and 38603 for staggered contour trenches. In this Basin, different maps showing locations of suitable sites for check dams, nala bunds, percolation tanks, and staggered contour trenches are depicted in Fig 26 to Fig 29.

Sindh River Basin

The total basin area of Sindh River basin in Madhya Pradesh is approximately 26421 sq.km. The Sindh River basin is located predominantly in the districts of Shivpuri and Gwalior in the northern portion of the Indian state of Madhya Pradesh. The Vindhya Range is the source of the Sindh River, which is a tributary of the Yamuna. The Sindh River Basin is about 245 kilometres in length. In Sindh River Basin, suitable sites were identified as 11050 for check dams, 2248 for nala bunds, 4701 for percolation tanks, and 6557 for staggered contour trenches. In this Basin, different maps showing locations of suitable sites for check dams, nala bunds, percolation tanks, and staggered contour trenches are depicted in Fig 30 to Fig 33.

Sone River Basin

In the case of the Sone basin, which has a total area of 29,330 sq. km in Madhya Pradesh. The geographical extent of the Sone sub-basin lies between 80° 6' to 85° 4' east longitudes and 22° 40' to 25° 42' north latitudes of the country. The main river in this sub-basin the Sone is an important right bank tributary of the Ganga River. The river originates at an elevation of 600 m at Sonbhadra in the Maikala range of hills in Madhya Pradesh. The total length of the river is 784 km, out of which about 500 km lies in Madhya Pradesh, 82 km in Uttar Pradesh and the remaining 202 km in Bihar. The river meets the Ganga river about 16 km upstream of Dinapur in the Patna district of Bihar. In Sone River Basin, suitable sites were identified as 3149 for check dams, 2272 for nala bunds, 10005 for percolation tanks, and 5649 for staggered contour trenches. In this Basin, different maps showing locations of suitable sites for check dams, nala bunds, percolation tanks, and staggered contour trenches are depicted in Fig 34 to Fig 37.

Tapi River Basin

The Tapi basin has a total area of 9,274 square kilometres in Madhya Pradesh. The Tapti River basin is situated in central India, encompassing portions of Madhya Pradesh, Maharashtra, and Gujarat. The river begins in the eastern Satpura Range in Madhya Pradesh, travels west through Maharashtra, and empties into the Cambay Gulf in Gujarat. The Tapti River basin in Madhya Pradesh includes portions of the districts of Betul, Hoshangabad, and Harda. In Tapi River Basin, suitable sites were identified as 4504 for check dams, 517 for nala bunds, 1916 for percolation tanks, and 6073 for staggered contour trenches. In this Basin, different maps showing locations of suitable sites for check dams, nala bunds, percolation tanks, and staggered contour trenches are depicted in Fig 38 to Fig 41.

Tons River Basin

The Tons basin has a total area of 13878 sq. km. The river meets Ganga after flowing 246 km in Madhya Pradesh, 7 km making boundary between Madhya Pradesh and Uttar Pradesh and finally 67 km in Uttar Pradesh. The geographical extent of the Tons sub-basin lies between 230 57’ 53.98’’ and 250 10’ 09.15’’ N latitude and 800 21’ 35.03’’ and 820 43’ 25.41’’ E longitudes. It covers five districts of Madhya Pradesh namely Rewa, Satna, Eastern part of Panna and Northern part of Sidhi and Katni district. It is bounded on north and east by Uttar Pradesh state. In Tons River Basin, suitable sites were identified as 4999 for check dams, 1264 for nala bunds, 4340 for percolation tanks, and 3684 for staggered contour trenches. In this Basin, different maps showing locations of suitable sites for check dams, nala bunds, percolation tanks, and staggered contour trenches are depicted in Fig 42 to Fig 45.

Wainganga River Basin

The Wainganga Basin which has a basin area 24736 sq. km in Madhya Pradesh. The Wainganga River basin is located in eastern Madhya Pradesh and includes portions of the Balaghat, Seoni, and Chhindwara districts. Before joining the Godavari River, the river originates in the Mahadeo Hills of Madhya Pradesh and flows through Maharashtra. During the monsoon season, the region receives considerable precipitation, which fosters the development of diverse flora and fauna. In Madhya Pradesh, the principal tributaries of the Wainganga River are the Chorbahuli, Thanwar, and Bagh rivers. In Wainganga River Basin, suitable sites were identified as 11520 for check dams, 1623 for nala bunds, 5500 for percolation tanks, and 11806 for staggered contour trenches. In this Basin, different maps showing locations of suitable sites for check dams, nala bunds, percolation tanks, and staggered contour trenches are depicted in Fig 46 to Fig 49.

Verification of suitable sites for different groundwater recharge structures

Verification of suitable sites for different groundwater recharge structures namely check dam, nala bund, percolation tank, and staggered contour trenches was done by 100 random samples of each type of suggested groundwater recharge structure on google earth pro software with visual interpretation. The overall accuracy of groundwater recharge structures like check dam, nala bund, percolation tank, and staggered contour trenches were found with good (satisfactory) agreement about 70%, 74%, 66%, and 68% respectively on river basin level. The validation accuracy may be increased with the field verification of suggested suitable sites for recharge structures.

This research has the potential to streamline groundwater recharge studies, improving efficiency and accuracy.

