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Textural changes In Fluvial Sediments As An Impact of Anthropogenic Interventions: Case Study Of A Small Mountainous River In Western Ghats, South West India

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ABSTRACT

A small mountainous river system in the Thiruvananthapuram District of Kerala State, South Western India has been subjected to textural analysis of fluvial sediments. The study area is Karamana river basin, impounded by two reservoirs, namely Aruvikkara and Peppara. Granulometric as well as statistical parameters of the sediments of the Upper Karamana catchment generally depend on the flow pattern controlled by the gradient of the terrain. The high flow energy of the upstream reaches is capable of transporting sand and other finer particles downstream leaving gravel and other coarser particles as lag concentrates. In addition to the natural processes, manmade structures like dams, check dams, bridges etc., also impart marked effect on grain size distribution along and across the river profile. The reservoirs retard the flow velocity and force water to deposit the particles in suspension upstream of the impoundment based on size and specific gravity. Pebbles and granules show comparatively higher proportions in the river stretch, where the gradients and local turbulence are higher. Sand dominates in the confluence zones of river channels with the reservoirs. Standard deviation varies between 0.58 Φ 5.84 Φ for the study area and the best sorted sediments are observed in the river reservoir confluence zones. Observed high positive skewness in the upstream reaches and negative skewness in the impounded areas. SEM studies revealed that the grains are subjected to very limited wear and tear. CM model reveals that particles in the river environment are transported mainly by rolling and partly by rolling and suspension. In reservoirs the transportation processes are graded suspension and uniform suspension. Sediment collected from the areas close to the impoundment behaves like those deposited from pelagic suspension, indicating turbulent free depositional environment prevailing in the area.

KEYWORDS: Karamana River, Grain size, Sediment transport, Texture, River Channel.

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1.0 INTRODUCTION

Extensive studies on grain size characteristics in different parts of the world reveal the existence of significant correlation between size frequency distribution and depositional processes. Grain size is a descriptive measure of clastic sediments. It is widely accepted and proved that variation in grain size of fluvial sediments is related to many aspects like channel morphology, source materials and process of weathering and, sorting processes during transportation and deposition.[1]Grain size determines the permeability and porosity of sedimentary aquifers as well, which in turn, have major social and economic relevance. It may yield information about the physical mechanisms acting during transportation as well as depositionin aquatic environments, which reflects the prevailing energy conditions. The natural hydrodynamic regime of a river channel is being altered by manmade structures like dams, check dams, bridges etc., andalso impart marked effect on grain size distribution along and across the river profile.[2] An attempt has been made in this study to understand the particle size distribution and depositional processes of the Karamana River, which hosts two reservoirs namely Aruvikkarra and Peppara.

The Karamana River Basin (702 km^2) is located between North latitudes 8° 05’ and 8° 45’ and east longitudes 76° 45’ and 77° 15’ (Fig.1). The river originates from Chemmunjimottai, a peak in the Western Ghat mountain ranges, at an altitude of 1717m amsl (above mean sea level). The Karamana river falls within the small (<10000 km2) mountainous river category (head water elevation between 1000m and 3000m amsl) of Milliman and Syvitski.[3] The crest of the Western Ghats constitutes the interfluves between the Karamana (west flowing) and the Thambraparni (east flowing) river basins. The river flows about 68 km before joining the Lakshadweep Sea near Thiruvallam.[2]The entire area falls within the jurisdiction of the Thiruvananthapuram district in Kerala State, South India. The area is bounded on the north by Vamanapuram river basin, south by Neyyar river basin and east by Thamraparni river basin. The Aruvikkara dam was constructed in the year 1930 across the Karamanariver near Aruvikkara town.The Peppara dam, an augmentation project of Aruvikkara water supply scheme, was constructed by the Kerala Water Authority (KWA) in the year 1984. Aruvikkara and Peppara reservoirs in the upper catchment of the Karamana river basin are the important water sources for catering the freshwater requirements of the fast developing capital city of Kerala State, Thiruvananthapuram. A better understanding of all the processes operating in river catchments, especially, in the fringe areas of urban agglomerations is very essential for laying down strategies for the judicious use of the pristine freshwater resources.