Atlas

of

Suitable Sites for Groundwater Recharge Structures in River Basins of MP

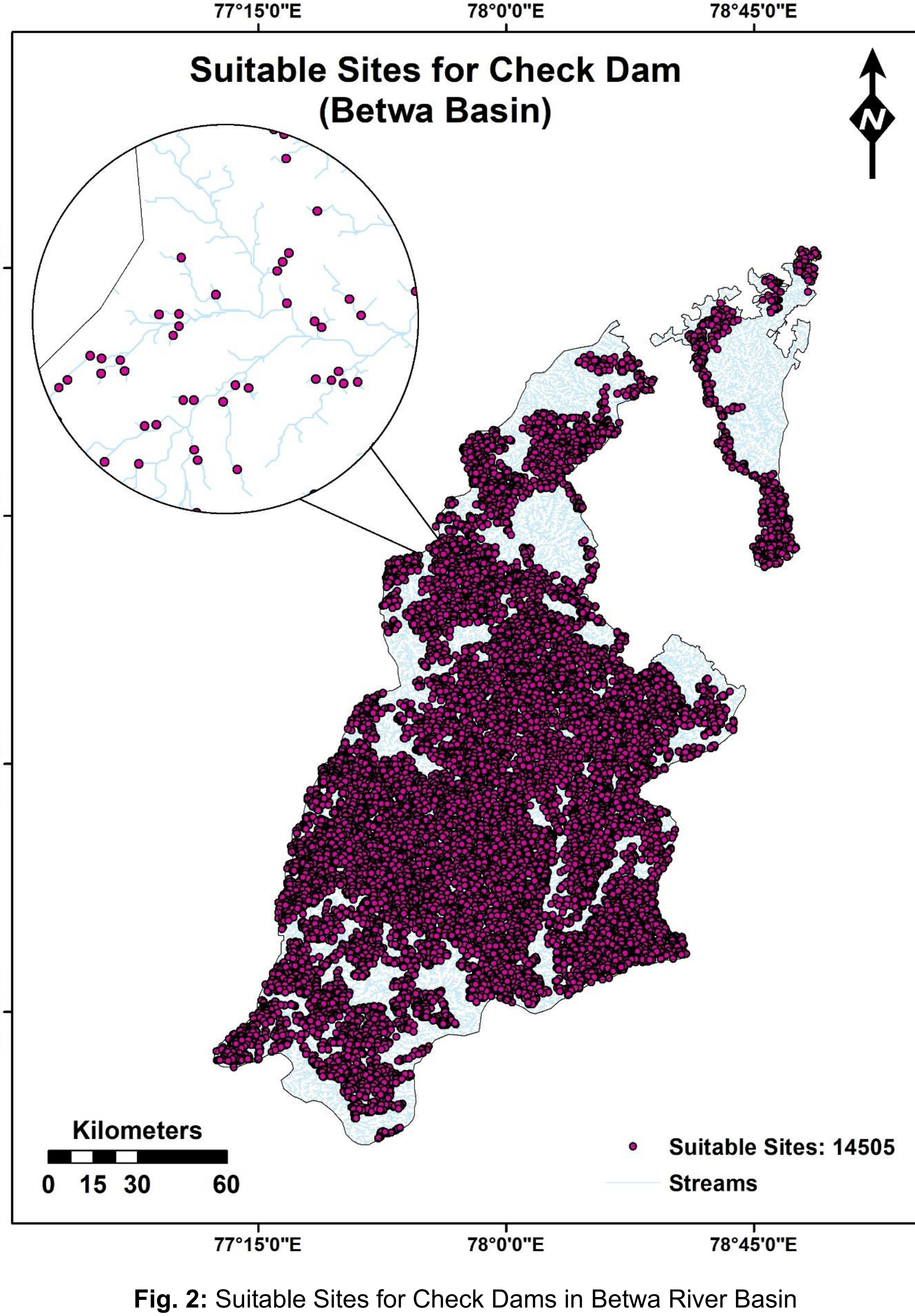

Fig. 2: Suitable Sites for Check Dams in Betwa River Basin

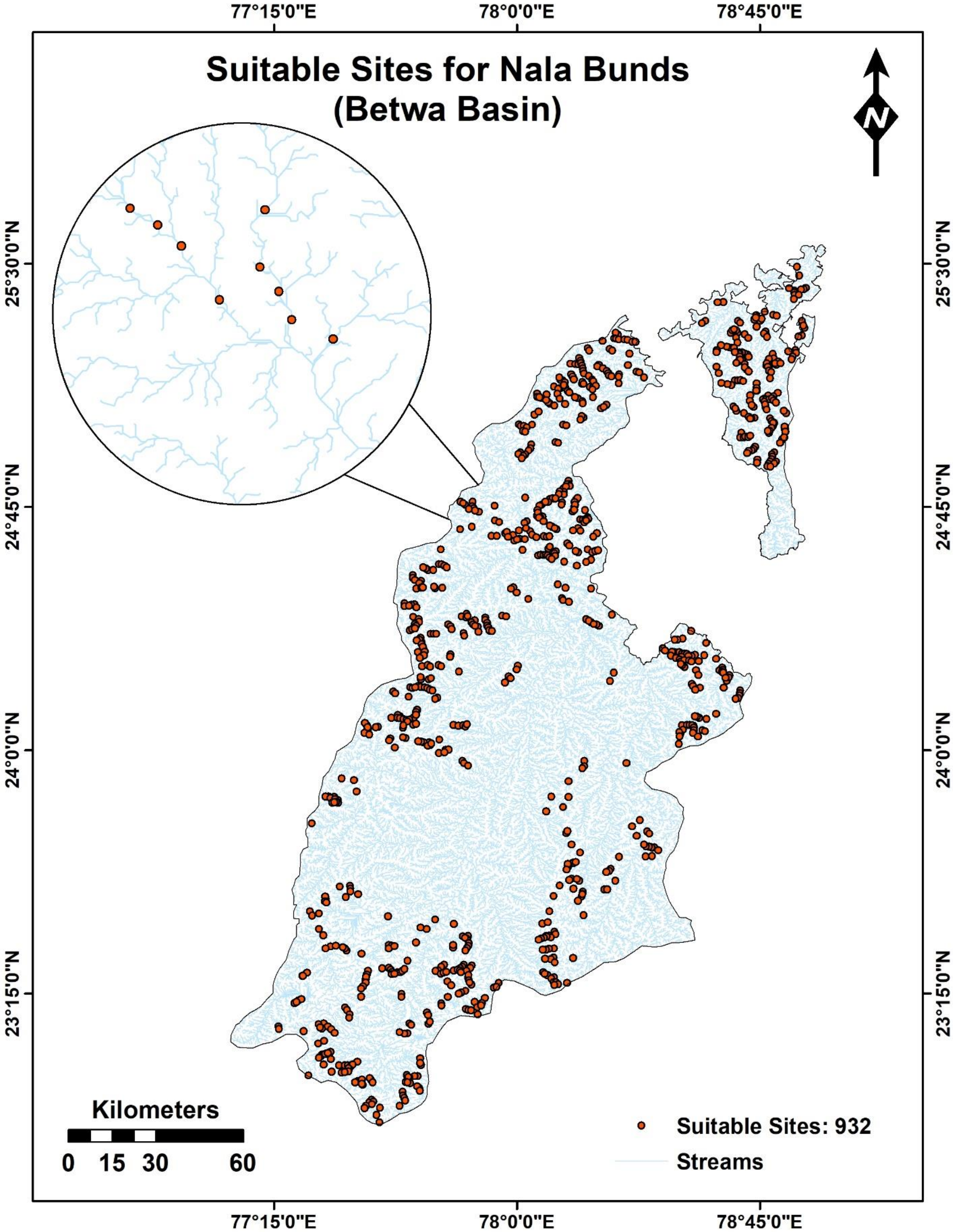

Fig. 3: Suitable Sites for Nala Bunds in Betwa River Basin

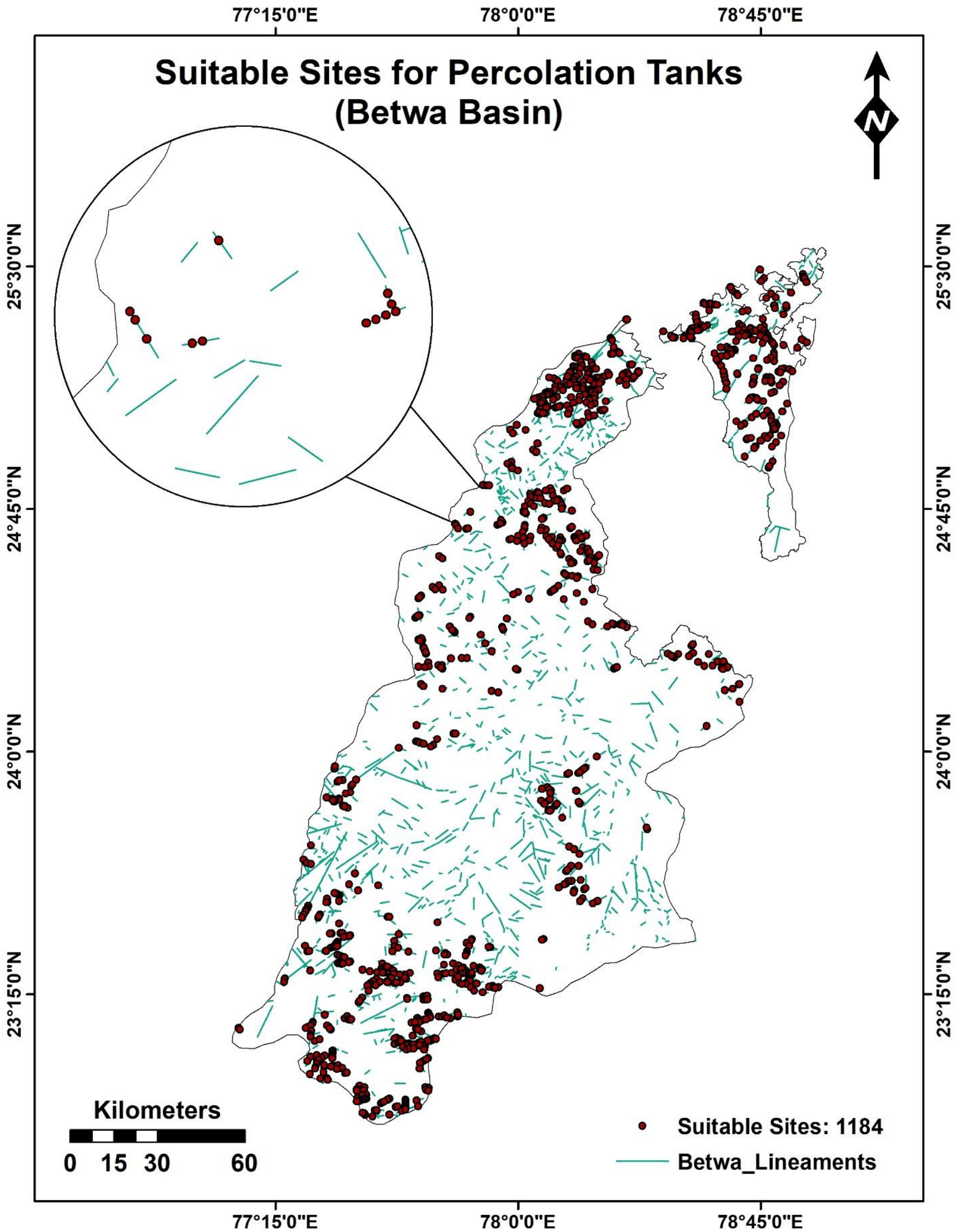

Fig. 4: Suitable Sites for Percolation Tanks in Betwa River Basin

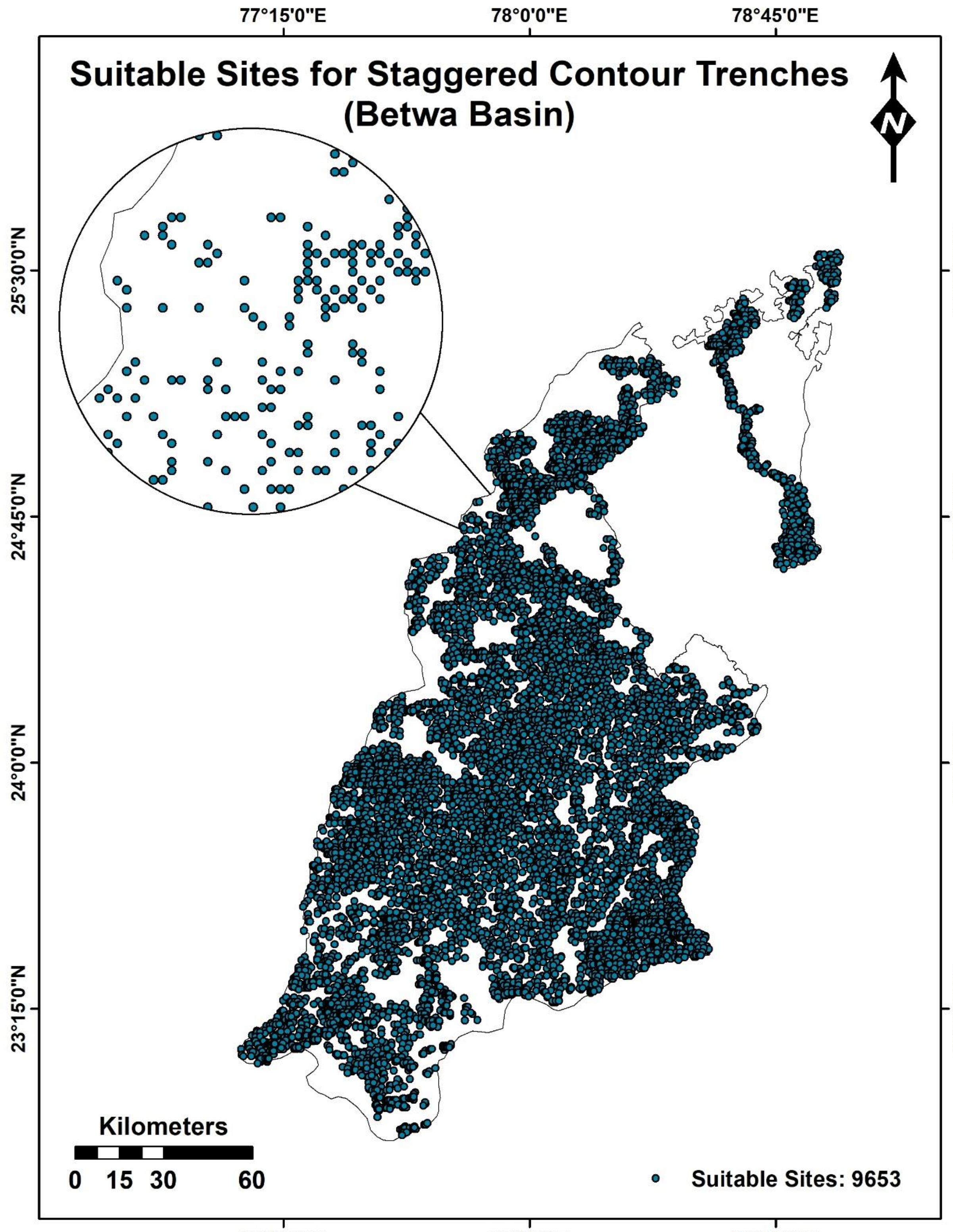

Fig. 5: Suitable Sites for Staggered Contour Trenches in Betwa River Basin

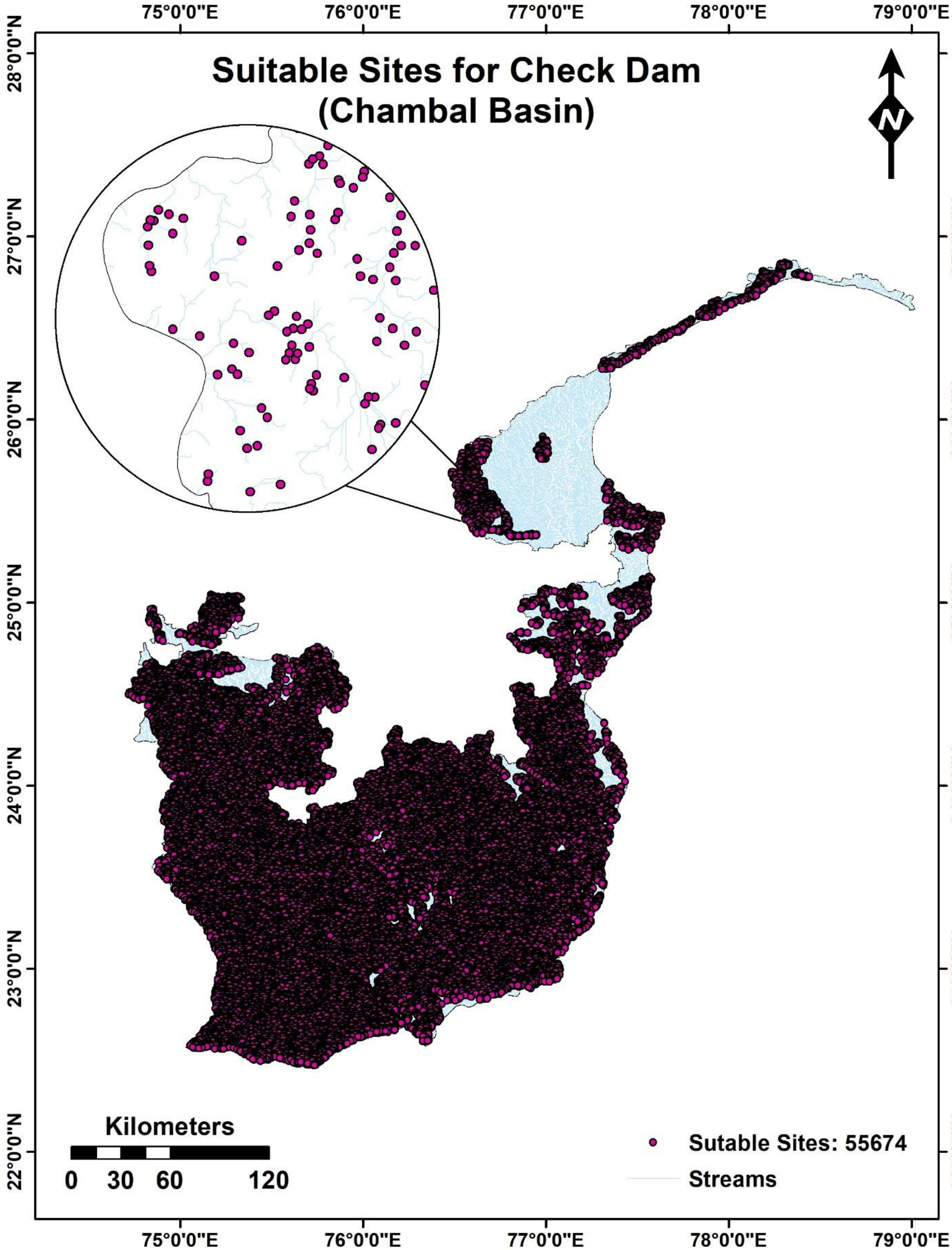

Fig. 6: Suitable Sites for Check Dams in Chambal River Basin

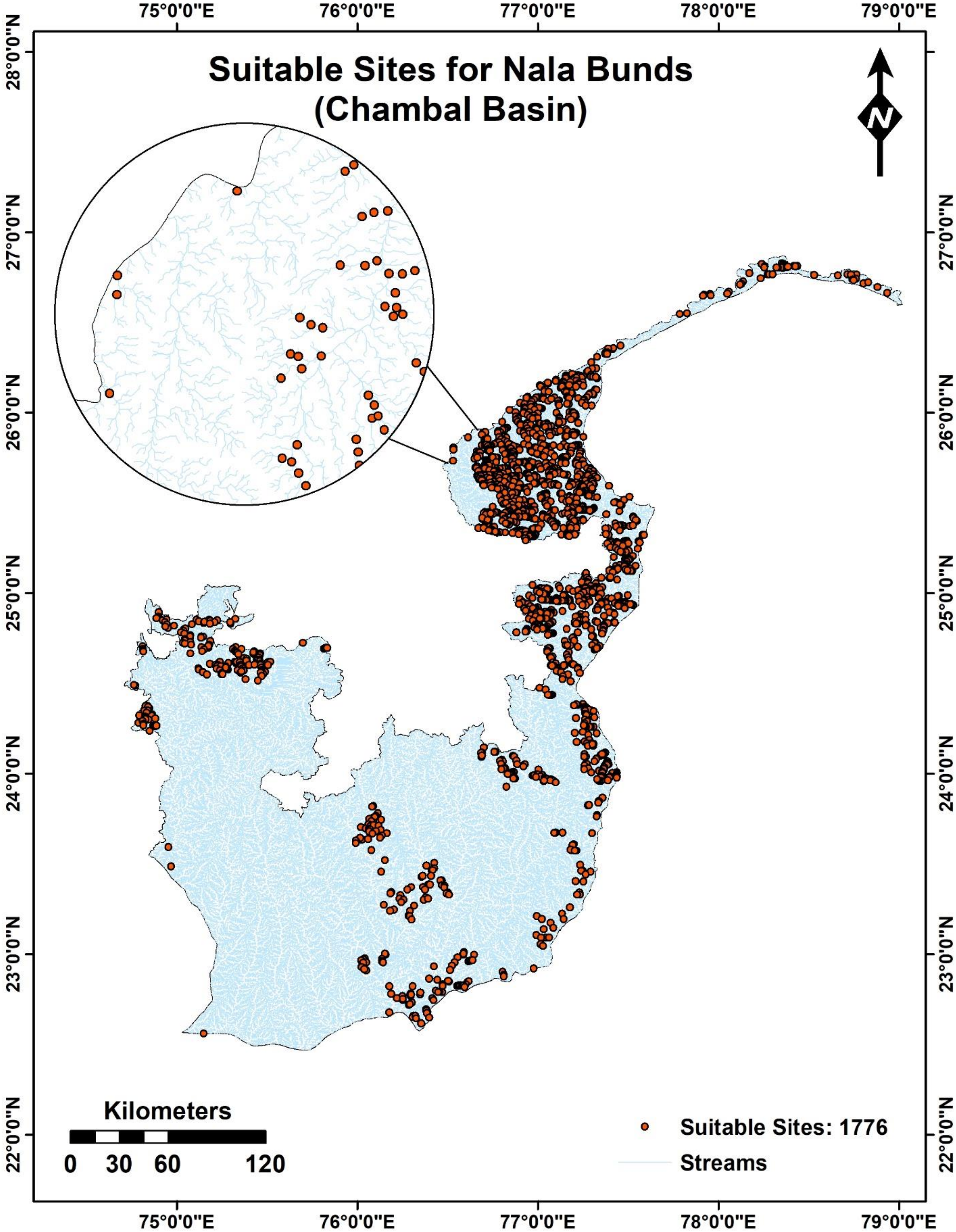

Fig. 7: Suitable Sites for Nala Bunds in Chambal River Basin

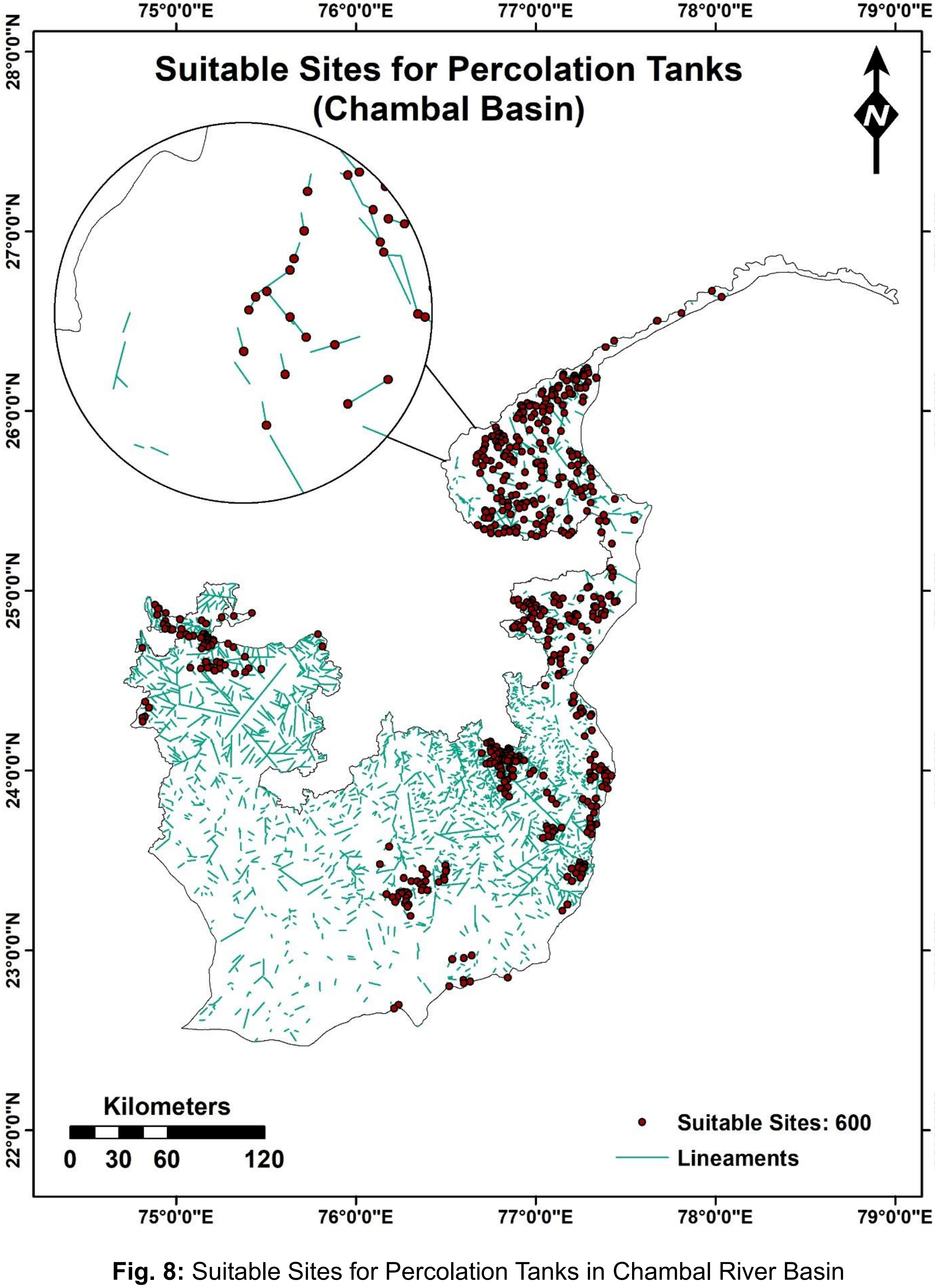

Fig. 8: Suitable Sites for Percolation Tanks in Chambal River Basin

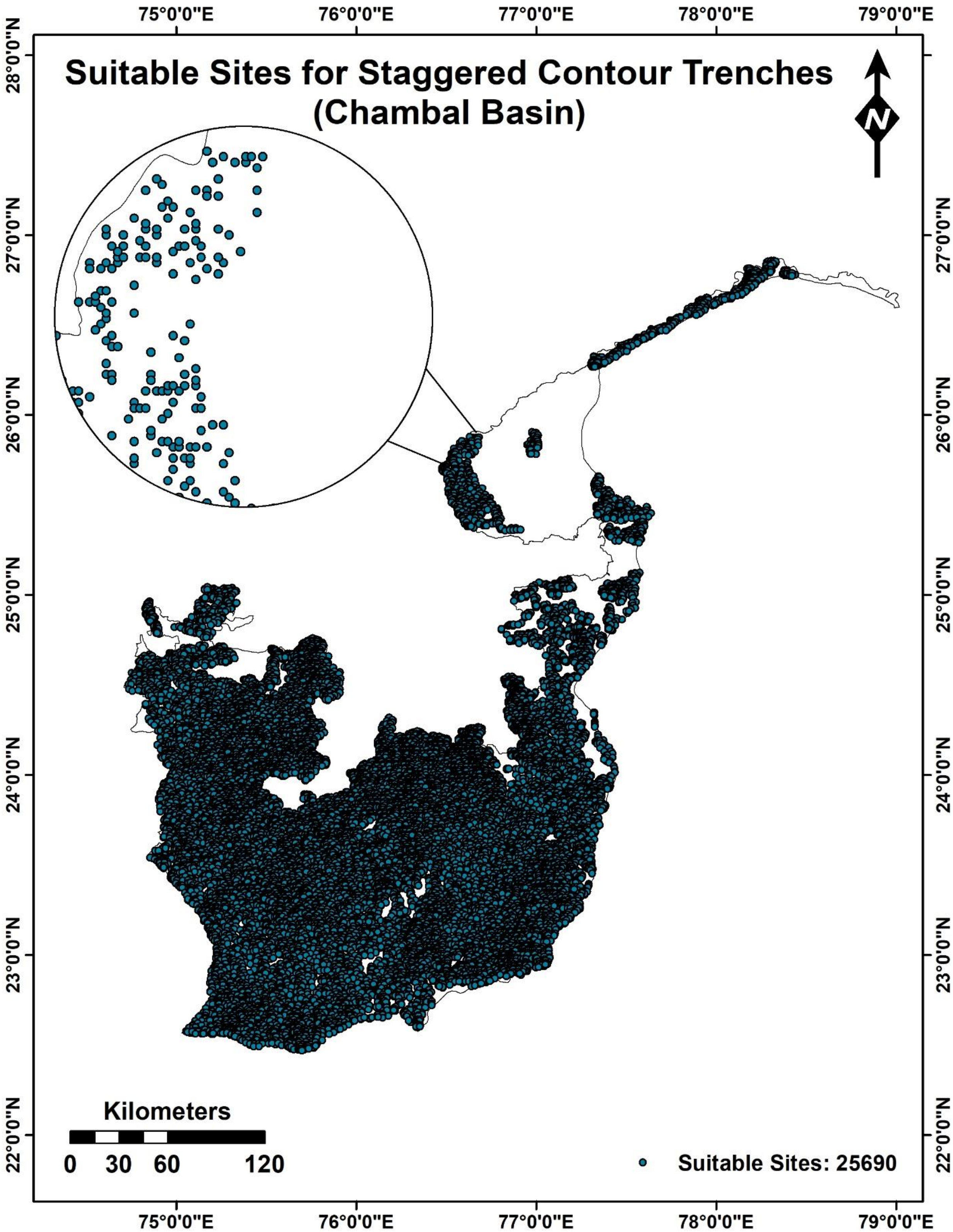

Fig. 9: Suitable Sites for Staggered Contour Trenches in Chambal River Basin

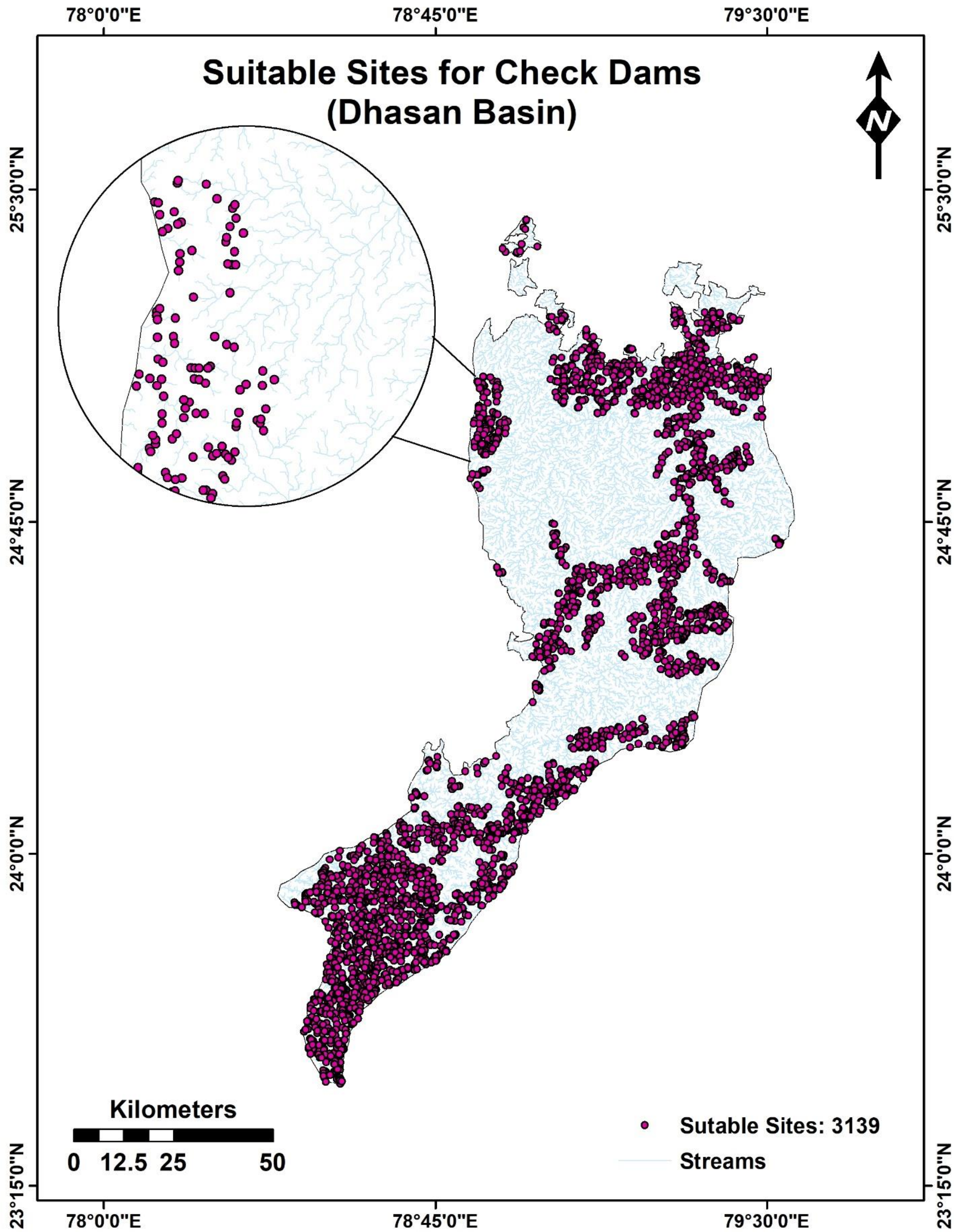

Fig. 10: Suitable Sites for Check Dams in Dhasan River Basin

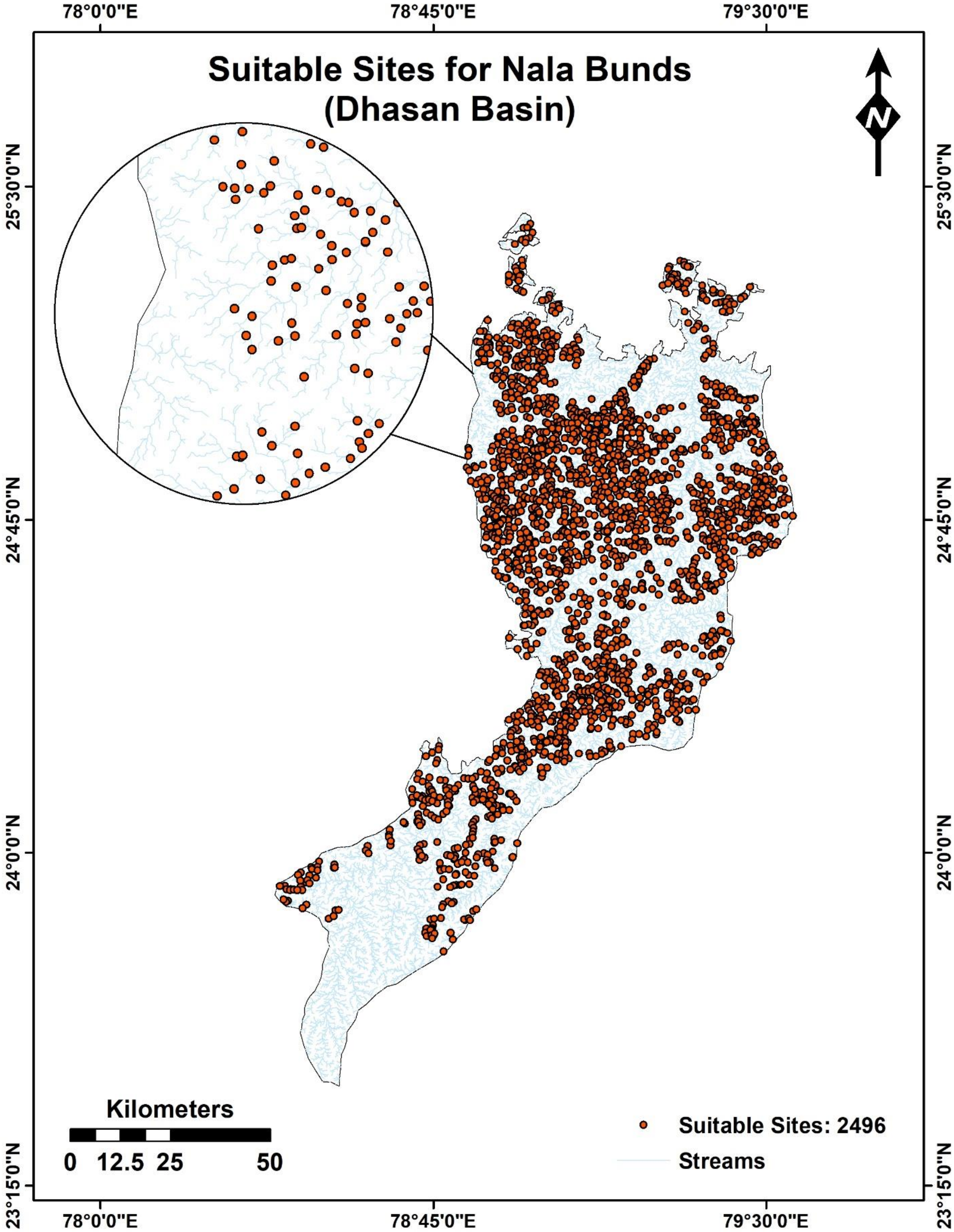

Fig. 11: Suitable Sites for Nala Bunds in Dhasan River Basin

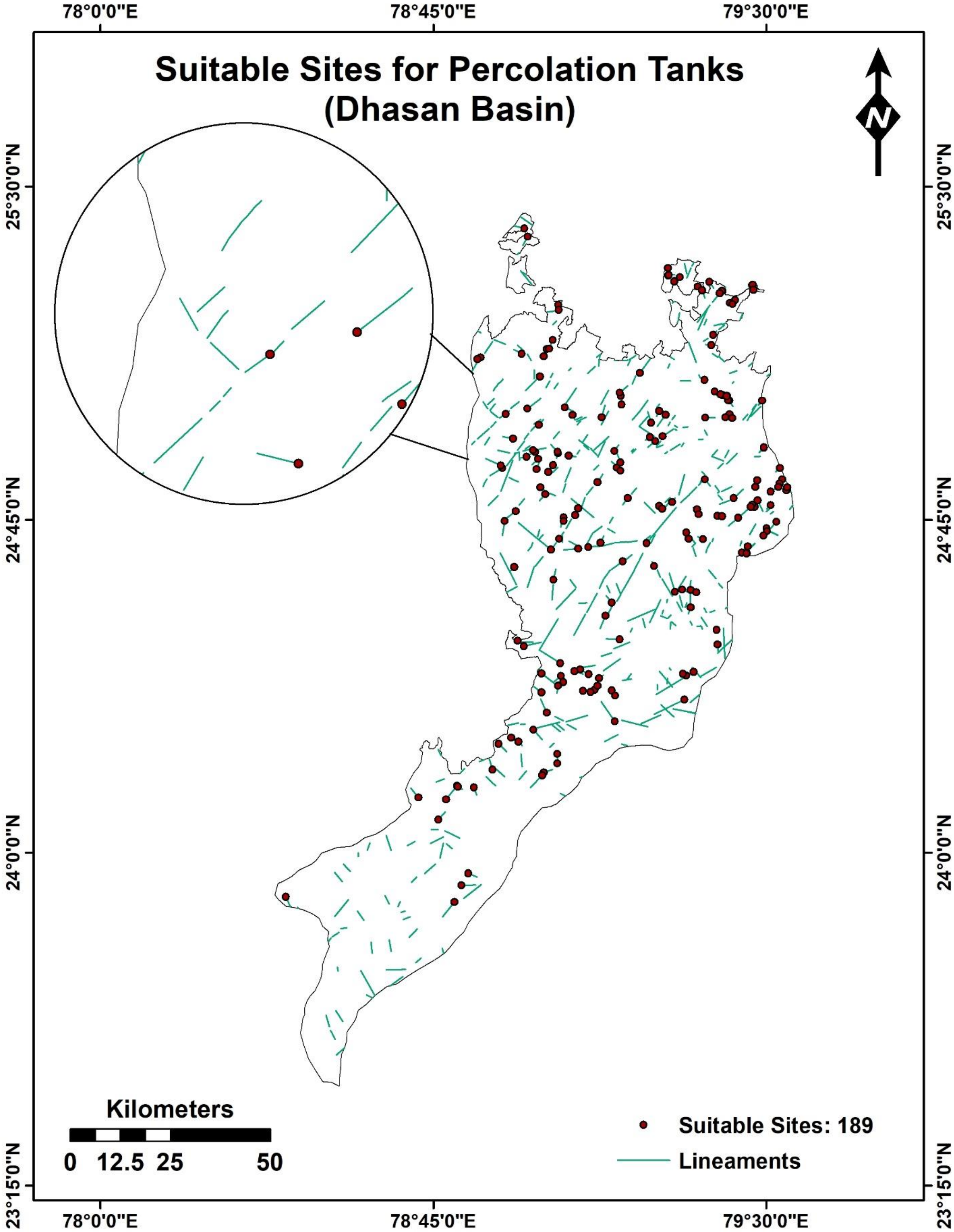

Fig. 12: Suitable Sites for Percolation Tanks in Dhasan River Basin

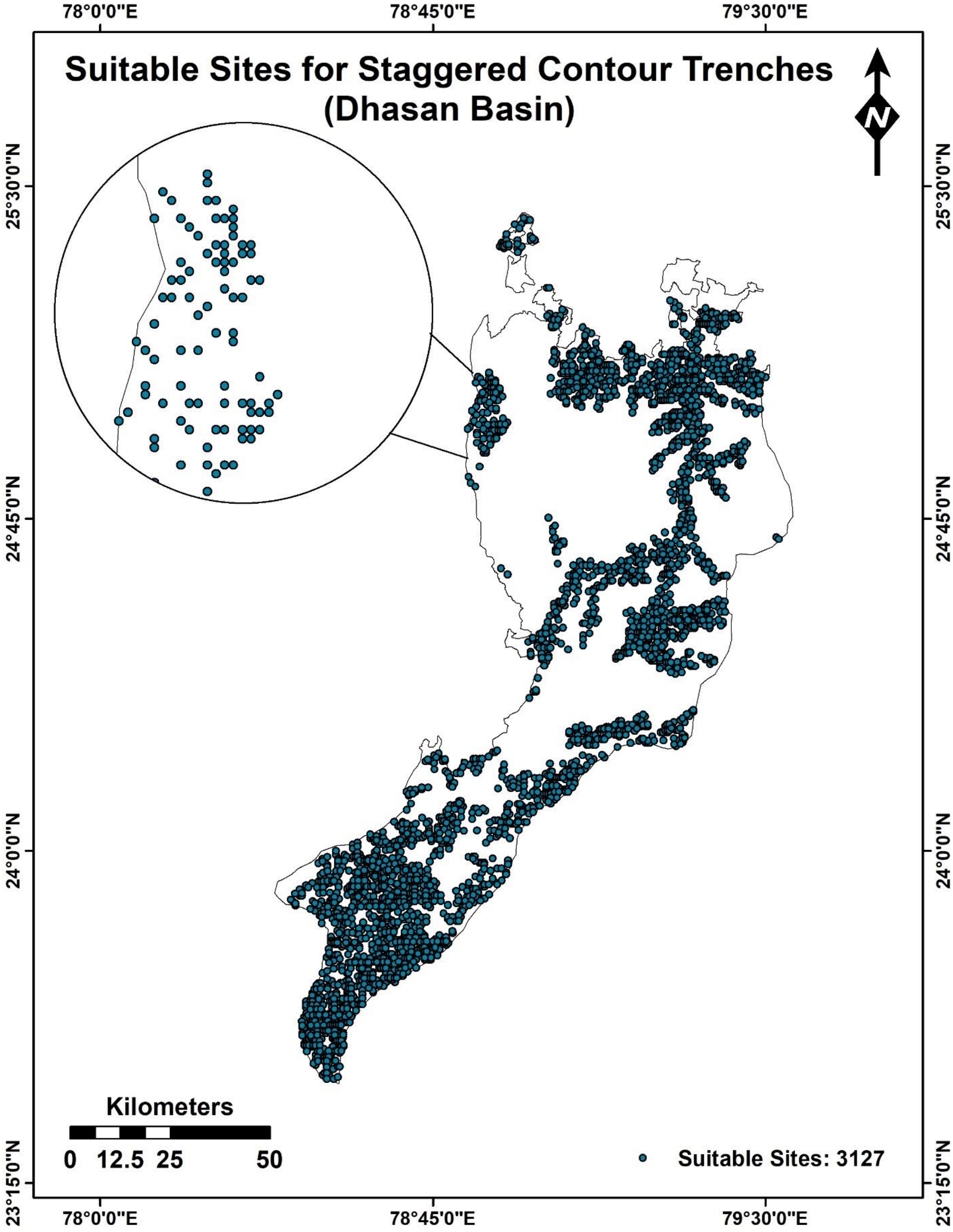

Fig. 13: Suitable Sites for Staggered Contour Trenches in Dhasan River Basin

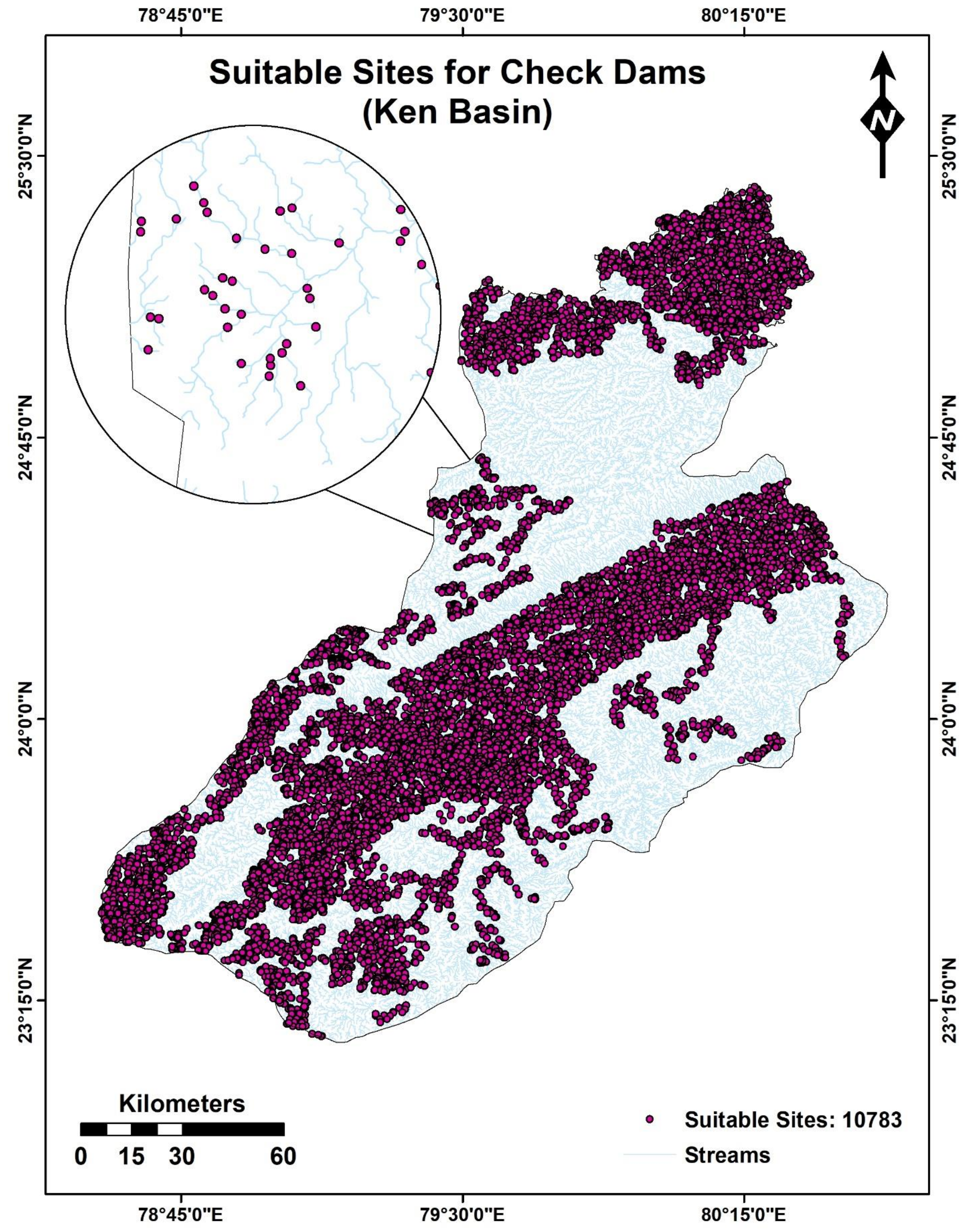

Fig. 14: Suitable Sites for Check Dams in Ken River Basin

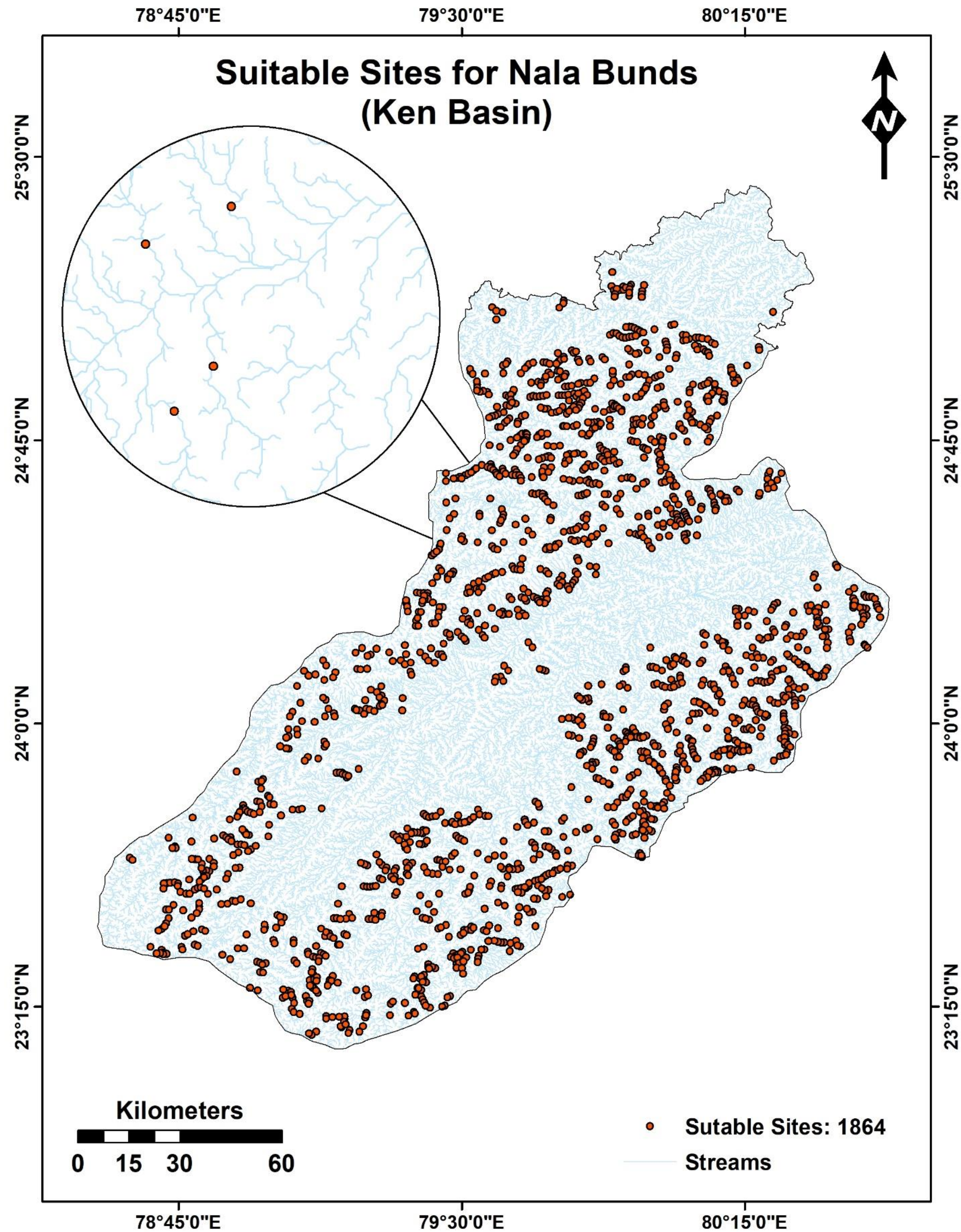