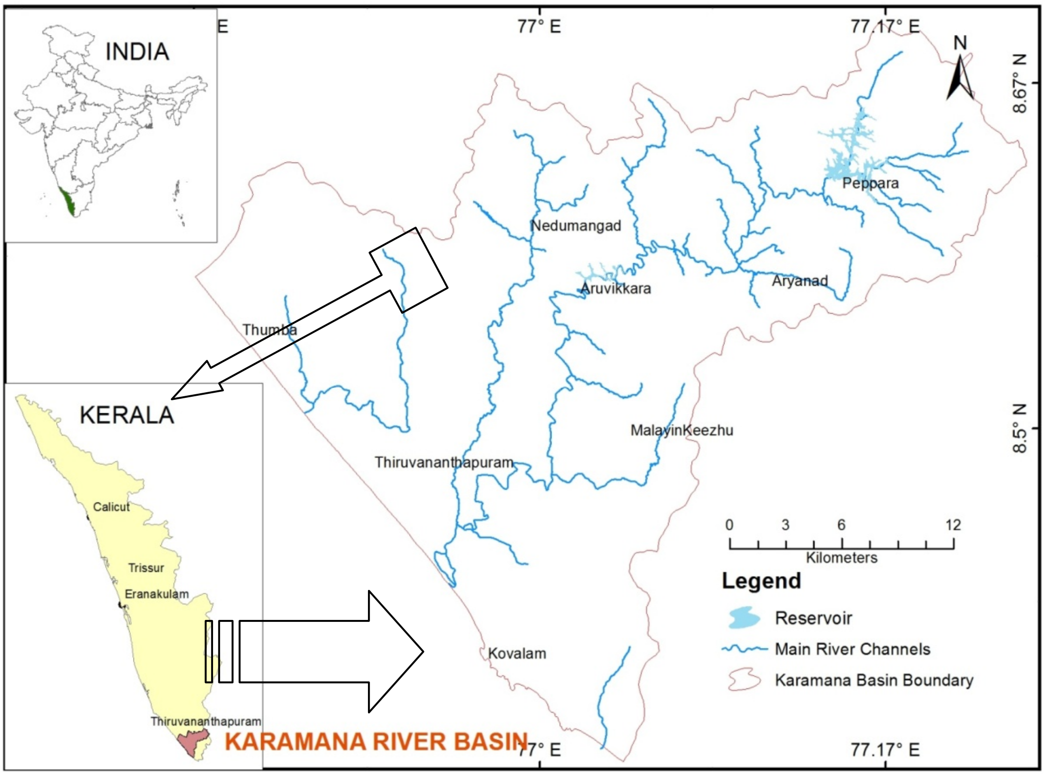

Fig. 1 Location map of the Study area

2.0 MATERIALS AND METHODS

Survey of India Topographical map of the study area was used as the base map. Secondary data was collected from various State and Central Government Departments, Universities and offices of various local bodies in the Study area. A total of 60 sediment samples were collected from the study area (tributaries / river: 50, Peppara reservoir: 7 and Aruvikkara reservoir: 3) for textural studiesalong the channels (Fig.2).25 samples from the reservoirs were also collected. Representative portions of the samples were sieved following Carver and Lewis.[4]Grain size parameters as well as statistical parameterswere calculated.[5,6]The characteristics of a depositional environmentand the process of deposition are reflected in the texture of the sediment. This relationship is particularly evident if the texture is represented by two parameters of the grain size distribution: C the one percentile and M the median diameter. CM patterns formed by sample points of a deposit are characteristic of the depositional environment.The depositional processes worked out using the CM - model established by Passega.[7]

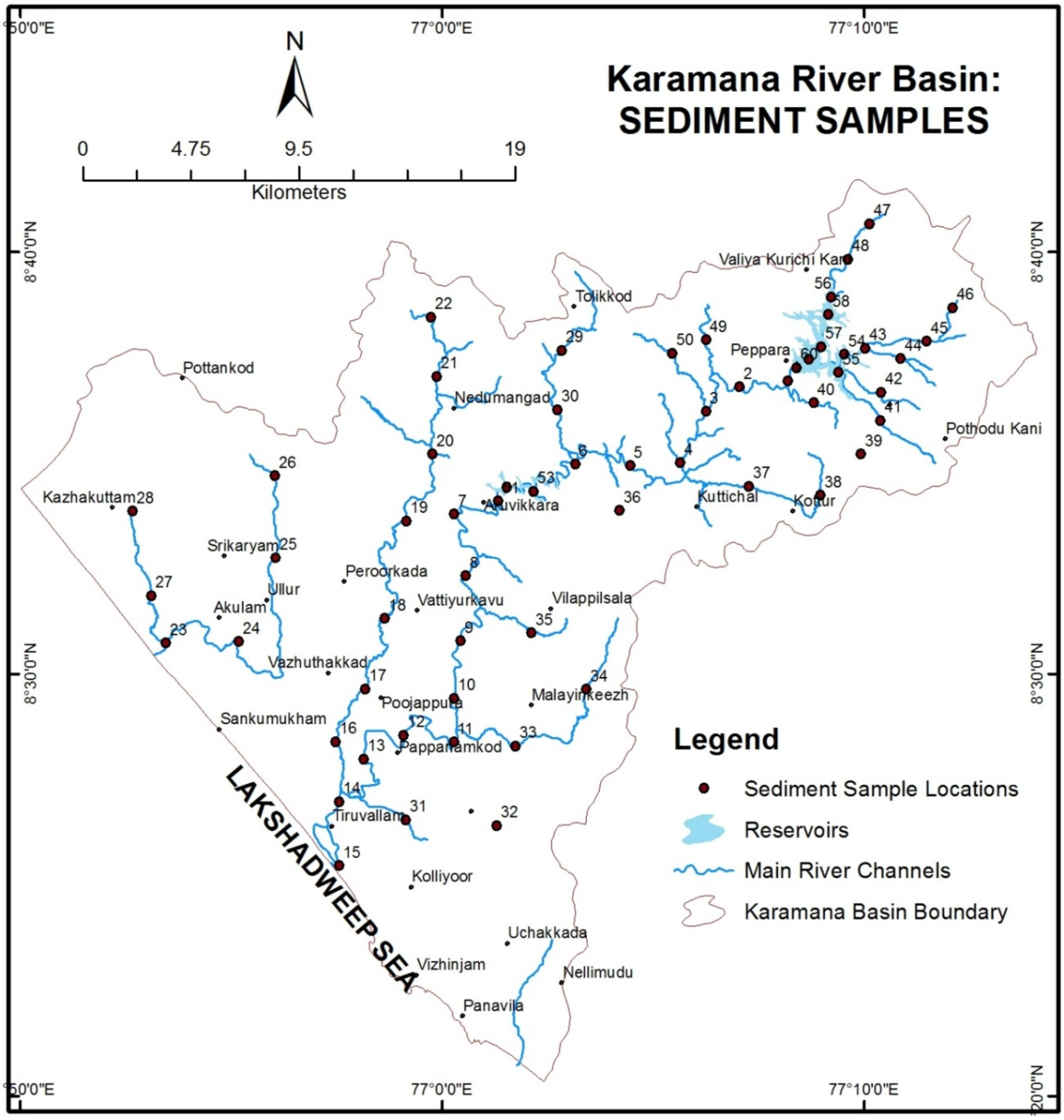

Fig.2 Sediment sampling locations

3.0 RESULTS AND DISCUSSION

3.1 Grain size variation

The sediment samples of the Karamana river catchment exhibits a spectrum of particle sizes ranging from pebbles to mud. Cobbles and boulders are excluded from the present study because of the difficulty in measuring size classes of these bigger particles.. Fig. 3 depicts the spatial variation of grain size fractions along the main channel of the Karamana river.