Fig. 15: Suitable Sites for Nala Bunds in Ken River Basin

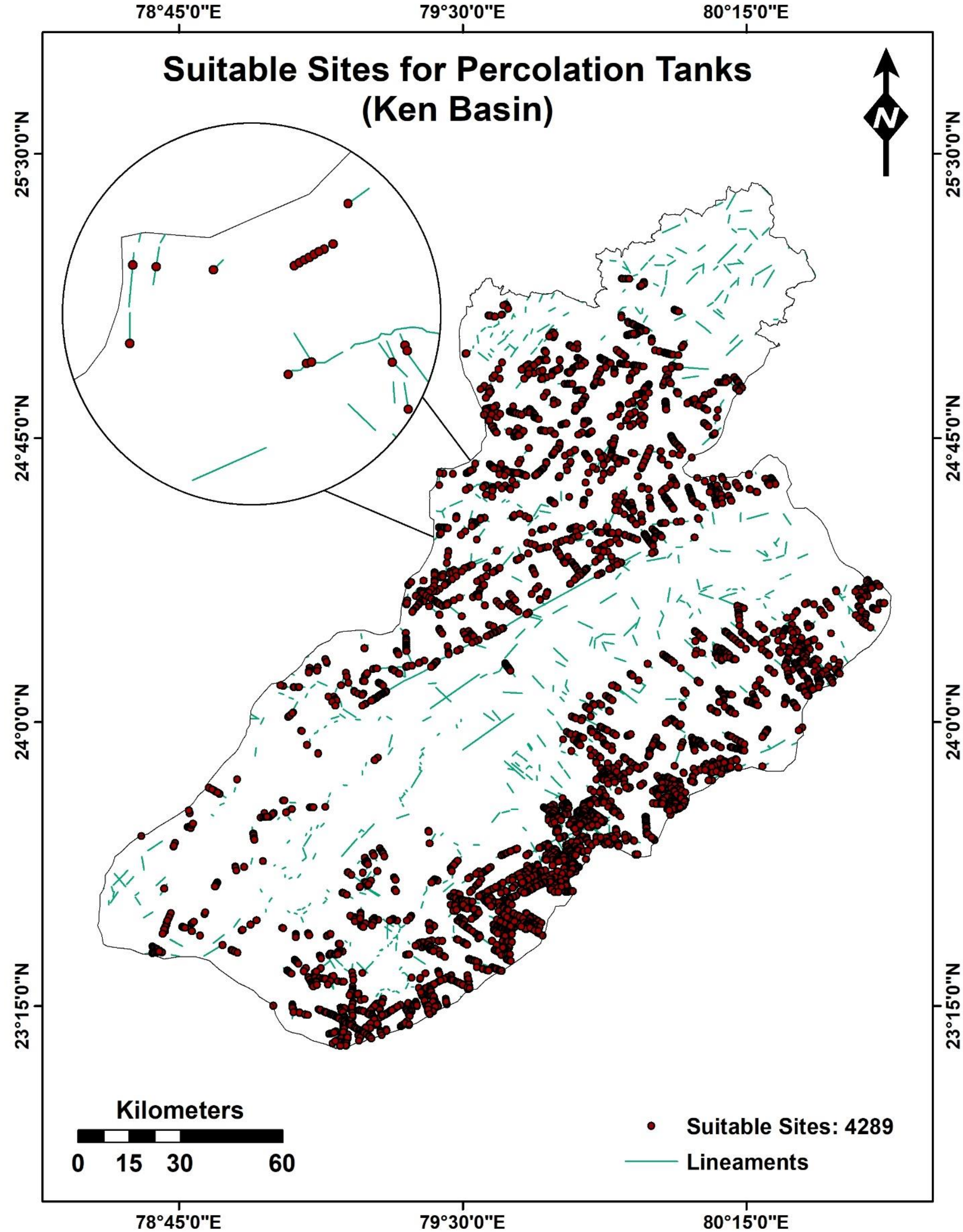

Fig. 16: Suitable Sites for Percolation Tanks in Ken River Basin

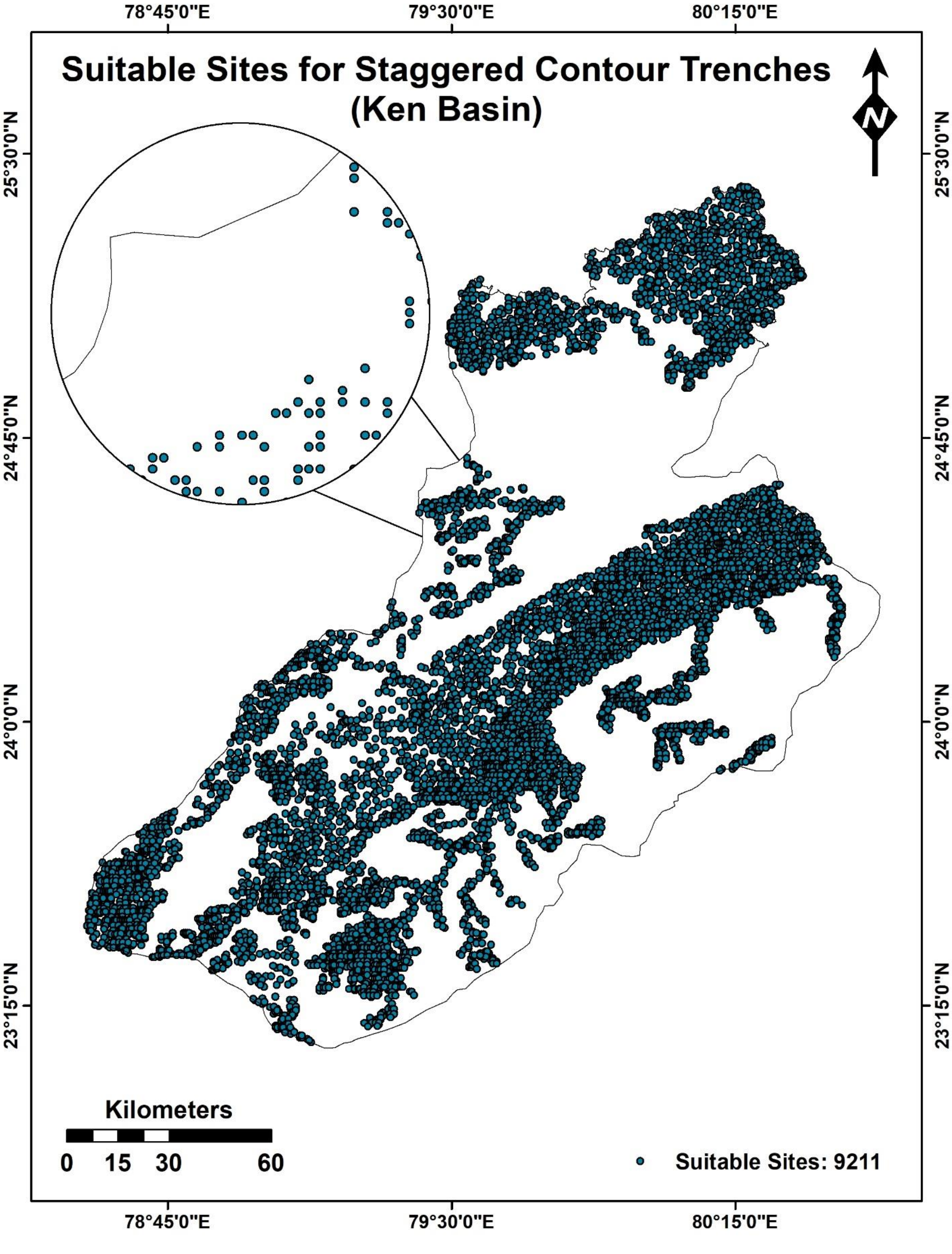

Fig. 17: Suitable Sites for Staggered Contour Trenches in Ken River Basin

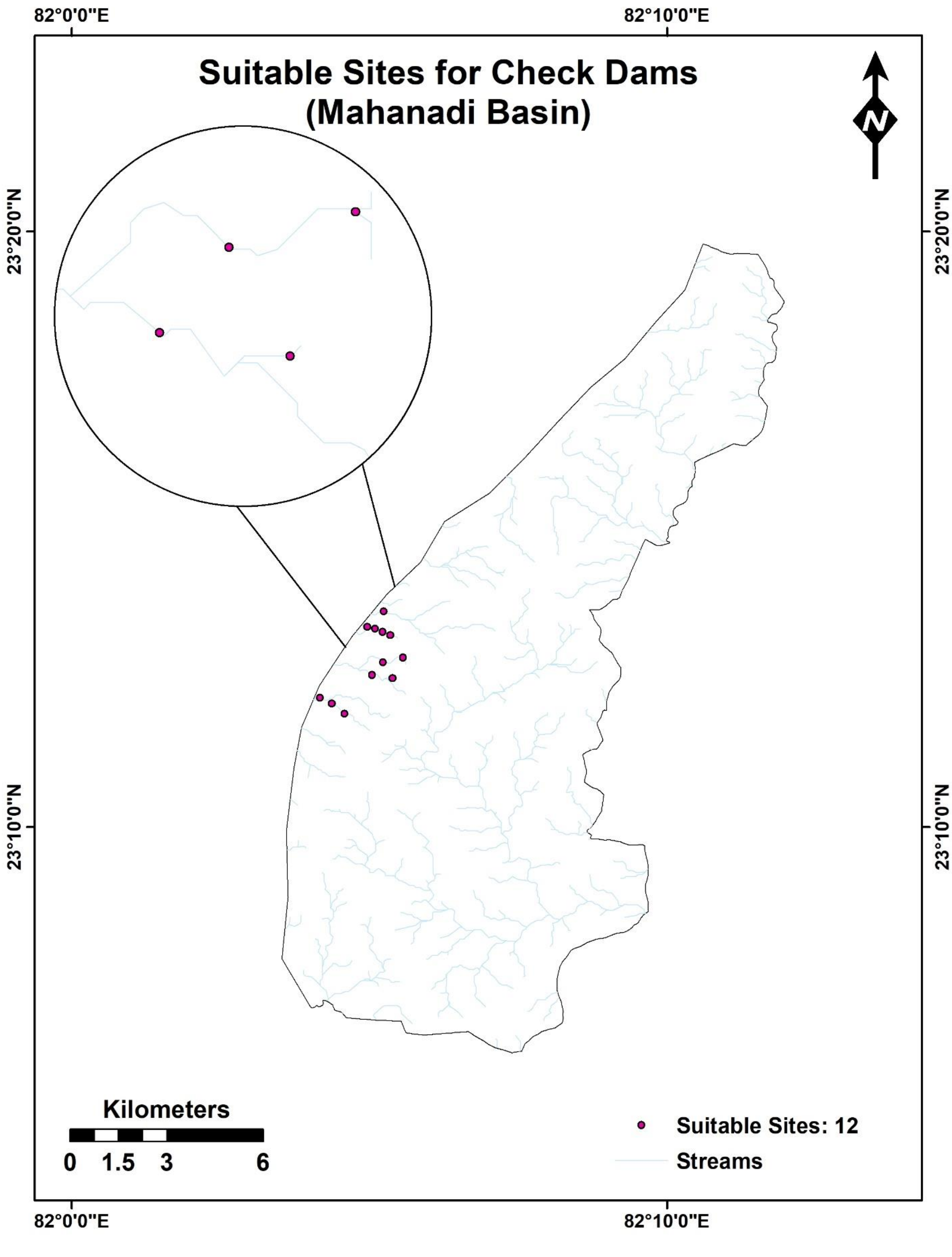

Fig. 18: Suitable Sites for Check Dams in Mahanadi River Basin

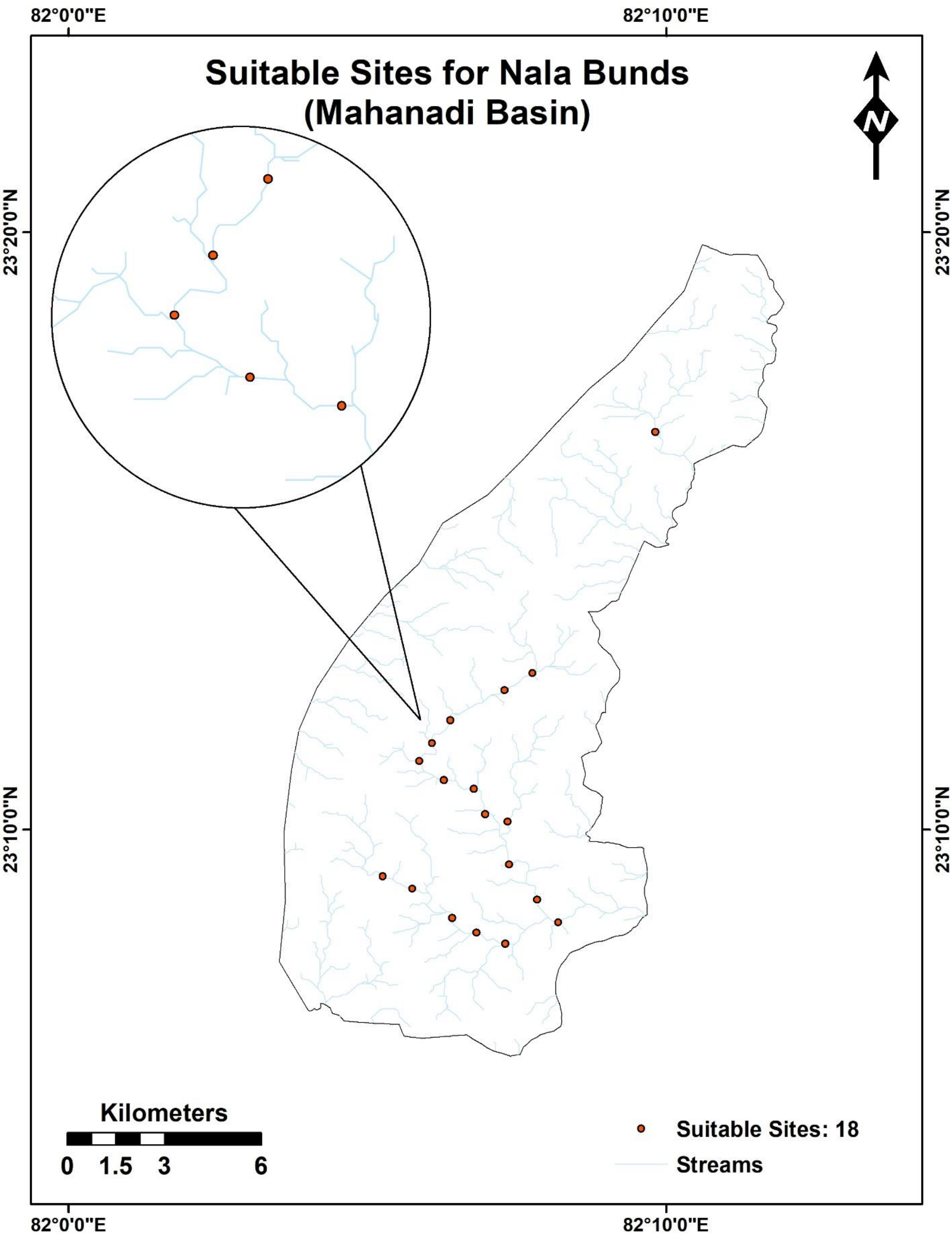

Fig. 19: Suitable Sites for Nala Bunds in Mahanadi River Basin

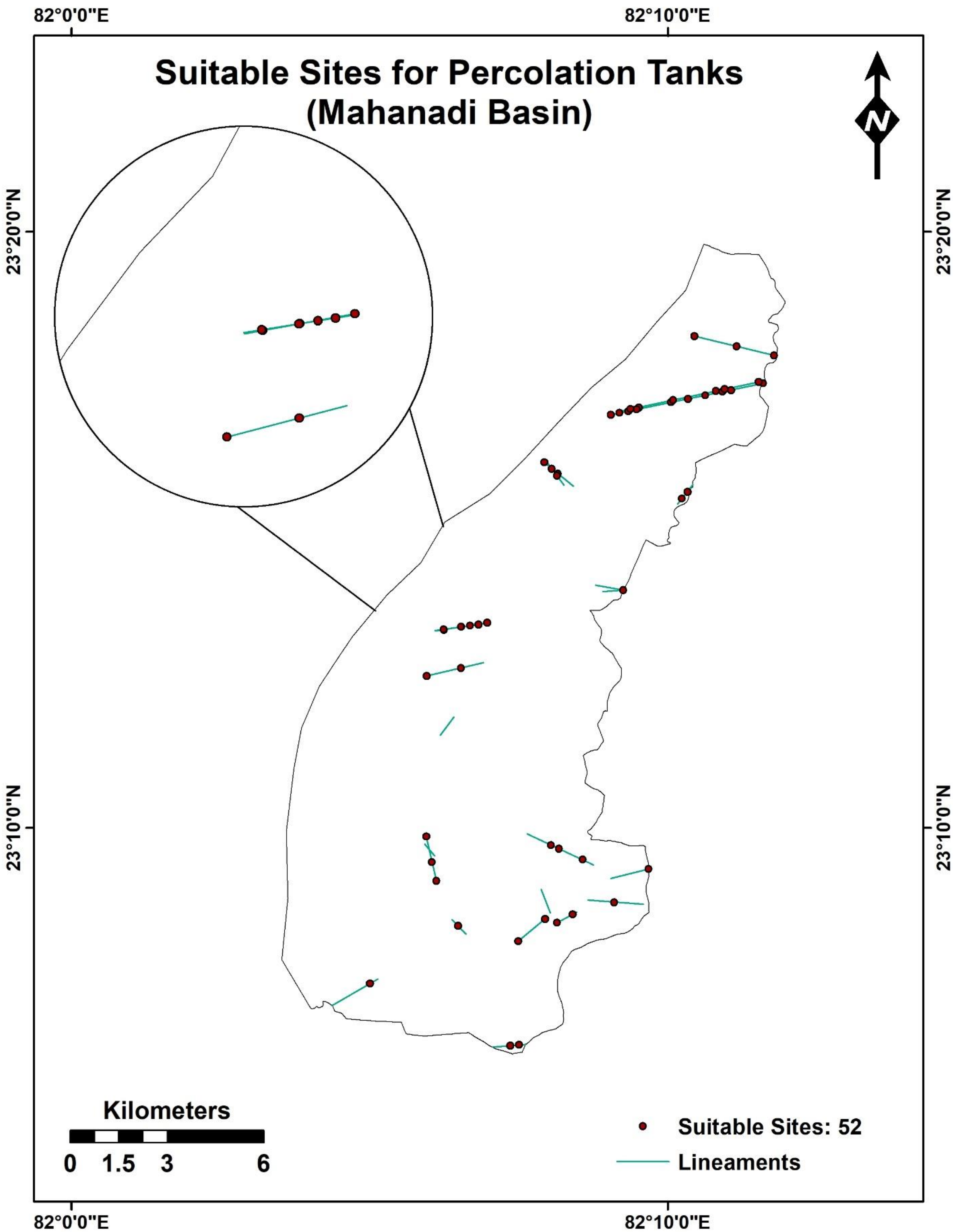

Fig. 20: Suitable Sites for Percolation Tanks in Mahanadi River Basin

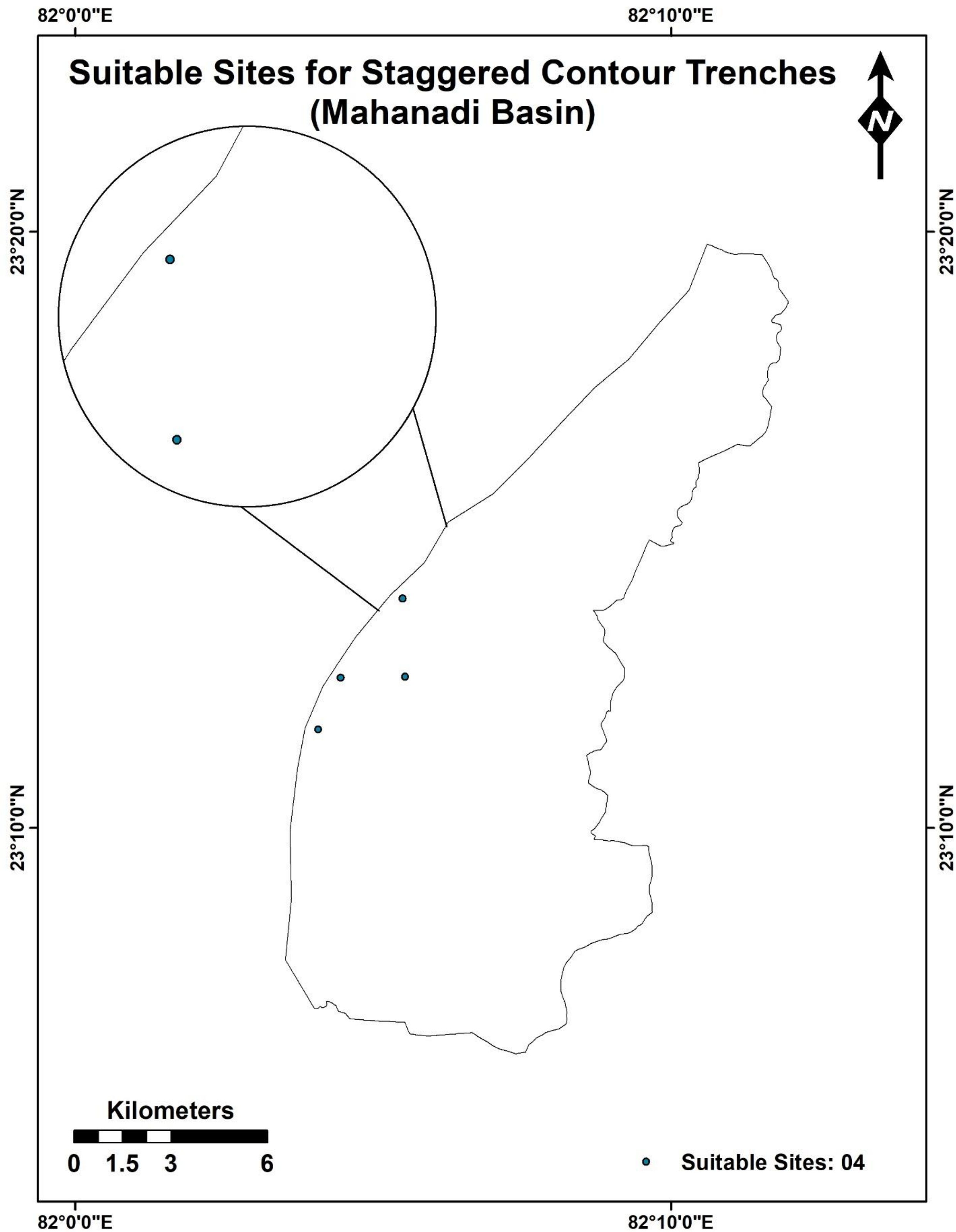

Fig. 21: Suitable Sites for Staggered Contour Trenches in Mahanadi River Basin

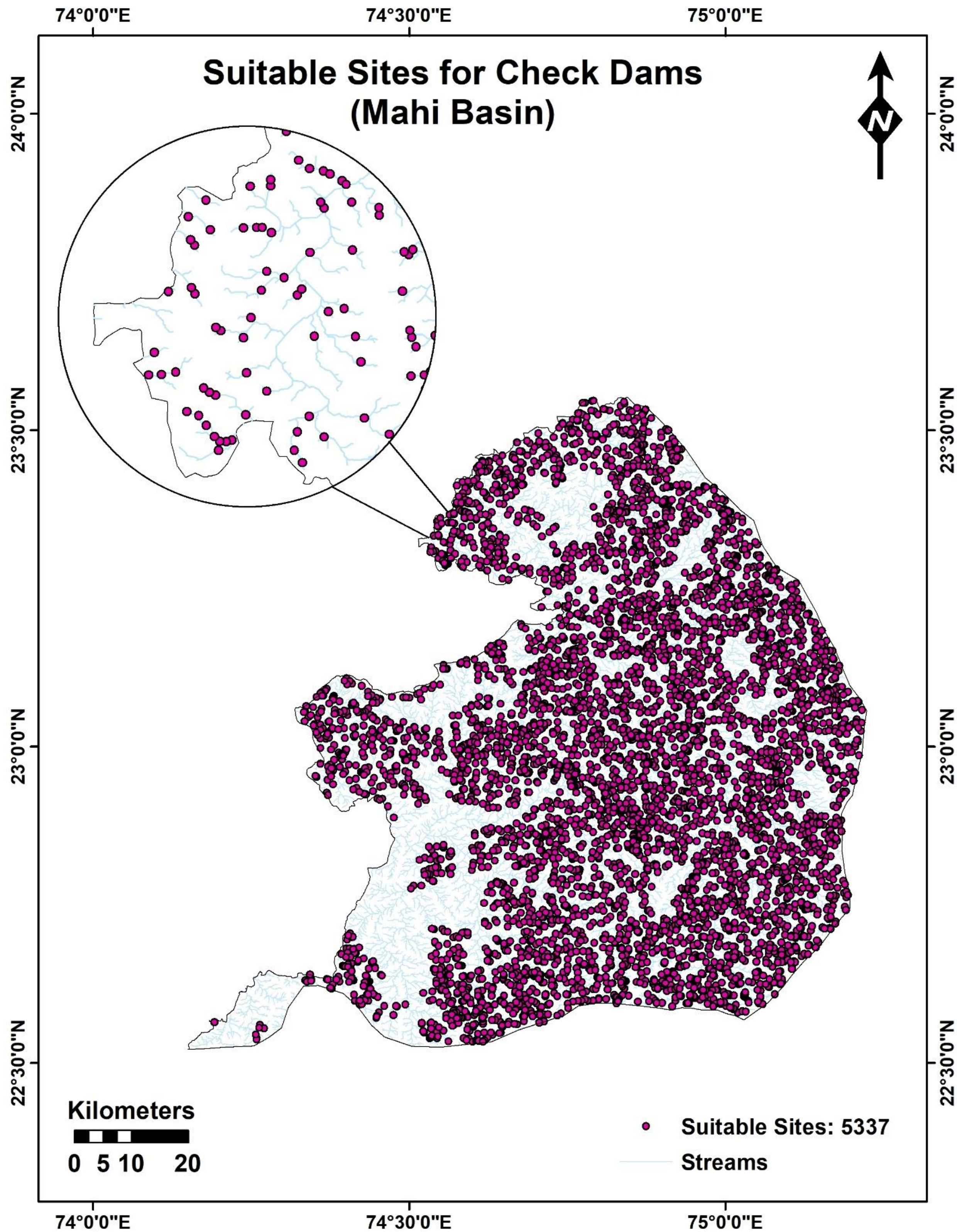

Fig. 22: Suitable Sites for Check Dams in Mahi River Basin

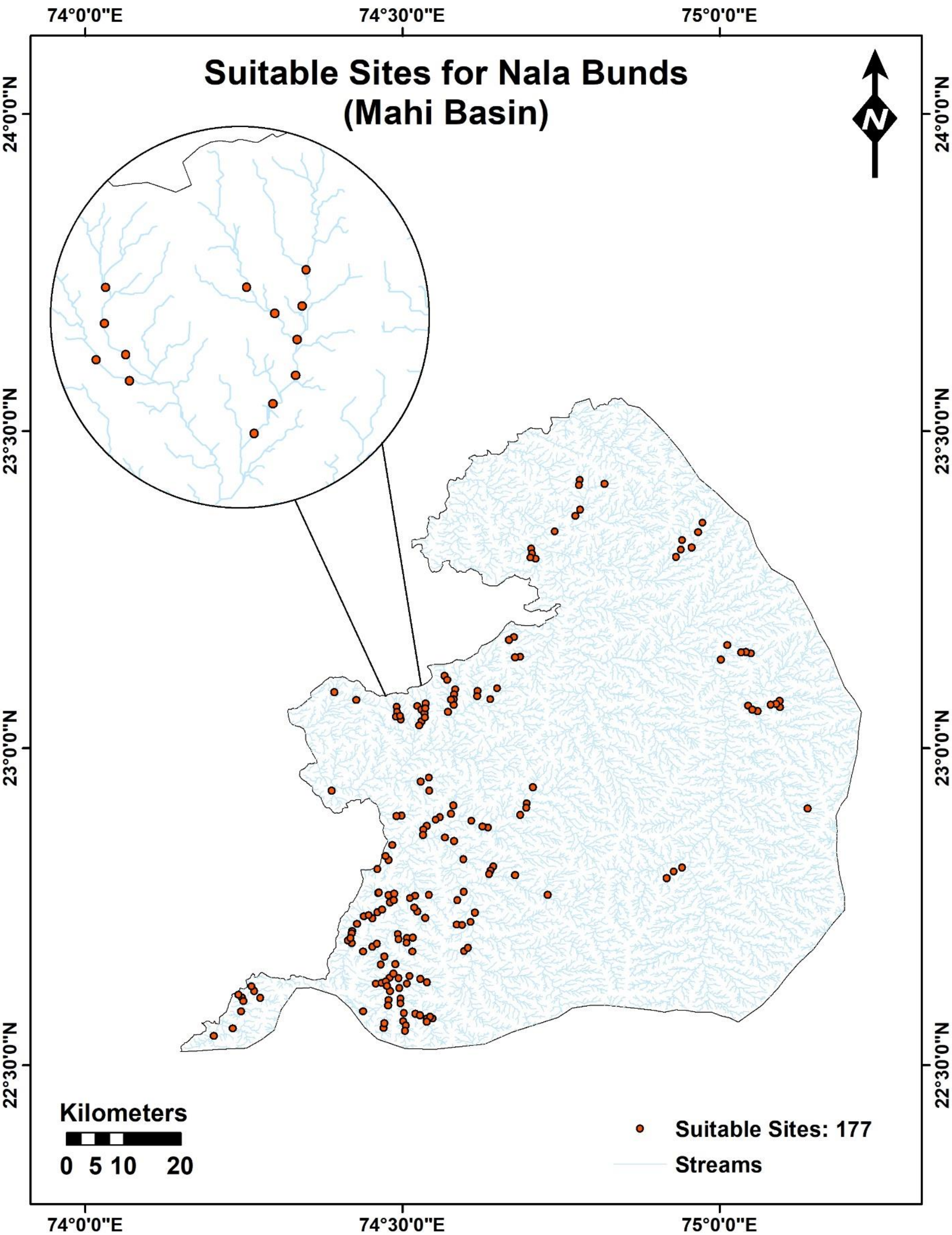

Fig. 23: Suitable Sites for Nala Bunds in Mahi River Basin

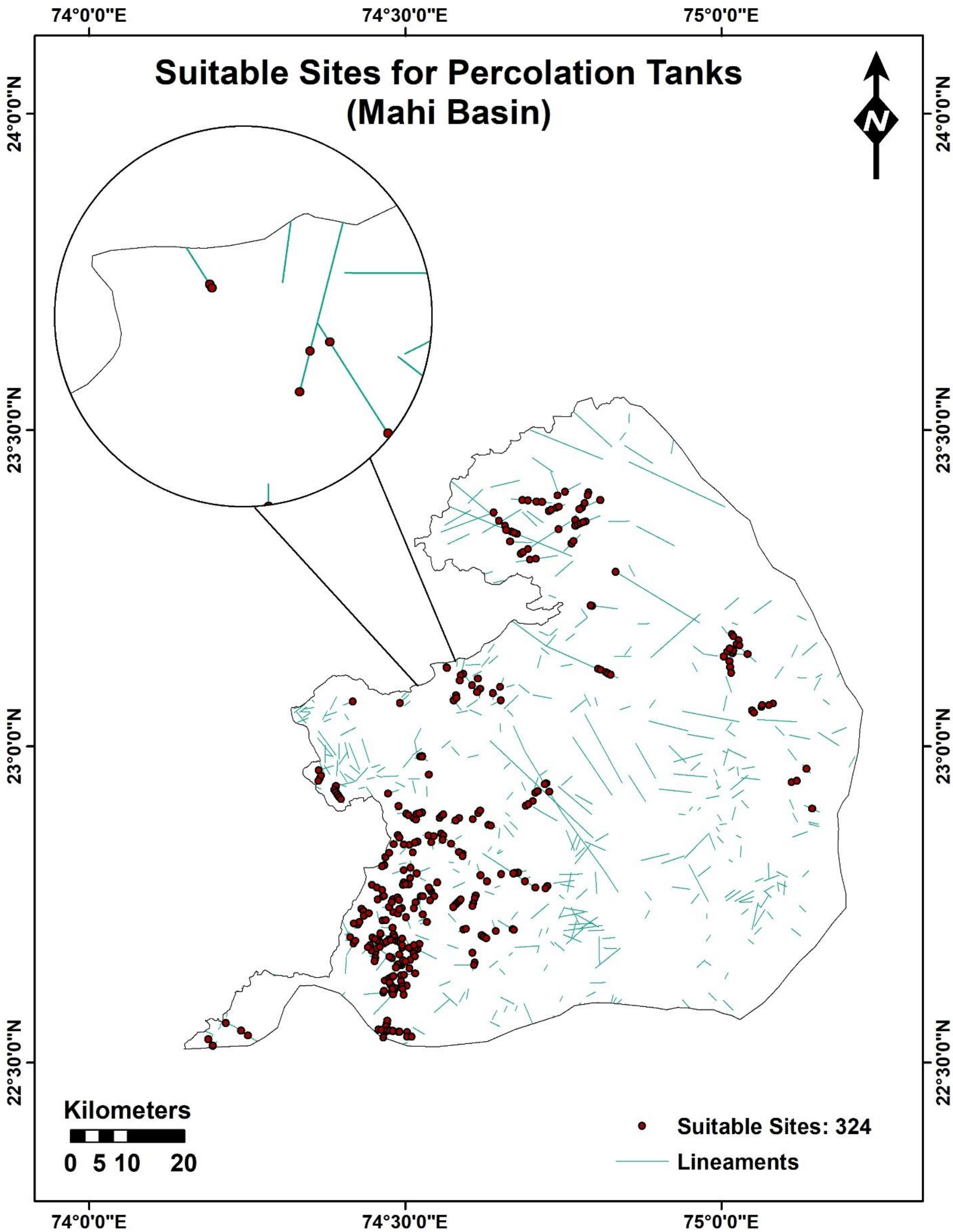

Fig. 24: Suitable Sites for Percolation Tanks in Mahi River Basin

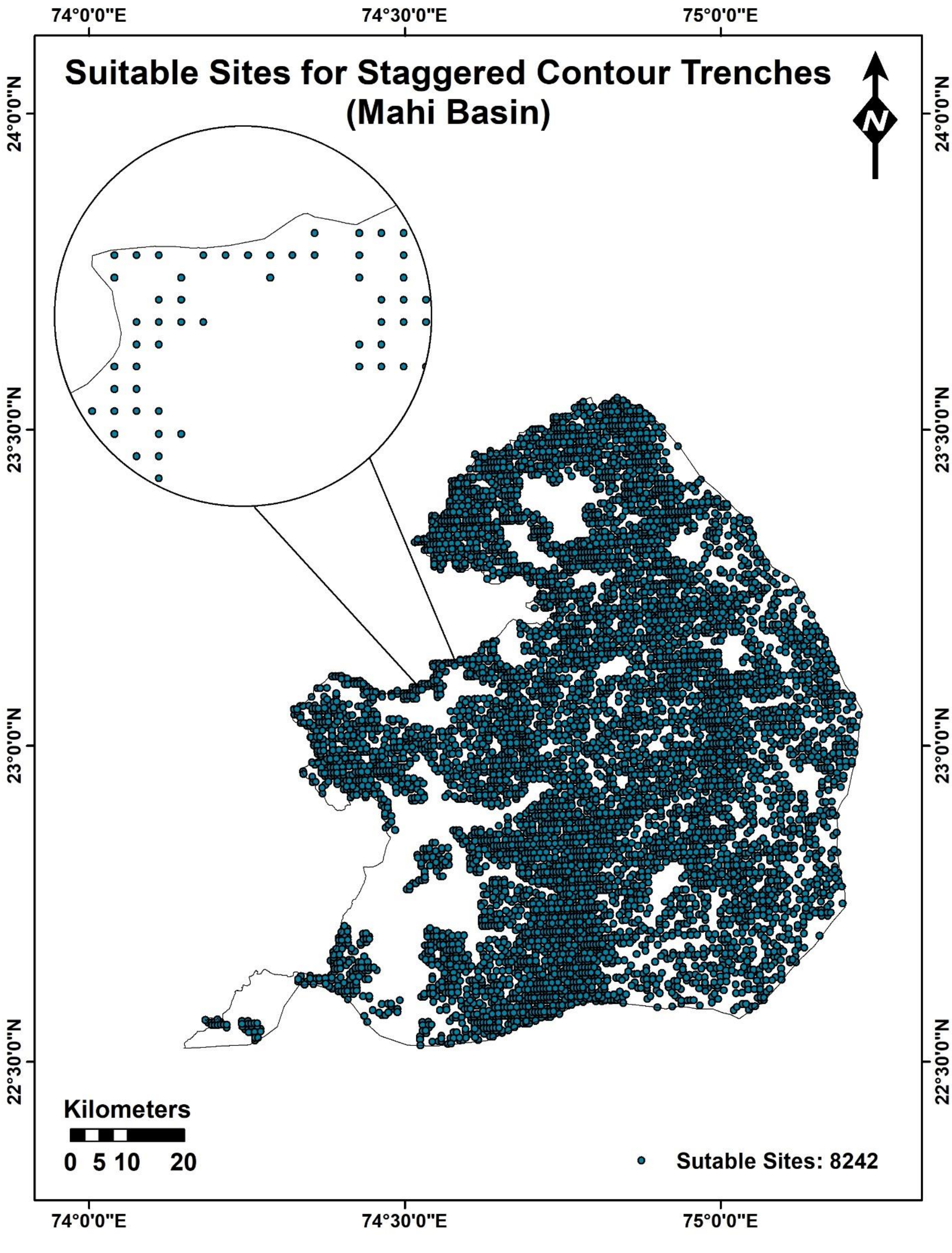

Fig. 25: Suitable Sites for Staggered Contour Trenches in Mahi River Basin

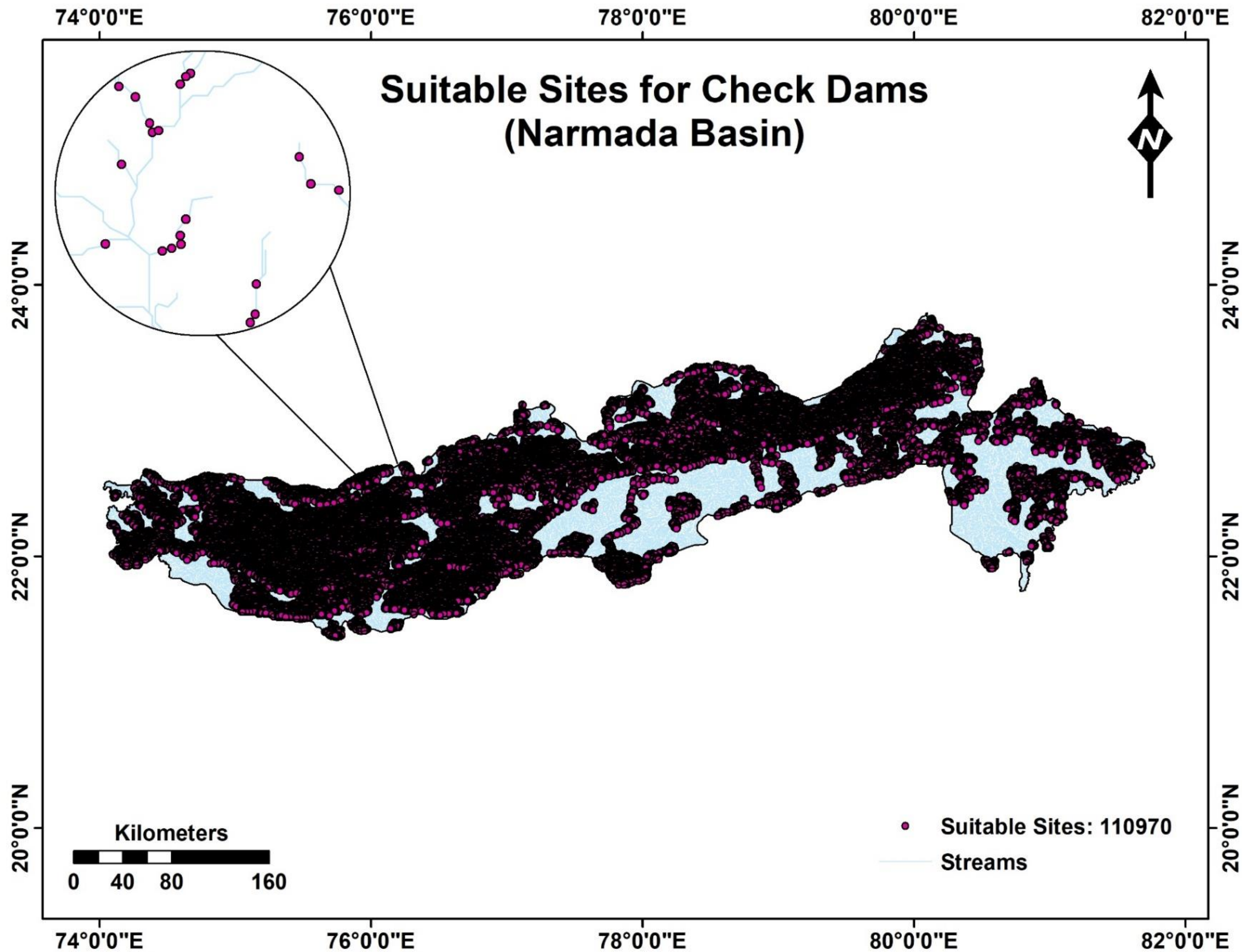

Fig. 26: Suitable Sites for Check Dams in Narmada River Basin

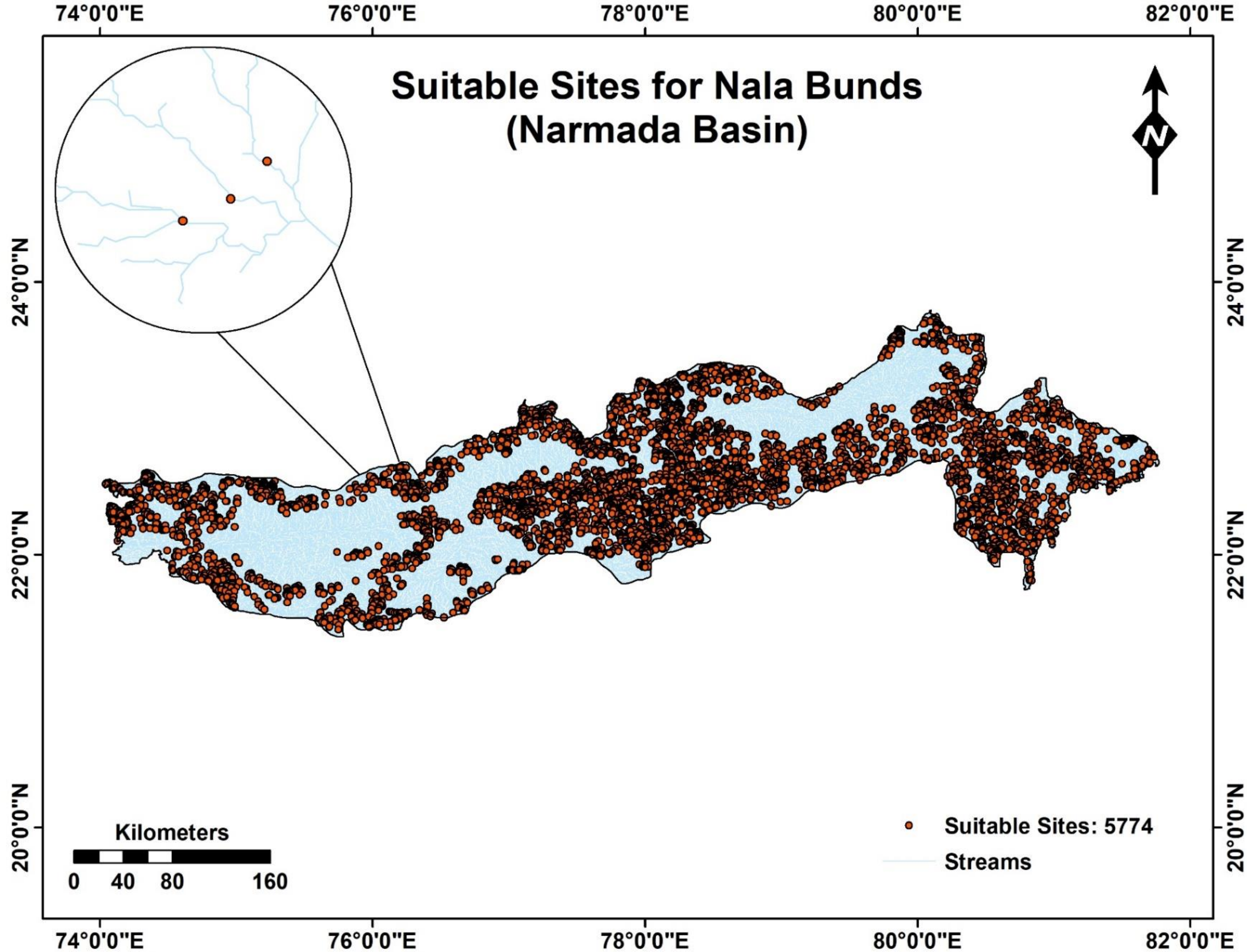

Fig. 27: Suitable Sites for Nala Bunds in Narmada River Basin

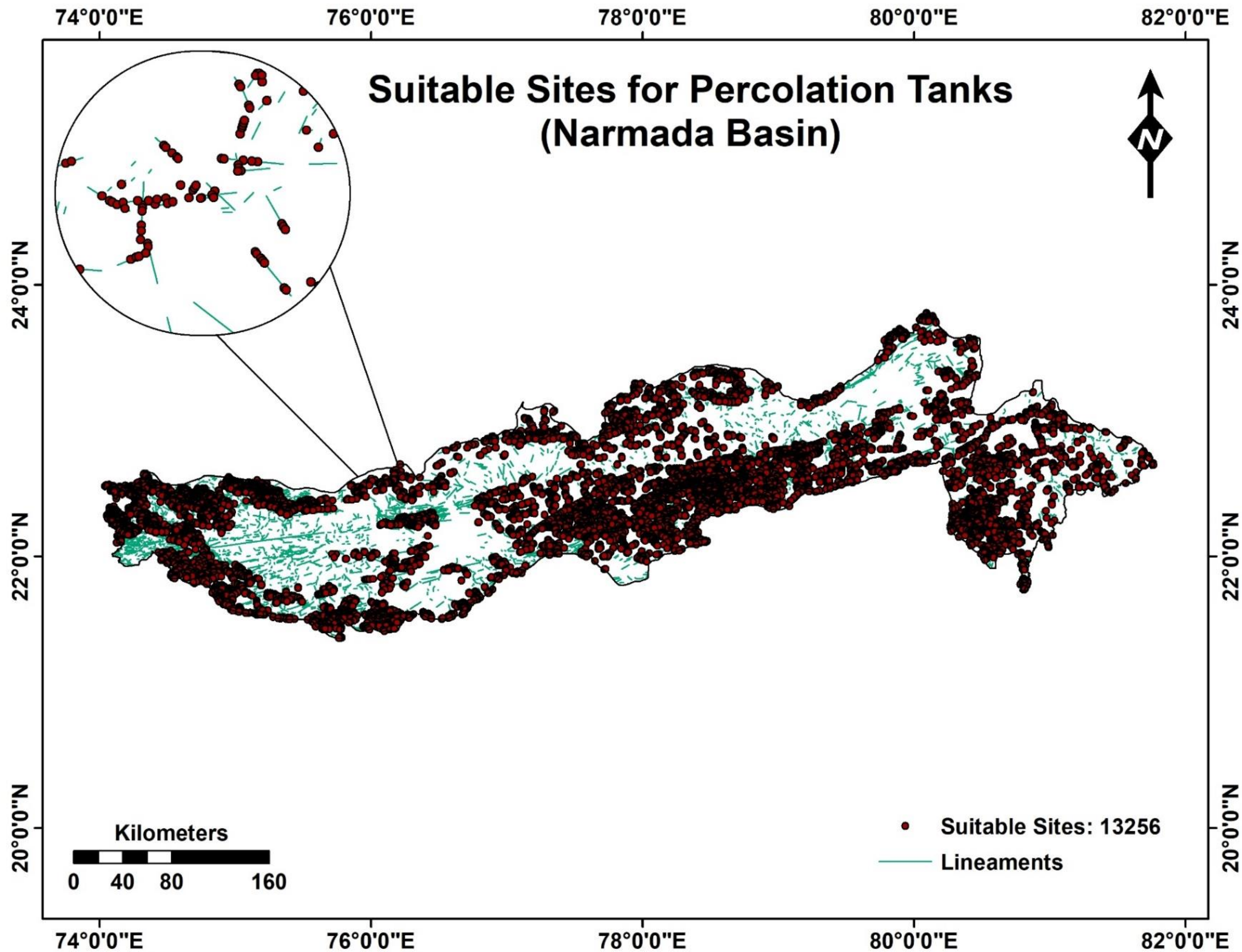

Fig. 28: Suitable Sites for Percolation Tanks in Narmada River Basin

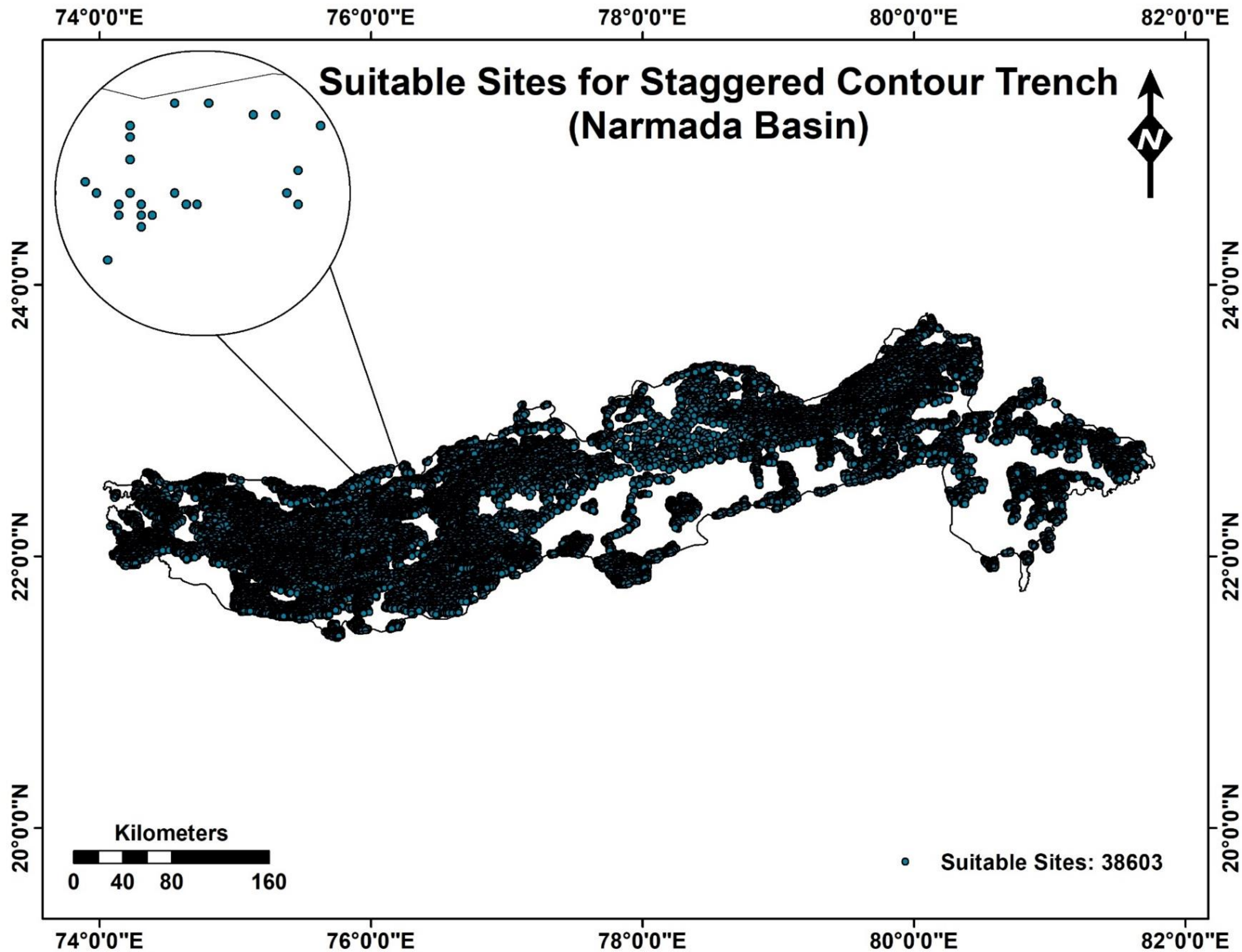

Fig. 29: Suitable Sites for Staggered Contour Trenches in Narmada River Basin