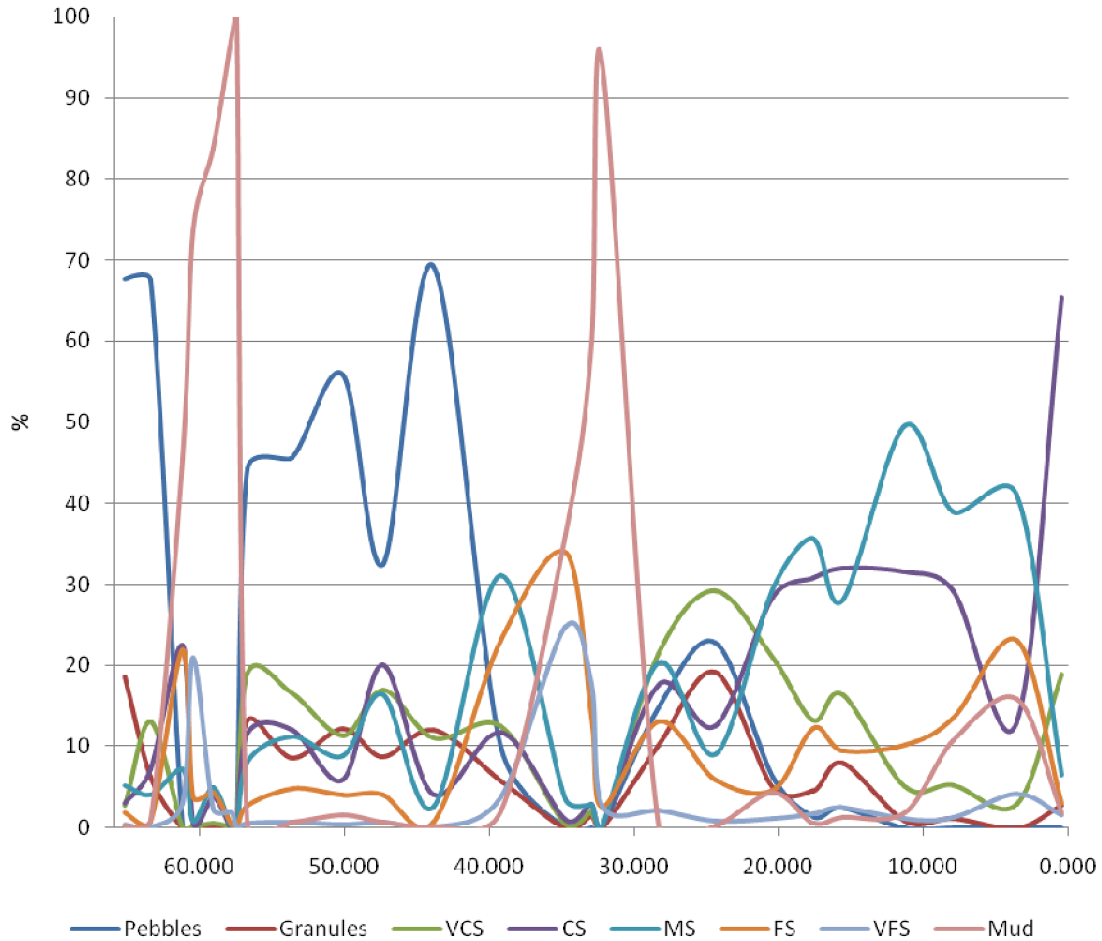

Fig. 3 Variation of Grain size fractions in the sediments of Karamana river system through the main river course. Distance measurements are from Karamana river confluence with Arabian sea (ie., river mouth).

River sediments are characterized by high amount of gravel with dominance of pebbles (av. 37.03%; range: 0.63–76.36%) over granules (av. 10.47%; range: 0.87 - 25.6%). The amount of pebbles decreases towards reservoirs and this change is more pronounced in the upper catchments (i.e., Peppara reservoir catchment) than the downstream reaches. As the river enters into the Peppara reservoir, the pebble content decreases drastically and touches a low average of 1.65% in the reservoir confluence. The sediments of Aruvikkara reservoir are devoid of pebbles.

The variation of granules indicates a complementary pattern to that of pebbles. This is very much so in the study area and the average content of granules is 9.99 % (0.25–25.6%). In general, the subsequent locations of pebble highs are the sites of granule enrichments, though that is not so proportional. It may be attributed to the progressive decrease in competency of the river water downstream which allows pebbles to settle first and then granules. In the upper reaches, progressive reduction in quantity of pebbles is compensated by an increase in the granule content. The similarities in the variation of pebbles and granules at certain locations in the downstream reaches indicate the close range of size. Pebbles in such locations are finer in nature and are almost hydraulically equivalent to granules. The marked change in the flow regime between tributaries and reservoirs also imparts a strong bearing on the grain size distribution in the study area.

The coarse and very coarse sand fractions show a similar variation to that of granules along the river channel. In the upper catchments the coarse sand content is almost stable along the river course but, shows a downward increase in the main river channel as well as in tributaries. The variation of medium sand shows deviation from its coarser entities by exhibiting a general increase towards the reservoirs and shows further decrease towards dam site. This is in consonance with the flow characteristics controlled by terrain gradient and/or engineering structures constructed across the river channels. It is noted that the medium sand shows its peak values at the confluence zones of the reservoirs. The fine sand and very fine sand contents are negligible in the river channels, especially in the tributaries. The fine sand content varies considerably in different locations both in tributaries and in the main channel. Fine sand shows a marked increase in the arms of the reservoir adjoining the confluence zones and increases further towards the dam site. Mud content is negligible in the tributaries and the main channel as the flow conditions do not facilitates its deposition within these stretches.