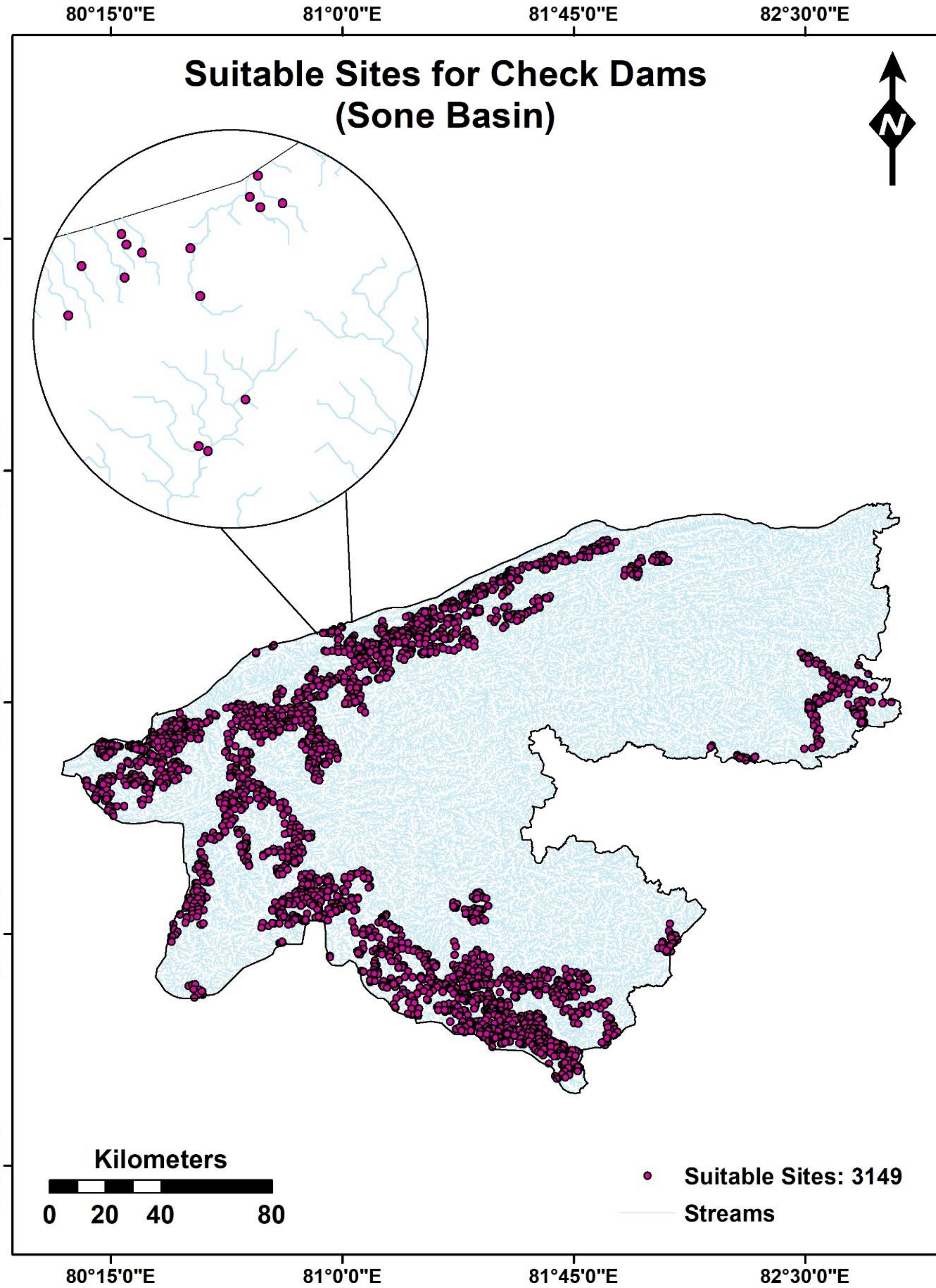

Fig. 30: Suitable Sites for Check Dams in Sone River Basin

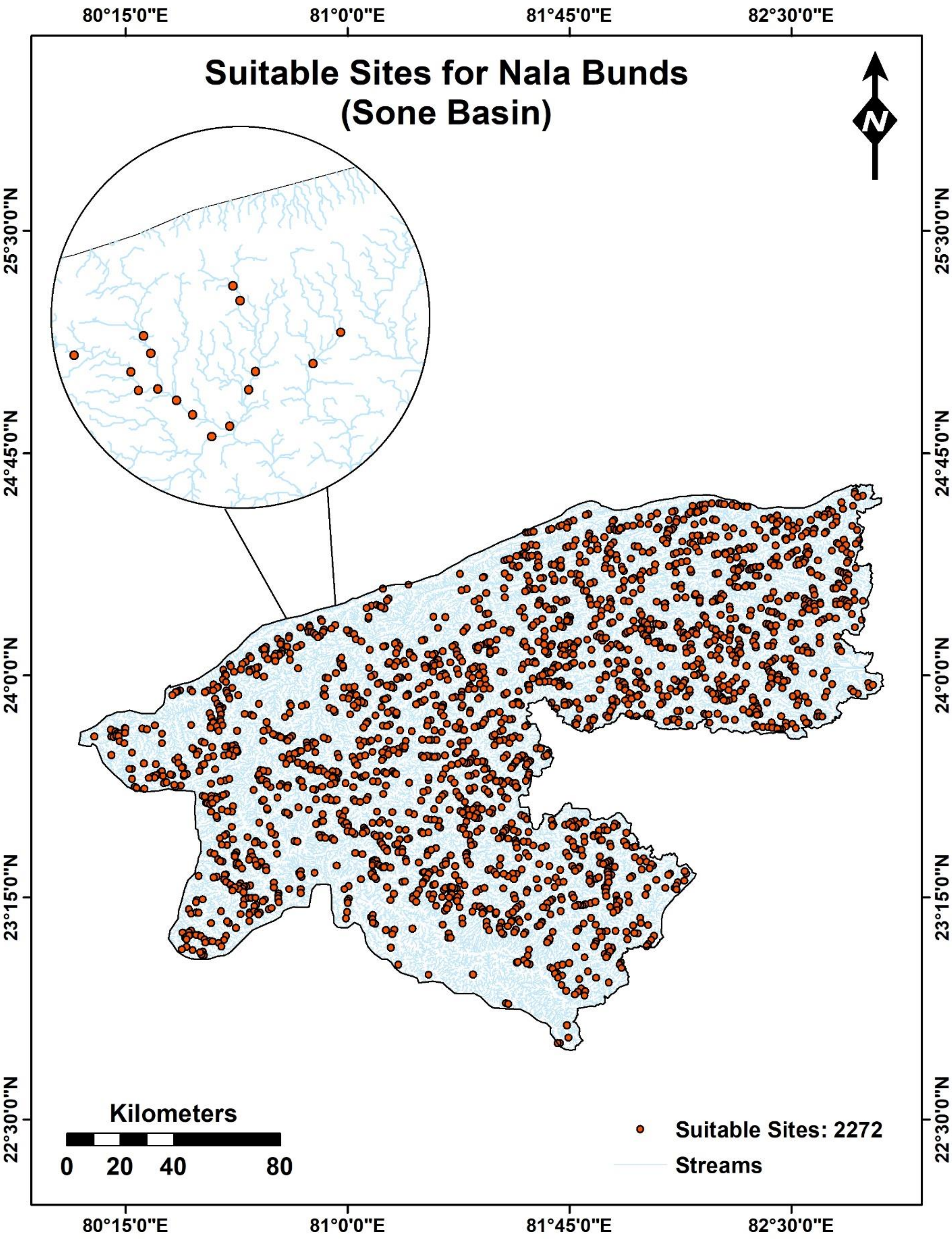

Fig. 31: Suitable Sites for Nala Bunds in Sone River Basin

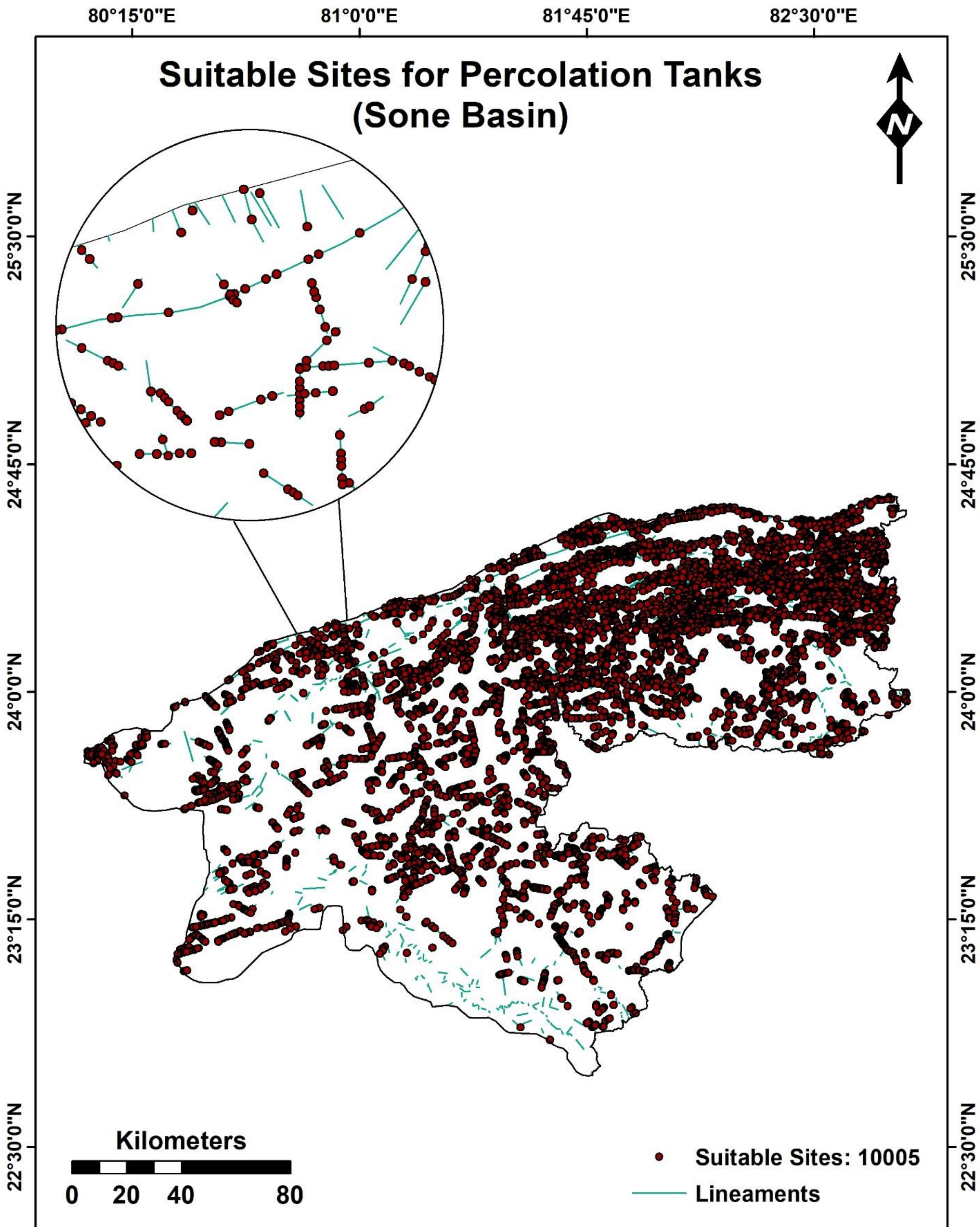

Fig. 32: Suitable Sites for Percolation Tanks in Sone River Basin

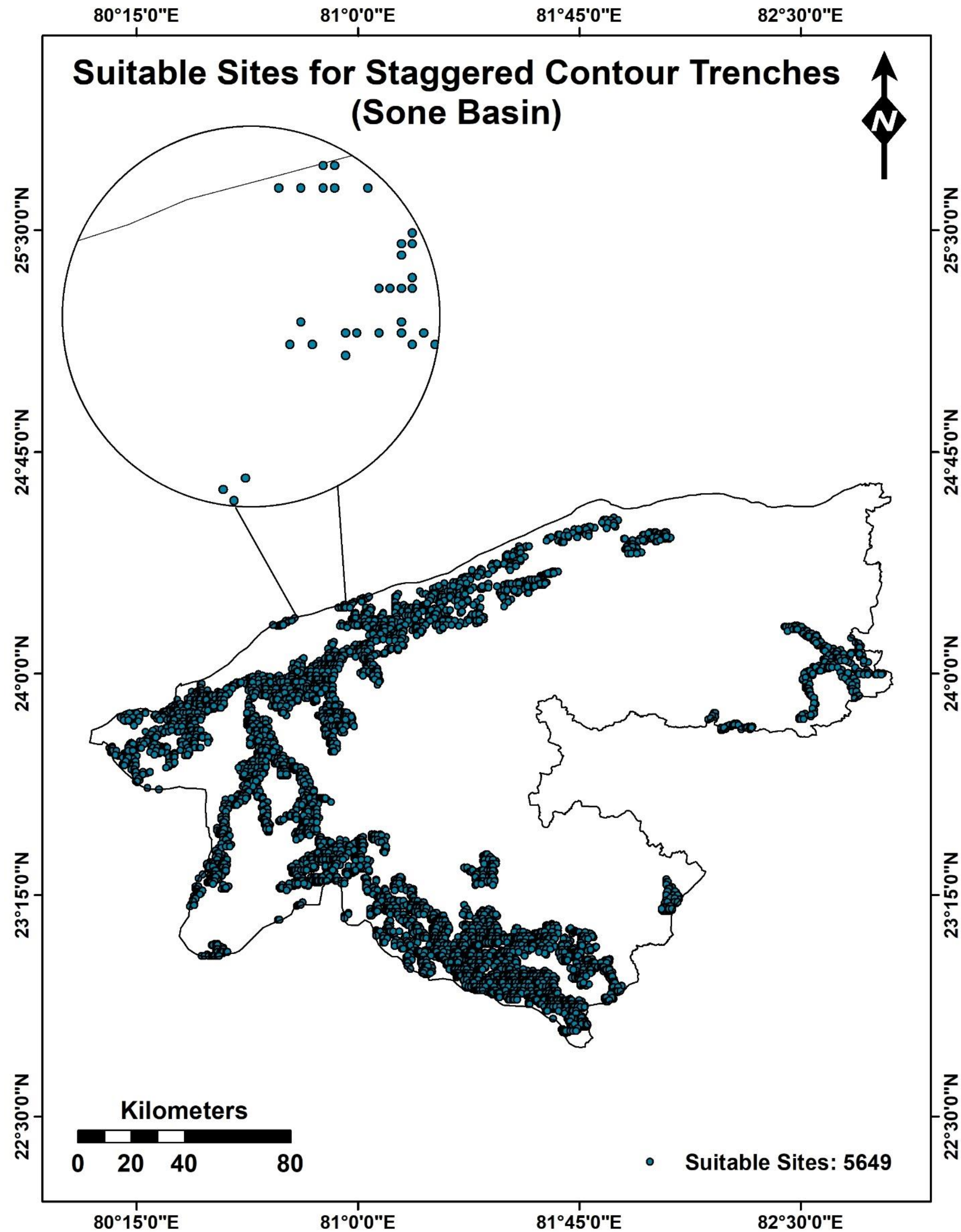

Fig. 33: Suitable Sites for Staggered Contour Trenches in Sone River Basin

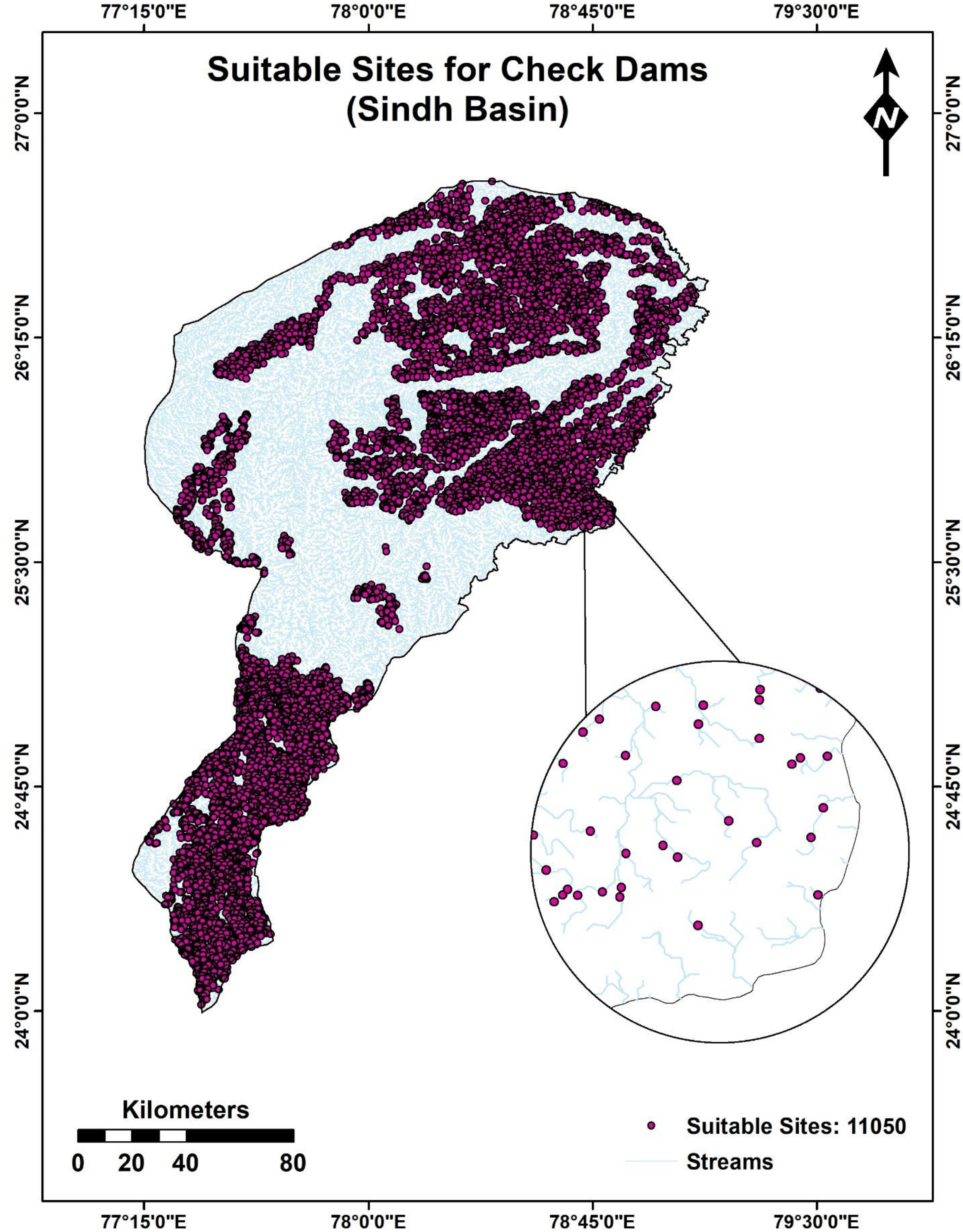

Fig. 34: Suitable Sites for Check Dams in Sindh River Basin

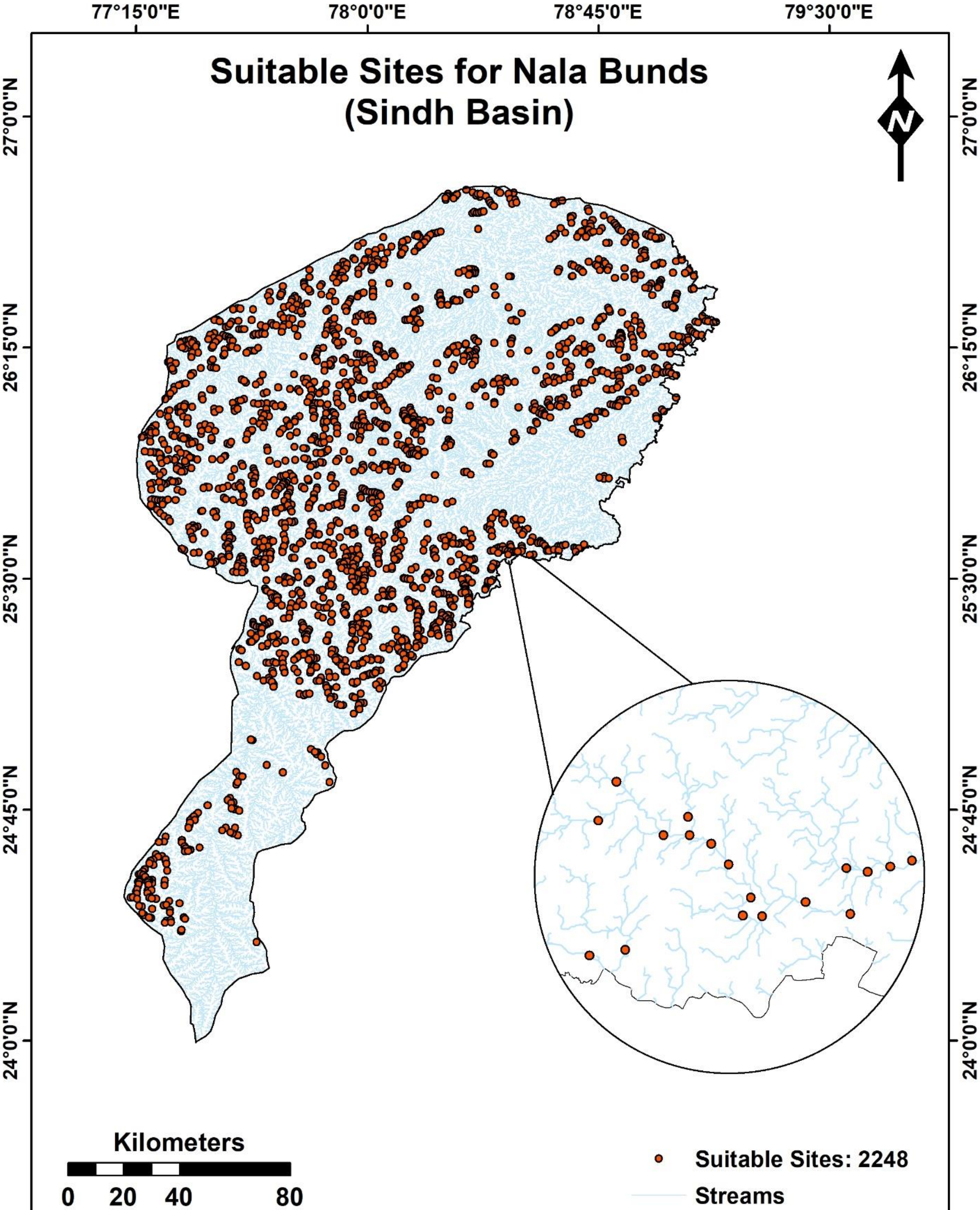

Fig. 35: Suitable Sites for Nala Bunds in Sindh River Basin

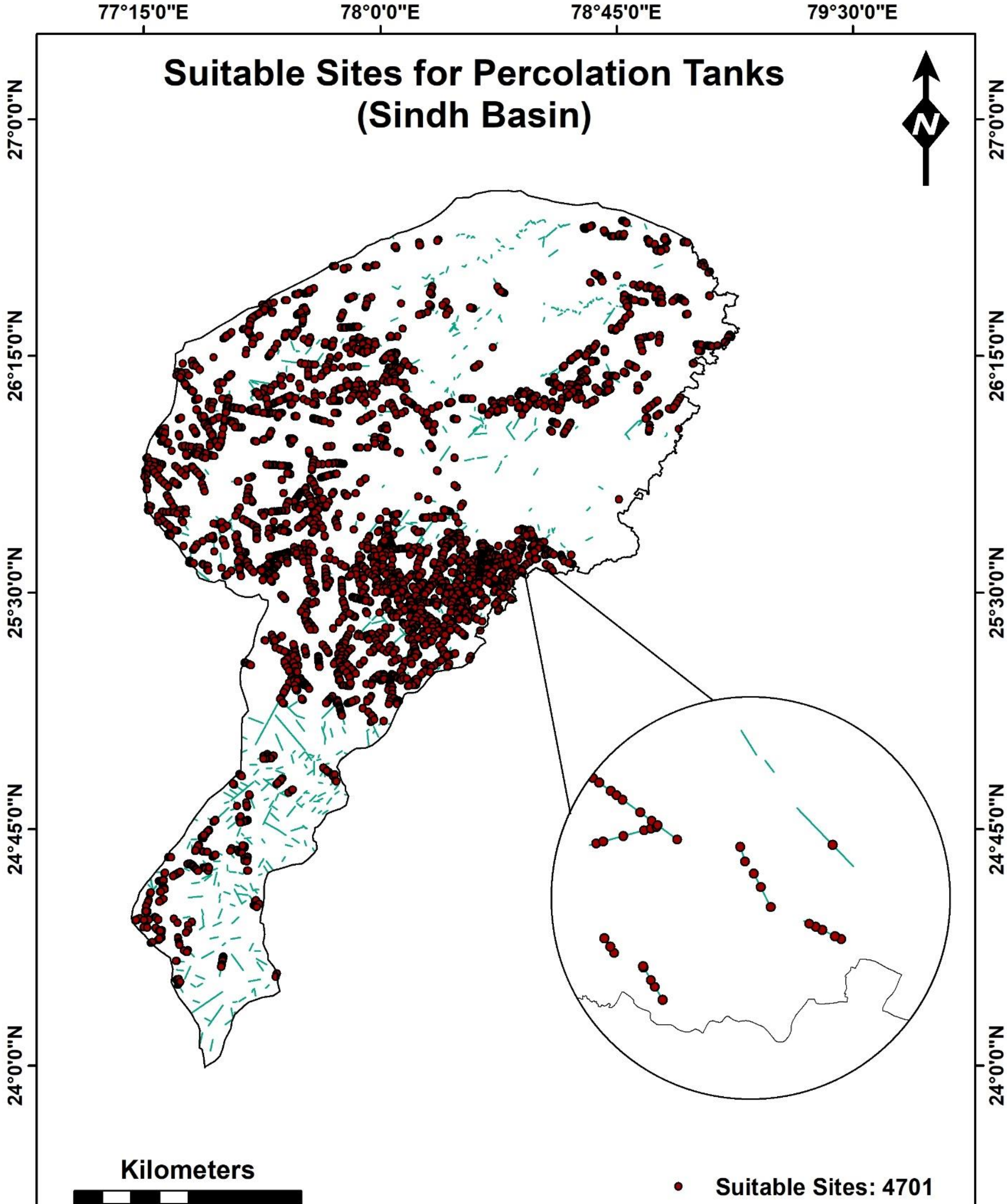

Fig. 36: Suitable Sites for Percolation Tanks in Sindh River Basin

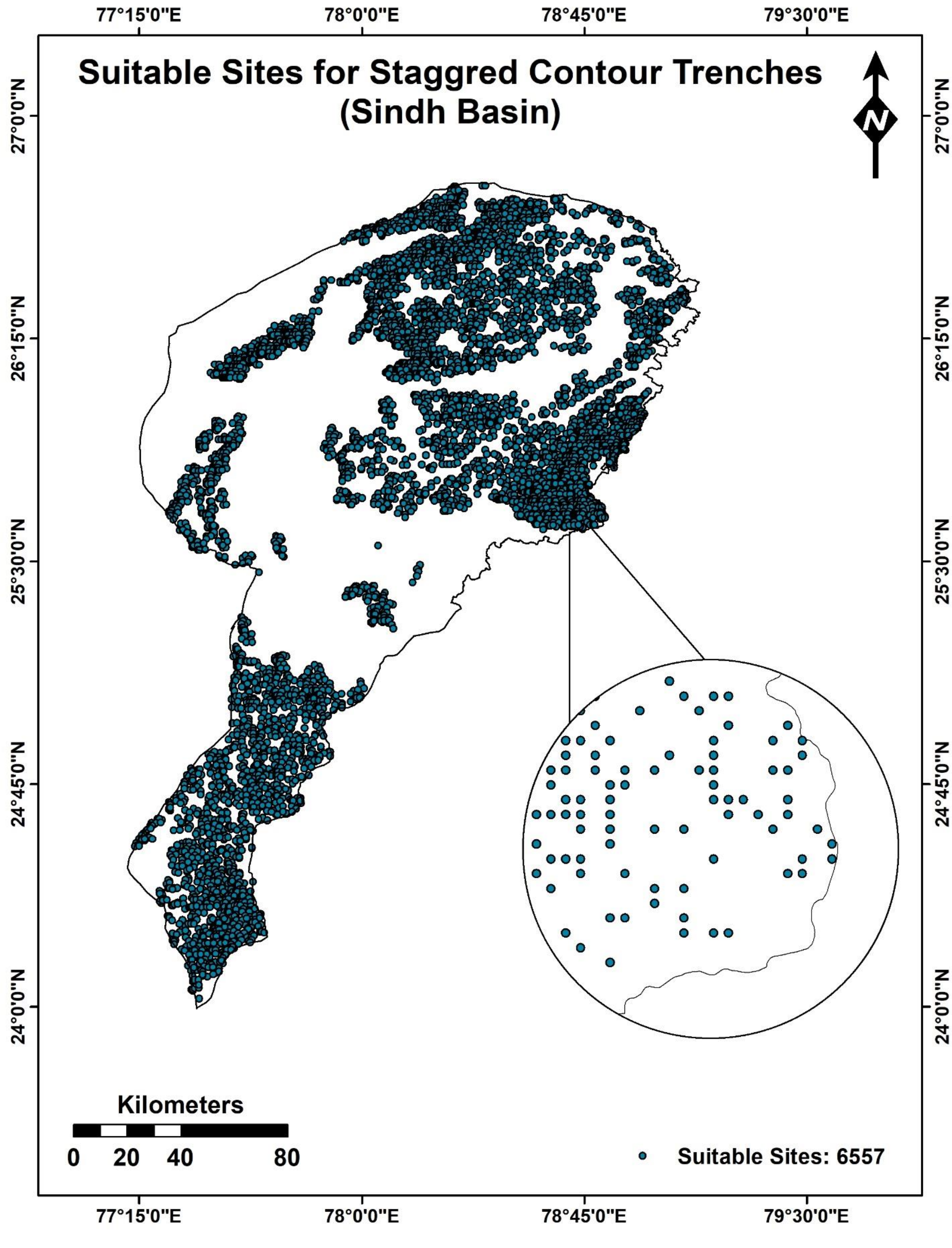

Fig. 37: Suitable Sites for Staggered Contour Trenches in Sindh River Basin

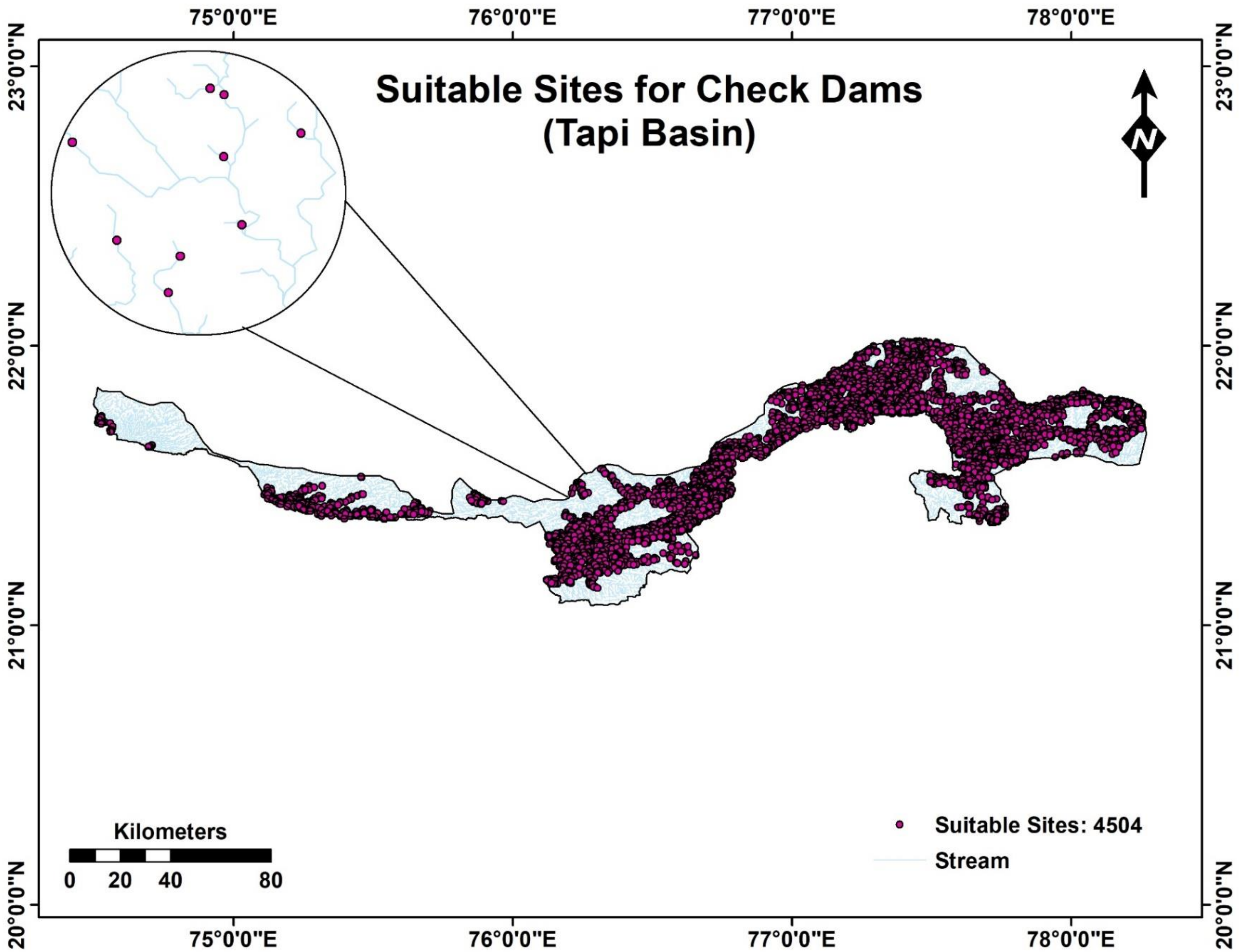

Fig. 38: Suitable Sites for Check Dams in Tapi River Basin

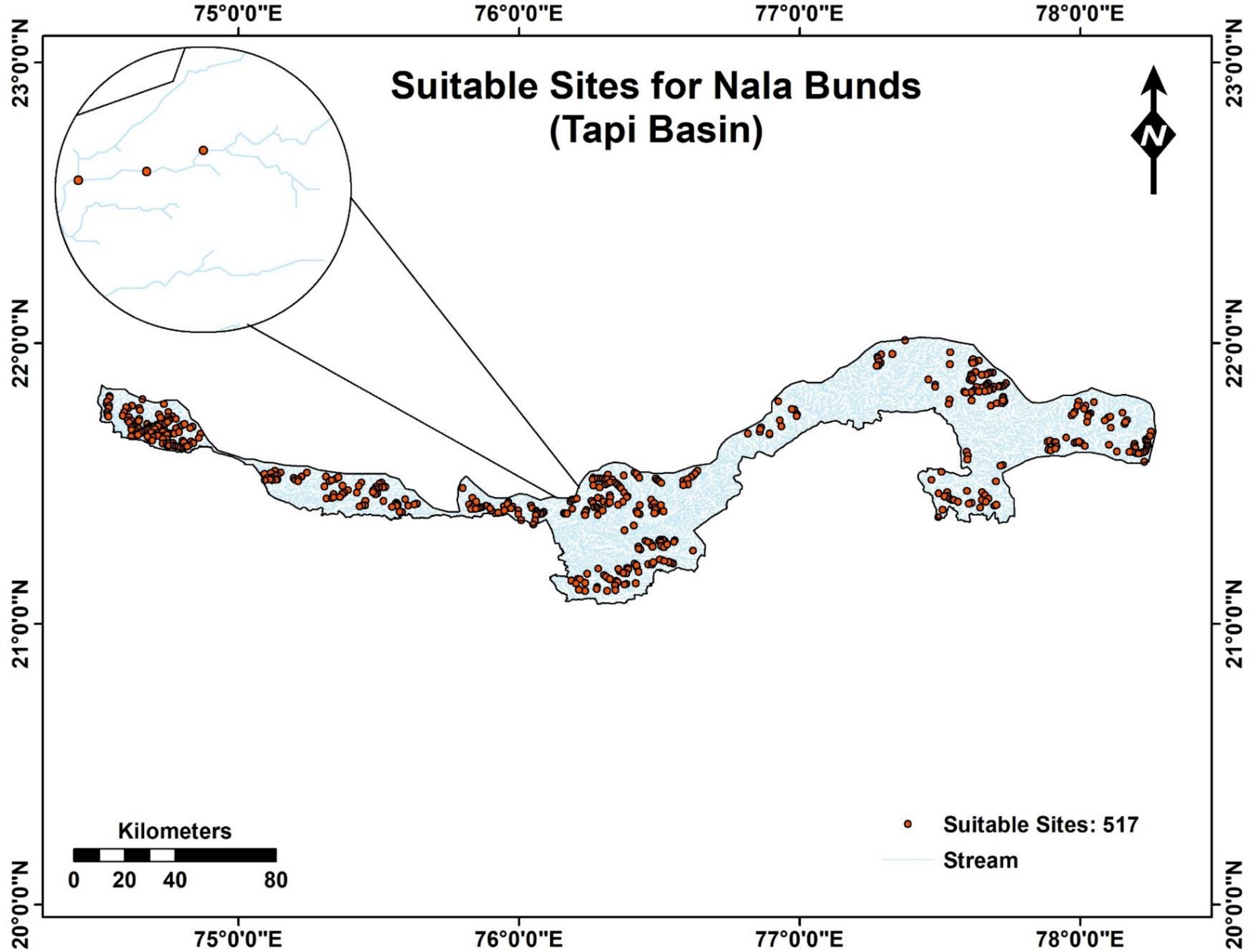

Fig. 39: Suitable Sites for Nala Bunds in Tapi River Basin

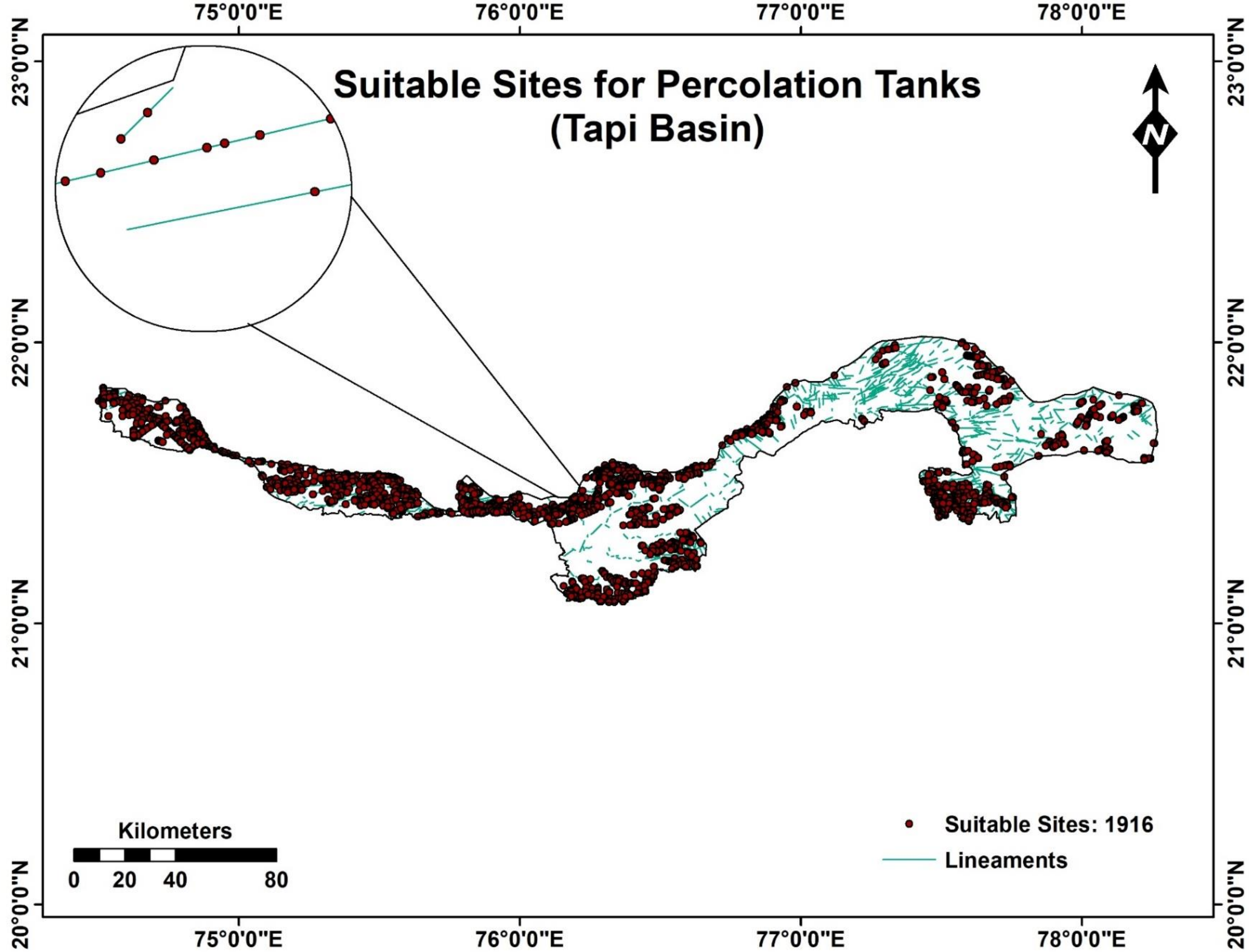

Fig. 40: Suitable Sites for Percolation Tanks in Tapi River Basin

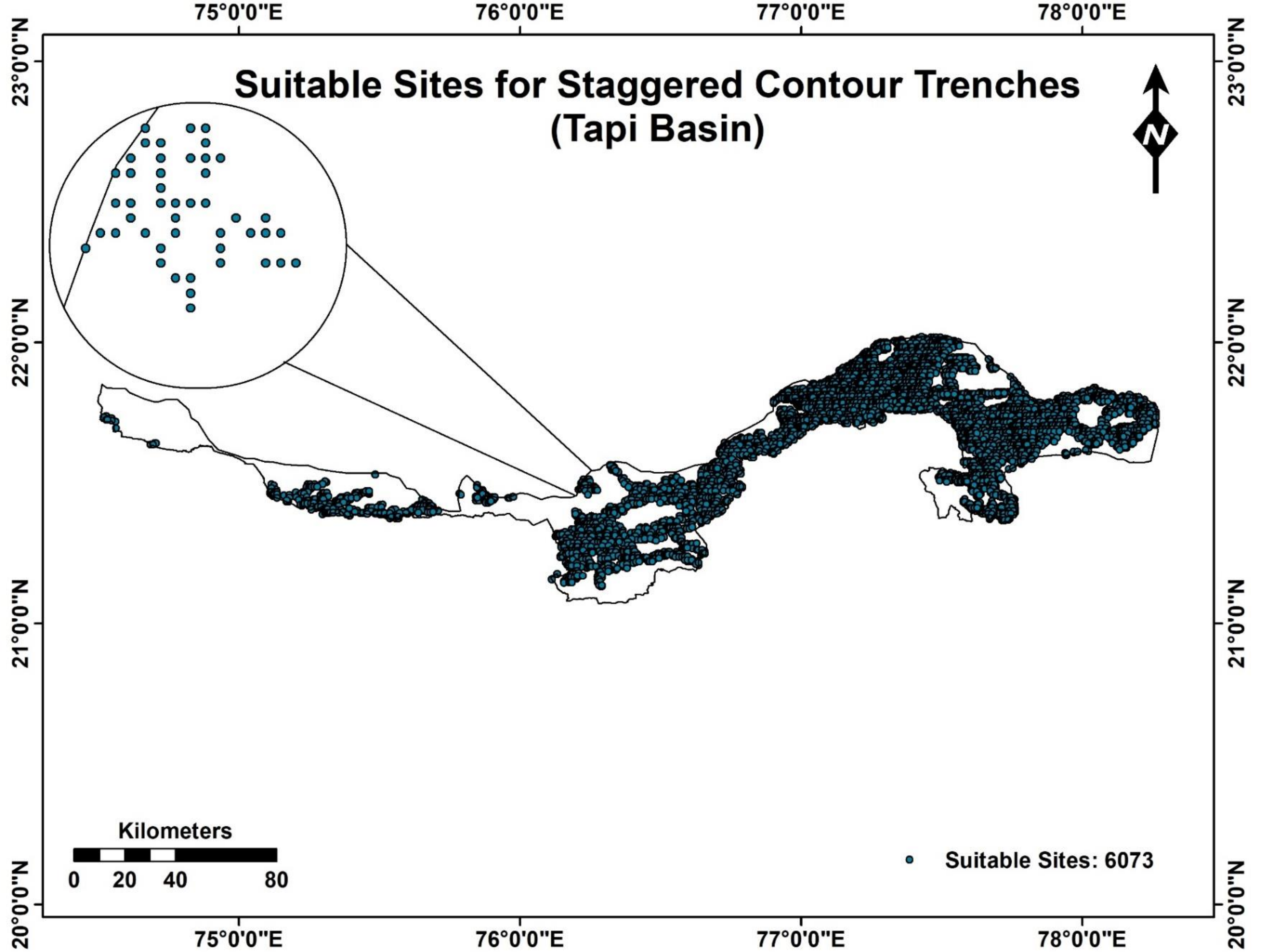

Fig. 41: Suitable Sites for Staggered Contour Trenches in Tapi River Basin

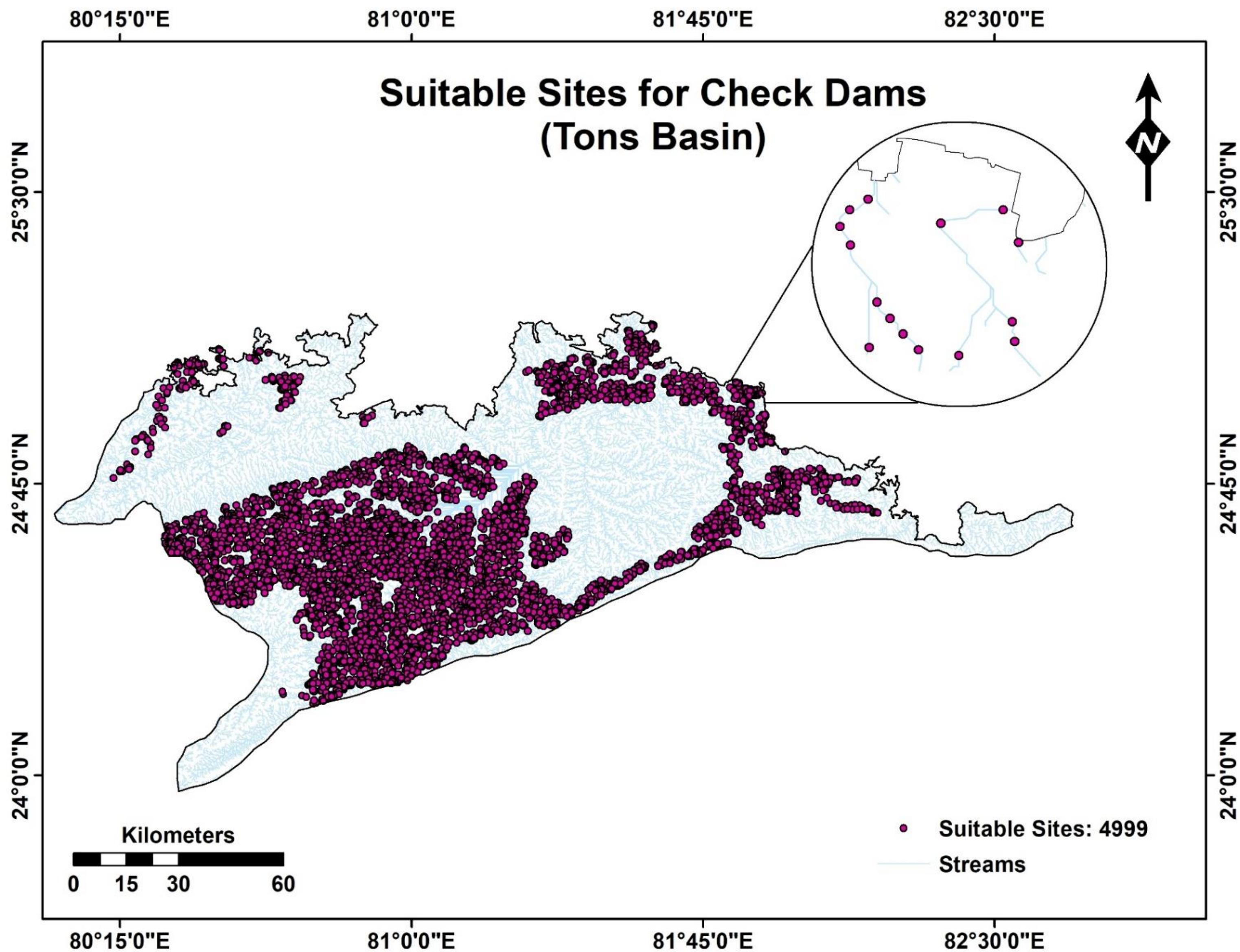

Fig. 42: Suitable Sites for Check Dams in Tons River Basin

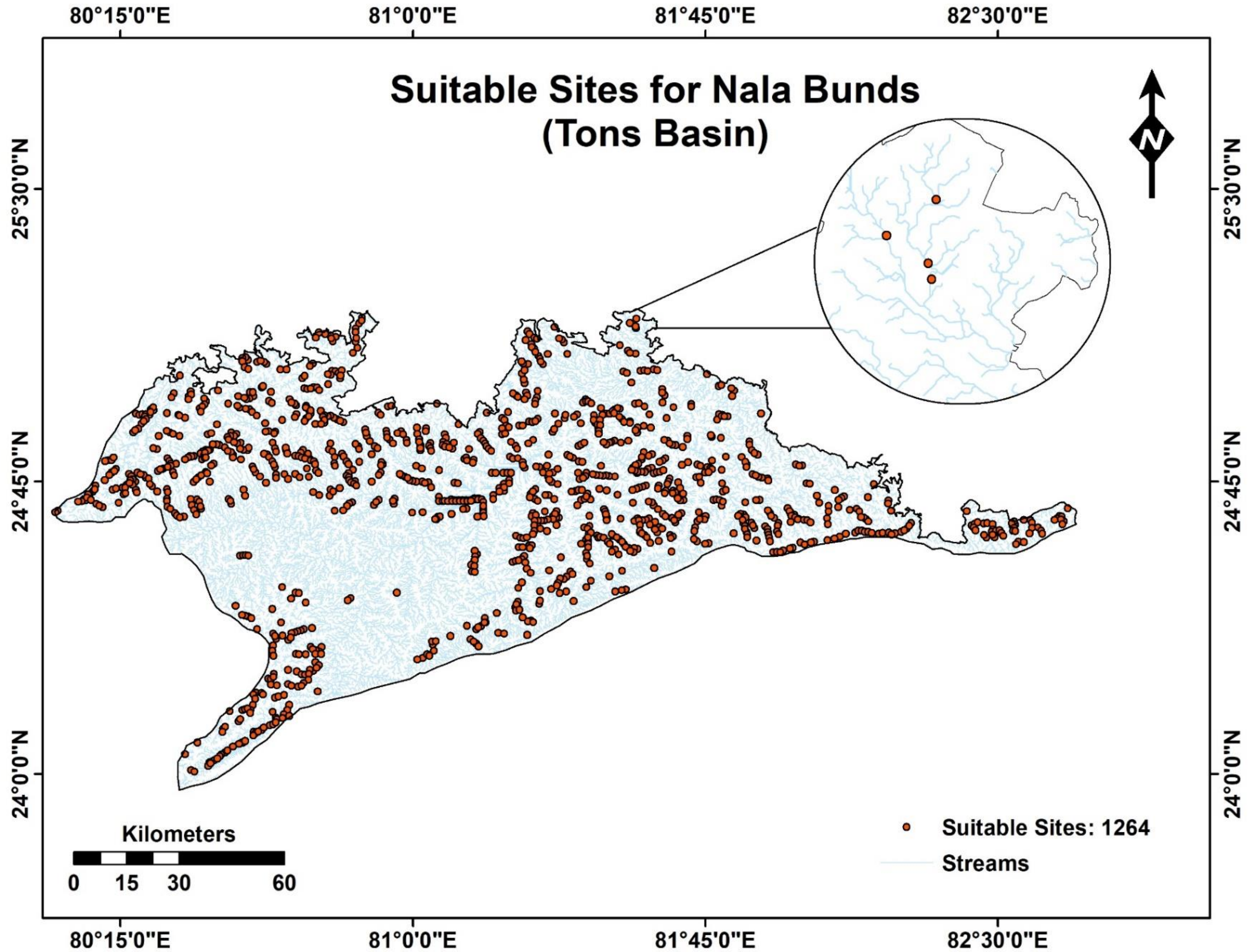

Fig. 43: Suitable Sites for Nala Bunds in Tons River Basin

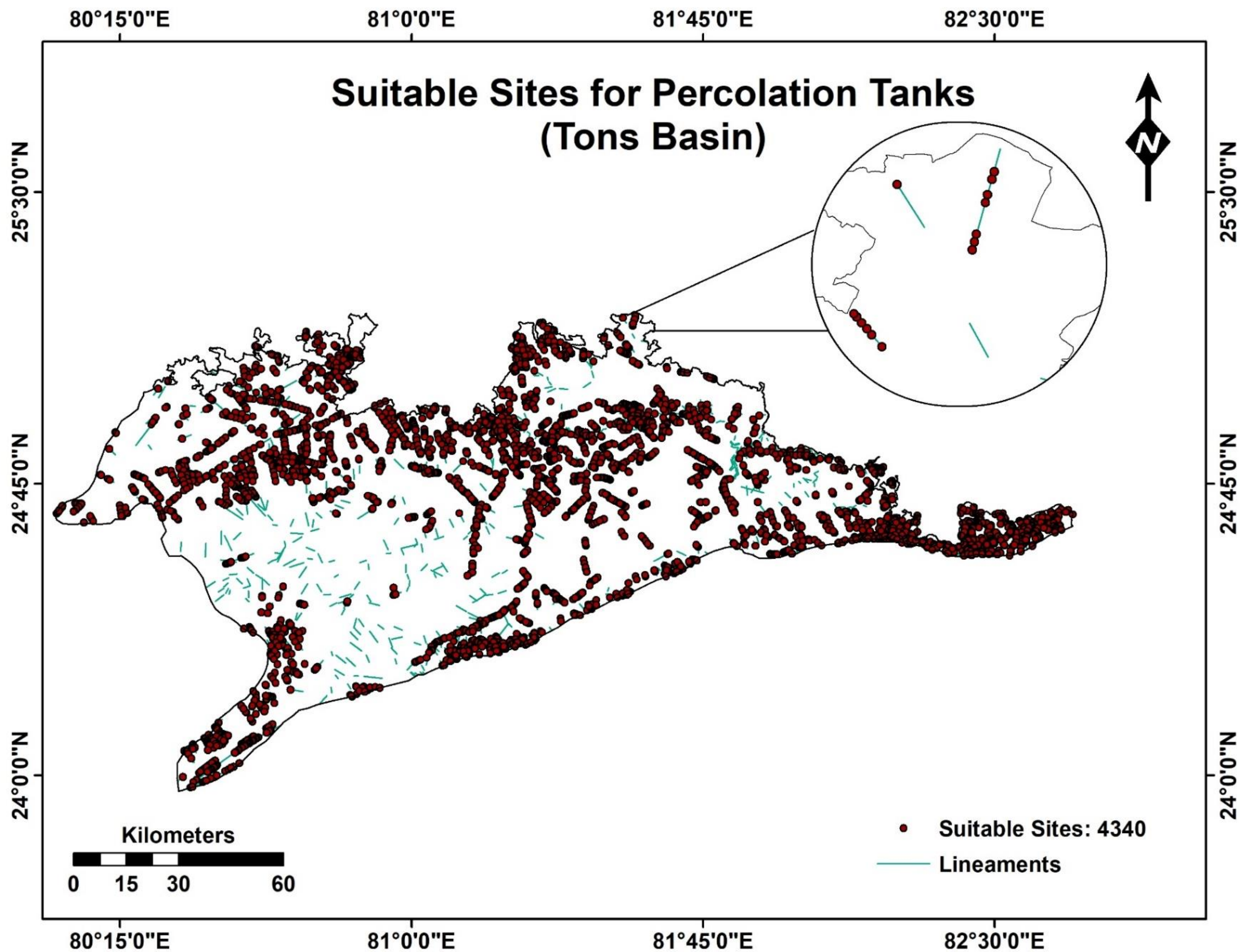