Within the reservoirs, coarser entities, which are encountered in the river are totally missing or present only in subtle quantities. The Aruvikkara and Peppara reservoirs are floored mainly by mud-rich sediments. The mud contents in the sediments of Aruvikkara and Peppara reservoirs averages 63.38% (36.24–94.36 %) and 72.53% (35.22–99.93%), respectively. The content of mud increases progressively towards the dam site with a complementary decrease in coarser fractions. The average sand content of Aruvikkara reservoir is 36.13% and that of Peppara is 27.43%. The fine and very fine sand fractions contribute about 80% of the sand content in Aruvikkara reservoir.

A scrutiny of the grain size variation along tributaries and the river channel reveals a size-based segregation or sorting of the sediment particles along the river course. The maximum population of each successive finer fraction shows a shift towards the reservoirs. It indicates a gradual decrease in the competency of the river downwards. The observed gradation of size fractions is not so pronounced in the lower tributaries of the Karamana river system. The upstream tributaries show distinct size based sorting / segregation of sediment particles, probably attributed to the combined effects of terrain characteristics as well as impoundment by the Peppara dam. The lower reaches of the study area is subjected to intense anthropogenic activities (e.g. sand mining from in-stream and flood plain areas, agricultural activities on river banks and lack of sufficient river flow due to the dams) than the upper reaches. This in turn is reflected in the spatial distribution of grain size fractions in the river stretch especially down to the Peppara dam.

Fig. 3 shows variation of different grain size fractions in the sub-basins, main channel, as well as the reservoirs. The tributaries and main channel record high content of gravel (pebble + granule) than sand and mud. The Peppara reservoir has high percentage of mud than the Aruvikkara reservoir, which is characterized by higher proportions of finer sand fractions (medium + fine + very fine). The transition zone of river and reservoir (ie, confluence zone) is occupied mainly by high proportions of coarse and medium sand fractions. These observations clearly bring out the difference in the hydrodynamic conditions prevailing in the respective sub-environments of the Karamana river basin.

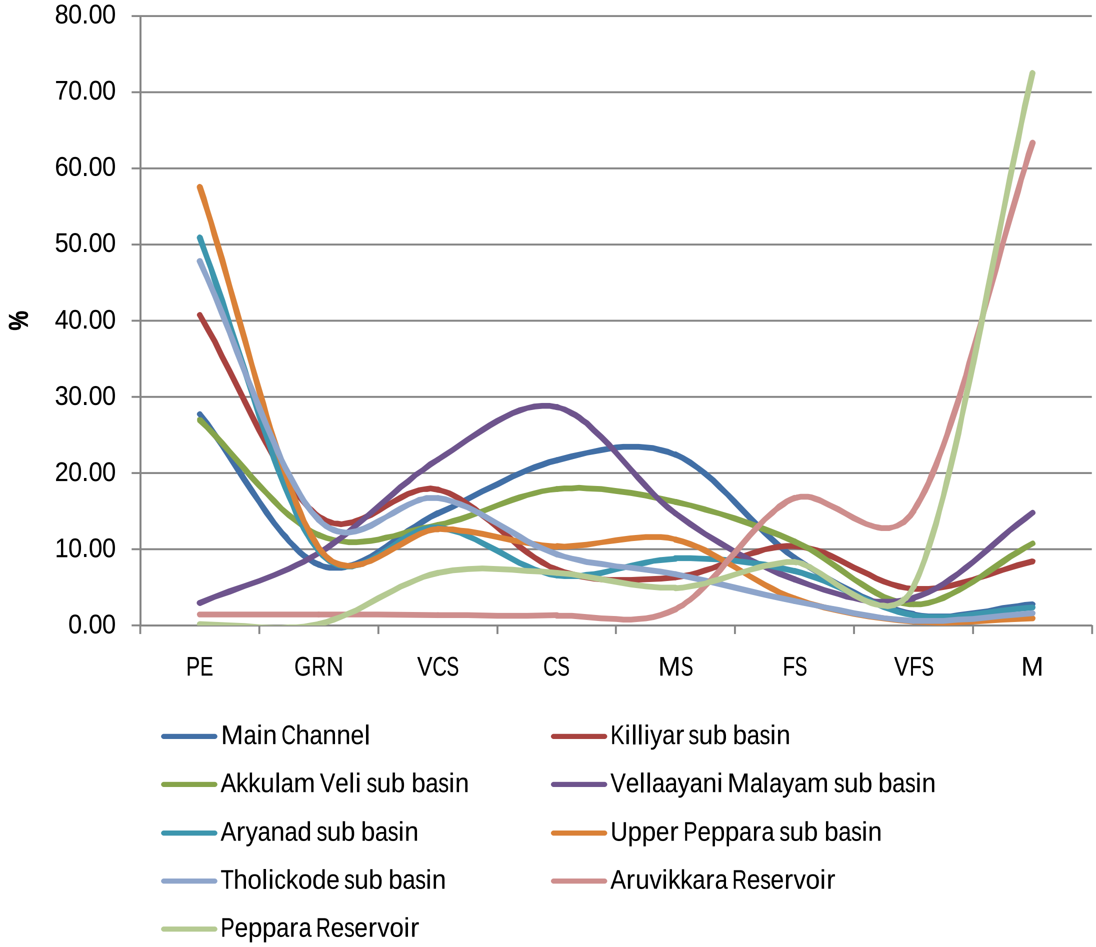

Fig. 4 Grain size distributions in the sediments of various sub environments in the study area (PE - pebble, GRN - Granule, VCS - very coarse sand, CS - Coarse sand, MS - Medium sand, FS - Fine sand, VFS - very fine sand, M - Mud).

3.2 Statistical parameters

The variations ofstatistical parameters computed for the sediments of Karamana river basin along the longitudinal profiles of the main channel are presented in Fig. 5.

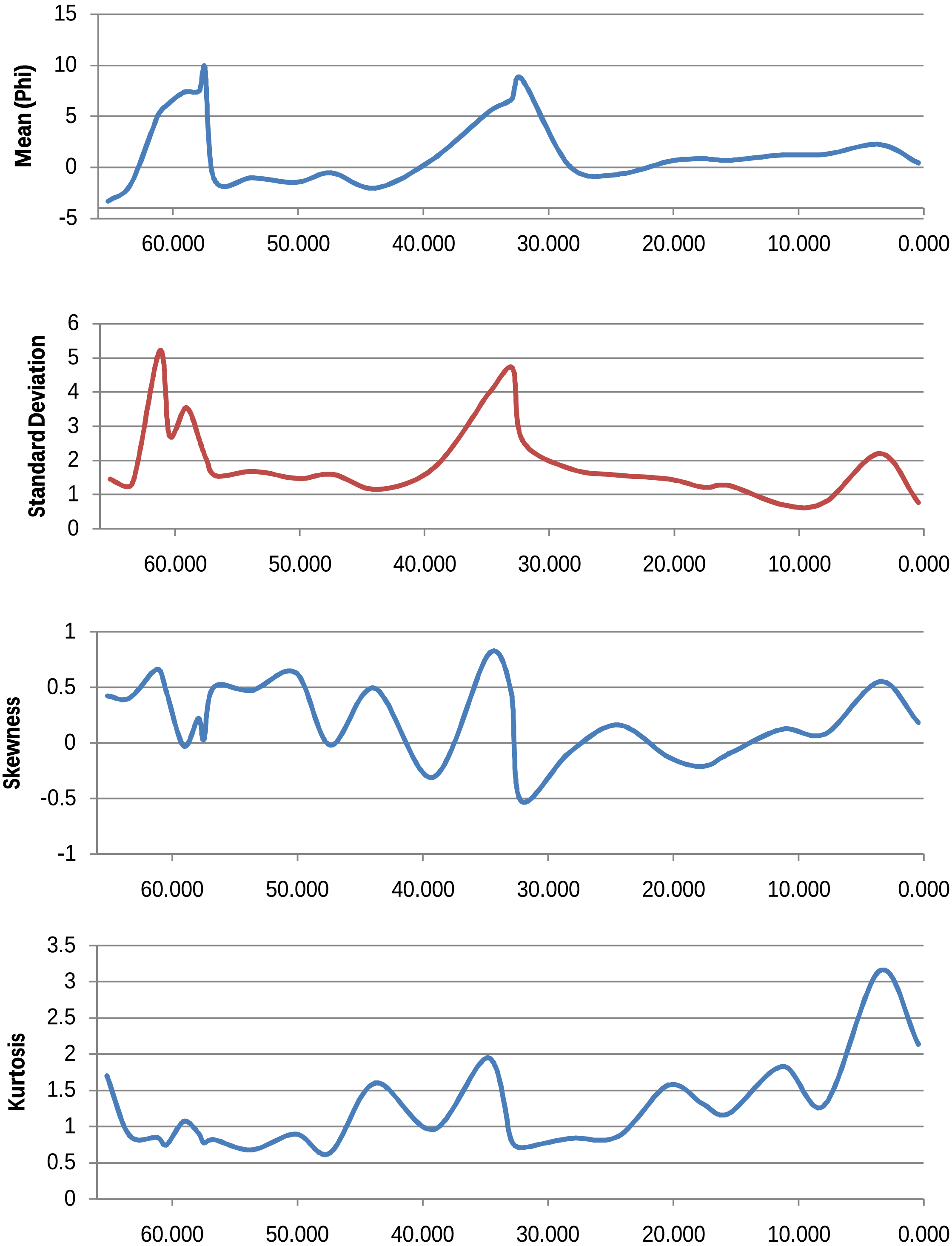

Fig. 5 Variation of statistical parameters of the sediments of Karamana river system through the main river course. Distance measurements are from Karamana river confluence with Arabian sea (ie., river mouth).

Mean size

The mean size of river sediments ranges from -3.3 to 1.77ф (pebble to medium sand). Contrary to river sediments, the reservoir sediments show markedly high phi mean values (i.e., decrease in actual grain size in mm). The mean values of Peppara reservoir sediments vary from 2.28 (fine sand) to 10.32 ф (clay) and that of Aruvikkara reservoir ranges from 2.15 to 8.95 ф. In general the phi mean values exhibit an increase towards dam.When the competency of the river water decreases, the coarser particles will be deposited first, while the finer be transported still further downstream.[8] However, it is evident that the competency of the river water fluctuates at many places due to natural (rapids, rocky exposures within river channels, etc.) and manmade structures (Peppara and Aruvikkara dams, check dams, bridges, etc.). Damming of river reduces its competency at significant levels which in turn results in deposition of suspended sediment in the reservoir behind the dam.[2]

Standard deviation

The sediment sorting improves when the spread size becomes narrow. It is shown that mean size and sorting correlates well in sand and pebble grades and correlation worsens as the grain size increases. In the river environment, the standard deviation varies between 0.58ф (moderately well sorted) and 2.33ф (very poorly sorted). Moderately well sorted and moderately sorted samples are from the river confluence zones of Peppara reservoir. In general sorting improves towards the river confluence zone but with distinct fluctuations at certain locations. The observed increase in sorting is attributed to differential transport of sediments downstream.[8]Once sediment attains maximum sorting values, any further fall in the competency of the transporting medium induces an increase in the content of finer particles in the sediments.[9] This once again imparts immaturity to the sediments. All the samples in the reservoir environments exhibit poorly to extremely poorly sorted particle dispersion. The abundance of finer particles especially silt and clay imparts broad particle dispersion which in turn causes very poor sorting of sediments.[10]