Fig. 44: Suitable Sites for Percolation Tanks in Tons River Basin

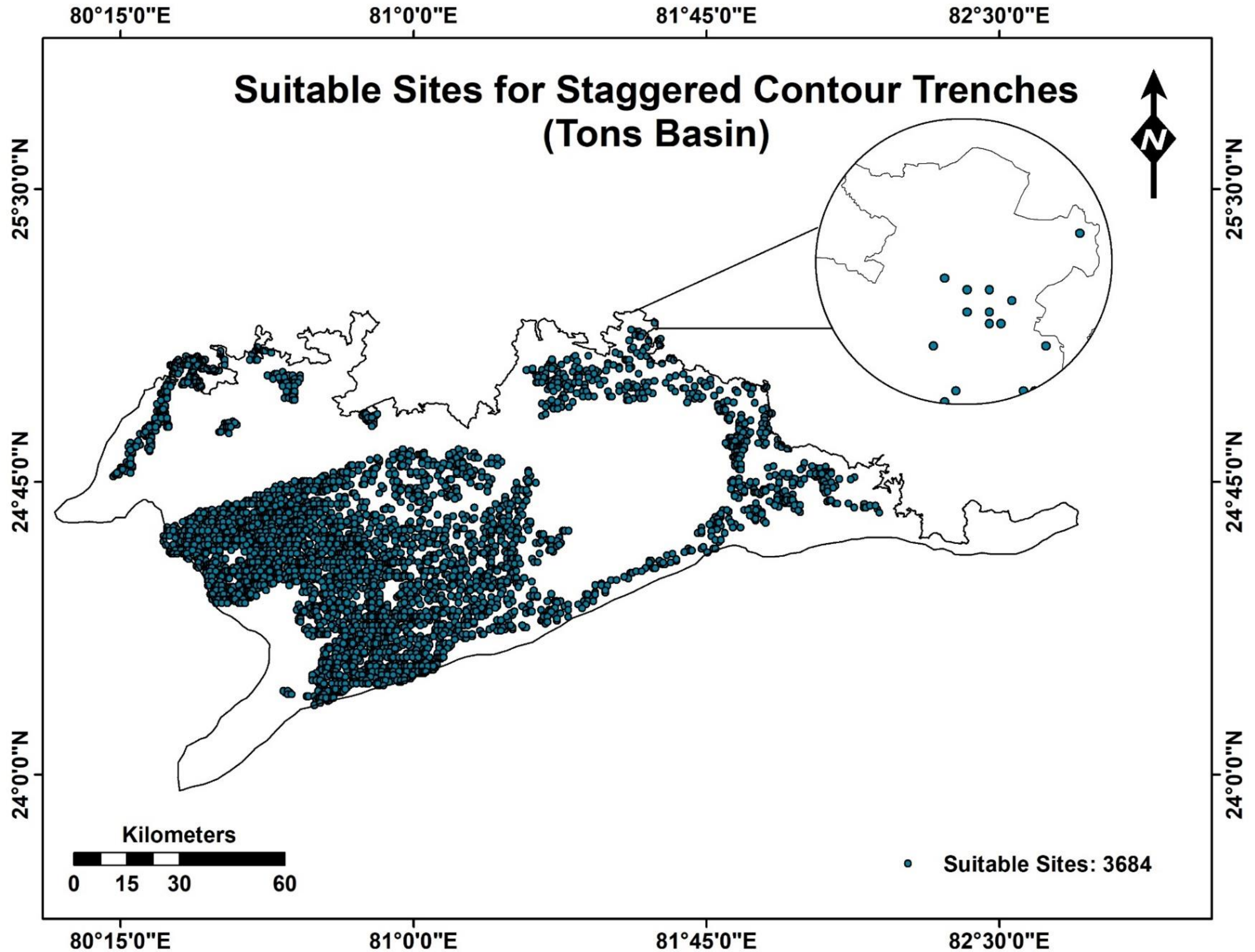

Fig. 45: Suitable Sites for Staggered Contour Trenches in Tons River Basin

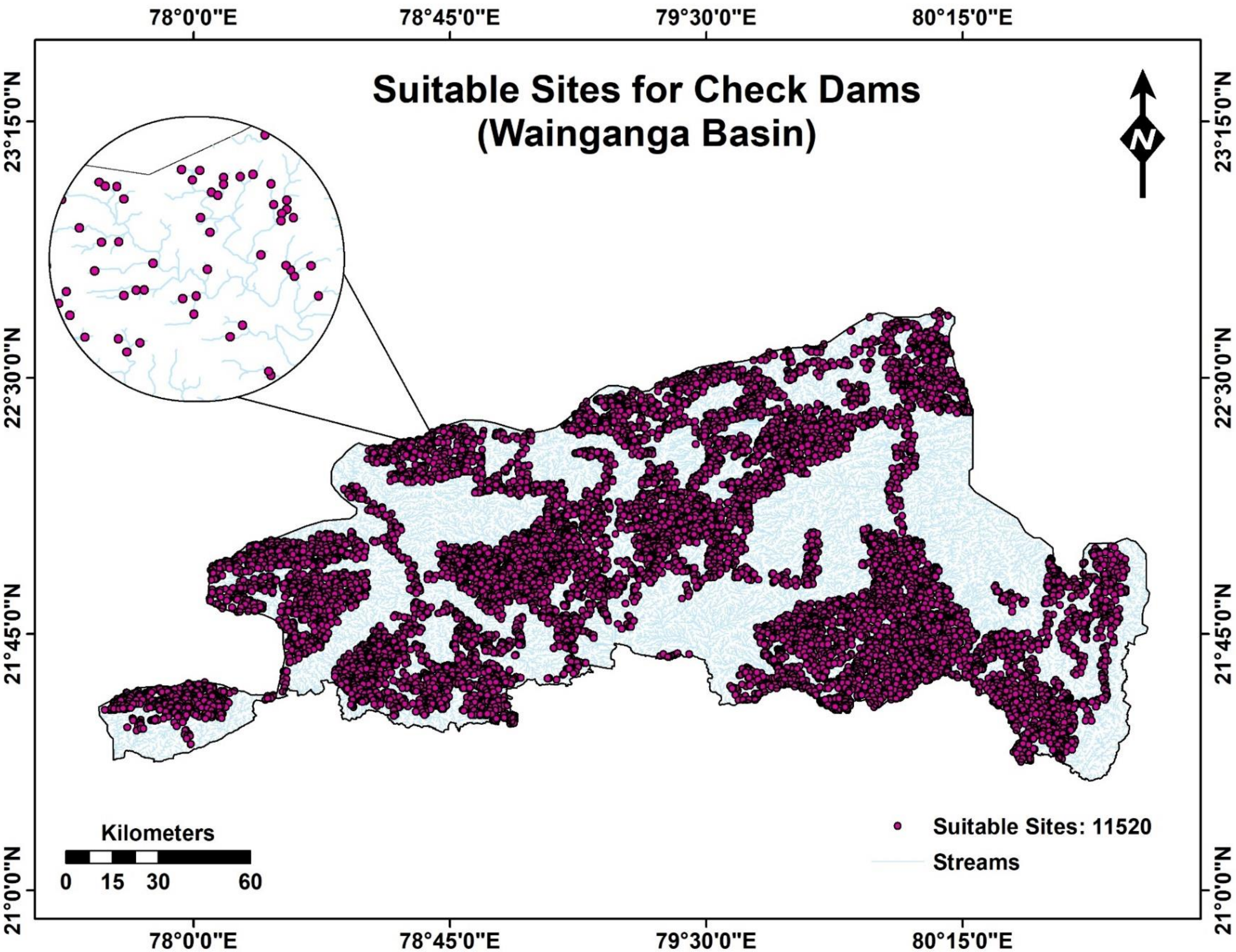

Fig. 46: Suitable Sites for Check Dams in Wainganga River Basin

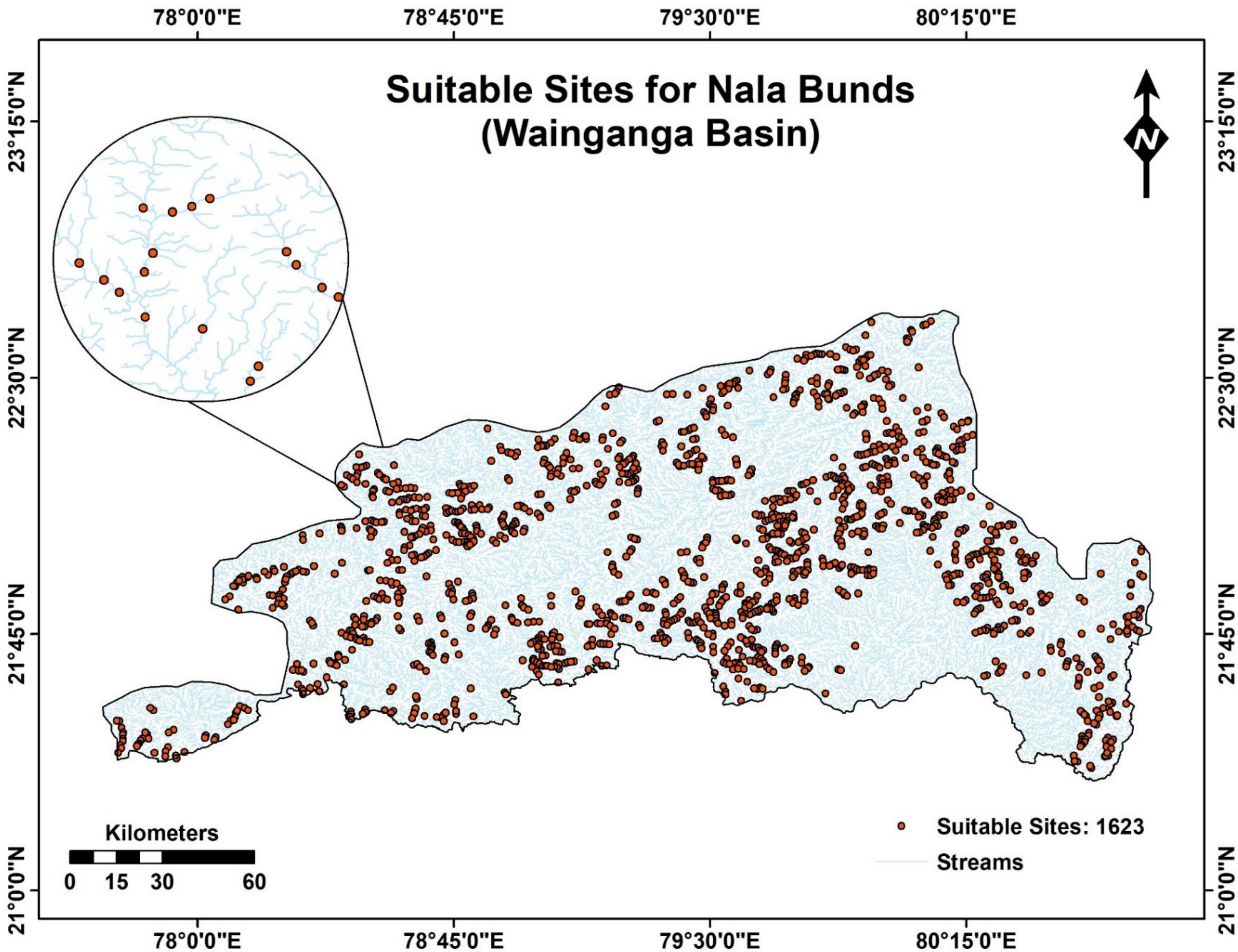

Fig. 47: Suitable Sites for Nala Bunds in Wainganga River Basin

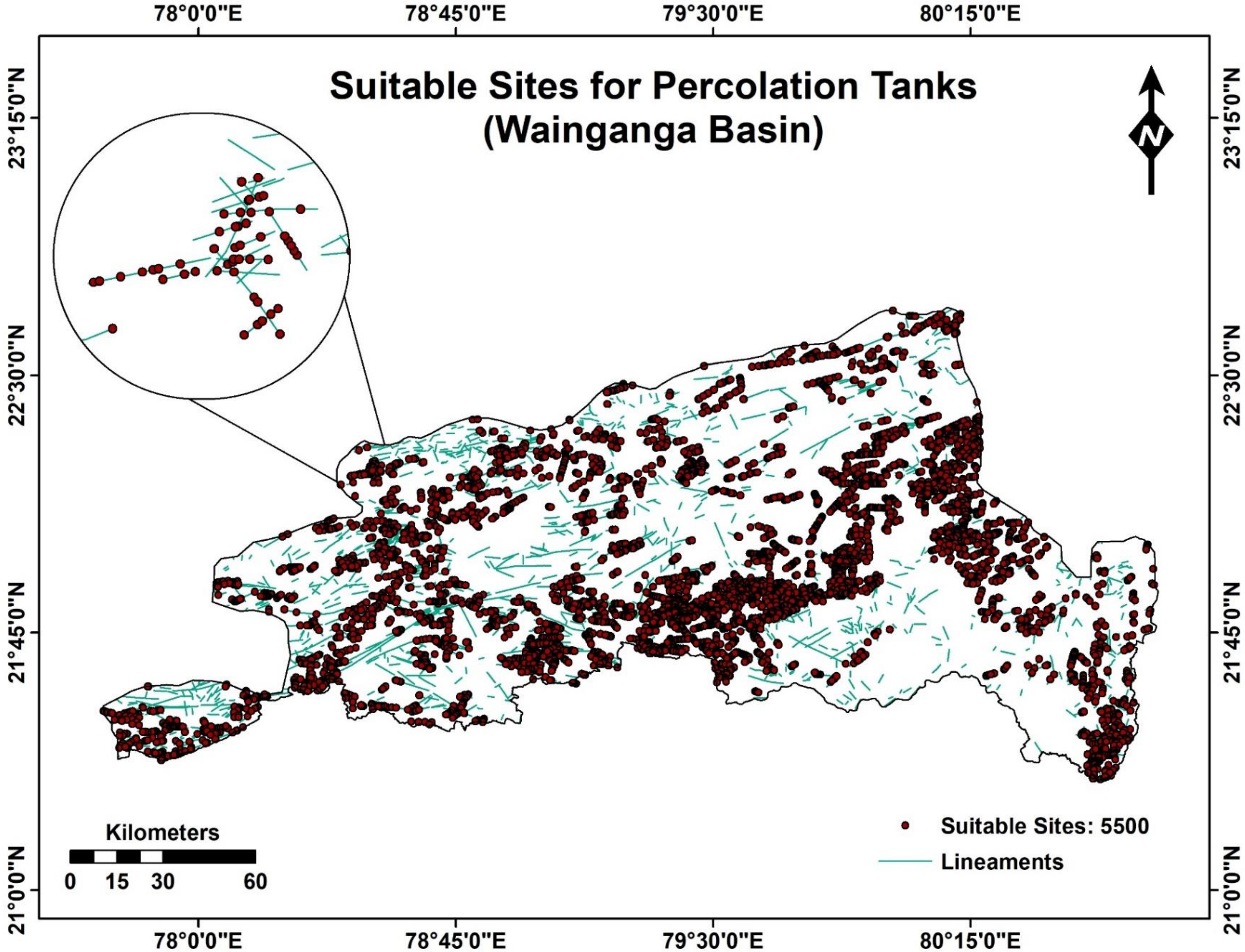

Fig. 48: Suitable Sites for Percolation Tanks in Wainganga River Basin

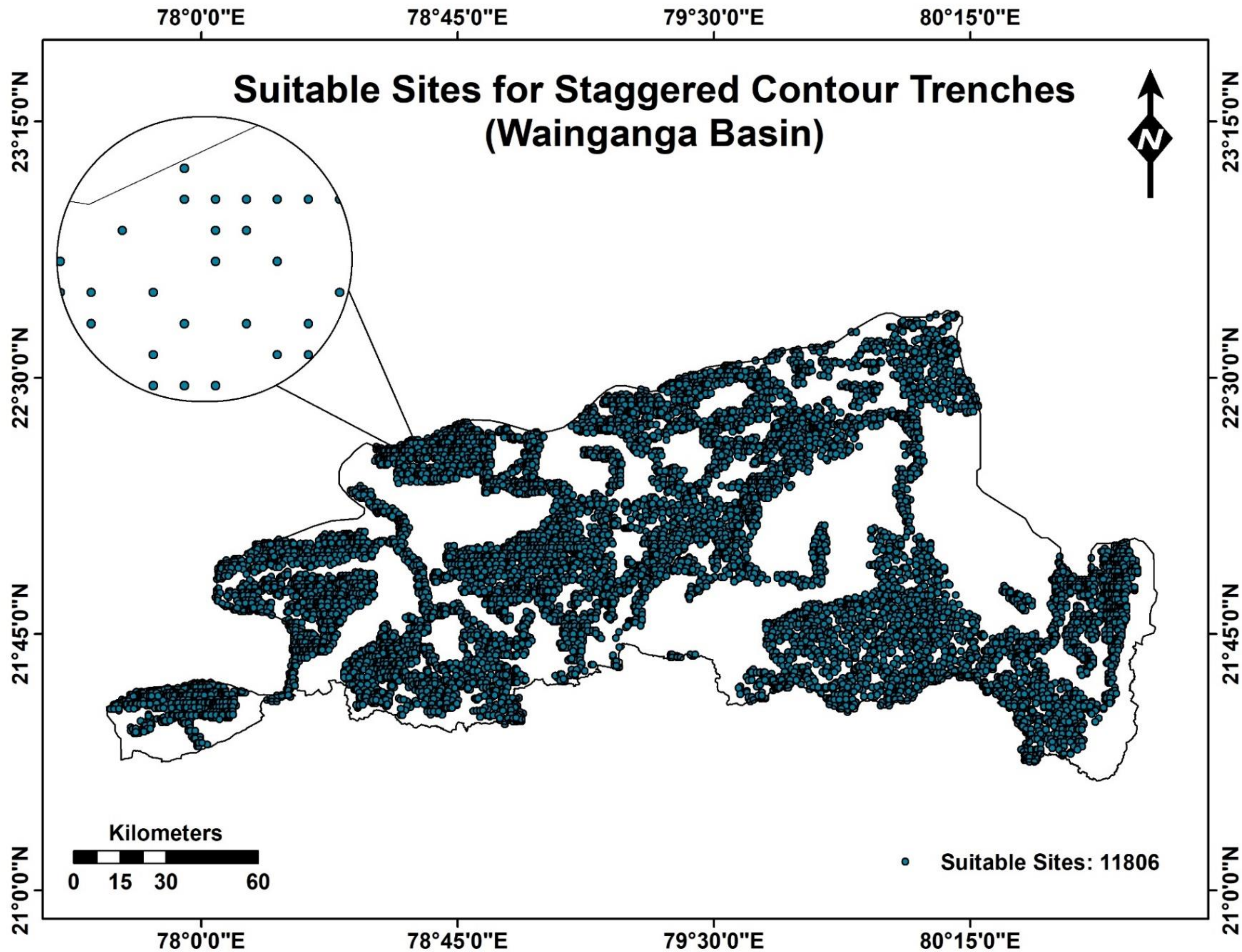

Fig. 49: Suitable Sites for Staggered Contour Trenches in Wainganga River Basin

AICRP on Irrigation Water Management
Department of Soil and Water Engineering

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