Skewness

In textural analysis skewness is considered as an important parameter because of its extreme sensitivity in sub-population mixing. Well sorted unimodal sediments are usually symmetrical with zero skewness. In a fine skewed population, the distribution of grains will be from coarser to finer entities and, the frequency curve chops at the coarser end and tails at the finer. The reverse condition is characteristic of coarse skewed sediments.[8]Coarse skewness in sediments could be attributed to two possible reasons, 1) addition of materials to the coarser terminal or 2) selective removal of the fine particles from a normal population by winnowing action.[11]The river sediments of the Aruvikkara and Peppara reservoir basins exhibit skewness values between -0.9 and 0.84. In Aruvikkara reservoir skewness varies from very coarse (-0.52) to very fine (0.81) category, while in Peppara, it varies from near symmetrical (-0.10) to very fine skewed. The variation of skewness is more complex in the reservoir environment. About 55% of the samples in the reservoir environment exhibit very fine skewness, 20% is symmetrical and others are fine and coarse skewed. Very fine skewness in the reservoir sediments is attributed to addition of silt and clay modes in the already deposited sediments. The presence of symmetrical and near symmetrical samples indicates an equal proportion of different modes.

Kurtosis

Kurtosis, the peakedness of the frequency curve, is a measure of the contrast between sorting at the central part of the size distribution and that of the tails. Kurtosis of the river sediments ranges from very platykurtic to extremely leptokurtic (0.47 - 7.99). The Aruvikkara reservoir sediments are very platykurtic to extremely leptokurtic (0.62 - 3.40) and that of Peppara reservoir are platykurtic to leptokurtic (0.67 - 1.25). In natural environments, the kurtosis values reflect fluctuations in the velocity of the depositing medium. Values greater than unity suggest greater fluctuations[11] in the energy conditions of the depositing medium. The fluctuations are more pronounced in reservoir environment than river / tributary environment.

3.3 Classification of sediments

River sediments

The textural classification for gravel bearing sand[9] is followed here to decipher sediment types,since most of the samples contain significant amount of gravel,. From Fig. 6, it is evident that the river sediments show a wide range of textural classes. Gravel dominates in the upstream part, but sand and gravelly sand are confined mainly to reservoir confluence. In the main river channel, the sediment types are gravel, sandy gravel and gravelly sand. The presence of gravel rich coarser sediments in river channels may be attributed to the local turbulence generated by the check dam and bridge in the vicinity of the sampling site. The abundance of sand rich sediments confined to the reservoir confluence zones indicates that the competency of the rivers / tributaries is getting reduced due to reservoir waters.

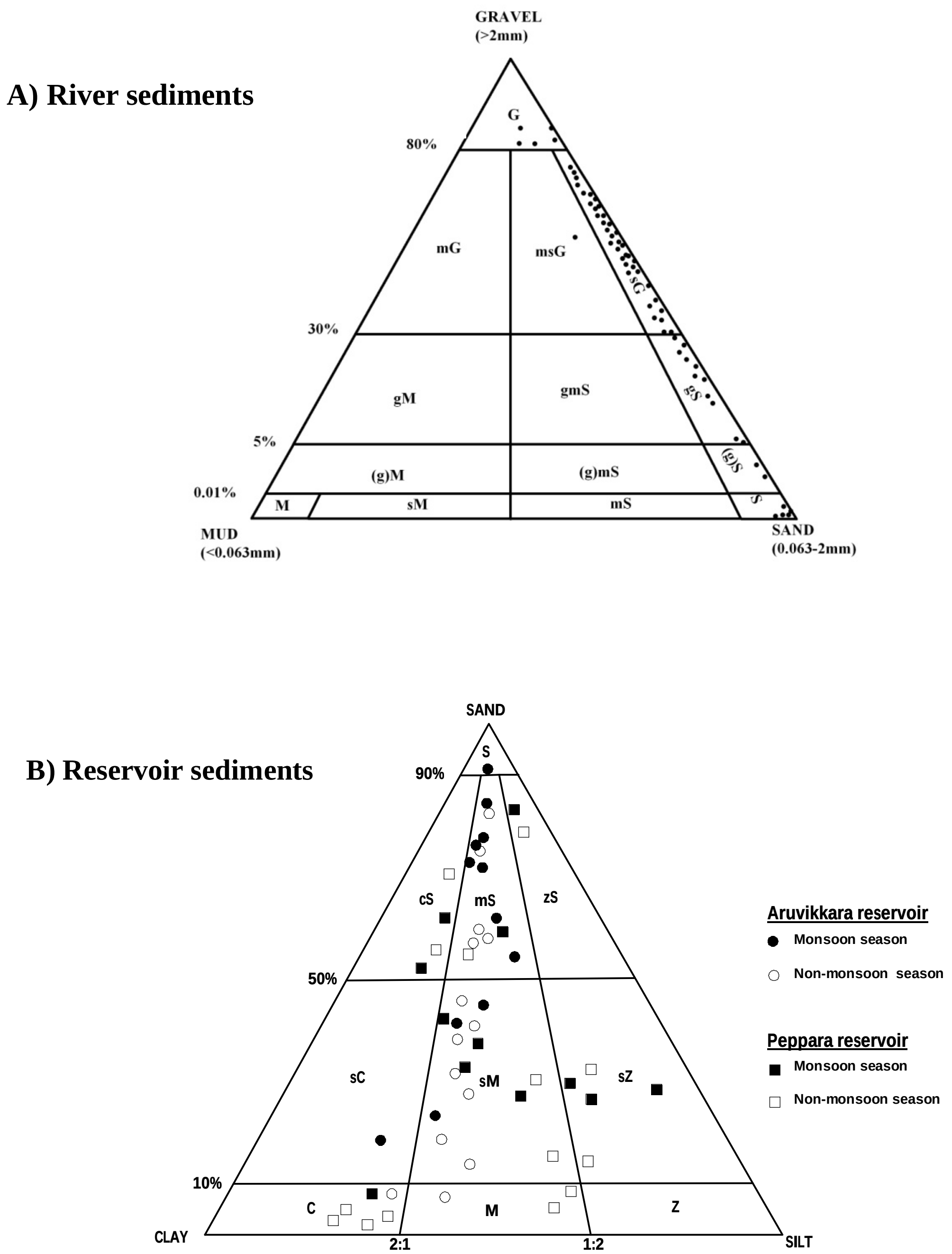

Fig. 6 Ternary diagrams showing the nature of surface sediments of the study. G - Gravel, sG - Sandy gravel, msG - Muddy sandy gravel, mG - Muddy gravel, gS - Gravelly sand, gmS - Gravelly muddy sand, gM - Gravelly mud, (g)mS - Slightly gravelly muddy sand, (g)S - Slighly gravelly sand, (g)M - Slightly gravelly mud, S - Sand, Z - Silt, C - Clay, cS - Clayey sand, sC - Sandy clay, mS - Muddy sand, sM - Sandy mud, M - Mud, zS - Silty sand and sZ - Sandy silt.

Reservoir sediments

The reservoirs are floored by a wide range of sediment types such as sandy mud, sandy silt, muddy sand, mud, clay and clayey sand. Muddy sand and sandy mud predominates in the Aruvikkara reservoir. Mud is detected in the immediate vicinity of the dam. Clay and slightly gravelly sandy mud are observed in the central part as well as lower right arm of the reservoir, respectively. In Peppara reservoir the sediment type vary considerably; clay is detected very near to the dam site and clayey sand, muddy sand, sandy silt and sandy mud blanket the reservoir arms. Presence of gravel is observed in some locations and this may be contributed either from slumping / caving of banks the reservoir or from minor tributaries. In general sand rich species dominates in the arms of the reservoir whereas mud rich species dominates near the dam site. Unlike the Peppara reservoir, Aruvikkara reservoir is floored mainly by sand dominant species indicating high-energy hydrodynamic regime prevailing in the reservoir most part of the year.

3.4 Surface textures

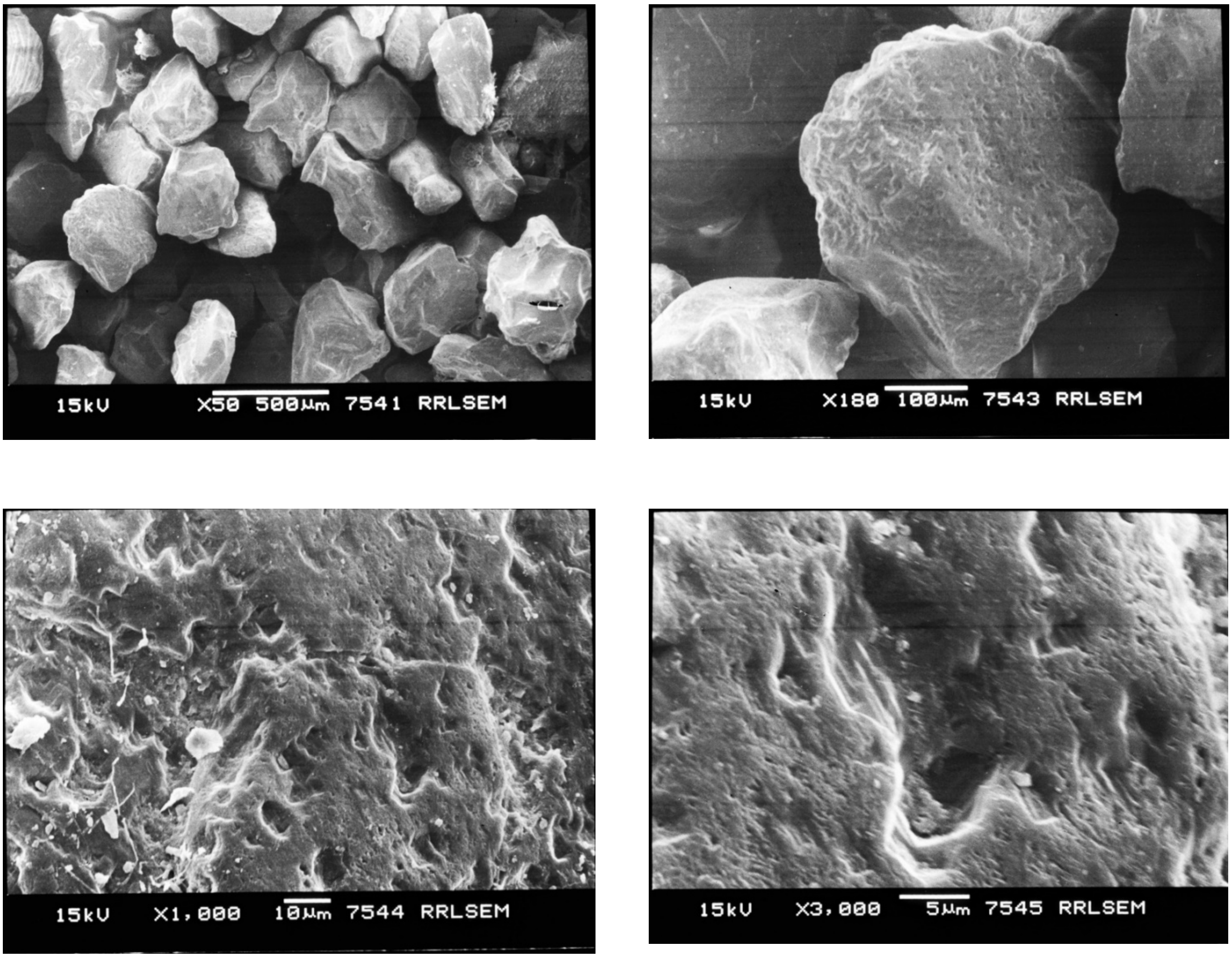

Fig. 7 Photomicrograph of quartz grains showing various micro relief features.

Many investigators opined that a systematic study of the Surface textures provide an insight into the history of transportation and deposition of clastic particles.[12,13,14] Already studied[2] the surface textural patterns of a few quartz grains collected from the Karamana river (Fig. 7). High magnification photographs exhibit 'V' shaped impact pits, which are in the primitive stages. These 'V's indicate that the grain under examination is subjected to only limited amount of wear and tear. The grains are angular to sub angular and with a variety of micro relief features of physical (V-shaped impact pits, fractures etc.) and chemical (solution structures and secondary silica growths on cavities) origin.

3.5 C M Pattern

The CM pattern of the river and reservoir sediments of the study area is depicted in Fig. 8. The figure represents a complete model of tractic current and consists of several segments such as NO, OP, PQ, QR and RS indicating different modes of sediment transport.[7]The position and size of these segments may vary, although some are much common than others.[7] Transport of sediment by a given mechanism implies that sediments of certain sizes are available under certain hydraulic conditions. The river sediments fall in the NO, OP and PQ segments. The rolling mode of transportation is prominent in the pebble rich tributary channels where the competency of the river water is enormously high due to the high gradient nature of the terrain. The segment OP consists of particles with diameter roughly between 4000 and 5000 microns of C, which are moved mainly by rolling and suspension. The segment PQ represents particles ranging from 1400 to 4000 microns of C and indicates that these particles are moved predominantly by suspension and partly by rolling. Sediments from the reservoir confluence zone fall mainly within the segment PQ indicating a marked change in the river competency. Unlike the river, the reservoir environment is characterised by well-defined QR and RS segments. The silt and clay rich sediments fall in the RS segment which indicates the role of uniform suspension in transporting these sediments. The clay rich sediments falls in the region marked as T in the diagram. This area is characterised by pelagic suspension and the samples are from the immediate vicinity of the dam. Some of the reservoir samples show notable deviation from the ideal pattern indicating the complexity in the transportational / depositional regime prevailing in the reservoir environment. Some of the scattered samples fall within type fields VII and VIII. The type VII is a uniform suspension deposit and the sediments of type VIII are deposits of finest uniform / pelagic suspensions.

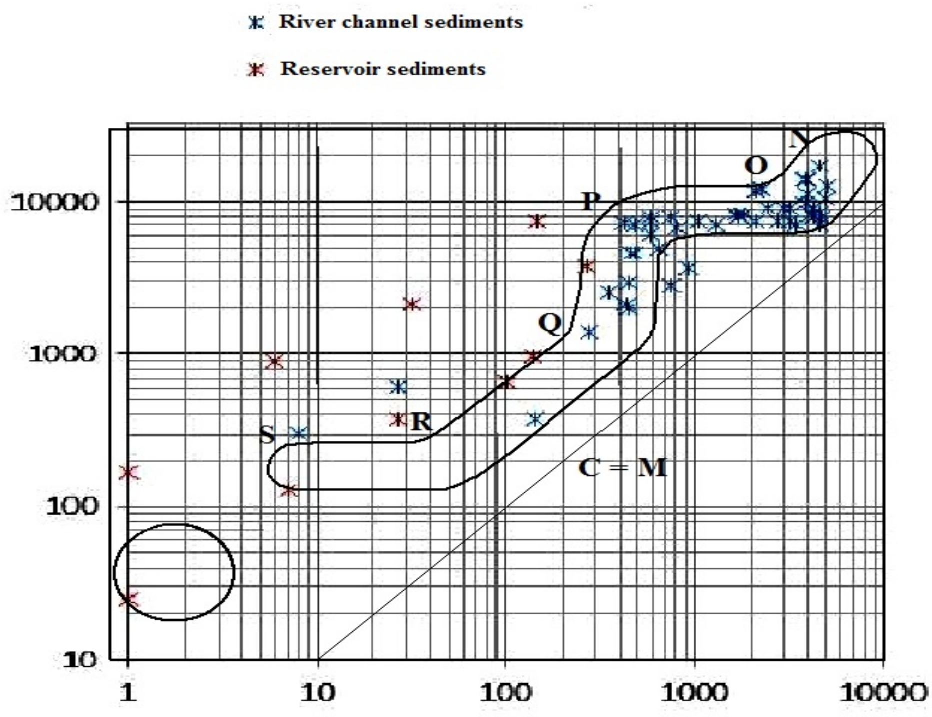

Fig. 8 CM Pattern for the sediments of the study area

4.0 CONCLUSIONS

The conclusions deduced from the presents study emphasizes that, the granulometric characteristics as well as statistical parameters of the sediments of the river basin generally depend on the flow pattern controlled by the gradient of the terrain. The high flow energy of the upstream reaches is capable of transporting sand and other finer particles downstream leaving gravel and other coarser particles as lag concentrates. The reservoirs retard the flow velocity and force water to deposit the particles in suspension upstream of the dam based on size and specific gravity. The surface textures of quartz grains established that they are angular to sub angular with moderate signatures of ‘V’ pits indicating the considerable extent of sub-aqueous collisions during transportation. CM model reveals that particles in the river environment are transported mainly by rolling and partly by rolling and suspension. In reservoirs, the transportation processes are graded suspension and uniform suspension. Sediment collected from areas close to the Peppara dam behaves like those deposited from pelagic suspension. This is a clear indication of a turbulent-free depositional environment in the deeper portions of the reservoir.The textural characteristics in the study area suggested that the river environment and its energy regime was changed drastically due to anthropogenic interventions by damming the river.

5.0 ACKNOWLEDGEMENTS

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